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REGIONAL COUNCIL
Te Pane Matua Taiao

Kapiti Coast groundwater resource investigation

Proposed framework for conjunctive water management

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Executive summary

The groundwater resources of the Kapiti Coast form an integral component of the hydrological cycle and have a significant role in sustaining freshwater ecosystems in riverine and wetland habitats. Significant use is also made of the groundwater resource for domestic, municipal, industrial and irrigation water supplies. Managing potential conflicts between maintenance of environmental values associated with the groundwater resource (including hydraulically connected surface water) and the potential social and economic benefits arising from water use presents a major resource management challenge.

Hughes and Gyopari (2011) proposed a framework for conjunctive water management in the Wairarapa Valley to enable integrated management of groundwater abstraction in a manner consistent with environmental flows and water levels established for hydraulically connected surface water resources. The conjunctive management framework is a departure from current approach specified in the Natural Resources Plan (NRP) which essentially manages groundwater and surface water as separate resources.

The proposed conjunctive management framework involves delineation of aquifer systems into three hydraulic connectivity categories:

- Category A: areas with a direct hydraulic connection with surface water where stream depletion effects due to groundwater abstraction may be mitigated by application of minimum flow or level cut-offs;
- Category B: areas where groundwater abstraction effects on surface water may be significant and can potentially be managed through the application of pumping controls depending on localised hydrogeological conditions and the rate of abstraction; and,
- Category C: areas of the groundwater system which exhibit limited connectivity to surface water where cumulative effects on surface water are best addressed through management in terms of a fixed allocation volume.

This report provides recommendations for developing and applying a similar framework for conjunctive management to the Kapiti Coast. Although adopting a similar overall approach, the recommended management framework differs from that proposed for the Wairarapa Valley to reflect the distinct hydrogeological setting and resource management issues in the Kapiti area. These differences include:

- Specific provision for management of localised effects of groundwater abstraction in terms of wetland and seawater intrusion as well as streamflow depletion;
- Classification of the entire regional groundwater system as either Category A or Category B to reflect the potential interconnection between aquifers of varying depths across the entire coastal plain; and
- Calculation of sustainable allocation volumes with reference to regional-scale effects on saline intrusion, unconfined aquifer drawdown as well as cumulative effects on baseflow discharge.

The proposed conjunctive management framework and recommended groundwater allocation volumes provide a relatively simple system that integrates localised and regional scale effects of groundwater abstraction to ensure sustainable management of current and future groundwater allocation based on current understanding of the hydrogeology and hydrology of the Kapiti Coast area.

Contents

1. Introduction

1.1 Background

In May 2011, Greater Wellington Regional Council (GWRC) published a technical report (Hughes and Gyopari, 2010) outlining a proposed framework for the management of groundwater and surface water abstraction in the Wairarapa Valley. This framework was based on the concept of conjunctive management whereby groundwater and surface water allocation is integrated to ensure the cumulative effects of water use are consistent with environmental flows and water levels established for hydraulically connected surface water resources.

The proposed conjunctive management framework developed for the Wairarapa Valley was the outcome of five years detailed investigation and modelling, particularly in terms of the potential nature of groundwater-surface water interaction in response to groundwater abstraction. The resulting management framework proposes modifications to existing groundwater management zones specified in GWRC's Natural Resources Plan (NRP)[1] to better manage the cumulative effects of groundwater abstraction on rivers, streams and wetlands. The framework also includes criteria for the application of pumping regulation to mitigate direct effects of groundwater abstraction on stream flows and establishes cumulative effects on surface water as a primary criterion for establishing sustainable groundwater allocation limits.

This report outlines the application of the conjunctive management framework to the Kapiti Coast based on principles that have been applied to water resource management elsewhere in the Wellington Region. The report draws extensively on the conceptual hydrogeological model developed by Gyopari *et.al* (2012) to delineate hydraulic connectivity zones to manage direct effects on surface water resulting from groundwater abstraction. The report also utilises the numerical groundwater model developed by Gyopari *et.al* (2012) to provide recommendations for management of sustainable groundwater allocation based on evaluation of a range of pumping scenarios.

1.2 Report objectives

The overall objective of the report is to provide recommendations for the application of a conjunctive management framework to the Kapiti Coast based on principles that have been applied to water resource management in both the Wairarapa Valley and Hutt Valley. The report delineates hydraulic connectivity zones to manage direct effects of groundwater abstraction on surface water resources and provides recommendations for sustainable allocation limits for individual groundwater management zones.

1.3 Report structure

The report comprises the following sections:

- Section 2 – *Management Framework*: An overview of the primary concepts and principles underlying conjunctive water management as well as an outline of the conjunctive management framework developed for

[1] WRC (1999)

management of groundwater and surface water allocation elsewhere in the Wellington Region.

- Section 3 – *Application of the Conjunctive Management Framework to the Kapiti Coast*: Recommendations for the application of the proposed conjunctive management framework to the Kapiti Coast including a proposed hydraulic connectivity zonation and specific management provisions for managing groundwater abstraction effects in terms of saline intrusion and effects on significant wetlands.

- Section 4 – *Recommendations for groundwater allocation:* An overview of the recommended approach to groundwater allocation on the Kapiti Coast including amendments to existing groundwater management zones, spatial extent of hydraulic connection categories and sustainable allocation volumes.

- Section 5 – *Summary and Discussion*

Appendices to the Report

- Appendix A – *Assessment of allocation options for the Otaki groundwater zone*: Documentation of numerical groundwater model scenarios evaluated to assess allocation options for the Otaki groundwater zone.

- Appendix B – *Assessment of allocation options for the Te Horo groundwater zone*: Documentation of numerical groundwater model scenarios evaluated to assess allocation options for the Te Horo groundwater zone.

- Appendix C – *Assessment of allocation options for the Waikanae groundwater zone*: Documentation of numerical groundwater model scenarios evaluated to assess allocation options for the Waikanae groundwater zone.

- Appendix D – *Assessment of allocation options for the Raumati groundwater zone*: Documentation of numerical groundwater model scenarios evaluated to assess allocation options for the Raumati groundwater zone.

2. Framework for conjunctive water management

Managing potential conflicts between maintenance of environmental values associated with groundwater resources (including hydraulically connected surface water) and the potential social and economic benefits arising from water use presents a major resource management challenge. Management of both localised and cumulative effects of abstraction on hydraulically connected surface waters is a key component of an effective framework for sustainable groundwater allocation to ensure environmental values can be maintained at or above thresholds established by the community.

The following section provides an overview of the conjunctive management framework developed by Hughes and Gyopari (2010) which has been adopted by the GWRC as the basis for sustainable management of groundwater allocation in the upcoming review of the Natural Resources Plan (NRP).

2.1 Overview of conjunctive water management

Recognising that surface water and groundwater resources within a catchment are fundamentally linked means that management of these resources needs to be undertaken in a coordinated way. Such an integrated approach has been termed *conjunctive water management* (Hughes and Gyopari, 2011).

In its simplest application, the term conjunctive water management describes '*the management of hydraulically connected surface water and groundwater resources in a coordinated way, such that the total benefits of integrated management exceed the sum of the benefits that would result from independent management of the surface and groundwater components'* (Sahuquillo and Lluria, 2003).

The term conjunctive water management is used to describe a framework for the management of groundwater allocation in the Wellington Region which recognises the hydraulic connection between groundwater and surface water and enables abstraction of groundwater in a manner that is consistent with environmental flow and water levels established for hydraulically connected surface water resources. A more detailed description of the basic concepts relating to groundwater / surface water interaction is provided in Hughes and Gyopari (2011).

2.2 Principles of the proposed conjunctive management framework for the Wairarapa Valley and Hutt River catchment

The proposed conjunctive management framework developed for the Wairarapa Valley (Hughes and Gyopari, 2011) and Hutt River catchment (Liquid Earth, 2013) comprises two main components:

1. Management of groundwater abstraction which has a direct or immediate effect on the surface water environment through application of pumping controls based on minimum flow or levels requirements established for hydraulically connected surface water; and

2. Establishment of fixed allocation volumes for individual groundwater management zones that recognise that groundwater abstraction may

cumulatively cause a reduction in river or stream baseflow. These allocation limits will apply where groundwater abstraction does not result in an immediate or direct streamflow depletion effect.

In order to implement the proposed conjunctive management framework, a three-tier management approach is proposed for managing groundwater abstraction according to the potential impact on surface water. The concept of '*hydraulic connectivity*' is utilised to differentiate those groundwater takes[2] which have a direct and immediate effect on surface water from those where there is a considerable lag between pumping and resulting effects on surface water.

Category A: Direct Hydraulic Connectivity

Category A includes areas of the hydrogeological system which exhibit direct connectivity with surface water. Stream depletion effects occur shortly following the commencement of groundwater abstraction, rapidly increase to a level close to the overall pumping rate and dissipate quickly once pumping stops. As a consequence, a high proportion of the overall volume of groundwater pumped from Category A areas effectively represents induced flow loss from local surface waterways. Due to the immediacy of impact, groundwater abstraction from Category A aquifers can be considered analogous to direct surface water abstraction and managed in terms of the environmental flow and water level regimes established for hydraulically connected surface waterbodies.

Category B: High Hydraulic Connectivity

Category B includes those areas of the hydrogeological system where groundwater abstraction effects on surface water may be significant and can potentially be managed through the application of pumping controls depending on localised hydrogeological conditions (e.g. local aquifer hydraulic parameters, abstraction rate and location of pumping with respect to surface waterbodies) and the rate of abstraction. This category represents the transition between direct and indirect effects on stream flow resulting from groundwater abstraction.

Category C: Moderate Hydraulic Connectivity

The Category C classification applies to those areas of the hydrogeological system where groundwater abstraction may contribute to an overall reduction in baseflow discharge at a catchment scale but where active regulation of pumping does not provide effective mitigation of potential effects on surface water. Cumulatively, these takes are more appropriately managed at a catchment or sub-catchment scale through the establishment of volumetric abstraction limits.

The hydraulic connection between any point in an aquifer system and a nearby hydraulically connected surface water body depends on a wide range of factors including the hydraulic characteristics of the intervening aquifer and streambed materials and the distance from the waterbody. Characterisation of the spatial

[2] In the context of this report the term 'take' is typically used to describe a pumping from a single well or water permit. The term 'abstraction' is generally utilised to describe cumulative groundwater pumping across an individual groundwater management zone.

and depth distribution of the various hydraulic connection categories is therefore a key component of the proposed conjunctive management framework.

In the Wairarapa Valley, this process involved detailed investigations and analysis of the regional hydrogeological setting assisted by the development and application of numerical groundwater models over a six year period (Hughes and Gyopari, 2011). A similar process was utilised to characterise the spatial variability in hydraulic connectivity across the Kapiti Coast for this report using the conceptual and numerical groundwater models developed by Gyopari *et.al* (2012).

2.2.1 Management of groundwater-surface water interaction

Under the proposed conjunctive management framework areas of the hydrogeological system where there is a direct hydraulic connection with surface water (identified as *Category A*) it is proposed that groundwater abstraction will effectively be managed as equivalent surface water abstraction. In those areas where there is a moderate to low hydraulic connection (*Category C*), groundwater abstraction will be managed in terms of a groundwater allocation volume established to limit the maximum cumulative depletion of baseflow at a catchment (or sub-catchment) scale. In intervening areas (*Category B*) it is proposed to manage groundwater abstraction through a combination of temporal pumping restrictions (i.e. river and stream minimum flow cut-offs) and groundwater allocation determined on the basis of local hydrogeological conditions and abstraction rates.

The following section provides a summary of the management controls for each hydraulic connection category. A more comprehensive description of the proposed management controls (including justification for the arbitrary thresholds adopted) is provided in Hughes and Gyopari (2011).

Category A

Category A defined the area within which groundwater abstraction is effectively managed as part of the environmental flow and water level regime established for relevant hydraulically connected surface water bodies. This category effectively encompasses the portion of the hydrogeological system which exhibits a direct and immediate hydraulic connection with surface water.

Spatial Definition	Generally limited to the Q1 gravel aquifers along the riparian margins of the major rivers systems.
Application	All groundwater takes which require resource consent (i.e. excludes permitted uses under RMA s14(b) and abstraction categorised as a permitted activity under the Natural Resources Plan).
Pumping Regulation	Groundwater takes requiring resource consent will be subject to minimum flow or water level controls set for hydraulically connected surface water bodies.

Allocation — Groundwater abstraction from Category A aquifers will be included in the primary allocation for hydraulically connected surface water based on the average weekly rate of groundwater abstraction.

Assessment Requirements — No specific assessment of stream depletion is required unless an applicant wishes to advance a case that the degree of hydraulic connection for an individual groundwater take does not meet criteria requiring application of minimum flow criteria. However, all takes will be assessed in terms NRP Policies relevant to other environmental effects such as well interference effects and saline intrusion.

Category B

Category B includes those components of the hydrogeological system which exhibit a moderate to high degree of connectivity with surface water but where application of pumping regulation may or may not provide effective mitigation of stream depletion effects depending on both local hydrogeological conditions and the rate of groundwater abstraction. The management regime for Category B can be summarised as:

Spatial Definition — The spatial extent of Category B has been determined for each water management zone based on observed hydrogeological characteristics and modelling of potential stream depletion effects resulting from groundwater abstraction.

Application — All takes with a weekly average abstraction rate **>5 L/s** require assessment of potential stream depletion effects.

Pumping Regulation — Groundwater takes from Category B areas will be subject to minimum flow or water level controls (based on those established for hydraulically connected surface water bodies) when the calculated stream depletion effect exceeds **60 percent (i.e. $q/Q>0.6$)** of the seasonal average pumping rate

Allocation — Calculated stream depletion effect from those takes subject to minimum flow control will be included in primary allocation for relevant hydraulically connected surface waterbodies with the balance of seasonal allocation counted as part of the total groundwater allocation for the relevant water management zone. Remaining takes (including those with a weekly average rate of take <5 L/s) will be counted as part of the total groundwater allocation for the relevant groundwater management zone.

Assessment Requirements — Hydrogeological assessment of potential stream depletion utilising relevant numerical or analytical modelling techniques based on the cumulative (direct) stream depletion effect on hydraulically connected surface water. Assessment of stream depletion effects should be based on continuous abstraction at the long-term average abstraction rate being sought.

Category C

The final component of the proposed conjunctive water management framework for the Wairarapa Valley is designated as Category C. This classification includes those components of the hydrogeological system which exhibit a moderate to low degree of connectivity with surface water where application of pumping regulation is unlikely to provide mitigation of stream depletion effects during low flow periods. These are assigned volumetric allocation limits that take account of the potential effects of groundwater abstraction on river or stream baseflow at a catchment scale.

3. Application of the conjunctive management framework to the Kapiti Coast

The Kapiti Coast encompasses the narrow coastal plain that extends along the western margin of the Tararua Range, from the northern boundary of the Wellington Region near Manakau to Paekakariki in the south. The area is predominantly flat-lying, with extensive urban development across the southern section of the coastal plain in the vicinity of Waikanae and Paraparaumu.

The Kapiti Coast contains a diverse range of hydrogeological settings hosted in a complex geological environment. The groundwater resources of the area have high environmental and cultural value in sustaining freshwater ecosystems and contribute to important economic and social values associated with the use of water for domestic, municipal, industrial and agricultural water supplies. In addition, remaining wetland areas on the coastal plain represent small remnants of the extensive lowland ecosystems which covered the area prior to European settlement. As a consequence, many of these groundwater dependent ecosystems (GDE's) have high ecological value.

The Kapiti Coast is traversed by two major river systems (the Otaki and Waikanae rivers) which drain the western slopes of the Tararua Range as well as numerous small streams which drain the Tararua foothills. While the Kapiti Coast typically experiences reliable rainfall, extended periods of low rainfall may occur, particularly during late summer and autumn. During these low rainfall periods flows in many of the smaller rivers and streams fall to relatively low levels, placing appreciable stress on environmental values associated with these water bodies. Pressure on water resources during low flow periods is exacerbated by water abstraction, particularly for municipal supply.

In many areas, available information indicates a significant degree of interaction between groundwater and surface water, particularly adjacent to the major river systems and along the coastal margin. As a consequence, groundwater abstraction in some areas has the potential to contribute to both local-scale and cumulative adverse effects on surface water environments.

In addition, hydrogeological information indicates that the groundwater resources contained in the alluvial sediments of the coastal plain form a stratified, semi-confined (leaky) aquifer system. As a consequence, abstraction of groundwater from deeper water-bearing layers has the potential to affect surface water features (e.g. streams, wetlands and lakes) which are hydraulically connected to shallow unconfined aquifers.

The following section provides an overview of the conceptual model of groundwater/ surface water interaction on the Kapiti Coast which to provides a basis for the application of the proposed conjunctive management framework to this area.

3.1 Hydrogeological setting

Gyopari, Mzila and Hughes (2012) provides a detailed description of the conceptual hydrogeological model for the Kapiti Coast. In summary, this analysis indicates that groundwater occurs in three distinctive hydrogeological settings, each with a characteristic pattern of groundwater/surface water interaction:

- Shallow unconfined Holocene (Q1) sand aquifers along the seaward margin of the coastal plain. These unconfined aquifers exhibit significant interaction with lowland streams and wetlands on the coastal plain;

- Shallow, moderate to highly permeable unconfined aquifers hosted in recent (Q1) alluvium adjacent to rivers and streams draining the Tararua Range. These unconfined aquifers exhibit a high degree of hydraulic connection to the major river systems draining across the coastal plain; and

- Semi-confined and confined aquifers occurring within the late Quaternary fluvioglacial outwash gravel sand and gravel deposits (Q2-Q8) underlying a majority of the coastal plain. These aquifer system exhibit a degree of hydraulic connection to overlying unconfined aquifers.

Figure 3.1 shows a simplified geological map of the Kapiti Coast area.

Available groundwater level and flow gauging information reflect the range of interconnection between groundwater and surface water in the various hydrogeological environments across the Kapiti Coast. For example:

- The larger rivers (Waikanae River, Otaki River and Waitohu Stream) lose water to the surrounding Q1 gravel aquifers downstream of their emergence from the Tararua foothills with some baseflow discharge occurring in their lower reaches. Several larger spring-fed streams (Waimeha Stream, Waimanu Stream and Rangiuru Stream) carry appreciable discharge from the margins of the Q1 alluvial aquifer systems in the Otaki and Waikanae groundwater zones. Groundwater levels in these aquifers tend to exhibit a hydrograph response which follows temporal variations in river stage reflecting their high permeability and hydraulic connection to surface water;

- Lowland streams on the coastal plain receive appreciable baseflow discharge from the Q1 sand aquifer. Some (although not all) wetland areas along the coastal margin also exhibit interconnection with the surrounding unconfined Q1 sand aquifer. Temporal water level variation in these aquifers tends to follow a distinct seasonal variation reflecting a combination of their relatively low permeability and temporal variations in rainfall recharge;

- Aquifers hosted within older Quaternary sediments (Q2, Q4 and Q6) typically exhibit limited direct interconnection with surface water. However, groundwater levels in these aquifers typically exhibit a relatively uniform seasonal variation (particularly in deeper water-bearing intervals) indicating a degree of interconnection with overlying aquifers[3].

Figure 3.2 shows a map of surface water environments on the Kapiti Coast which show some degree of interconnection with surrounding groundwater resources.

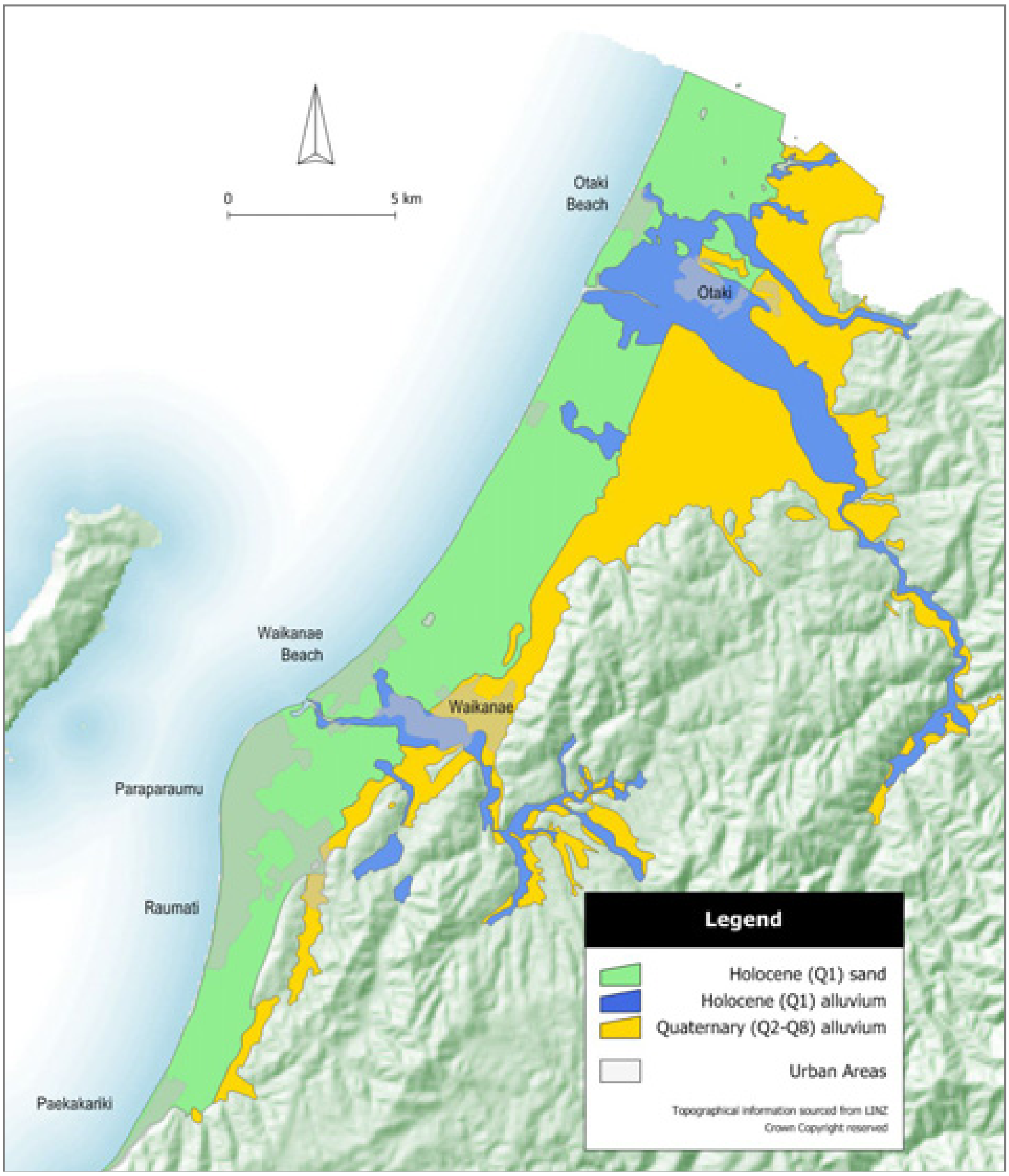

Figure 3.1: Simplified geological map of the Kapiti Coast (adapted from GNS Wellington QMap coverage). The figure shows the spatial distribution of the Q1 sand deposits (green) along the coastal margin, the Q1 alluvium along the margins of the Otaki River, Waikanae River and Waitohu Stream (blue) as well as the older Quaternary sand and gravel sediments (yellow) which form a succession of alluvial terraces along the western margin of the Tararua foothills and extend westwards toward the coastal underneath the younger Q1 sand and gravel materials.

[3] This hydraulic connection is also demonstrated by the drawdown frequently observed in shallow aquifers in response to extended duration abstraction from deeper semi-confined water-bearing layers.

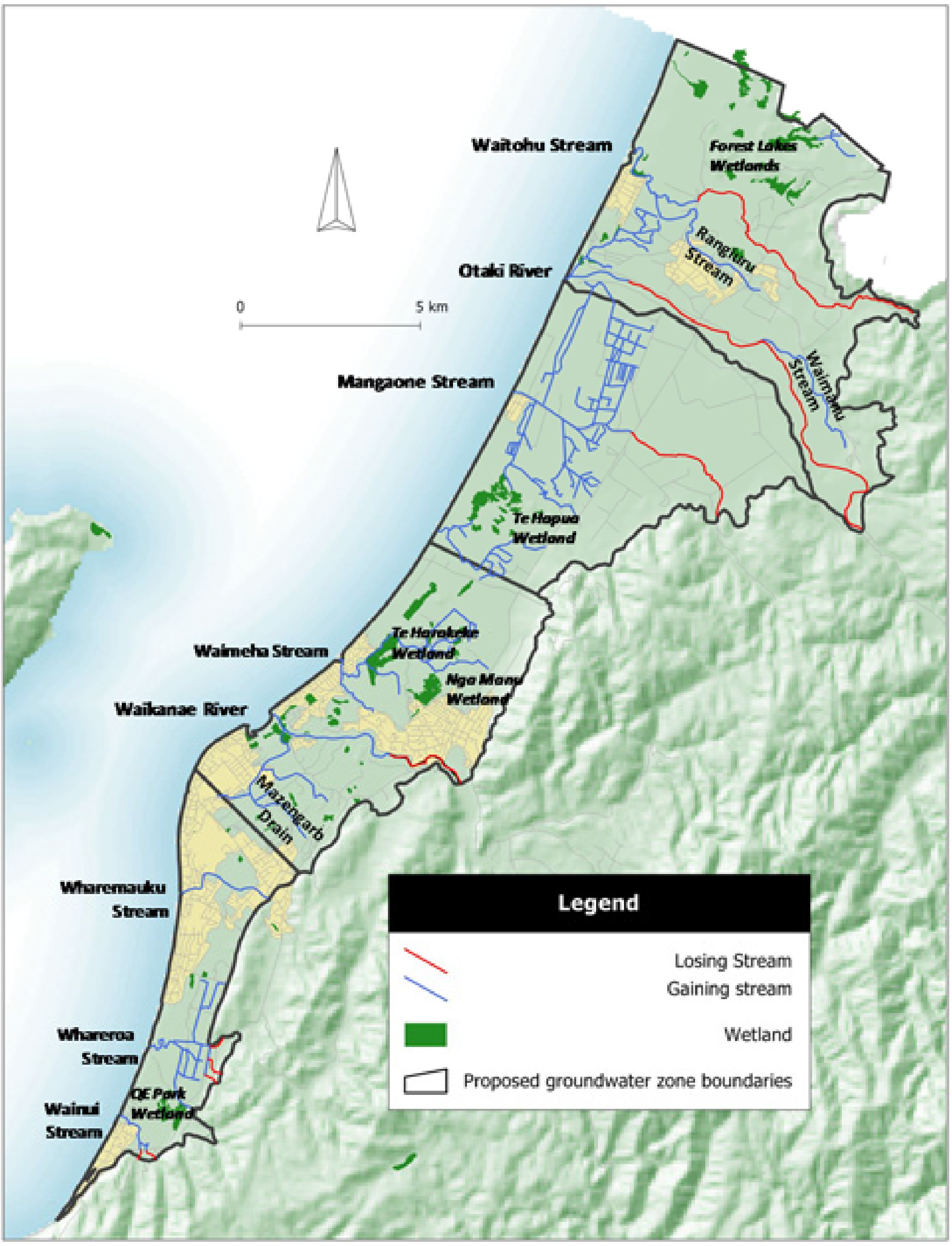

Figure 3.2: Spatial distribution of gaining and losing streams and major wetlands on the Kapiti Coast

3.1.1 Hydraulic connectivity zones

The geographic distribution of Category A and Category B classifications is shown in **Figure 3.3** below. The figure shows a majority of the Kapiti Coast is classified as Category B, except for relatively small areas of Q1 gravels extending to a depth of 20 metres adjacent to the Waitohu Stream, Otaki River, Waikanae River and Waimeha Stream which are classified as Category A. Delineation of these zones is based on the conceptual hydrogeological model developed by Gyopari *et al.* (2012) which has been refined and validated by the numerical model analysis outlined in Appendices A to D of this report.

The Category A classification applied to areas along the riparian margin of the major river systems reflects the highly permeable nature of the associated Q1 gravels and the observed extent of groundwater/surface water interaction along these waterways described in Gyopari *et al.* (2012). This high degree of hydraulic connection between the Q1 alluvium and adjacent surface water resources is validated by numerical modelling of various abstraction scenarios.

The Category B classification proposed for a majority of groundwater resource on the Kapiti Coast reflects the stratified nature of the alluvial materials comprising the coastal plain which effectively comprise a single stratified leaky (semi-confined) aquifer system. As demonstrated by numerical modelling, groundwater abstraction from deeper water-bearing layers on the coastal plain results in vertical leakage from overlying aquifers. As a consequence, groundwater abstraction from any depth has the potential to result in the drawdown of groundwater levels in the shallow unconfined aquifer which in turn is hydraulically connected to streams and wetlands. As a consequence, the Category C classification applied by Hughes and Gyopari (2010) to deeper (nominally) confined aquifers in the Wairarapa Valley is not relevant to the Kapiti Coast.

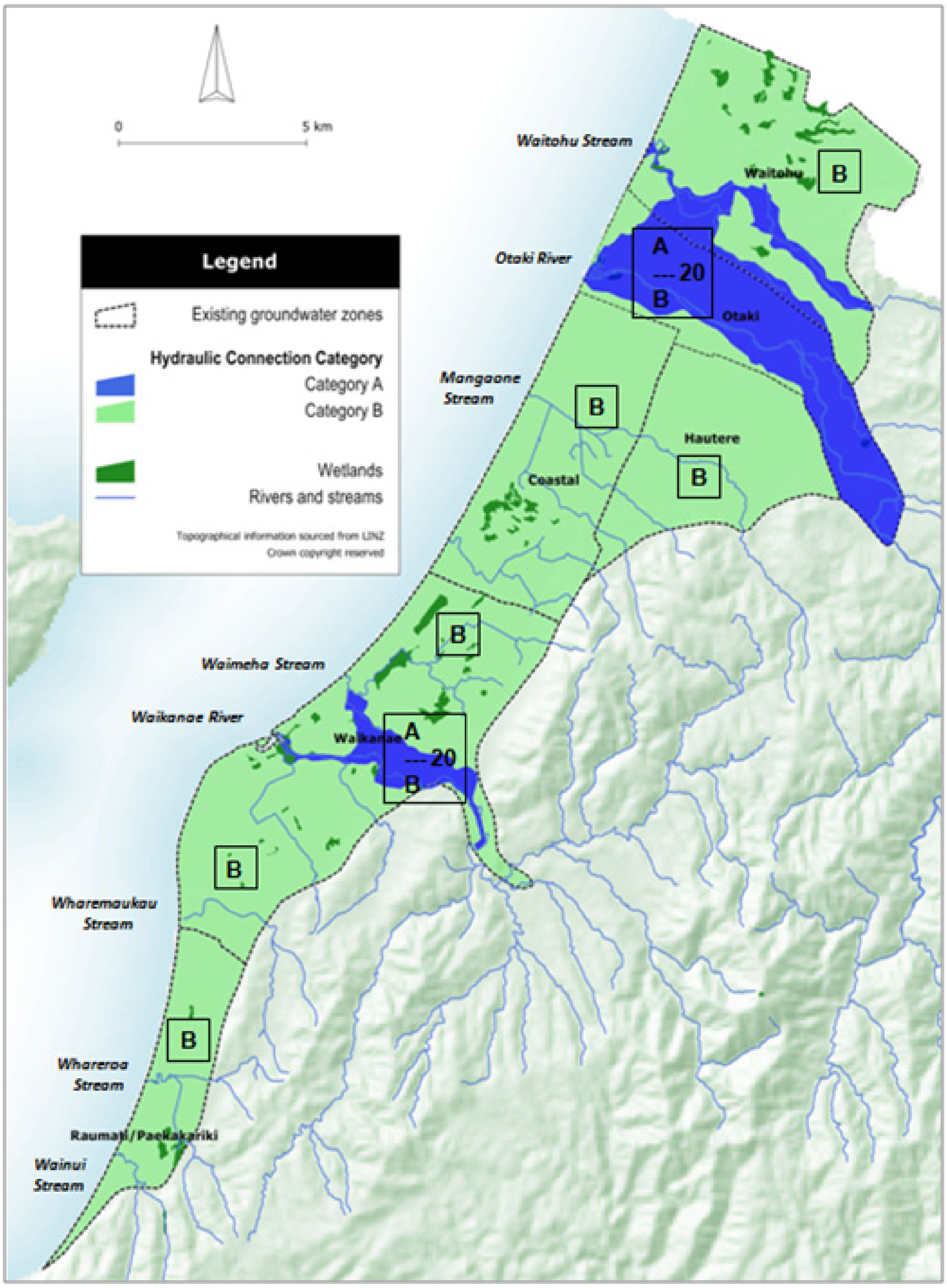

Figure 3.3: Spatial and depth distribution of proposed hydraulic connectivity zones for the Kapiti Coast

3.2 Complimentary groundwater resource management considerations

As outlined in **Section 2** of this report, the proposed conjunctive management framework (Hughes and Gyopari, 2010) was developed to suit the hydrogeological setting of the Wairarapa Valley where, due to a combination of geology and geography, groundwater occurs in a series of three closed basins. In these areas, all recharge from rainfall or river flow loss eventually exits the aquifer system via baseflow to the Ruamahanga River and tributaries. As a consequence, abstraction of groundwater ultimately results in a reduction in baseflow discharge from the aquifer system. The proposed conjunctive management framework was established to manage the localised and cumulative effects of groundwater abstraction on surface water flows.

In contrast, the groundwater resources of the Kapiti Coast are hosted in a narrow coastal aquifer system. In this hydrogeological setting, recharge from rainfall or river flow loss either discharges to surface water features (including rivers, streams, wetlands and lakes) along the coastal margin or discharge offshore via diffuse leakage. The throughflow of groundwater is an important consideration for groundwater resource management on the Kapiti Coast as it acts to prevent the landward movement of saline water into aquifers underlying the coastal plain (a process termed *saline intrusion*). Groundwater also plays an important role in sustaining the ecology of wetland areas occurring on the coastal plain.

Therefore, while management of the cumulative effects of groundwater abstraction on surface water baseflow is an important consideration on the Kapiti Coast, sustainable management of the groundwater resource also has to take into account both localised and cumulative effects in terms of:

- Preventing saline intrusion into coastal aquifers
- Avoiding adverse effects on significant wetland areas

3.2.1 Saline intrusion

The aquifers underlying the coastal plain on the Kapiti Coast are typical in that they exhibit a gradational boundary between the freshwater contained in terrestrial aquifers and the saline water present in offshore sediments. The shape and position of this boundary is a function of the volume of freshwater flowing through the aquifer. Under natural conditions this boundary normally occurs seaward of the coastal margin extending further inland with depth as shown in **Figure 3.4**[4]. This vertical gradation reflects the density contrast between fresh water and sea water which contains high concentrations of dissolved ions[5].

[4] Although illustrated as a sharp boundary, the interface between fresh groundwater and seawater is gradational (commonly referred to as the 'saline interface)

[5] The density of sea water is typically between 2 to 3 percent higher than fresh water (1,020 to 1,030 kg/m^3 compared to 1,000 kg/m^3 for fresh water)

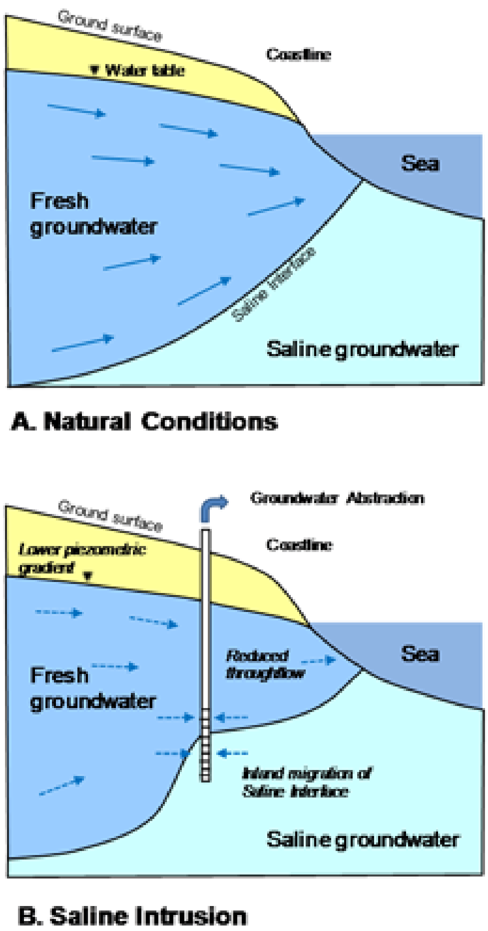

Figure 3.4: Schematic illustration of saline intrusion in a coastal aquifer

Changes to the volume of groundwater throughflow in a coastal aquifer due to groundwater abstraction will result in a change in the position of the saltwater-freshwater boundary. Significant groundwater abstraction from coastal aquifers has the potential to result in inland migration of the saline interface resulting in a net reduction in water quality in wells along the coastal margin.

The two primary mechanisms utilised to manage the risk of saline intrusion in coastal aquifer systems are:

- Establishment of a fixed groundwater allocation volumes which ensures adequate through-flow is maintained to mitigate saline intrusion risk; or

- Maintenance of a minimum piezometric level at the coast

Both options are considered relevant to ensure the sustainable management of groundwater resources on the Kapiti Coast. Coastal drawdown (and associated potential for saline intrusion) is considered in the determination of the proposed groundwater allocation volumes listed in **Section 4.2** of this report. However, the magnitude of drawdown occurring at the coast for any given volume of allocation is at least partly dependent on the location of pumping. Obviously, groundwater abstraction closer to the coast increases the potential for saline intrusion to occur due to localised drawdown effects. Specification of a minimum coastal groundwater level provides a means to ensure the risk of saline intrusion is either avoided or appropriately mitigated for any possible pumping configuration.

It is therefore proposed that a policy be established in the Natural Resources Plan which classifies activity status for individual groundwater takes as follows:

- Any groundwater take (in conjunction with all other lawfully established groundwater takes) resulting in groundwater levels at the coastal margin falling below 2 m asl is classified as *discretionary* activity in the Natural Resources Plan
- Any groundwater take (in conjunction with all other lawfully established groundwater takes) resulting in groundwater levels at the coastal margin falling below 1 m asl is classified as a *non-complying activity* in the Natural Resources Plan

The suggested policy would ensure that the risk of saline intrusion associated with localised drawdown resulting from individual groundwater takes is appropriately managed, either through avoidance of significant drawdown at the coast or application of appropriate mitigation.

3.2.2 Wetlands

Wetlands are a significant component of the hydrology of the Kapiti Coast, particularly along the seaward margin of the coastal plain. The potential for groundwater abstraction to adversely impact on hydraulically connected surface water bodies (including wetlands) has been recognised by classification of a majority of coastal plain as Category B.

Jones and Gyopari (2005) recommended the establishment of a 150 metre buffer zone around '*significant*' wetland areas to regulate groundwater abstraction and drainage by the way of the following rules suggested for inclusion in the NRP:

- Rule 1: Any groundwater abstraction of <20 m^3/day within the buffer zone is a *discretionary* activity
- Rule 2: Any groundwater abstraction of >20 m^3/day within the buffer zone is a *non-complying* activity
- Rule 3: The construction of construction of new drains, dewatering systems or the diversion of surface water within the buffer zone is a *non-complying* activity.

Work undertaken by Allen (2010) described various 'types' of wetlands on the Kapiti Coast which have differing sensitivity to the potential effects of groundwater abstraction, with some effectively disconnected from the underlying water table (i.e. perched) and therefore potentially unaffected by drawdown resulting from groundwater abstraction. However, implementation of buffer zones would enable a relatively simple mechanism to manage potential effect of groundwater abstraction on wetland areas which, on the Kapiti Coast, include some regionally significant ecological domains.

However, the proposed buffer zones would not necessarily protect wetland areas from drawdown resulting from groundwater abstraction resulting from larger groundwater takes either screened in the shallow unconfined Holocene sand aquifer outside the 150 metre buffer zone or in underlying semi-confined aquifers. Modelling of groundwater abstraction scenarios outlined in Appendix A to D clearly shows that regardless of location, groundwater abstraction from deeper aquifers on the Kapiti Coast has the potential to result in drawdown of water levels in the shallow coastal aquifer systems which host significant wetland areas across the Kapiti Coast. This observation is supported by recent water level monitoring which indicates the potential for drawdown in shallow aquifer in the Waikanae area in response to large-scale abstraction for the KCDC Waikanae River Recharge Project.

Work undertaken for the MacKays to Peka Peka Expressway Project included detailed assessment of the ecology of wetland areas located along the Expressway alignment. This assessment, while not covering the entire coastal plain (for example, the Te Hapua wetland complex at Peka Peka was not within the scope of the assessment) highlighted the sensitivity of high value wetland areas to relatively small changes in natural groundwater levels. Technical Report 26 (Ecological Impact Assessment) prepared for the project (NZTA, 2012) undertook a detailed evaluation of terrestrial ecology between QE Park and Peka Peka Road and concluded that in significant wetland areas:

In our view reductions in groundwater levels of 20cm would have significant adverse effects on a wetland. A reduction of 5cm is less likely to have a measurable effect[6]

Assessment of potential effects on wetland hydrology and ecology associated with the MacKays to Peka Peka Expressway Project were primarily focussed on long-term changes to wetland hydrology due to construction effects (e.g. changes in land contour and replacement of natural soil materials) rather than shorter-term effects associated with groundwater abstraction. It is therefore considered that a drawdown of 0.2 metres represents an appropriate threshold for the management of cumulative effects of groundwater abstraction over the short to medium-term to avoid significant adverse effects on wetland areas. It is however recognised that in certain circumstances it may be appropriate to manage groundwater abstraction to restrict cumulative drawdown effects to a lesser magnitude[7].

Specification of a maximum cumulative drawdown resulting from groundwater abstraction effectively replaces the wetland buffer proposed by Jones and Gyopari (2005) as it manages effects of groundwater abstraction regardless of location. However, given the high value of these environments and their

[6] Ecological Impact Assessment, Page 125

[7] For example, it is noted that the *Proposed National Environmental Standards on Ecological Flows and Water Levels* (MfE, 2008) identified an interim limit for wetland water levels of '*No change in water levels, beyond the water level variation that has already been provided for by existing resource consents....*"

susceptibility to relatively minor hydrogeological changes it is recommended that restriction on drainage activities proposed by Jones and Gyopari (2005) is retained.

It is therefore proposed that a policy be established in the Natural Resources Plan which classifies activity status for groundwater abstraction (and land drainage activities) as follows:

- Any groundwater take which results in the cumulative drawdown in the unconfined aquifer within 150 metres of a significant wetland exceeding the natural range of groundwater level variation is classified a *discretionary* activity

- Any groundwater take which results in the cumulative drawdown in the unconfined aquifer within 150 metres of a significant wetland exceeding 0.2 metres of the natural range of groundwater level variation is classified a *non-complying* activity

- The construction of construction of new drains, dewatering systems or the diversion of surface water within 150 metres of a significant wetland is a *non-complying* activity

3.2.3 Localised stream depletion effects

Under the conjunctive management framework proposed for the Wairarapa Valley (Hughes and Gyopari, 2010), groundwater takes from areas classified as Category B are managed solely as groundwater takes where q/Q <0.6 and the rate of stream depletion is less than 10 L/s (calculated using the seasonal average abstraction rate). While this approach is reasonable in the Wairarapa Valley where a majority of streams potentially affected by groundwater abstraction are relatively large (e.g. a MALF of 250 L/s or higher), low flow discharge in many streams draining the coastal plain on the Kapiti Coast is much lower.

In order to ensure appropriate protection of stream ecology in these smaller streams, it is recommended that the criteria for application of pumping regulation on Category B groundwater takes be amended to include additional criteria of greater than 10% of MALF in streams with a MALF less than 100 L/s as follows:

Groundwater takes from Category B areas will be subject to minimum flow or water level controls (based on those established for hydraulically connected surface water bodies) when the calculated stream depletion effect exceeds 60 percent (i.e. q/Q > 0.6) of the seasonal average pumping rate or is greater than:

- 10 L/s in streams with a MALF greater than 100 L/s

- 10% of MALF in streams with a MALF less than 100 L/s

The main surface waterways (e.g. Waitohu Stream, Otaki River, Mangaone Stream and Waikanae River) have a MALF figures exceeding 100 L/s so the modified criteria would typically apply to smaller streams draining the coastal plain (with the possible exception of the Waimeha Stream)[8].

It is also noted that in the absence of specific allocation criteria for individual rivers and streams, GWRC utilises the proposed interim allocation limits specified in MfE (2008) of:

- 30% of MALF for rivers and streams with mean flows of less than or equal to 5 m^3/s
- 50% of MALF for rivers and streams with mean flows greater than 5 m^3/s

These allocation limits were utilised as a guide to manage establishing cumulative groundwater allocation in the Wairarapa Valley following the methodology adopted by Hughes and Gyopari, 2011). Similar criteria have been adopted for establishing cumulative groundwater allocation for individual groundwater management zones in this report as outlined in Appendix A to D[9].

3.3 Summary

The conjunctive management framework proposed by Hughes and Gyopari (2010) for the Wairarapa Valley provides a mechanism to manage both the localised and cumulative effects of groundwater abstraction on surface water flows. The proposed hydraulic connectivity zonation classifies restricted areas of highly permeable Q1 alluvium along the margins of the Waitohu Stream, Otaki River and Waikanae River as Category A. All other areas of the groundwater system are classified as Category B to reflect the overall ‘leaky’ nature of the groundwater system.

Sustainable management of the groundwater resources in this area also requires consideration of other management criteria including saline intrusion and effects on significant wetlands. Specific policies are proposed for the Kapiti Coast to manage these effects in a manner consistent with the proposed conjunctive management framework.

[8] Although it is noted that many of these streams have insufficient gauging data to reliable quantify MALF other than on a regionalised (i.e. catchment area) basis

[9] Note these criteria are separate from that use to determine the applicability of pumping regulation to small streams (i.e. effect <10% of MALF where MALF <100 l/S)

4. Recommendations for groundwater allocation

The following section provides an overview of the recommended approach for applying the conjunctive management framework to the Kapiti Coast.

4.1 Groundwater allocation zones

For the purposes of resource management WRC (1994) divided the Kapiti Coast into six groundwater management zones. These zones group areas of similar hydrogeological characteristics on the basis of landform, subsurface geology, hydraulic properties, and aquifer chemistry and are currently used as the primary units for groundwater allocation in the Natural Resources Plan (NRP).

Refinement of the regional conceptual hydrogeological model by Gyopari, Mzila and Hughes (2012) identified several areas where the boundaries of the existing groundwater management zones appear to be relatively arbitrary and do not necessarily reflect the spatial and depth distribution of specific hydrogeological environments. Re-analysis of the overall framework for groundwater allocation resulted in the rationalisation of the six existing groundwater management zones into the four revised zones illustrated in **Figure 4.1** below. The proposed zones include:

- **Otaki groundwater zone** - this zone amalgamates the existing Otaki and Waitohu zones to better reflect the extent of Q1 gravels associated with the Otaki River and Waitohu Stream as well as the underlying geology where older Q5 and Q6 deposits are exposed at the ground surface due to the regional tilt of sediments infilling the South Wanganui Basin. The proposed zone boundary is also modified to better reflect the extent of Quaternary sediments along the Tararua foothills (following the extent of greywacke basement exposure defined on the Wellington QMap coverage).

  Combining of the existing Otaki and Waitohu groundwater zones into a single management unit is intended to reflect the lack of a distinct hydraulic boundary between these areas. However, slightly modified versions of these zones have been retained as sub-zones to reflect the differing nature of groundwater/surface water interaction in the Otaki River and Waitohu Stream catchments.

- **Te Horo groundwater zone** - this zone combines the existing Hautere and Coastal groundwater zones. This recognises the continuity of the Quaternary gravel deposits comprising the Hautere Plain under the Holocene (Q1) sand deposits along the coastal margin. The revised groundwater zone boundary along the eastern side of the Hautere Plain also follows the extent of greywacke basement defined on the QMap coverage. The northern boundary is slightly modified to more accurately reflect the geological transition to Q1 alluvium in the Otaki Valley and the southern boundary is shifted slightly north of the current boundary with the Waikanae groundwater zone.

- **Waikanae groundwater zone** - this zone essentially remains the same as the current zone with relatively minor adjustments to the zone boundaries. These adjustments include:

  - a slight shift and re-alignment of the northern boundary to finish at the greywacke exposure on the northern side of Hadfield Road to reflect the approximate southerly extent of the Otaki fan and better align with assumed groundwater flow directions (e.g. Kampman and Caldwell, 1983) rather than Peka Peka Road;

  - truncation of the groundwater zone boundary near the start of the Reikorangi Valley to reflect the exposure of greywacke basement in the bed of the Waikanae River near this location; and,

  - movement and re-alignment of the southern boundary to better reflect the southerly extent of the Waikanae River alluvial fan (based on bore logs) and the alignment of the flow divide between Wharemakau Stream and Mazengarb Drain indicated by piezometric contours (GWRC, 2005);

  - The **Raumati groundwater zone** essentially remains the same as the current Raumati-Paekakariki zone with the modifications to the northern boundary with the Waikanae zone as listed above and amendments to the eastern boundary to follow the QMap greywacke basement exposure.

It is noted that the proposed groundwater management zones do not necessarily denote hydraulically separate components of the regional groundwater system. Rather most zones have 'soft' boundaries based on hydraulic divides or key geological and/or hydrogeological changes in the water-bearing strata. It is noted that analysis of numerical model results (including those outlined in Appendix A to D) indicate that the magnitude of cross boundary effects for the pumping scenarios analysed[10] is relatively minor.

[10] E.g. assuming abstraction is relatively evenly distributed across one or more groundwater zones.

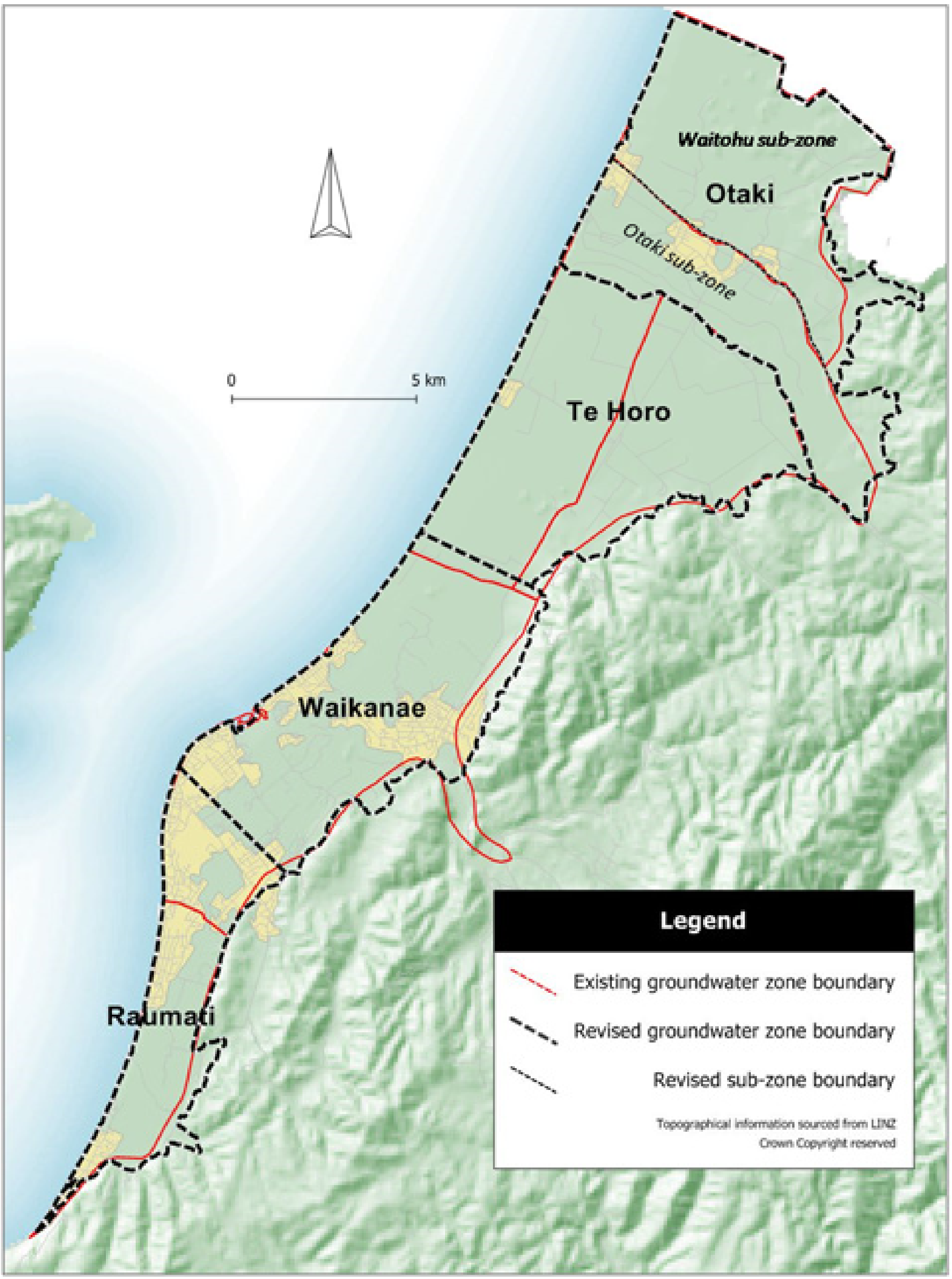

Figure 4.1: Proposed groundwater management zones for the Kapiti Coast

4.2 Groundwater allocation

Appendices A to D of this report outline results of a range of pumping scenarios run on the numerical groundwater model developed for the Kapiti Coast (Gyopari *et al.* 2012) to evaluate sustainable groundwater allocation options for each groundwater management zone. The model scenarios utilise an iterative process to identify an optimum sustainable groundwater allocation volume based on an evaluation of model results against three primary management criteria which include:

- Changes in total modelled surface water discharge (i.e. cumulative effects on baseflow);

- Drawdown at the coast (i.e. saline intrusion potential); and
- Drawdown in the unconfined aquifer underlying the coastal plain; (i.e. potential effects on significant wetlands).

The modelling process is illustrated in **Figure 4.2** below and details of the optimisation process provided in the Appendices A to D.

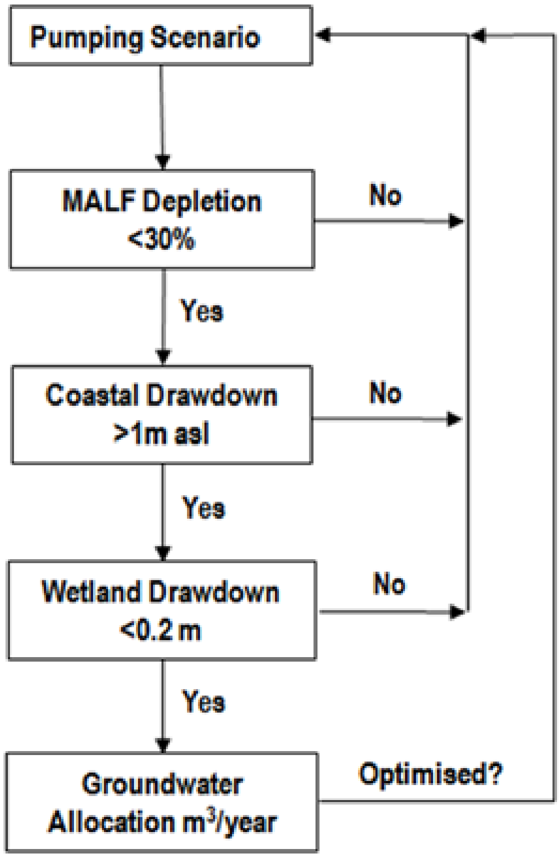

Figure 4.2: Schematic illustration of the iterative modelling process utilised evaluate pumping scenarios and determine groundwater allocation limits

The recommended allocation volume for each groundwater zone represent a volumetric limit for groundwater abstraction based on an assumption that pumping is relatively evenly distributed across the zone. In reality, groundwater abstraction is likely to be concentrated in localised areas, in which case the recommended policies for managing saline intrusion, localised stream depletion effects and impacts on significant wetland areas (outlined in **Section 3**) may become the factors which ultimately constrain allocation for individual groundwater takes rather that the cumulative allocation volume. This is particularly relevant as the boundaries of the revised groundwater zones are essentially arbitrary divisions (albeit based on physical features or observed changes in subsurface geology) within a continuous flow system. In this case of large takes situated near groundwater zone boundaries, the need to apportion groundwater allocation between adjacent zones is best determined through the resource consent assessment process

The following sections provide an outline of the proposed application of the conjunctive water management framework to each groundwater zone including the management recommendations outlined in **Section 3,** as well as the sustainable groundwater allocation determined from groundwater modelling results.

4.2.1 Otaki groundwater zone

The Otaki groundwater zone extends across the coastal plain from the southern margin of the Otaki River valley to the northern boundary of the Wellington Region, combining the existing Otaki and Waitohu groundwater zones. To the east of SH1 the southern boundary of the Otaki groundwater zone follows the prominent river terrace that forms a hydraulic divide between the Q2 gravels of the Hautere Plain and the Q1 alluvium of the Otaki River floodplain. To the west of SH1 this boundary becomes less well defined, particularly near the coast where it is partially obscured by Holocene sand deposits. The eastern boundary follows the approximate contact between the Q5 and Q6 alluvial terraces (and associated alluvial fans) and the greywacke bedrock of the Tararua foothills.

Primary surface water features in the Otaki groundwater zone include the Otaki River and the Waitohu Stream. Both streams exhibit significant interaction with the adjacent unconfined aquifer, losing water downstream of their emergence from the Tararua foothills and gain appreciable baseflow in their lower reaches. Some smaller spring-fed streams also occur on the Otaki River floodplain including Waimanu Stream east of SH1 and Rangiuru Stream which drains into the Otaki River near Otaki Beach.

Although the groundwater resource in the Q1 gravels and underlying Q5/Q6 alluvium are laterally continuous across the zone (essentially forming a single groundwater resource), due to the varying nature of groundwater/surface water interaction in the Otaki River and Waitohu Stream catchments, the larger zone is sub-divided into two smaller units (the Otaki sub-zone and Waitohu sub-zone) for groundwater allocation purposes to reflect the differing nature of groundwater / surface water interaction in these catchments.

Figure 4.3 shows an outline of the proposed hydraulic connectivity classification for the Otaki groundwater zone and relevant surface water features. Modelling undertaken to develop groundwater allocation options for the Otaki groundwater zone are detailed in **Appendix A** and summarised in **Table 4.1** below.

Allocation Reference Criteria	• Drawdown at the coastal margin (<1m) • Drawdown in unconfined aquifer in the vicinity of significant wetlands (<200 mm) • Cumulative depletion of surface water discharge (<30% of MALF)
Hydraulic Connectivity	The Category A classification is applied to the entire Otaki sub-zone and the Q1 alluvium along the

Classification

riparian margin of the Waitohu Stream to a depth of 20 m bgl. Groundwater takes from within this classification will be included in the allocation for the relevant surface waterway (either the Otaki River or Waitohu Stream) and subject to the relevant minimum flow.

The Category B classification is applied to the remainder if the Otaki groundwater zone. Allocation criteria for groundwater takes from the Category B area include:

- Assessment of stream depletion effects on adjacent surface waterways. Where q/Q > 0.6 or 10 L/s (or >10% of MALF in the case of small streams) the take will be subject to pumping regulation based on the relevant surface water minimum flow.
- Cumulative drawdown at the coastal margin. Groundwater takes likely to result in the piezometric head falling below 1 m asl will be classified as non-complying activities.
- Drawdown of <0.2m in the shallow unconfined aquifer adjacent to significant wetland areas (particularly in the vicinity of Forest Lakes and the Otaki River mouth).

Recommended Groundwater Allocation

Otaki sub-zone: no groundwater allocation (due to Category A classification managed as part of Otaki River allocation and minimum flow)

Waitohu sub-zone: 1.08 x 10^6 m^3/year (based on maximum allowable wetland drawdown of 200mm)

Table 4.1: Groundwater Allocation Options for the Otaki groundwater zone (recommended option highlighted)

Sub-Zone	**Allocation Reference Criteria**	**Hydraulic Connectivity Classification**	**Groundwater Allocation Options**			
Otaki	• Wetland Drawdown (<0.2m) • Coastal Drawdown (<1 metre)	Category A to all depths	**No groundwater allocation - all groundwater abstraction managed in terms of Otaki River allocation and minimum flows**			
Waitohu	• Wetland Drawdown (<0.2m) • Cumulative MALF depletion for Waitohu zone (<30% MALF) • Coastal Drawdown (<1 metre)	Category A to 20 m in Q1 alluvium Category B elsewhere	MALF Depletion % 8.1 **16.2** 32.0	Wetland Drawdown (m) 0.10 **0.20*** 0.40	Coastal Drawdown (m) 0.10 **0.13** 0.15	Groundwater Allocation (m^3 x 10^6) 0.54 **1.08** 2.16

*Groundwater allocation of 1.08 million cubic meters (6000m3/day over 180 days) is based on maximum allowable wetland drawdown of 200mm. The 7-day MALF for the Waitohu stream is 150 l/s and the maximum permissible depletion is 30% of MALF. The maximum permissible coastal drawdown is 1m. The calculated MALF depletion at the proposed allocation rate is 24.4 l/s (16.2% of MALF). The calculated coastal drawdown at this allocation is 0.13m. The calculations are discussed further in Appendix A (Figure A16 and Table A2).

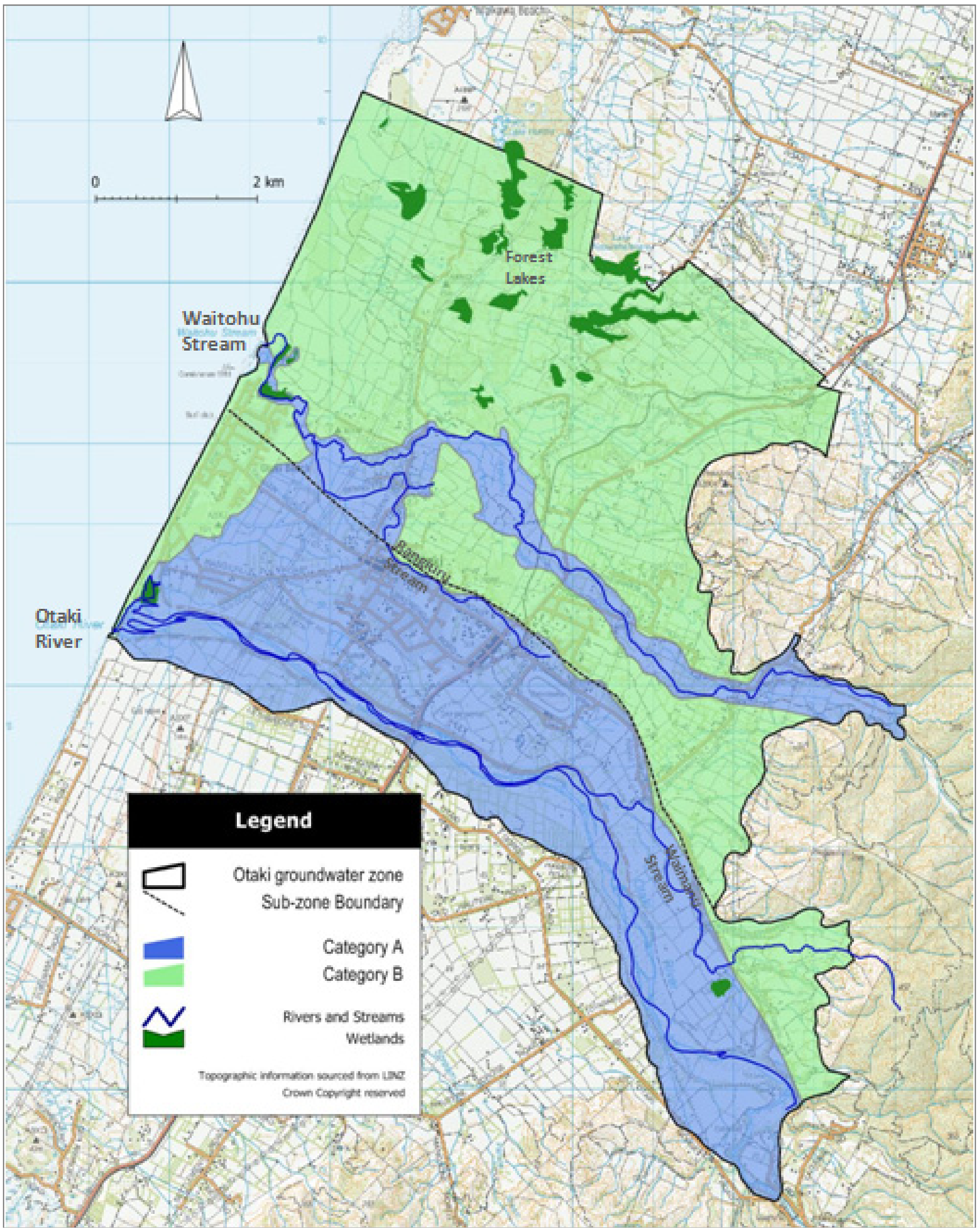

Figure 4.3: Map of the proposed hydraulic connectivity zonation for the Otaki groundwater zone showing the location of significant surface water features and denoting the extent of the Otaki and Waitohu sub-zones

4.2.2 Te Horo groundwater zone

The Te Horo groundwater zone extends across the coastal plain from the Otaki River in the north to a southern boundary running parallel with Peka Peka Road combining the existing Hautere and Coastal groundwater management zones. The eastern boundary follows the contact between the coastal plain and the Tararua foothills.

Groundwater resources in this area are hosted in a thick succession of alluvial gravel materials accumulated on the alluvial fan formed by the Otaki River over the late Quaternary period. These materials host a succession of water-bearing intervals which become increasingly well confined at depth. West of the prominent marine terrace running parallel to SH1 the upper portion of the alluvial materials have been replaced by Holocene sand and gravel deposits up to 35 metres thick accumulated as a result of shoreline progradation over the past 6,500 years forming a shallow unconfined aquifer system.

The primary surface water feature in the Te Horo groundwater zone is the Mangaone Stream which traverses the coastal plain to reach the coast at Te Horo Beach. The Mangaone stream loses water to the underlying unconfined aquifer as it crosses the Hautere Plain and gains flow from the unconfined sand aquifer over its lower reaches. Significant wetland areas occur in the Te Hapua complex located near Peka Peka

Figure 4.4 shows an outline of the proposed hydraulic connectivity classification for the Te Horo groundwater zone and relevant surface water features. Modelling undertaken to develop groundwater allocation options for the Te Horo groundwater zone is detailed in **Appendix B** and summarised in **Table 4.2** below.

Allocation Reference Criteria

- Drawdown at the coastal margin (<1 metre)
- Drawdown in unconfined aquifer in the vicinity of significant wetlands (<0.2m)
- Cumulative depletion of surface water discharge (<30% MALF)
- Allocation from all aquifers (< 30% of LSR)

Hydraulic Connectivity Classification

The entire Te Horo groundwater zone is classified as Category B to reflect the leaky (semi-confined) nature of the deeper water-bearing layers within the alluvial gravel materials and the associated potential for abstraction from all depths to affect water levels and flows in surface water features hydraulically connected to the Holocene sand aquifer. Allocation criteria for groundwater takes from the Te Horo groundwater zone include:

- Assessment of stream depletion effects on adjacent surface waterways. Where q/Q > 0.6 or 10 L/s (>10% of MALF in the case of small streams) the take will be subject to pumping regulation based on the relevant surface water minimum flow. This type of assessment is likely to be of most relevance to shallow groundwater takes in the immediate vicinity of the downstream section of Mangaone Stream (i.e. west of SH1).
- Cumulative drawdown at the coastal margin. Groundwater takes likely to result in a cumulative reduction in piezometric head to less

than 1 m asl at the coast will be classified as non-complying activities.

- Drawdown in the shallow unconfined aquifer adjacent to significant wetland areas (particularly in the vicinity of the Te Hapua complex). This assessment would have to take into account cumulative drawdown resulting from takes in the Waikanae groundwater zone.

Recommended Groundwater Allocation

1.62 x 10^6 m^3/year (based on maximum permissible allocation of 30% LSR)

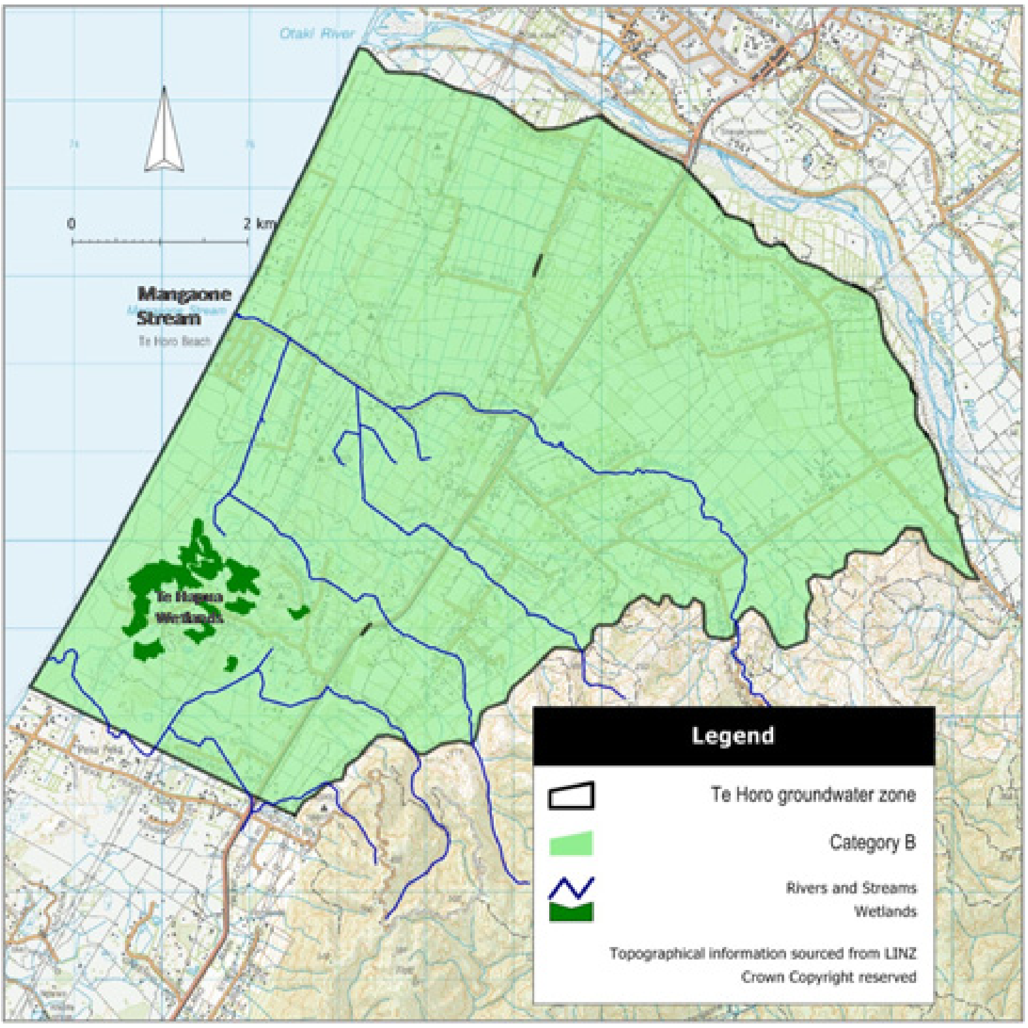

Figure 4.4: Map of the proposed hydraulic connectivity zonation for the Te Horo groundwater zone showing the location of significant surface water features

Table 4.2: Groundwater Allocation Options for the Te Horo groundwater zone (recommended option highlighted)

Allocation Reference Criteria	Hydraulic Connectivity Classification	Groundwater Allocation Options				
		MALF Depletion (%)	Wetland Drawdown (m)	Coastal Drawdown (m)	Allocation (m^3/year x 10^6)	LSR %
• Wetland Drawdown (<0.2m) • Cumulative MALF depletion for Te Horo Zone (<30% MALF) • Coastal Drawdown (<1 metre) • maximum permissible allocation of 30% LSR	All Category B	5.1	0.03	0.04	0.41	7.3
		8.9	0.05	0.12	0.70	12.7
		10.3	0.062	0.20	0.82	14.7
		13.3	0.08	0.23	1.05	19
		20.1	**0.12**	**0.24**	**1.62**	**30***
		22.9	0.13	0.27	1.81	32.7
		26.0	0.15	0.52	2.05	37.1
		27.7	0.16	0.58	2.19	39.6
		68.4	0.39	0.62	5.40	97.7

*Groundwater annual allocation of 1.62 million cubic meters (9000m3/day over 180 days) is based on maximum allocation equivalent to 30% LSR. The 7-day MALF for the Mangaone stream is 203 l/s and the maximum permissible depletion is 30% of MALF. The maximum permissible coastal drawdown is 1m. The calculated MALF depletion at the proposed allocation rate is 41.7 l/s (20.1% of MALF). The calculated coastal drawdown at this allocation is 0.24m. The calculations are discussed further in Appendix B (Figure B10 and Table B2).

4.2.3 Waikanae Groundwater Zone

The Waikanae groundwater zone extends across the coastal plain from the Peka Peka Road in the north to Paraparaumu Beach in the south.

Groundwater resources in the Waikanae groundwater zone are hosted in a succession of alluvial gravel materials accumulated on the alluvial fan of the Waikanae River over the late Quaternary period. These materials contain form a complex geological and hydrogeological environment reflecting the accumulation of sediments on an active alluvial fan during successive climate cycles during the late Quaternary Period. A simplified conceptual model for the area comprises two deeper semi-confined aquifers overlain by a shallow unconfined aquifer hosted in the Holocene sand deposits accumulated along the coastal margin. Recent (Q1) alluvium forms a narrow highly permeable riparian aquifer along the margins of the Waikanae River and Waimeha Stream[11].

The major surface water feature in the Waikanae groundwater zone is the Waikanae River which drains form headwaters in the Tararua Range to the coast at Otaihanga. The Waikanae River loses appreciable flow immediately downstream of its emergence onto the coastal plain and gains baseflow over its lower reaches. Smaller streams draining the coastal plain include the Waimeha Stream, Wharemakau Stream, Mazengarb Drain and Ngarara Stream, all of which receive baseflow from the unconfined Holocene sand aquifer. Significant wetlands in the area include the Te Harakeke Wetland, Nga Manu Wetland, El Rancho Wetland and Tini Bush.

Figure 4.5 shows an outline of the proposed hydraulic connectivity classification for the Waikanae groundwater zone and relevant surface water features. Modelling undertaken to develop groundwater allocation options for the Waikanae groundwater zone is detailed in **Appendix C** and summarised in **Table 4.3** below.

Allocation Reference Criteria	• Drawdown at the coastal margin (<1m) • Drawdown in unconfined aquifer in the vicinity of significant wetlands (<200mm) • Cumulative depletion of surface water discharge (<30% MALF)
Hydraulic Connectivity Classification	The Category A classification is applied to the unconfined aquifer hosted in Q1 alluvium adjacent to the Waikanae River and Waimeha Stream to a depth of 20 m bgl. Groundwater takes from within this classification will be included in the allocation for the relevant surface waterway (either the Waikanae River or Waimeha Stream) and subject to the relevant minimum flow. The Category B classification is applied to the

[11] A former channel of the Waikanae River diverted by channel works in the late 1800's

remainder if the Waikanae groundwater zone. Allocation criteria for groundwater takes from the Category B area include:

- Assessment of stream depletion effects on adjacent surface waterways. Where q/Q > 0.6 or 10 L/s (>10% of MALF in the case of small streams) the take will be subject to pumping regulation based on the relevant surface water minimum flow. This assessment is likely to be most relevant to shallow takes along the margins of the Waikanae River floodplain or located in relatively close proximity to smaller streams on the coastal plain.

- Cumulative drawdown at the coastal margin. Groundwater takes likely to result in a cumulative reduction in piezometric head to less than 1 m asl at the coast will be classified as non-complying activities.

- Drawdown in the shallow unconfined aquifer adjacent to significant wetland areas (including the Te Harakeke, El Rancho and Ngarara wetlands) should not exceed 0.2m.

Recommended Groundwater Allocation

2.7 x 10^6 m^3/year (based on maximum allowable wetland drawdown)

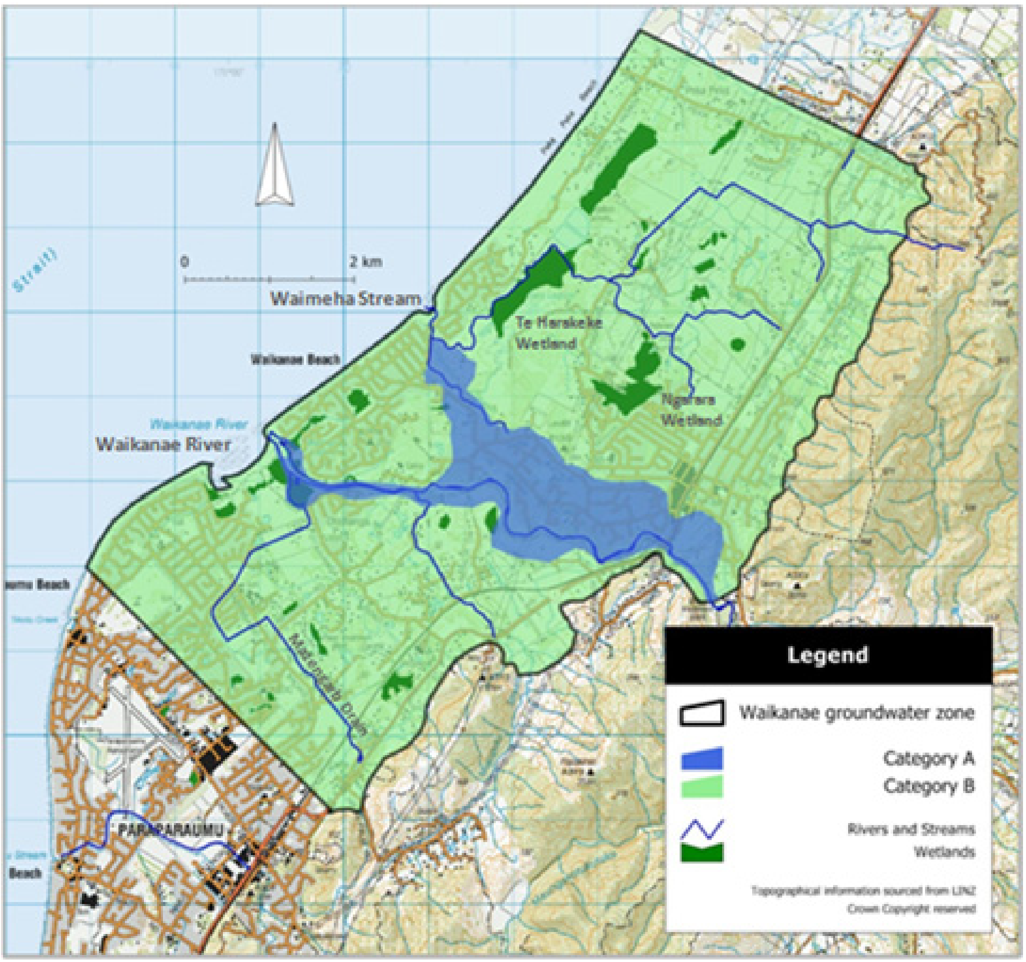

Figure 4.5: Map of the proposed hydraulic connectivity zonation for the Waikanae groundwater zone showing the location of significant surface water features

Table 4.3: Groundwater Allocation Options for the Waikanae groundwater zone (recommended option highlighted)

Allocation Reference Criteria	Hydraulic Connectivity Classification	Groundwater Allocation Options			
• Wetland Drawdown (<0.2m) • Cumulative MALF depletion for Waikanae zone (<30% MALF) • Coastal Drawdown (<1 metre)	Category A to 20 metres in Q1 alluvium adjacent to Waikanae River and Waimeha Stream Category B elsewhere	MALF Depletion (%)	Wetland Drawdown (m)	Coastal Drawdown (m)	Allocation (m^3/year x 10^6)
		5.9	0.18	0.58	2.43
		7.5	**0.20**	**0.65**	**2.70**
		8.5	0.25	0.81	3.53
		11.2	0.37	0.85	4.66
		15.6	0.44	1.53	6.47

*Groundwater annual allocation of 2.7 million cubic meters (36,000m3/day over 75 days) is based on maximum allowable wetland level drawdown of 0.20m. The 7-day MALF for the Mangaone stream is 934 l/s and the maximum permissible depletion is 30% of MALF (MALF fully allocated to surface water). The maximum permissible coastal drawdown is 1m. The calculated MALF depletion at the proposed allocation rate is 70 l/s (7.5% of MALF). The calculated coastal drawdown at this allocation is 0.20m. The calculations are discussed further in Appendix B (Figure B10 and Table B2).

4.2.4 Raumati groundwater zone

The Raumati groundwater zone encompasses the southern margin of the Kapiti Coast, extending across the coastal plain from the Paraparaumu Beach in the north to Paekakariki in the south.

The northern boundary with the Waikanae groundwater zone runs NW-SE across the coastal plain from Paraparaumu Beach. Although somewhat arbitrary, this boundary approximates the southern margin of the Waikanae River fan where laterally continuous gravel layers in the Waikanae area are replaced by a thick sequence of sand accumulated by longshore drift.

The Raumati groundwater zone is drained by three primary surface water catchments. The Wharemakau Stream flows westward across the coastal plain reaching the sea at Raumati Beach, Whareroa Stream drains the middle section of the Raumati groundwater zone to the north of QE Park, while the Wainui Stream flows from the foothills to the coast immediately north of Paekakariki. Wetland areas occur in the vicinity of Raumati and in QE Park.

Allocation Reference Criteria

- Drawdown at the coastal margin (<1m)
- Drawdown in unconfined aquifer in the vicinity of significant wetlands (<0.2m)
- Cumulative depletion of surface water discharge(<30% MALF)

Hydraulic Connectivity Classification

The entire Raumati groundwater zone is classified as Category B to reflect the leaky (semi-confined) nature of the deeper water-bearing layers (typically gravel or coarser sand) within the sedimentary sequence. Allocation criteria for groundwater takes from the Category B area include:

- Assessment of stream depletion effects on adjacent surface waterways. Where q/Q > 0.6 or 10 L/s (>10% of MALF in the case of small streams) the take will be subject to pumping regulation based on the relevant surface water minimum flow. This assessment is likely to be most relevant to shallow takes along the margins of the Wharemakau, Whareroa and Wainui streams (which have MALF figures <100 L/s).
- Cumulative drawdown at the coastal margin. Groundwater takes likely to result in a cumulative reduction in piezometric head to less than 1 m asl at the coast will be classified as non-complying activities. Given the limited width of the coastal plain, coastal drawdown is likely to be a significant management

consideration for any large-scale takes in this area.

- Drawdown in the shallow unconfined aquifer adjacent to significant wetland areas shall not exceed 0.2m

Recommended Groundwater Allocation	**1.23 x 10^6 m^3/year** (based on cumulative MALF depletion)

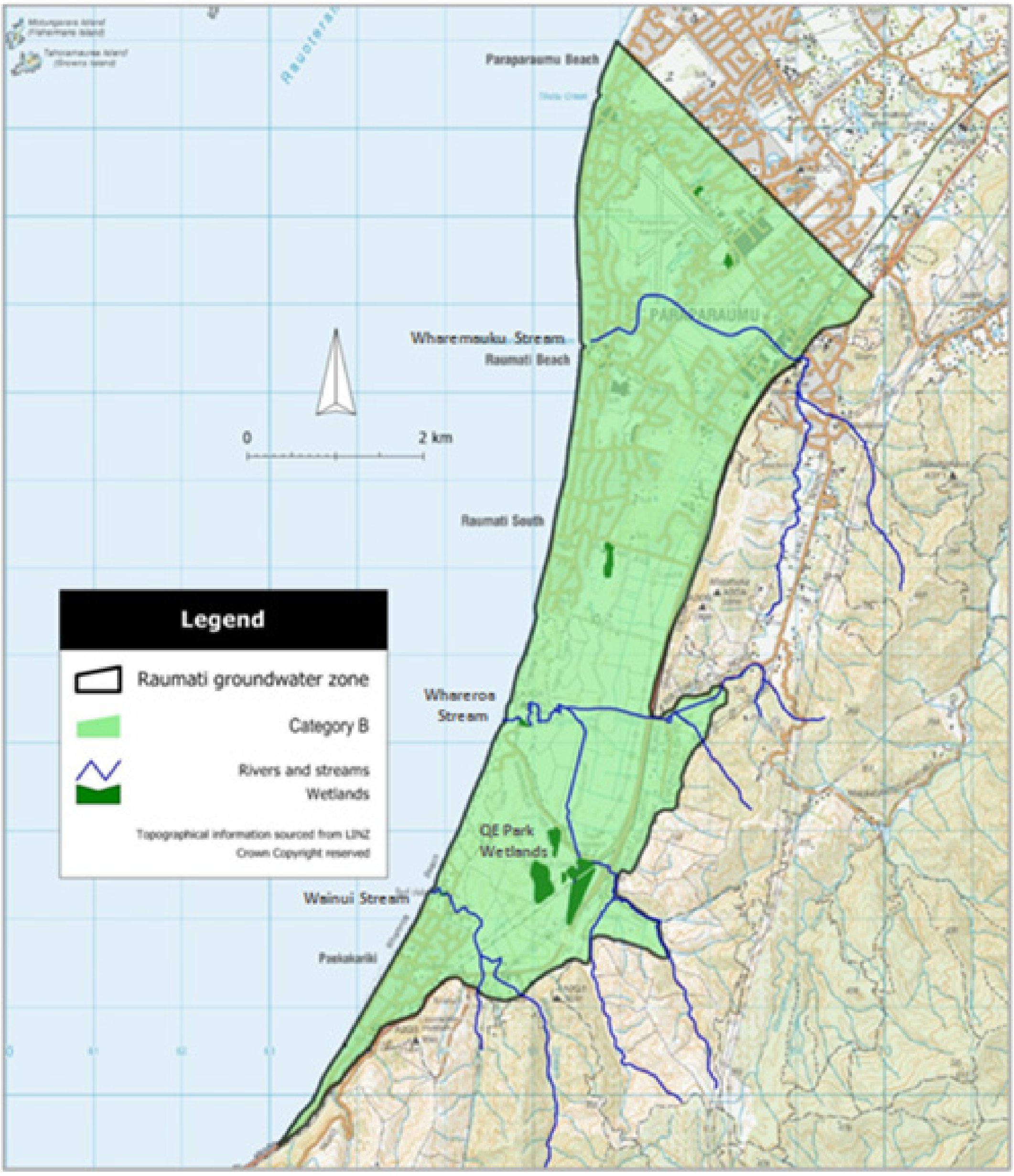

Figure 4.6: Map of the proposed hydraulic connectivity zonation for the Raumati groundwater zone showing the location of significant surface water features

Table 4.4: Groundwater Allocation Options for the Raumati groundwater zone (recommended option highlighted)

Allocation Reference Criteria	Hydraulic Connectivity Classification	Groundwater Allocation Options			
		MALF Depletion (%)	Wetland Drawdown (m)	Coastal Drawdown (m)	Allocation (m^3/year x 10^6)
• Wetland Drawdown (<0.2m) • Cumulative MALF depletion for Raumati zone (<30% of MALF) • Coastal Drawdown (<1 metre)	All Category B	10	0.05	0.12	0.41
		13	0.06	0.16	0.55
		20	0.10	0.24	0.82
		26	0.12	0.32	1.09
		30	**0.14**	**0.36**	**1.23**
		33	0.15	0.40	1.37

*Groundwater annual allocation of 1.23 million cubic meters (6833m3/day over 180 days) is based on the maximum permissible depletion is 30% of MALF. The 7-day MALF for the Raumati stream is 74 l/s. The maximum permissible coastal drawdown is 1m. The calculated MALF depletion at the proposed allocation rate is 22.2 l/s. The calculated coastal drawdown at this allocation is 0.36m. The calculated wetland level drawdown at this allocation rate is 0.14m. The calculations are discussed further in Appendix B (Figure B10 and Table B2).

4.3 Summary

The preceding section outlines the application of the proposed conjunctive management framework to the Kapiti Coast. The recommended management framework varies from that proposed for the Wairarapa Valley by Hughes and Gyopari (2010) to reflect the different hydrogeological setting and specific groundwater management issues occurring in the Kapiti area. These differences include:

- The hydraulic connectivity zonation only includes the Category A and Category B classifications. This reflects the 'leaky' nature of groundwater systems on the Kapiti Coast where abstraction from deeper water-bearing layers is likely to result in drawdown in shallow unconfined aquifers which are hydraulically connected to surface water features (e.g. streams, wetlands);

- Calculation of sustainable groundwater allocation volumes is based on the evaluation of three primary management criteria which include coastal drawdown, drawdown in the unconfined aquifer adjacent to significant wetlands and cumulative effects on surface water baseflow;

- While included in the calculation of sustainable groundwater allocation volumes, specific management criteria are proposed for managing saline intrusion risk and effects on wetlands associated to manage localised effects of groundwater abstraction;

- Criteria for identification of Category B groundwater takes subject to pumping regulation are amended to include a criteria for small streams (i.e. q/Q >10% of MALF where MALF <100 L/s)

The proposed hydraulic connectivity categories reflect the relatively restricted distribution of high permeability alluvial deposits to the immediate margins of the major river systems. These areas are classified as Category A with allocation and minimum flows managed in accordance with those established for relevant rivers and streams. Classification of remaining areas of the Kapiti Coast as Category B reflect a combination of the leaky nature of the aquifer system and the potential for hydraulically connected surface water features (particularly wetlands and small streams) to be affected by both regional and local-scale effects associated with groundwater abstraction.

5. Future water resource management

Hughes and Gyopari (2010) provided a detailed assessment of some of the potential issues associated with the implementation of the proposed conjunctive management framework in the Wairarapa Valley. A majority of the issues identified are also relevant for the future management of groundwater resources on the Kapiti Coast and are summarised in the following section.

5.1 New and replacement consent applications

Adoption of the proposed conjunctive management framework will have significant implications for the management of both new and existing resource consents. In particular, the proposed framework will result in the application of pumping controls (i.e. minimum flow cut-offs) on a number of groundwater takes which are currently unrestricted as and when they are reviewed or replaced.

Greater Wellington has developed guidance to assist the resource consent process (including applications for new and replacement resource consents) in the Wairarapa Valley until future amendments to current policies for groundwater allocation are adopted in the Natural Resources Plan. This guidance includes:

- Procedures for processing of new consent applications;
- Procedures for processing of replacement consent applications;
- Minimum information requirements to support technical assessments;
- Application of step-down and minimum flow conditions on groundwater takes with a direct or high degree of hydraulic connection (i.e. Category A or Category B);
- Methods/procedures for calculating, recording and managing groundwater and surface water allocation.

It is recommended a similar methodology for managing new and replacement resource consents be developed and implemented for the Kapiti Coast using the methodology developed for the Wairarapa Valley as a template.

5.2 Management of future surface and groundwater allocation

Due to the relatively low demand for groundwater and surface water abstraction across a majority of the Kapiti Coast (in comparison to the Wairarapa Valley), implementation of the proposed conjunctive management framework is unlikely to result in major issues associated with over-allocation of surface or groundwater resources (the Waikanae groundwater zone/Waikanae River may be an exception). However, the exact nature of any issues arising, and the appropriate response, can only be determined once both groundwater and surface water allocation volumes have been finalised as part of the upcoming NRP review process.

5.3 Policies to support implementation of proposed management framework

Hughes and Gyopari (2011) identified a number of supporting policies that may be required to support implementation of the conjunctive management framework including:

- Where not already established, application of common expiry dates to for resource water permits (surface and groundwater) within individual water management zones to enable changes to the management of existing resource consents to be applied in a consistent and transparent manner;

- Possible exemptions from pumping regulation (i.e. minimum flow restrictions) for certain types of groundwater takes located in Category A or Category B areas. Such exemptions would enable provision to be made for essential water supplies such as municipal, water scheme and certain industrial uses which support public health and/or animal welfare considerations;

- Establishment of defined reliability of supply criteria for different categories of water use. These criteria could be utilised to assist setting allocation volumes for individual water users as well as to ensure that future allocation does not adversely affect the reliability of supply for existing water users; and,

- Policies either reviewing existing consented allocation or facilitating the transfer of allocation between individual water users to improve allocative efficiency.

5.4 Aligning allocation with actual use

At the current time water permits issued by Greater Wellington authorising groundwater abstraction in the Kapiti Coast typically specify a maximum instantaneous and daily rate of take and set a maximum (volumetric) seasonal allocation. However, both metered water use data and irrigation abstraction modelling undertaken elsewhere in the Wellington Region (e.g. Gyopari and McAlister 2010 a, b and c) suggest that actual groundwater abstraction (in terms of peak abstraction rates and seasonal usage) is significantly lower than consented volumes. Data collected through various metering studies typically show peak (weekly) water usage typically ranges between 60 and 75 percent of the maximum consented rate. However, on an annual basis seasonal water usage is generally much lower at around 30 percent of the total consented volume.

The mismatch between consented allocation and actual use significantly reduces allocative efficiency. This situation has potential implications for efficient and sustainable management of groundwater and surface water resource including:

- Where fixed volumes of water are available for allocation (either in terms of groundwater or surface water), allocation of water to individual users in excess of their ‘reasonable’ needs can prevent additional users accessing the available resource;

- The potential environmental effects of groundwater abstraction (such as potential stream depletion effects) may be significantly over-estimated when based on consented volumes;

- As water resources approach or reach full allocation incentives may increase for existing users to transfer the unused portion of their allocation under RMA s136. This may result in unanticipated environmental effects as cumulative water use increases, particularly if existing allocation limits do not adequately incorporate uncertainty regarding resource availability and interconnection between surface and groundwater. Increased utilisation of consented allocation may also result in a reduction in supply reliability for existing resource users if this has not already been factored into existing allocated volumes.

Due to the relatively levels of groundwater allocation on the Kapiti Coast at the current time, issues associated with allocative efficient are not a major issue for water resource management. However, to ensure the effectiveness of future water resource management it is recommended that policies developed to improve allocative efficiency elsewhere in the Wellington Region also be applied on the Kapiti Coast.

5.5 Wetlands

Potential effects on wetlands are identified as a significant groundwater resource management consideration on the Kapiti Coast. The proposed management framework outlined in **Section 3** attempts to provide a framework for the sustainable management of groundwater abstraction effects on hydraulically connected surface water bodies including wetlands. However, it is recognised that the proposed management approach could be improved by:

- Better definition of the location and spatial extent of ‘significant’ wetland areas; and

- Improved understanding of the likely significance of groundwater level drawdown on wetland hydrology and ecology

6. Summary

Groundwater and surface water resources on the Kapiti Coast exhibit a high degree of interconnection and sustain important freshwater ecosystems in riverine and wetland habitats. Significant use is also made of these water resources to provide domestic, municipal, industrial and agricultural water supplies which are vital to the economic and social wellbeing of the community.

Hughes and Gyopari (2011) proposed a methodology for conjunctive management of groundwater and surface water resources in the Wairarapa Valley to enable management of groundwater abstraction in a manner consistent with environmental flows and water levels established for hydraulically connected surface water resources. In recent times the proposed framework had been utilised for managing groundwater allocation in the Wairarapa Valley in anticipation of potential changes to current provisions of the Natural Resources Plan through the current Plan review process.

In its original form, the proposed conjunctive management framework was principally intended to manage the localised and cumulative effects of groundwater abstraction on hydraulically connected surface water. The recommended management framework for the Kapiti Coast outlined in this report modifies this approach to reflect the different hydrogeological setting and specific groundwater management issues occurring in the Kapiti Coast area. These differences include:

- The hydraulic connectivity zonation only includes the Category A and Category B classifications. This reflects the ‘leaky’ nature of groundwater systems on the Kapiti Coast where abstraction from deeper water-bearing layers is likely to result in drawdown in shallow unconfined aquifers which are hydraulically connected to surface water features (e.g. streams, wetlands);

- Calculation of sustainable groundwater allocation volumes is based on the evaluation of three primary management criteria which include coastal drawdown, drawdown in the unconfined aquifer adjacent to significant wetlands and cumulative effects on surface water baseflow;

- While included in the calculation of sustainable groundwater allocation volumes to account for regional-scale effects, specific management criteria are proposed for managing saline intrusion risk and effects on wetlands associated with localised effects of groundwater abstraction;

- Criteria for identification of Category B groundwater takes subject to pumping regulation are amended to include a criteria for small streams (i.e. $q/Q > 10\%$ of MALF) which are common on the Kapiti Coast.

The proposed hydraulic connectivity categories for the Kapiti Coast reflect the relatively restricted distribution of high permeability alluvial deposits to the immediate margins of the major river systems. These areas are classified as Category A with allocation and minimum flows managed in accordance with those established for relevant rivers and streams.

Classification of remaining areas of the Kapiti Coast as Category B reflects a combination of the leaky nature of the aquifer system and the potential for hydraulically connected surface water features (particularly wetlands and small streams) to be affected by both regional and local-scale effects associated with groundwater abstraction. Specific management criteria are proposed for managing the localised effects of groundwater abstraction in the vicinity of significant wetlands. Specific management criteria area also proposed to manage the risk of seawater intrusion in coastal areas.

Groundwater allocation volumes are recommended for four groundwater management zones on the Kapiti Coast. These zones replace the six groundwater management zones specified in the current Natural Resources Plan to better reflect the spatial and depth distribution of specific hydrogeological environments. The proposed sustainable allocation volumes are derived from analysis of various pumping scenarios using the numerical groundwater model developed by Gyopari *et al.* (2010) with the calculated cumulative effects of groundwater abstraction assessed in terms of three primary management criteria:

- Cumulative effects on stream baseflow
- Drawdown at the coast
- Unconfined aquifer drawdown in the vicinity of significant wetlands

Overall, the recommended framework for groundwater allocation on the Kapiti Coast provides a means to sustainably manage future groundwater allocation in a manner which incorporates both local and cumulative effects on key management values. The methodology utilised to apply the conjunctive management framework takes a suitable conservative approach which acknowledges potential uncertainties inherent in a complex hydrogeological environment.

7. References

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Jones, A., Gyopari, M., 2005; *Investigating the sustainable use of shallow groundwater on the Kapiti Coast*. Greater Wellington Technical Publication, February 2005.

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NZTA, 2012; *MacKays to Peka Peka Expressway Project Assessment of Environmental Effects Report*. Prepared by Beca, Boffa Miskell and Incite, March 2012.

Wellington Regional Council, 1999; *Natural Resources Plan for the Wellington Region*. Wellington Regional Council Publication WRC/RP-G-PP/31.

Appendix A: Assessment of allocation options for the Otaki groundwater zone

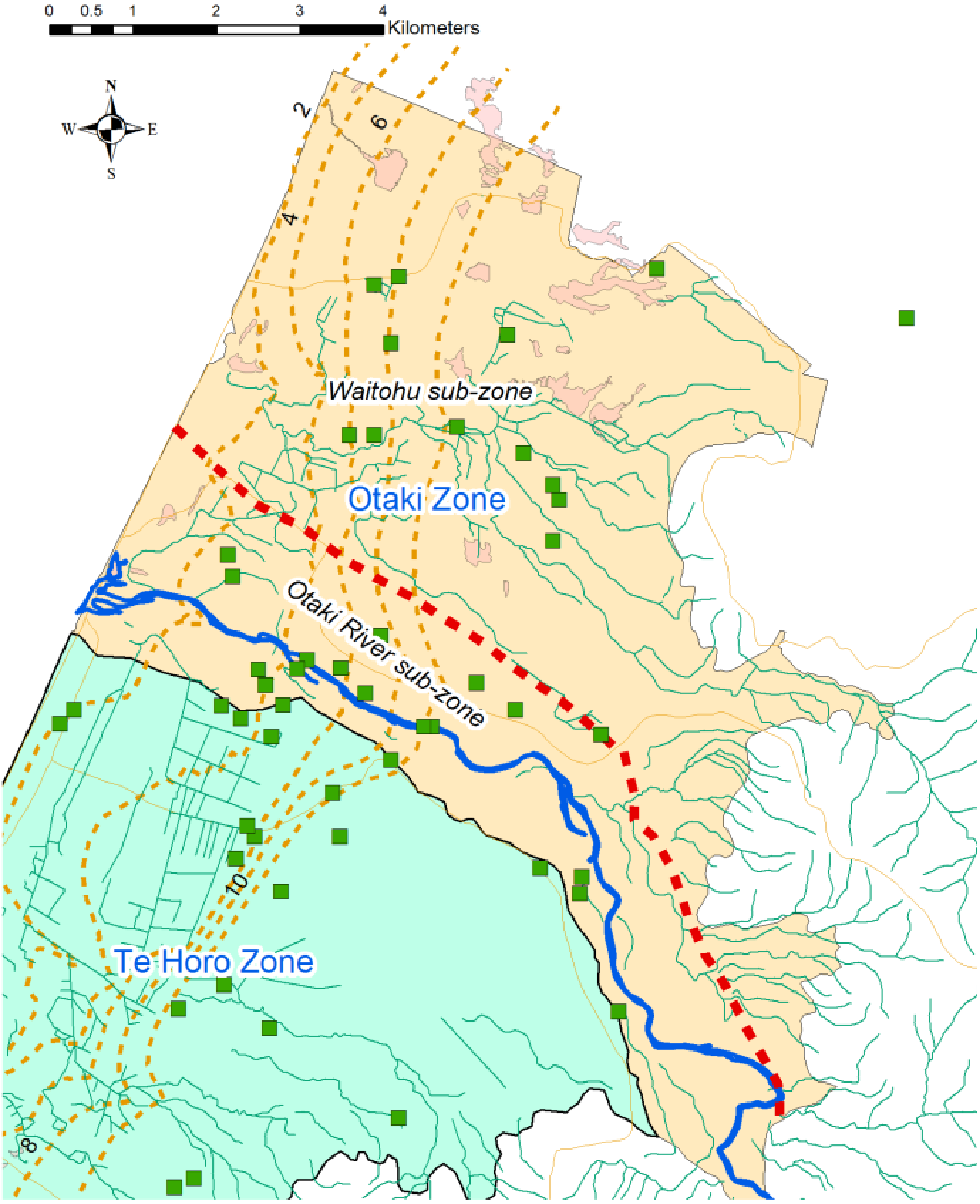

Figure A1: Otaki Groundwater Management Zone

Table A1: Summary of the Otaki Groundwater Management Zone

Delineation	The Otaki groundwater zone amalgamates the existing Otaki and Waitohu zones to better reflect the extent of Q1 gravels associated with the Otaki River and Waitohu Stream as well as the underlying geology where older Q5 and Q6 deposits are exposed at the ground surface due to the regional tilt of sediments infilling the South Wanganui Basin. The proposed zone boundary is also modified to better reflect the extent of Quaternary sediments along the Tararua foothills (following the extent of greywacke basement exposure defined on the Wellington QMap coverage). The Otaki zone is divided into two sub-zones namely the Otaki and the Waitohu sub-zone to reflect the differing groundwater-surface water interactions in these zones.
Catchment Boundary	The Otaki groundwater zone extends across the coastal plain from the southern margin of the Otaki River valley to the northern boundary of the Wellington Region, combining the existing Otaki and Waitohu groundwater zones. To the east of SH1 the southern boundary of the Otaki groundwater zone follows the prominent river terrace that forms a hydraulic divide between the Q2 gravels of the Hautere Plain and the Q1 alluvium of the Otaki River floodplain. To the west of SH1 this boundary become less well defined, particularly near the coast where it is partially obscured by Holocene sand deposits. The eastern boundary traces the approximate contact between the Q5 and Q6 alluvial terraces (and associated alluvial fans) and the greywacke bedrock of the Tararua foothills.
Area	
Principal surface water systems	The primary surface water features for the Otaki groundwater zone are the Otaki River and the Waitohu Stream. The Otaki River derives most of its flows from the Tararua Ranges. Concurrent gauging runs in the Otaki indicate significant flow losses between Pukehinau and Crystal Bend gauging sites. The River gains some flows in the lower reaches. The Waitohu Stream drains a relatively small catchment in the foothills east of Otaki. Due to the relatively short, steep nature of the catchment, flows in this stream tend to respond rapidly to rainfall events and recede relatively quickly. The middle reaches of the Waitohu Stream frequently dry up during the summer period reflecting interaction with the surrounding unconfined aquifer.
Aquifer sequences:	In the Otaki River valley an unconfined/semi-confined aquifer system occurs in a sequence of coarse, highly permeable gravel and sand within the Q2 alluvial deposits between 20 to 35 metres below ground in the area to the west of SH1. This aquifer system is extensively utilised for municipal and irrigation water supply. Given the relatively low permeability values observed in Q2 deposits elsewhere on the Kapiti Coast, the high values exhibited in this aquifer system are interpreted to possibly reflect reworking of the poorly sorted, silt-rich Q2 gravel materials along the thalweg of the Otaki River possibly during an interstadial period in the late stages of the Otiran glaciation. The spatial extent of this aquifer system is not particularly well defined but extends west of SH1 toward the coast and between the current Otaki River at least as far north as the Waitohu Stream. Elsewhere in the Otaki groundwater zone, groundwater is found extensively throughout the Holocene (Q1) sand deposits along the coastal margin and in older (Q5 and Q6) alluvial deposits. However, due to the relatively fine-grained nature of these deposits well yields are typically low except in isolated, coarser gravel layers within the Q5/Q6 deposits in the Pukehou area.

<table>
<tr><td>Hydraulic connectivity</td><td colspan="3">The entire Otaki groundwater sub-zone is classified as Category A to reflect the leaky (semi-confined) nature of the deeper water bearing layers below the Q1 gravels. Abstraction from deeper layers in this sub-zone is modelled to induce almost immediate losses from the Otaki River. It is also noted that a relatively direct hydraulic connection to the Otaki River is illustrated by the rapid groundwater level response to stage changes in the Otaki River (GWRC, 2012).
The Waitohu sub-zone is characterised by Holocene sands at the surface and relatively less transmissive Q1 sand and late Quarternary (Q5/Q6) alluvial deposits at depth. This zone hosts significant surface water features such as wetlands and small lakes within the Holocene sand materials. Abstraction from all depths has a potential to affect water levels and flows in surface water features hydraulically connected to the Holocene sand aquifer. The Waitohu sub zone is classified as Category B except in Q1 gravels along the Waitohu Stream channel which should be classified as Category A up to a depth of 20m.
Allocation criteria for groundwater takes from the Otaki groundwater management zone include:
• The Otaki River sub-zone is classified as Category A to all depths and it is recommended that allocation from this sub-zone is managed as equivalent to surface water abstraction from the Otaki River i.e. allocation should be referenced to MALF conditions in the Otaki River. Cumulative drawdown below the Q1 gravels in the Otaki River is unlikely to result in significant wetland drawdown or significant drawdowns at the coast.
• The Waitohu sub-zone is classified as Category B to all depths except in Q1 gravels along the Waitohu Stream (to a depth of 20m) which are classified as Category A. All other areas, including areas traversed by the Waimanu Stream, are classified as Category B.
• It is recommended allocation from the Waitohu Stream and adjacent Category A alluvium is referenced to flows in the Waitohu Stream at 7 day MALF conditions.
• Allocation from Category B areas should be referenced to drawdowns in the shallow unconfined aquifer adjacent to significant wetlands. This assessment should take into account cumulative drawdown resulting from abstraction in the Waitohu groundwater sub-zone. Drawdown should not exceed 2m.
• Groundwater takes should be referenced to coastal aquifer drawdowns. Cumulative abstractions should not result in more than 1 m of drawdown at the coastline.</td></tr>
<tr><td>Otaki Sub-zone Recharge</td><td colspan="3">Average annual recharge is 9.3x10^{6}m^{3} with a lower quartile recharge of 7.7x10^{6}m^{3}. Average daily recharge is 258,333m^{3} with a lower quartile of 213,888m^{3}</td></tr>
<tr><td>Waitohu Sub-zone Recharge</td><td colspan="3">Average annual recharge is 11.84x10^{6}m^{3} with a lower quartile recharge of 8.92x10^{6}m^{3}. Average daily recharge is 32,439m^{3} with a lower quartile of 24,438m^{3}</td></tr>
<tr><td>Existing NRP zones</td><td colspan="3">Otaki Groundwater Management zone.</td></tr>
<tr><td rowspan="2">Current consented Allocation as at December 2013</td><td>No of groundwater takes</td><td>m^{3}/day</td><td>x10^{6} m^{3}/year</td></tr>
<tr><td>19</td><td>6,531</td><td>1.134</td></tr>
</table>

Hydrogeology summary

The primary hydrogeological features of the Otaki management zone are the primary aquifers underlying the Otaki and Waitohu sub-zones (GWRC, 2012):

- Q1 alluvium associated with the Otaki River and Waitohu Stream host highly permeable unconfined aquifers with transmissivity values in excess of 30,000m^{2}/day in shallow river gravels with a median value of 4,500 m^{2}/day. These highly permeable unconfined conditions extend to between 20 to 30 metres below ground.

- In the Otaki River valley an unconfined/semi-confined aquifer system occurs in a sequence of coarse, highly permeable gravel and sand within the Q2 alluvial deposits below the Q1 alluvium. These sequences include Q4 gravels, Q5 sand and gravels and Q6 weathered gravels at depth.

- In the Waitohu valley an unconfined/ semi confined system occurs in sequence of fine to medium sand and silt with occasional gravels and peat layers. These sequences are represented by Holocene sands with thickness of around 20 metres inland up to 40 metres near the coast. These sands have generally low hydraulic conductivity. A series of Q2 to Q6 gravels form alluvial terraces up to 30 metres thick along the northern margin of the Otaki and Waitohu flood plains and at depth. The depth to the basement is about 130 m blg.

Hydrology and surface water allocation management

Flow gaugings indicate a flow loss of approximately 1,200 L/s from the Otaki River between Pukihinau and Lower Transmission Lines. The Waitohu Stream loses about 80 L/s between the Water Treatment Plant and Otaki Golf Club. The baseflow for the streams in the catchment are approximated at Waimanu (170 L/s), Rangiuru (275 L/s) and Waitohu (80-100 L/s). The middle Waitohu Stream periodically runs dry and gains some flow in the lower reaches. The MALF for the Otaki River is estimated at 3,900 L/s.

Zone management objectives

The principal management objective in the Otaki zone is to ensure the sustainable allocation of groundwater resources with respect to freshwater ecosystems and prevention of saltwater intrusion. The protection of instream values of the Otaki River, Waitohu Stream, Waimanu Stream and Rangiuru Stream are the primary criteria for developing sustainable allocation options in this zone. However, recommended management options also reference wetland drawdowns and drawdown at the coastal margin.

Numerical modelling

The numerical groundwater flow model for the Kapiti Coast was used to assess the sustainability of the current groundwater abstractions and to develop allocation options for the Otaki groundwater management zone. Full details of the model and the calibration process are provided by Gyopari, Mzila and Hughes (2012). The model has been principally used to evaluate the cumulative effects of abstraction on the surface water environment and coastal drawdown in developing options.

Zone water budget

The numerical groundwater flow model has enabled a temporal characterisation of the natural water balance for the Otaki zone using a version of the 19-year calibration simulation (1993-2011) which has no groundwater abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated (by comparing the no-abstraction and abstraction scenarios). Of particular relevance to assessing the sustainability of abstraction, the model enables quantitative assessment of the potential cumulative depletion effects resulting from groundwater pumping on the surface water environment in the Otaki water management zone.

The principal water balance components for the Otaki zone are rainfall recharge and surface water/groundwater fluxes. Figure A2 shows the modelled annual rainfall recharge for the Otaki sub zone for the period 1992 to 2011. The average annual recharge for this period is 9.3x106 m3 with a lower quartile recharge of 7.7x106 m3. This translates to an average daily recharge of 25,480m3 with a lower quartile of 21,100 m3. Figure A3 shows the modelled annual rainfall recharge for the Waitohu sub-zone for the same period. The average annual recharge for the Waitohu sub zone is 11.8x106 m3 with a lower quartile recharge of 8.9x106 m3. This translates to an average daily recharge of 32,329 m3 with a lower quartile of 24,384 m3.

The simulated natural fluxes (in the absence of groundwater abstraction) between the Otaki River and the Waitohu Stream and groundwater within the Otaki groundwater management zone are illustrated in Figures D4 and D5. The positive fluxes (Figure A4) for the Otaki River shows that the river mostly loses flow (net flow loss) between the Tararua foothills and the coast. The mostly negative values (Figure A5) for the Waitohu Stream show that the stream mostly gains flow from groundwater. The net gain for the Waitohu Stream is supported by local groundwater baseflow discharge, particularly in the lower plains. The baseflow is lowest during summer and the discharges are consistent with measured base flow of approximately 6,900m^3/day (80 L/s) to 8,640 m^3/day (100 L/s).

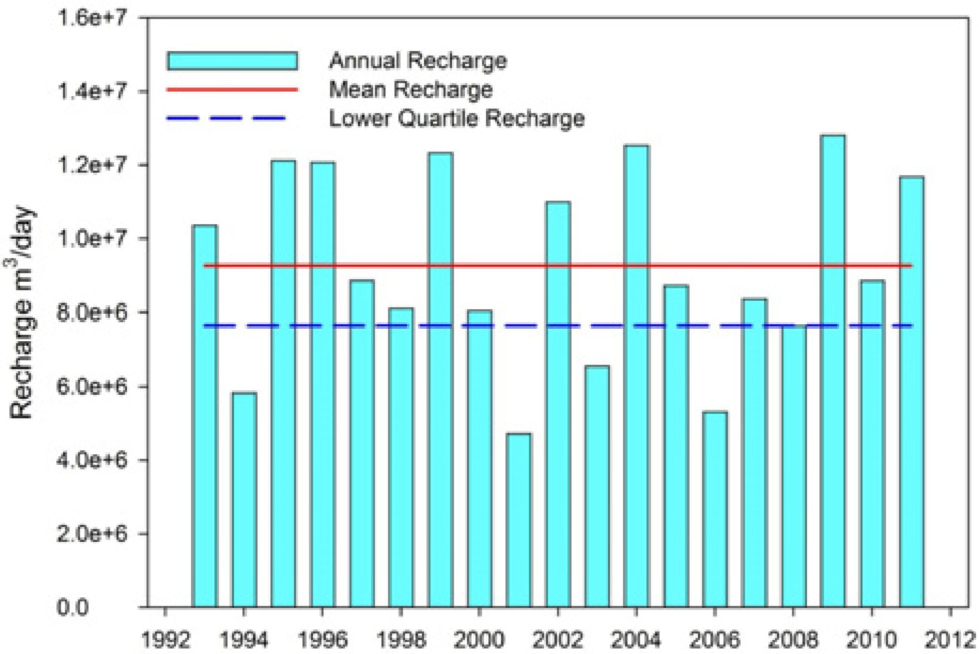

Figure A2: Modelled annual rainfall recharge (1993-2011) for the Otaki sub-zone between 1992 and 2012. A mean annual recharge of 9.3x10^{6}m^3 is indicated as is the lower quartile value of 7.7x10^{6}m^3 (dashed line).

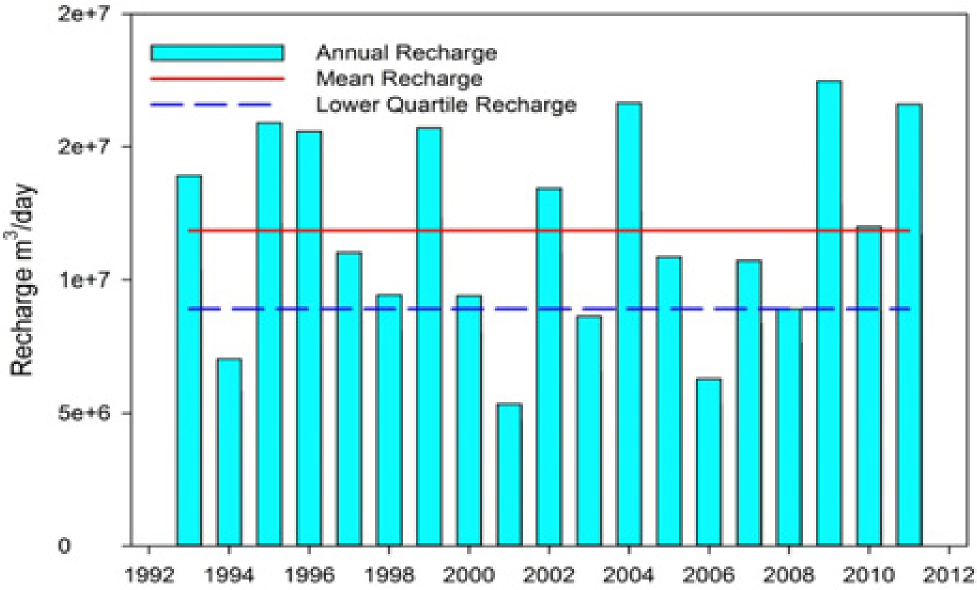

Figure A3: Modelled annual rainfall recharge (1993-2011) for the Waitohu sub-zone between 1992 and 2012. A mean annual recharge of 11.8x10^{6}m^3 is indicated as is the lower quartile value of 8.9x10^{6}m^3 (dashed line).

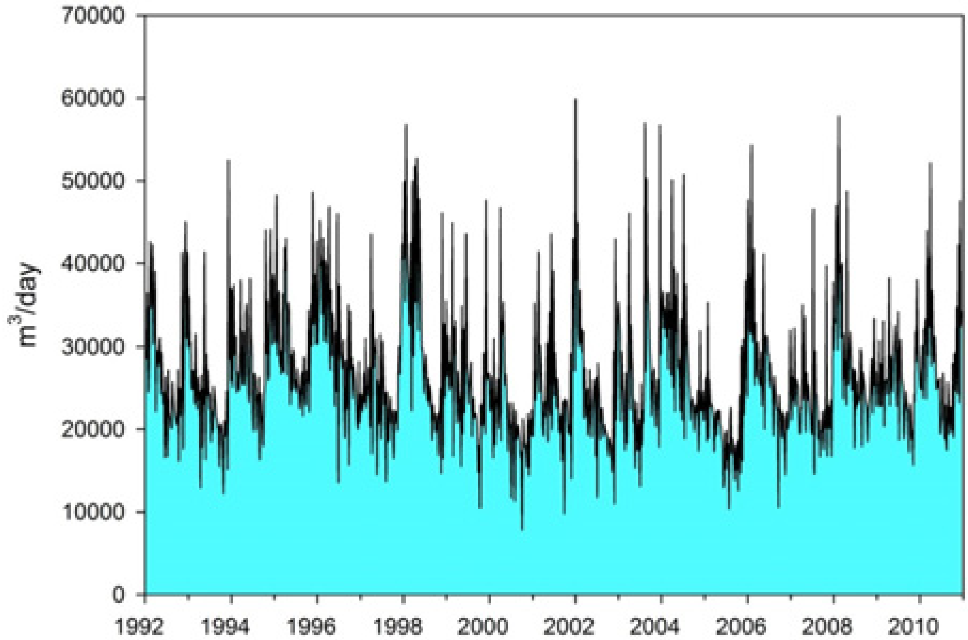

Figure A4: Simulated net natural surface water fluxes to the Otaki River in the Otaki groundwater management zone when no groundwater abstraction is occurring. The positive fluxes represent flow from the Otaki River to groundwater (i.e. losing system). This plot shows the net loss over the entire reach of the Otaki River.

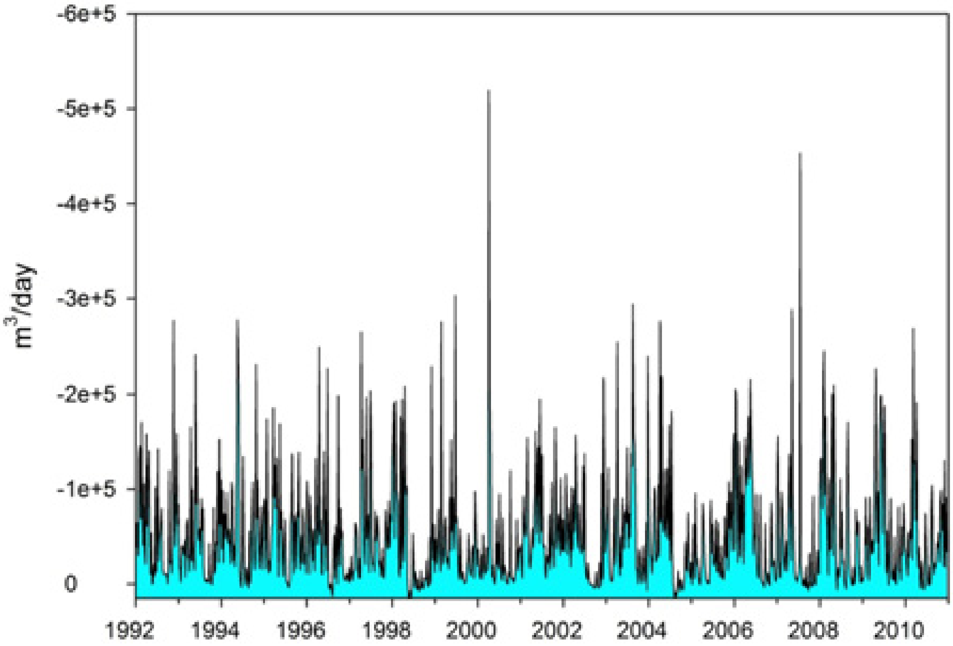

Figure A5: Simulated net natural surface water fluxes to the Waitohu Stream in the Otaki zone when no groundwater abstraction is occurring. The negative fluxes represent flow from groundwater to the stream (i.e. gaining system). This plot shows the net gain over the entire reach of the Waitohu Stream. The plot also shows some positive values during the dry season i.e. net loss from the Waitohu Stream to groundwater.

Current abstraction

Current abstraction from the Otaki zone was simulated for the 19-year transient model run and the water balance outputs were compared to the baseline (no-abstraction) simulation. The effects of groundwater abstraction on the surface water environment were then evaluated by comparing the two sets of water balance outputs.

Figure A6 shows the modelled surface water depletion resulting from current abstraction in the Otaki zone. Figure A7 shows a detailed portion of Figure A6 for the period 2004 to 2006 to illustrate the response of the groundwater system to abstraction. The scenario shows that seasonal abstraction has increased between 1998 and 1999 to peak at about 8,000 m^3/day. The total modelled depletion of surface water is around 85 to 98% of the total abstraction rate throughout the simulation period. The magnitude of the resulting surface water depletion effect is calculated at 7,800 m^3/day which is approximately 3% of the 7-day MALF of the Otaki River. Seasonal depletion peaks at the end of each irrigation season with a sharp reduction thereafter. However there is residual depletion that occurs throughout the winter seasons.

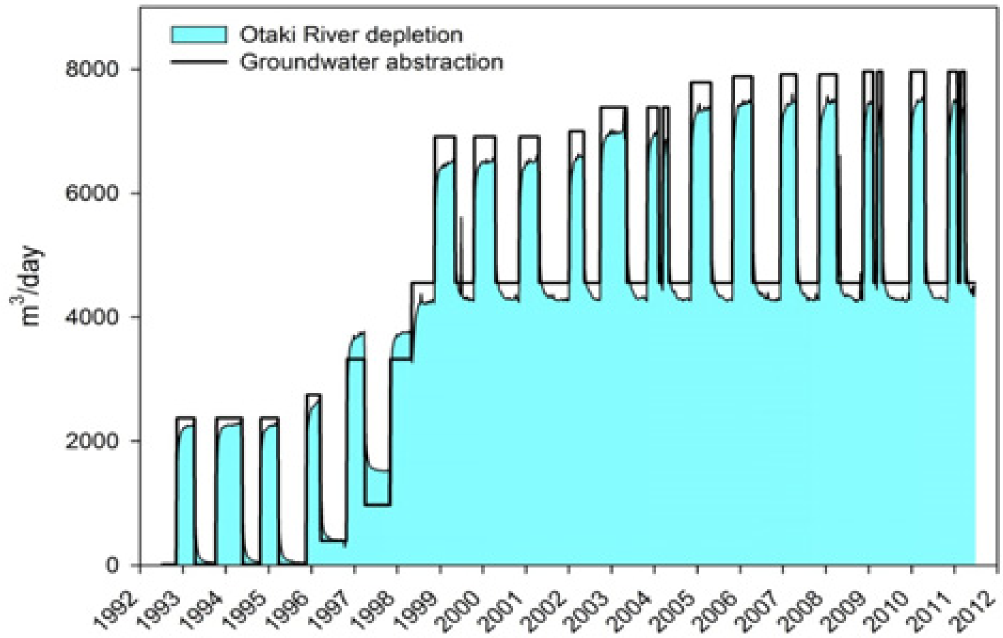

Figure A6: Simulated historic abstraction and associated surface water depletion in the Otaki zone (1992-2012). A depletion equivalent to 85 to 95% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

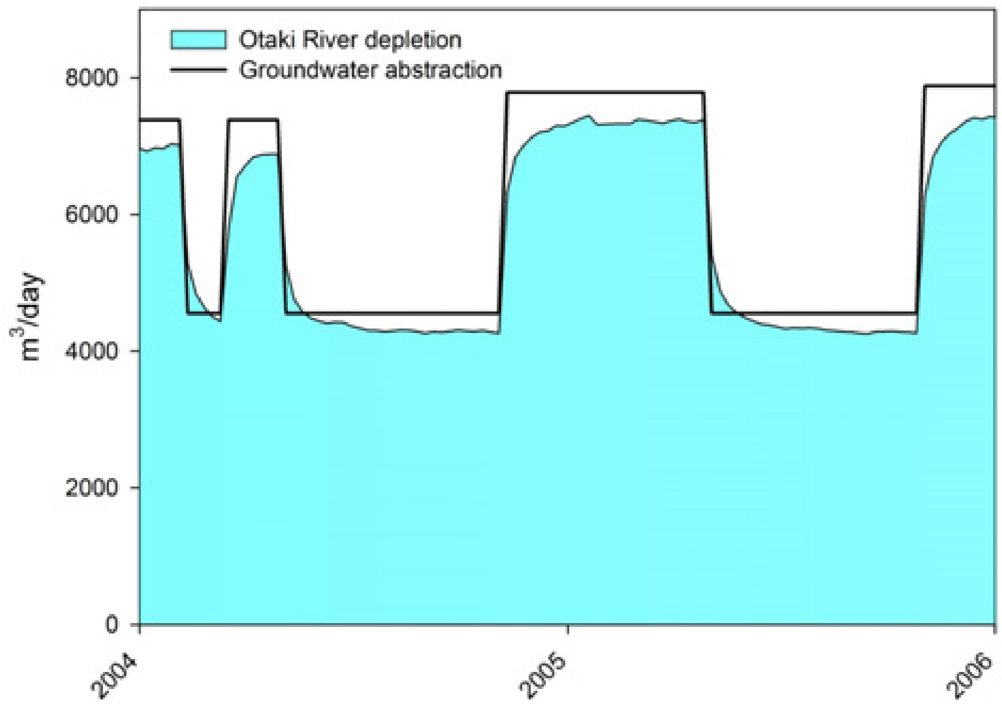

Figure A7: Details of Figure A6-Simulated historic abstraction and associated surface water depletion in the Otaki zone between 2004 and 2006. The plot demonstrates the lag between start and termination of seasonal pumping and surface water depletion. Surface water depletion responds almost immediately to pumping. Abstraction and depletion peak during the summer and continue through the winter at approximately 50% of summer volumes.

Abstraction scenarios for the Otaki sub-zone

The transient groundwater flow model for the Kapiti Coast was used to simulate 'synthetic' abstraction scenarios to further characterise the relationship between groundwater abstraction and the surface water environment that includes surface water depletion, wetland drawdown and coastal drawdown. For these scenarios, the transient run of 19 years was maintained in order to represent all climatic variations within this period.

The following scenarios were simulated:

Scenario 1: A synthetic distributed array of wells pumping from the Q2 to Q6 sands at depths between 60 and 130m bgl (i.e screened below the Q1 alluvium). This scenario allows identification of the proportion of the surface water depletion effect associated with abstraction (q/Q) from deeper semi-confined aquifers. The output from Scenario 1 is shown in Figure A8.

Scenario 2: as in Scenario 1 above but located 500 m from the Otaki River. This scenario demonstrates the proportion of the surface water depletion effect associated with abstraction (q/Q) from deeper semi-confined aquifer and away from the Otaki River main channel. The output from Scenario 2 is shown in Figure A8 for the Otaki sub zone.

Scenario 3: Abstraction from the shallow Q1 gravels only. This scenario provides comparative surface water depletion to confirm if the Otaki River sub-zone could be classified as Category A or B. The output for this Scenario is shown in Figure A8.

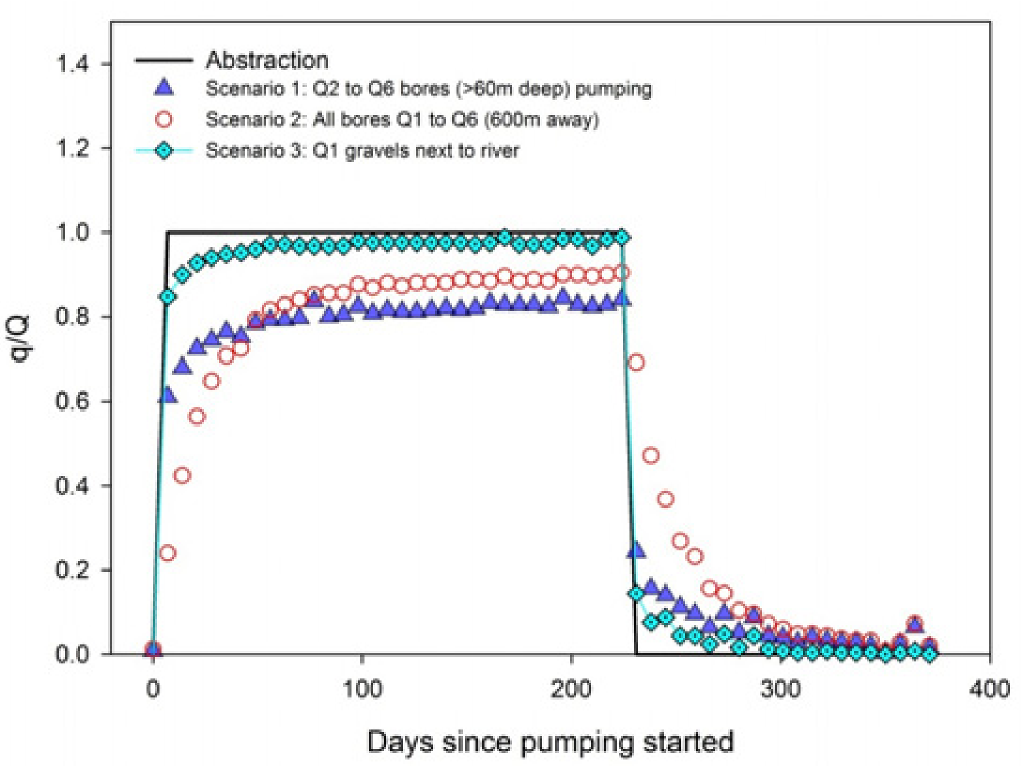

Figure A8 shows simulated surface water depletion resulting from synthetic abstractions in the Otaki River sub-zone. The model predicts that total seasonal abstraction depletion is between 80 and 100% of the total abstraction rate thereby indicating a high degree of connectivity between the aquifer and the Otaki River.

Figure A8 shows that abstraction from shallow Q1 gravels has an associated river depletion rate which approaches 100% of the abstraction rate (q/Q=1). Abstraction from the deeper aquifers > 60m bgl results in an almost immediate depletion of 60% of the abstraction rate and the depletion reaches 80% of abstraction (q/Q=0.8) within 40 days. The data also shows the effects of abstraction from bores located approximately 600m from the Otaki River. There is a distinct lag in depletion, the depletion rate reaches 80% of the abstraction rate within 50 days and reaches 90% (q/Q=0.9) after 180 days of abstraction. All scenarios show an almost immediate reduction in depletion when pumping stops. However, depletion continues throughout the winter season albeit at a lower rate. The analysis demonstrates that regulation of pumping in deeper or shallow gravels is likely to provide a means to control or mitigate surface water depletion effects.

Groundwater Management Options for the Otaki sub-zone

Groundwater-surface water interaction zones

- Due to the high degree of connectivity between aquifers (unconfined and semi-confined) and the Otaki River, the entire Otaki sub-zone should be classified as Category A.
- Abstraction from the Otaki sub-zone results in less than minor effects in identified wetlands.
- Abstraction from the Otaki sub-zone results in less than minor coastal drawdown.

Groundwater allocation

- Groundwater allocation is not required for this sub-zone since it is proposed that all groundwater takes will be managed as part of the allocation for the Otaki River under the Category A classification.

Waitohu sub-zone

Modelled abstraction effects 1992-2012

Groundwater abstraction for the Waitohu sub zone was simulated for the 19-year transient model run and is shown in Figure A9. Seasonal abstraction (estimated actual demand) increased from approximately 2,700 m3/day between 1993 and 2002 to around 3,500 m3/day over the subsequent period. Also shown in Figure A6 is the simulated surface water depletion resulting from historical abstraction. The model predicts that total seasonal depletion is between 45 and 60% of total the abstraction thereby indicating a moderate degree of connectivity between the aquifer and the stream in this sub-zone.

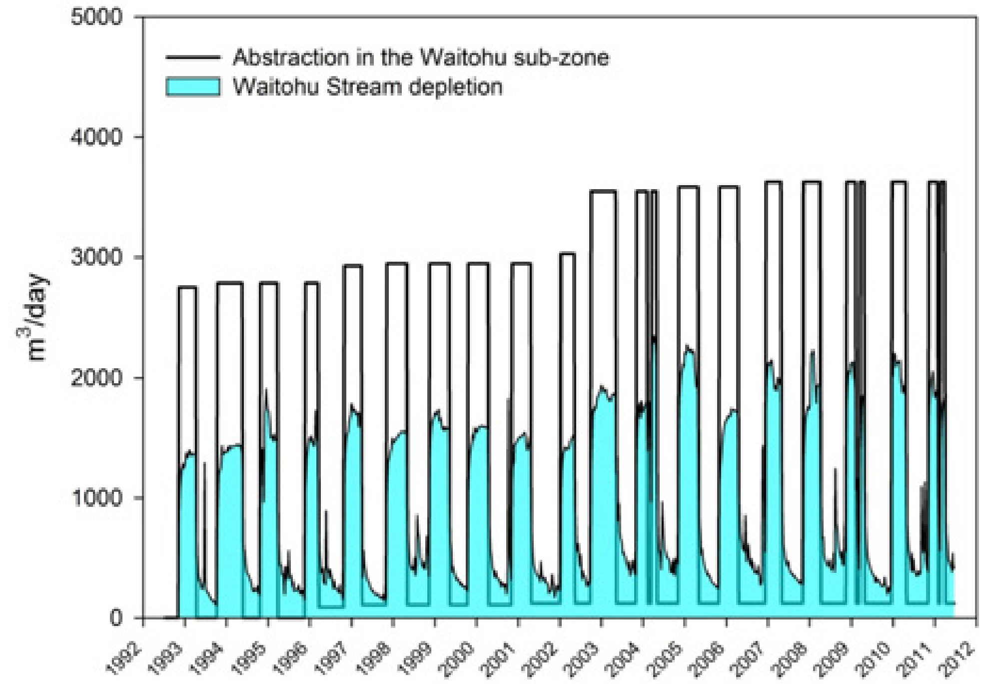

Figure A9: Simulated historic abstraction and associated surface water depletion in the Waitohu sub-zone (1992-2012). A depletion equivalent to 45 to 60% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

Figure A10 shows in detail the simulated depletion curve over the 2004 to 2006 seasons for total pumping from the sub-zone. Surface water depletion responds almost immediately to pumping. Abstraction and depletion peak during the summer. The peak depletion rate is approximately 50% of abstraction (q/Q=0.5) and depletion continues through the winter. Stream depletion shows immediate reduction when pumping stops.

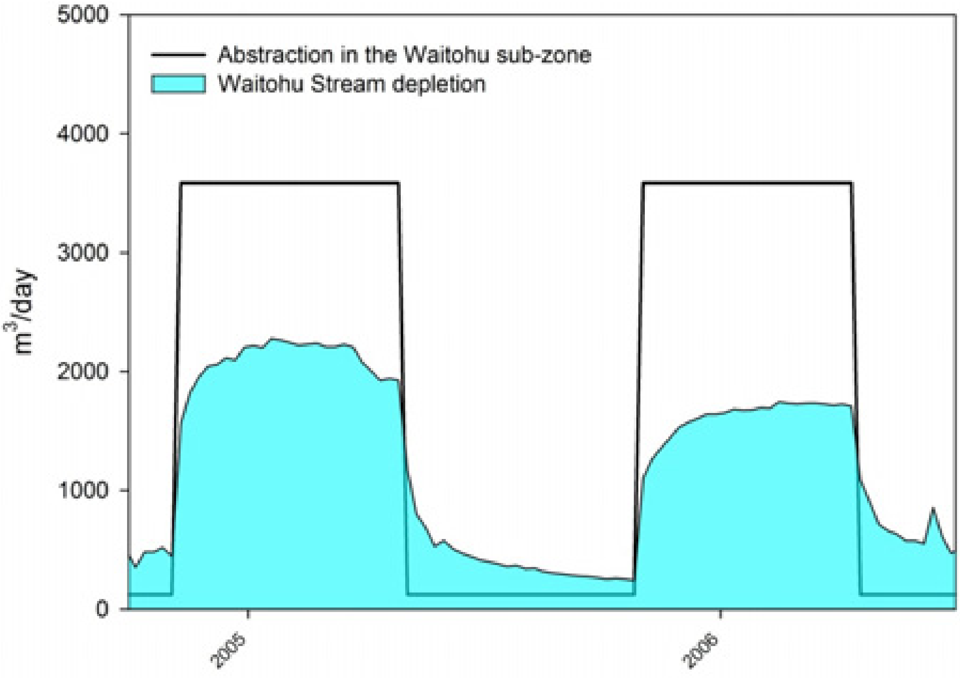

Figure A10: Details of Figure A9-Simulated historic abstraction and associated surface water depletion in the Waitohu sub-zone zone between 2004 and 2006. The plot demonstrates the lag between start and termination of seasonal pumping and surface water depletion. Surface water depletion responds almost immediately to pumping. Abstraction and depletion peak during the summer. The peak depletion rate is approximately 50% of abstraction (q/Q=0.5) and depletion continues through the winter due to rainfall effects.

Sensitivity of Stream depletion from abstraction

Figure A11 shows the sensitivity of depletion to abstraction from different levels in the aquifer system of the Waitohu sub-zone. The data shown indicate that abstraction from Q1 gravels near the Waitohu Stream results in a depletion factor of approximately 0.9 i.e. stream depletion accounts for 90% of abstraction. Stream depletion effects due to abstraction are almost immediate. Abstraction from Q2 to Q6 gravels at depths of more than 60m and below Q1 gravels results in a depletion ratio of approximately 0.8. This indicates a high degree of connectivity between the deep underlying aquifers below Q1 gravels to the Waitohu Stream. However, the depletion effect is more attenuated than in shallower Q1 gravels.

Figure A11 also shows that stream depletion is less sensitive to abstraction from Holocene sands away from the stream channel and the maximum stream depletion ratio is calculated to be about 0.3. However, it should be noted that Holocene sands in the Waitohu sub-zone are hydraulically connected to other surface water features such as shallow lakes and wetlands. Abstraction from these shallow sands could result in significant water level drawdown in these surface water features.

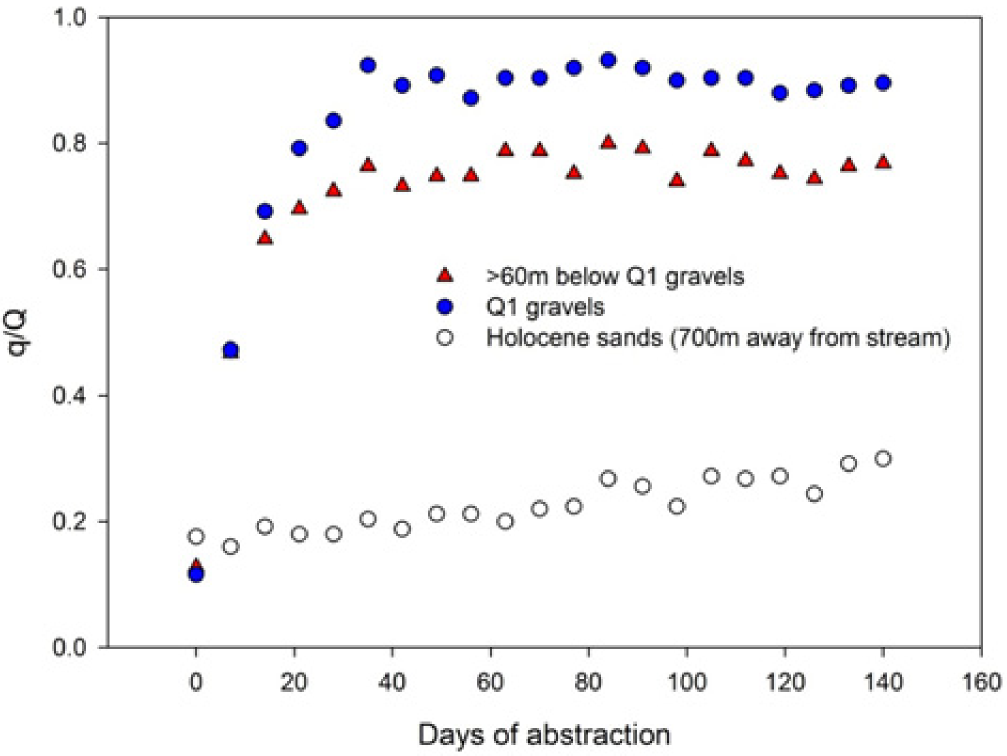

Figure A11: Ratio of surface water depletion (q) to pumping rate (Q) for the Waitohu sub zone pumping from Q1 gravels (only), Q2 to Q6 below Q1 gravels (only) and Holocene sands 700m from the Waitohu Stream

Abstraction scenarios

The transient groundwater flow model was used to simulate 'synthetic' abstraction scenarios to further characterise the relationship between groundwater abstraction from fully screened wells in the aquifer system and surface water depletion, wetland drawdown and coastal aquifer drawdown. The abstraction is through an array of 24 fully screened wells uniformly distributed throughout the Waitohu sub-zone.

The following abstraction scenarios were simulated:

- Scenario 1: Abstraction from the fully screened well array at a rate of 3000 m^3/d with each bore pumping at 125 m^3/day. Pumping was seasonal and the rate was held constant for 160 days during the summer season. The model was run for 19 years in order to represent all climatic conditions.

- Scenario 2: Same as scenario 1 except the total abstraction was increased to 6000 m^3/day (i.e. 250 m^3/day per well)

- Scenario 3: Same as Scenario 1 except the total abstraction was increased to 12,000 m^3/day (i.e. 500 m^3/day per well)

  Figure A12 shows surface water depletion from Scenarios 1 to 3 when fully screened wells distributed across the Waitohu groundwater sub-zone are pumped at 3,000 m^3/day, 6,000 m^3/day and 12,000 m^3/day respectively. Figures D13 and D 14 also show simulated wetland drawdown and coastal drawdown resulting from the pumping scenarios.

<u>Scenario 1</u>: Figure A12 shows the results of Scenario 1 in terms of surface water depletion effect when the fully screened wells are pumped at 3,000 m^3/day. The figure indicates that the total depletion effect is approximately 1,050 m^3/day indicating a total effect of about 35% of the pumping rate (i.e. a depletion factor of 0.35). The stream depletion under Scenario 1 abstraction is equal to 7.7% of the Waitohu Stream 7-day MALF. When pumping ceases, there is an initial sharp decline in depletion then followed by a slow recession in the depletion throughout the following months. It is significant to note here that by ceasing pumping there is only a moderate impact on the surface water depletion rates.

Figure A13 shows the ratio of depletion to pumping for all the three scenarios. The plot demonstrates that the depletion factor (q/Q) is independent of pumping rate and that after 150 days of pumping, the depletion factor is about 40% of the pumping rate (i.e. depletion factor q/Q=0.4). The plot appears to have levelled off by 150 days and it appears unlikely that cumulative depletion would increase over the longer pumping durations.

Figure A14 shows the results of Scenario 1 in terms of wetland drawdown effect when fully screened wells are pumped at 3,000 m^3/day. The figure indicates that the total wetland drawdown is relatively small with a maximum drawdown of approximately 100mm after 4000 days of pumping. The maximum drawdowns are related to the driest years in the model runs. The drawdown decreases to about 80mm by the end of the simulation period. The wetland drawdowns are relatively small when compared to the maximum allowable wetland drawdown of 200mm indicating that Scenario 1 abstraction has no significant effect on wetland drawdown. When pumping ceases, there is a slow recession in the drawdown throughout the following months before the start of the next abstraction period. It is significant to note here that by ceasing pumping there is very little immediate impact on wetland drawdown. Therefore the regulation of takes on the basis of wetland drawdown would not provide an effective means to mitigate the effects of this pumping during dry periods.

Figure A15 shows the results of Scenario 1 in terms of coastal deep aquifer drawdown effect when fully screened wells are pumped at 3,000m^3/day. The figure indicates that the total coastal drawdown is relatively small (maximum of approximately 100mm) when compared to the maximum allowable coastal drawdown of 1m. This indicates that Scenario 1 abstraction has no significant effect on coastal drawdown. When pumping ceases, there is a sharp decline in the drawdown. It is significant to note here that by ceasing pumping there has an immediate impact on coastal drawdown. Therefore the regulation of takes on the basis of coastal drawdown would provide an effective means to mitigate the effects of this pumping during dry periods. However the effects of all abstraction scenarios is in unlikely to result in initiation of saltwater intrusion and the drawdown effects are regarded as less than minor and will not be discussed further.

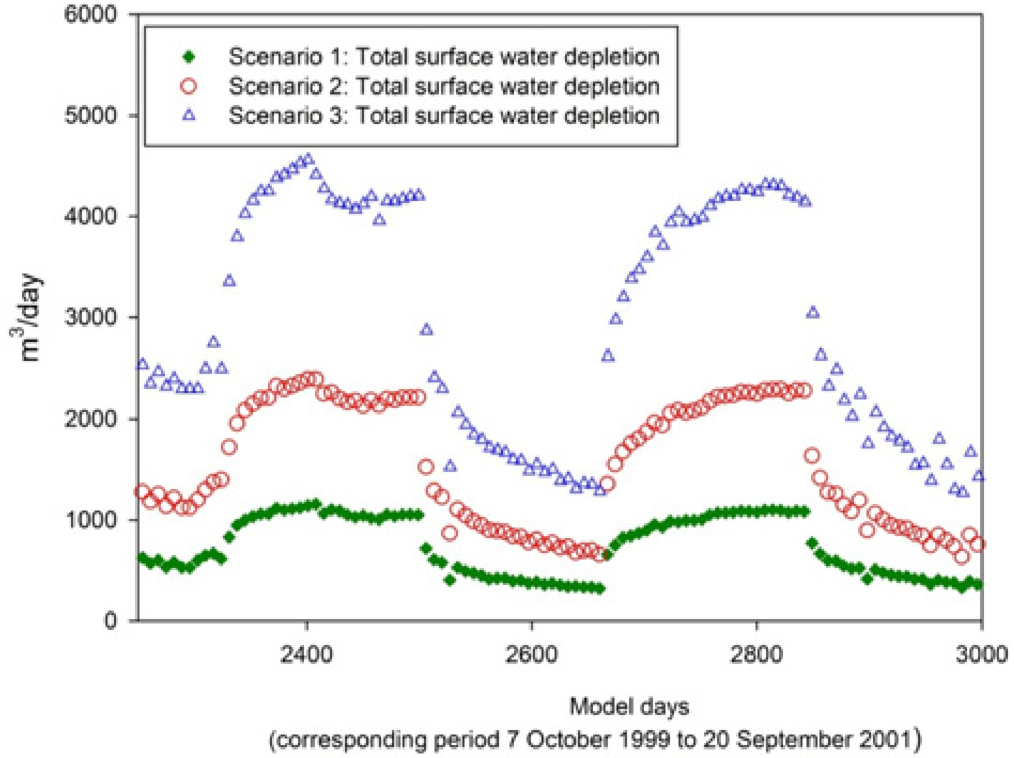

Figure A12: Scenarios 1 to 3 output – surface water depletion in the Waitohu zone resulting from pumping an array of synthetic fully screened wells outside Q1 gravels at 3,000m³/day (Scenario 1), 6,000m³/day (Scenario 2) and 12,000m³/day (Scenario 3) for 180 days seasonal abstraction

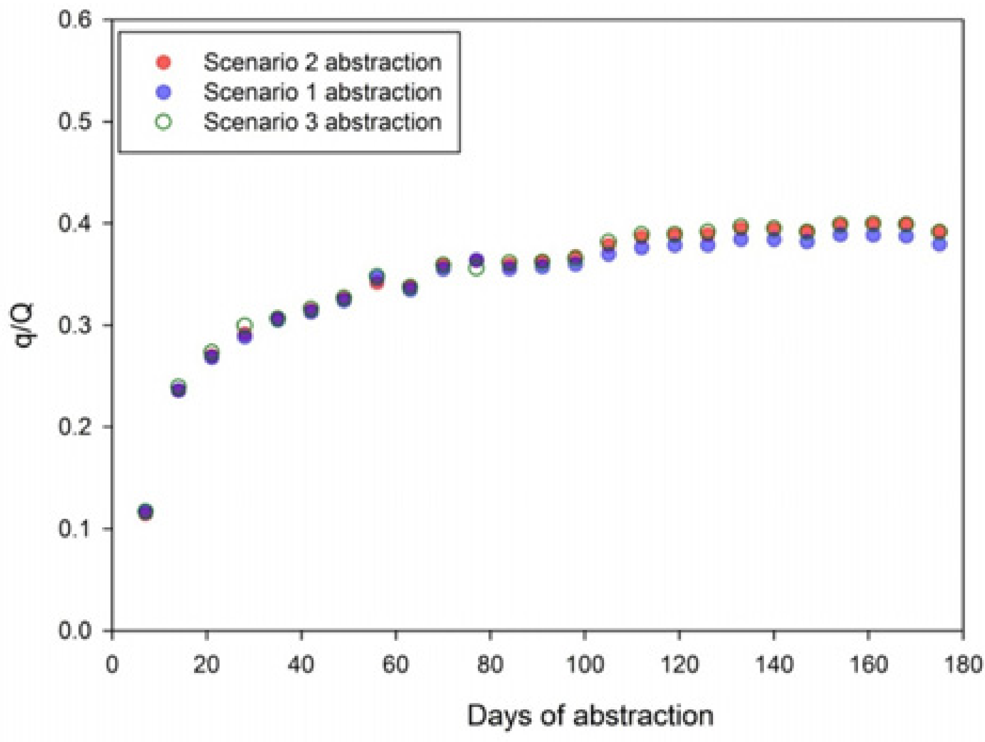

Figure A13: Scenarios 1 to 3 – ratio of surface water depletion (q) to pumping rate (Q) in the Waitohu zone resulting from pumping an array of synthetic fully screened wells outside Q1 gravels at 3,000m3/day (Scenario 1), 6,000m3/day (Scenario 2) and 12,000m3/day (Scenario 3) for 180 days seasonal abstraction

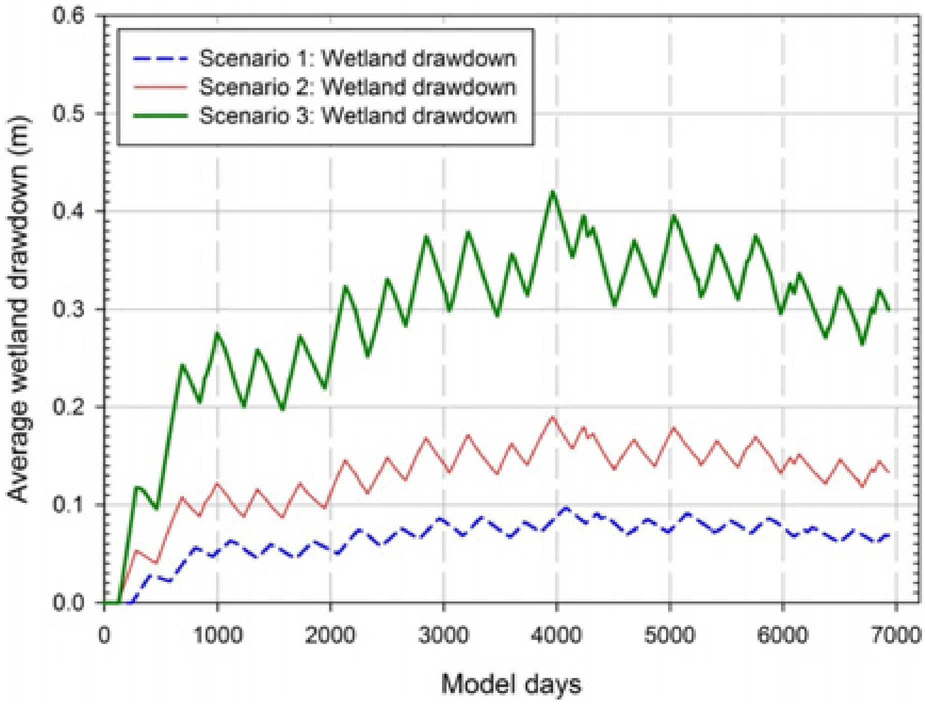

Figure A14: Scenarios 1 to 3 output – wetland drawdowns in the Waitohu zone resulting from pumping an array of synthetic fully screened wells outside Q1 gravels at 3,000m3/day (Scenario 1), 6,000m3/day (Scenario 2) and 12,000m3/day (Scenario 3) for a 19 year model run

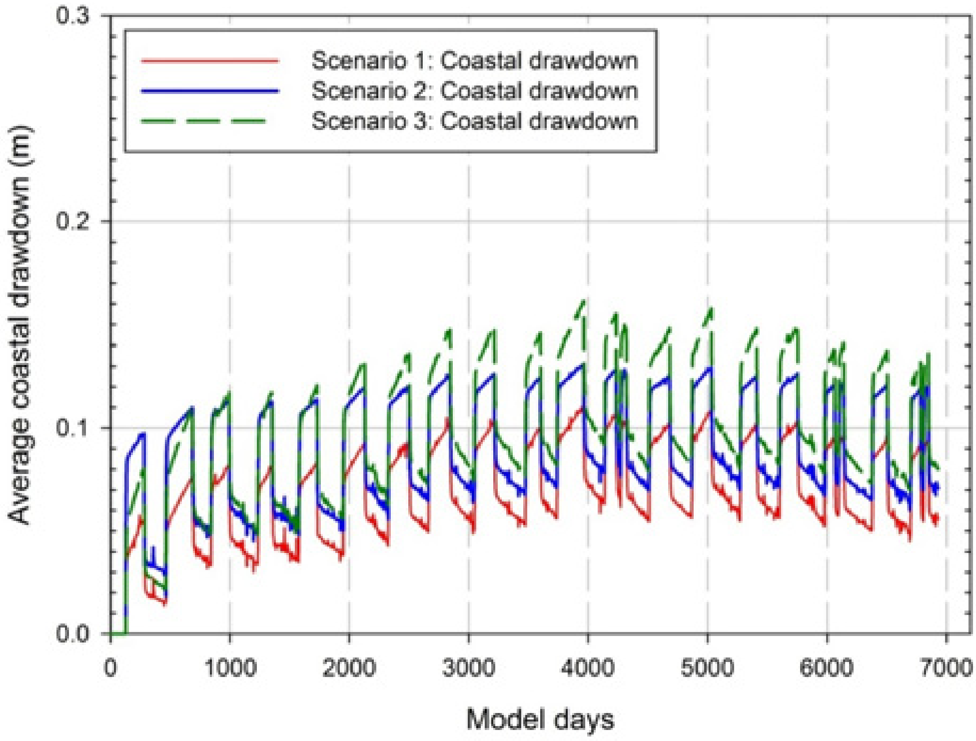

Figure A15: Scenarios 1 to 3 output – coastal aquifer drawdowns in the Waitohu zone resulting from pumping an array of synthetic fully screened wells outside Q1 gravels at 3,000m3/day (Scenario 1), 6,000m3/day (Scenario 2) and 12,000m3/day (Scenario 3) for a 19 year model run

Scenario 2: Figure A12 shows the results of Scenario 2 in terms of surface water depletion effect when fully screened wells are pumped at 6,000 m^3/day. The figure indicates that the total depletion effect is approximately 2,100 m^3/day indicating a total effect of about 35% of the pumping rate (i.e. a depletion factor of 0.35). The stream depletion under Scenario 1 abstraction is equal to 15% of the Waitohu Stream 7-day MALF. When pumping ceases, there is an initial sharp decline in depletion then followed by a slow recession in the depletion throughout the following months. It is significant to note here that by ceasing pumping there is only a moderate impact on the surface water depletion rates.

Figure A13 shows the ratio of depletion to pumping for all the three scenarios. The plot demonstrates that the depletion factor (q/Q) is independent of pumping rate and that after 150 days of pumping, the depletion factor is about 40% of the pumping rate (i.e. depletion factor q/Q=0.4). The plot appears to have levelled off by 150 days and it appears unlikely that cumulative depletion would increase over the longer pumping durations.

Figure A14 shows the results of Scenario 2 in terms of wetland drawdown effect when fully screened wells are pumped at 6,000 m^3/day. The figure indicates that the total wetland drawdown is relatively high (approximately 200mm) when compared to the maximum allowable wetland drawdown of 200mm indicating that Scenario 2 abstraction has significant effect on wetland drawdown. When pumping ceases, there is a slow recession in the drawdown throughout the following months before the start of the next abstraction period. It is significant to note here that by ceasing pumping there is very little immediate impact on wetland drawdown. Therefore the regulation of takes on the basis of wetland drawdown would not provide an effective means to mitigate the effects of this pumping during dry periods. The plot appears to have receding after 4000 days.

Scenario 3: Figure A12 shows the results of Scenario 3 in terms of surface water depletion effect when fully screened wells are pumped at 12,000 m^3/day. The figure indicates that the total depletion effect is approximately 4,800 m^3/day indicating a total effect of about 35% of the pumping rate (i.e. a depletion factor of 0.4). The stream depletion under Scenario 3 abstraction is equal to 37% of the Waitohu Stream 7-day MALF. When pumping ceases, there is an initial sharp decline in depletion then followed by a slow recession in the depletion throughout the following months. It is significant to note here that by ceasing pumping there is only a moderate impact on the surface water depletion rates.

Figure A13 shows the ratio of depletion to pumping for all the three scenarios. The plot demonstrates that the depletion factor (q/Q) is independent of pumping rate and that after 150 days of pumping, the depletion factor is about 40% of the pumping rate (i.e. depletion factor q/Q=0.4). The plot appears to have levelled off by 150 days and it appears unlikely that cumulative depletion would increase over the longer pumping durations.

Figure A14 shows the results of Scenario 3 in terms of wetland drawdown effect when fully screened wells are pumped at 12,000 m^3/day. The figure indicates that the total wetland drawdown is relatively high (approximately 400mm) when compared to the maximum allowable wetland drawdown of 200mm indicating that Scenario 3 abstraction has significant effect on wetland drawdown. When pumping ceases, there is a slow recession in the drawdown throughout the following months before the start of the next abstraction period. It is significant to note here that by ceasing pumping there is very little immediate impact on wetland drawdown. Therefore the regulation of takes on the basis of wetland drawdown would not provide an effective means to mitigate the effects of this pumping during dry periods.

Groundwater management options for the Waitohu sub-zone

Groundwater-surface water interaction zones

- Recent alluvium (Q1) associated with the Waitohu and Waimanu Streams should be classified as Category A to a depth of 20m to reflect the direct hydraulic connection with the two streams. Figure A1 shows the spatial extent of the proposed Category A classification.

- Beneath Category A, Category B should extend from 20m to all aquifer depths.

- The entire catchment outside Category A should be classified as Category B to reflect the hydraulic connection with surface water features such as wetlands.

Groundwater allocation

- Aquifers in the proposed Waitohu sub-zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.

- The groundwater allocation criterion for this zone should be referenced to the 7-day MALF for the Waitohu Stream averaged across three sites; WSI, Taylors Bridge and Mouth. This flow incorporates groundwater baseflow to surface water for the entire zone. The estimated 7-day MALF at this location is 150 L/s (12,960m^3/day).

- The groundwater allocation criterion for this zone should be referenced to wetland level drawdown averaged across all wetlands and small lakes in this sub-zone. The maximum allowable wetland drawdown due to abstraction has been suggested to be 200mm. However, due to uncertainty in hydraulic connection between the deep aquifer and wetlands a maximum wetland drawdown of 250mm is suggested. It is suggested that shallow groundwater abstraction to a depth of 20m of more than 5 L/s should not be permitted within 150m of wetlands.

- The groundwater allocation criterion for this zone should also be referenced to coastal aquifer drawdown. It is suggested that a maximum drawdown of 1m at the coastline is adopted. Simulations indicate that deep coastal drawdowns due to abstractions is relatively small.

- A depletion factor of 0.4 should be adopted for the Category B components of the Waitohu water management sub-zone to reflect the dominance of the more productive semi-confined aquifer in surface water depletion.

- Annual allocation should be based on a pumping duration of 180 days.

Figure A16 and Table D2 outlines options for groundwater allocation in the Waitohu sub-zone based on the potential cumulative effect of abstraction on baseflow, wetland and coastal drawdowns.

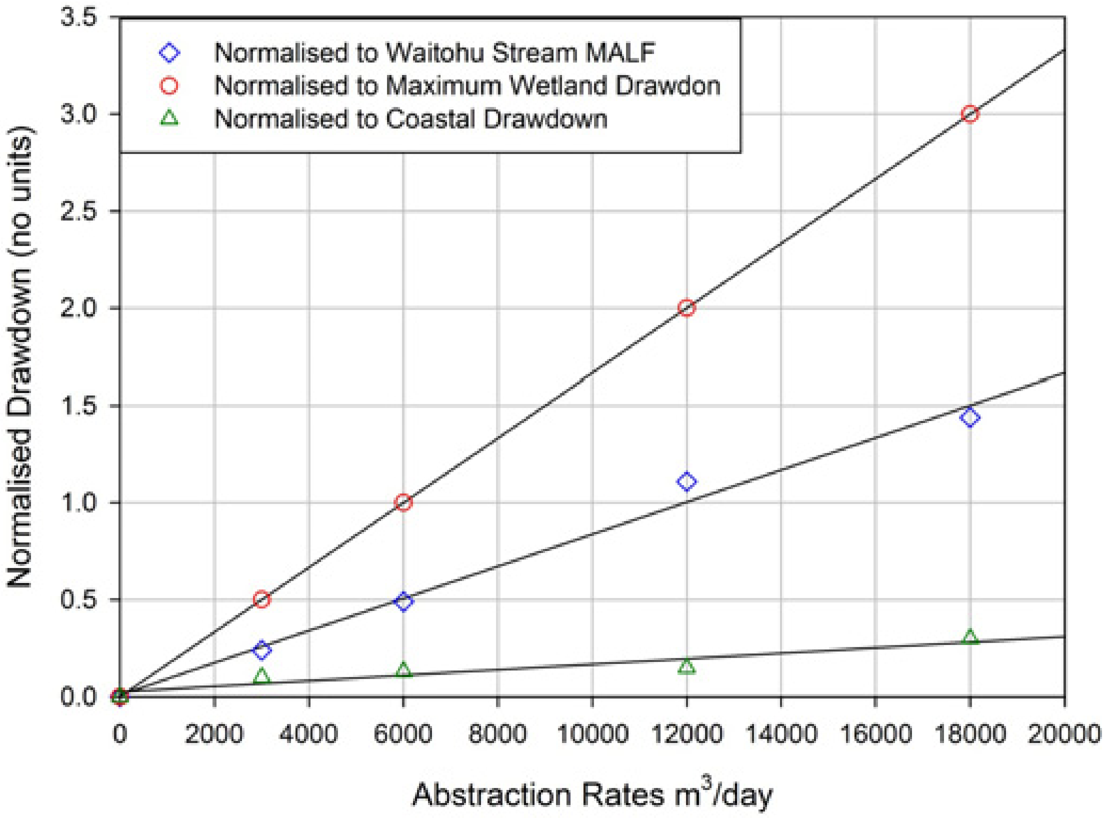

Figure A16: Allocation envelopes abstracting from all three aquifers in the Waitohu sub-zone. Wetland drawdown is normalised to 0.2m, stream depletion is normalised to 30% of MALF (45L/s) and drawdown at the coast is normalised to 1m. The normalisation values are the maximum allowable depletions or drawdown to limit adverse environmental effects. A normalised wetland drawdown of 1.0 intersects the abstraction rate at 6,000m^3/day (i.e. the proposed maximum abstraction rate to limit wetland drawdown to less than 200mm (0.20m).

Table A2: Groundwater allocation options for the Waitohu water management sub-zone

Cumulative Depletion of Waitohu Stream %MALF (*150) l/s	Allocation m^3/day	Allocation m^3/year X10^6	Cumulative Depletion L/s	Wetland Drawdown mm (Max.200mm)	Coastal Drawdown m (Max. 1m)	LSR %
8.1% MALF	3,000	0.54	12.2	100	0.10	7.2
16 % MALF	6,000	1.08	24.4	200	0.13	24
32% MALF	12,000	2.16	49	400	0.15	42

*Referenced only to the Waitohu Stream, combined MALF for the sub zone could be significantly higher.

Table A3: Kapiti Summary Table: Groundwater Allocation Proposal

	Controlling factors	Proposed new Allocation	Current Allocation	Notes
Otaki Otaki Sub-zone	MALF Depletion	This zone is all Cat A to all depths	16,900 m^3/d 5.152x10^6 m^3/yr (*all cat A from Otaki River no groundwater allocation)*	Use 20% of Otaki Malf (788 l/sec). Current allocation (350 l/s) (GW + SW) <50%allocated Wetland drawdown=0.07m Coastal drawdown = 0.22m
Otaki Waitohu Sub-zone	(1) Wetland drawdown 1–allow maximum 200 mm (2) MALF (150 l/sec)-allow up to 30% depletion. (3) LSR allow up to 30% (4) Coastal Drawdown- allow up to 1m	6,000 m^3/d 1.08x$10^6$$m^3/yr$	9,677 m^3/d Over allocated 3.02x$10^6$$m^3/yr$ Over allocated	Wetland drawdown =200mm Stream depletion = 21% of MALF (32 L/s) Coastal drawdown = 0.14m LSR = 24%

- Wetland drawdown is the controlling factor for the Waitohu Sub-zone
- \MALF depletion is the controlling factor for the Otaki River

Appendix B: Assessment of allocation options for the Te Horo groundwater zone

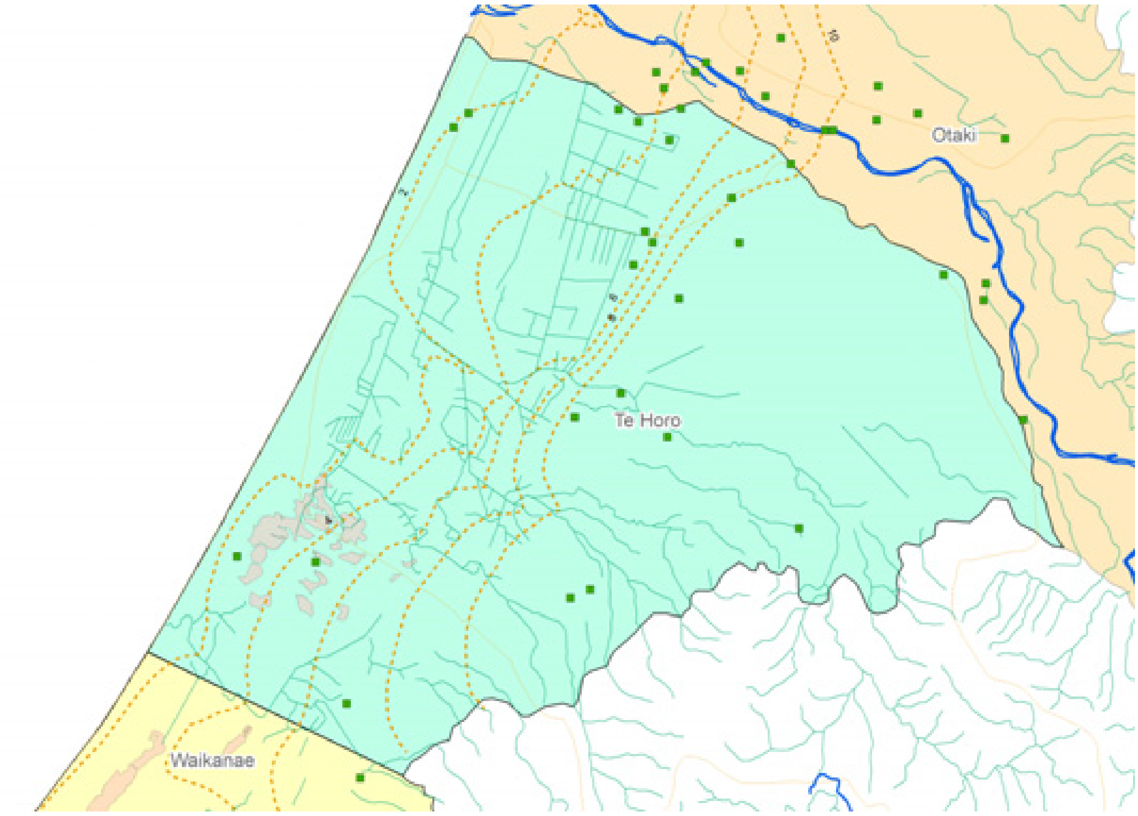

Figure B1: Te Horo Groundwater Management Zone

Table B1: Summary of the Te Horo Groundwater Management Zone

Delineation	The Te Horo groundwater zone extends across the coastal plain from the Otaki in the north to a southern boundary running parallel with Peka Peka Road this zone combines the existing Hautere and Coastal groundwater zones. This recognises the continuity of the Quaternary gravel deposits comprising the Hautere Plain under the Holocene (Q1) sand deposits along the coastal margin. The revised groundwater zone boundary along the eastern side of the Hautere Plain also follows the extent of greywacke basement defined on the QMap coverage;
Area	52.3 km^2
Boundaries	The southern boundary of the proposed Te Horo groundwater zone marks the approximate transition between the Otaki and Waikanae river alluvial fans. This boundary is shifted slightly north of the existing Waikanae/Coastal zone boundary to extend from the large greywacke outcrop north of Hadfield Road toward the coast, parallel to the estimated groundwater flow direction (Kampman and Caldwell, 1983). The northern boundary is similarly modified from the existing Hautere/Otaki and Coastal/Otaki zone boundaries to more accurately reflect the geological transition to Q1 alluvium in the Otaki River valley.
Principal surface water systems	The primary surface water feature for the Te Horo groundwater zone is the Mangaone Stream which traverses the coastal plain to reach the coast at Te Horo Beach. The Mangaone stream losses water to the underlying unconfined aquifer as it crosses the Hautere Plain and gains flow from the unconfined sand aquifer over the lower reaches. Significant wetland areas in the Te Hapua complex located near Peka Peka.

<table>
<tr><td>Aquifer sequences:</td><td colspan="3">Groundwater resources in this area are hosted in a thick succession of alluvial gravel materials accumulated on the alluvial fan formed by the Otaki River over the late Quarternary period. These materials host a succession of water bearing intervals which become increasingly well confined at depth. West of the prominent marine terrace running parallel to SH1 the upper portion of the alluvial materials have been replaced by Holocene sand and gravel deposits up to 35 meters thick accumulated as a result of shoreline progradation over the past 6,500 years forming a shallow unconfined aquifer system.</td></tr>
<tr><td>Hydraulic connectivity</td><td colspan="3">The entire Te Horo groundwater zone is classified as Category B to reflect the leaky (semi-confined) nature of the deeper water bearing layers within the alluvial gravel materials and the associated potential for abstraction from all depths to affect water levels and flows in surface water features hydraulically connected to the Holocene sand aquifer. Allocation criteria for groundwater takes from the Te Horo groundwater zone include:
• Assessment of stream depletion effects on adjacent surface waterways. Where q/Q>0.6 or 10 L/s (10% of MALF in the case of small streams) the take will be subject to pumping regulation based on the relevant surface water minimum flow. This type of assessment is likely to be of most relevance to shallow groundwater takes in the immediate vicinity of the downstream section of Mangaone Stream (i.e. west of SH1)
• Cumulative drawdown at the coastal margin. Groundwater takes likely to result in a cumulative reduction in piezometric head to more than 1 m asl at the coast will be classified as non-complying activities.
• Drawdown in the shallow unconfined aquifer adjacent to significant wetland areas (particularly in the vicinity of the Te Hapua complex). This assessment would have to take into account cumulative drawdown resulting from takes in the Te Horo groundwater zone.</td></tr>
<tr><td>Te Horo zone recharge</td><td colspan="3">Average annual recharge is 7.04x10^6 m^3 with a lower quartile recharge of 5.53x10^6 m^3.
Average daily recharge is 19,275 m^3 with a lower quartile of 15,150 m^3</td></tr>
<tr><td>Existing NRP zones</td><td colspan="3">Te Horo groundwater management zone.
Hautere groundwater management zone.</td></tr>
<tr><td rowspan="2">Current consented Allocation as at December 2013</td><td>No of groundwater takes</td><td>m^3/day</td><td>x10^{6}m^3/year</td></tr>
<tr><td>19</td><td>5,142</td><td>1.099</td></tr>
</table>

Hydrogeology summary

The primary hydrogeological features of the Te Horo management zone are the three primary aquifers underlying the Hautere plains (WRC, 1994):

- A water-bearing gravel layer between 10 to 30 metres below ground exhibiting moderate permeability;
- A water-bearing gravel layer between 40 to 70 metres below ground exhibiting low to moderate permeability containing groundwater with elevated iron concentrations; and,
- A poorly defined sequence of low permeability water-bearing gravels between 90 and 150 metres below ground characterised as containing elevated boron levels.

Overall, available data indicate the Te Horo groundwater zone comprises a thick sequence of alluvial materials accumulated on the alluvial fan formed by the ancestral Otaki River during late Quaternary Period. The stratigraphic succession comprises at least three (possibly more at depth) units which represent active erosion and deposition during successive glacial and interglacial cycles. These materials host an extensive groundwater resource which comprises laterally extensive water-bearing layers (generally comprising moderately to well sorted gravels) separated by intervening layers of low permeability materials (fine sand, silt, and poorly sorted gravels) to form a stratified aquifer system which becomes increasingly confined with depth.

Available water level information indicate infiltration of rainfall and runoff from the Tararua foothills is the primary source of recharge in the Te Horo groundwater zone.

Hydrology and surface water allocation management

Streamflow gaugings also indicate a flow loss of approximately 50 L/s from the Mangaone Stream to the unconfined aquifer as it crosses the Hautere Plain. Downstream of the Holocene marine terrace the Mangaone Stream gains between 150 to 200 L/s from the surrounding Holocene (Q1) sand aquifer. This includes baseflow to the Mangaone Stream itself as well as discharge via a series of springs at the base of the marine terrace along Te Waka Road into an extensive artificial drainage network on the coastal plain. An unknown component of groundwater throughflow is discharged offshore.

Zone management objectives

The principal management objective in the Te Horo zone is to ensure the sustainable allocation of groundwater resources with respect to freshwater ecosystems and prevention of saltwater intrusion. The protection of instream values of the Mangaone Stream, the Te Hapua wetland complex system and prevention from saltwater intrusion from cumulative effects of groundwater abstraction and baseflow depletion are the primary criteria for developing sustainable allocation options in this zone.

Numerical modelling

The numerical groundwater flow model for the Kapiti Coast was used to assess the sustainability of the current groundwater abstractions and to develop allocation options for the Te Horo groundwater management zone. Full details of the model and the calibration process are provided by Gyopari, Mzila and Hughes (2012). The model has been principally used to evaluate the cumulative effects of abstraction on the surface water environment and coastal drawdown in developing options.

Zone water budget

The numerical groundwater flow model has enabled a temporal characterisation of the natural water balance for the Te Horo zone using a version of the 18-year calibration simulation (1993-2011) which has no groundwater abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated (by comparing the no-abstraction and abstraction scenarios). Of particular relevance to assessing the sustainability of abstraction, the model enables quantitative assessment of the potential cumulative depletion effects resulting from groundwater pumping on the surface water environment in the Te Horo water management zone.

The principal water balance components for the Te Horo zone are rainfall recharge and surface water/groundwater fluxes. Figure B2 shows the modelled annual rainfall recharge for the Te Horo zone for the period 1992 to 2010. The average annual recharge for this period is 18.7×10^6 m^3 with a lower quartile recharge of 15.1×10^6 m^3. This translates to an average daily recharge of 51,161 m^3 with a lower quartile of 41,301 m^3.

The simulated natural fluxes (in the absence of groundwater abstraction) between the Mangaone Stream and groundwater within the Te Horo zone are illustrated in Figure B3. The negative fluxes show that the Mangaone Stream gains flow from the Hautere Plain to the coast. As a consequence, low flow discharges in the stream is supported by local groundwater baseflow discharge, particularly on the coastal plain. The baseflow is lowest during summer and the discharges are consistent with measured base flow of approximately 6,500 m^3/day (75 L/s).

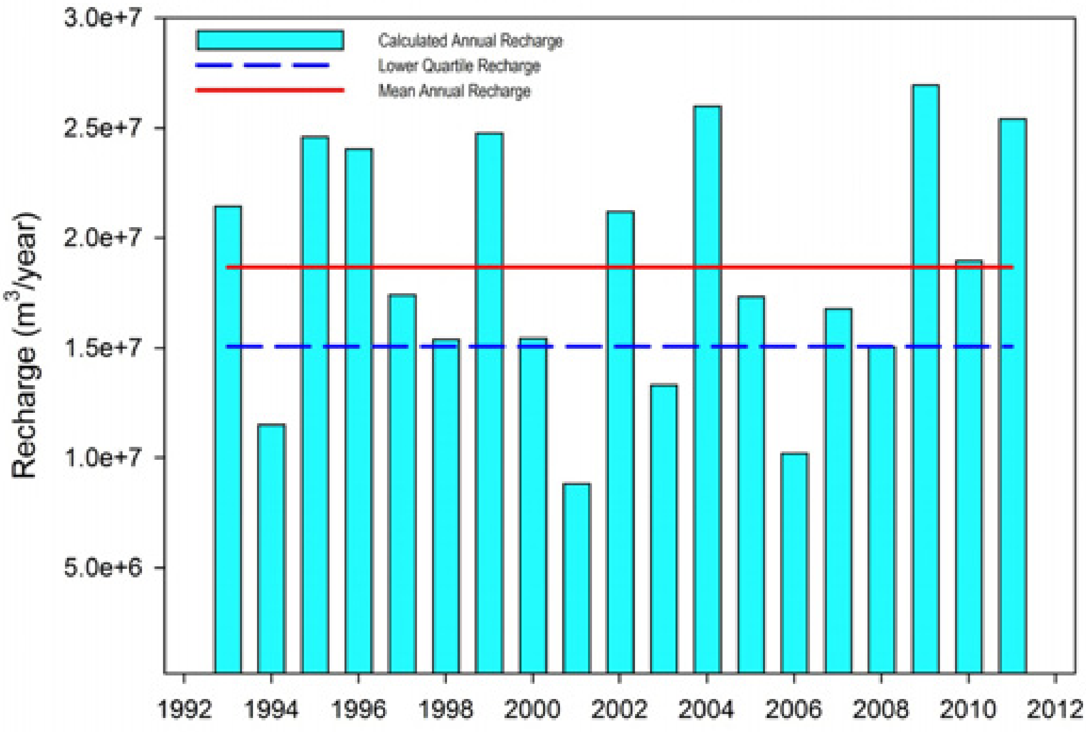

Figure B2: Modelled annual rainfall recharge (1993-2011) for the Te Horo zone between 1992 and 2012. A mean recharge 51,161 m^3/day is indicated as is the lower quartile value of 41,301 m^3/day (dashed line).

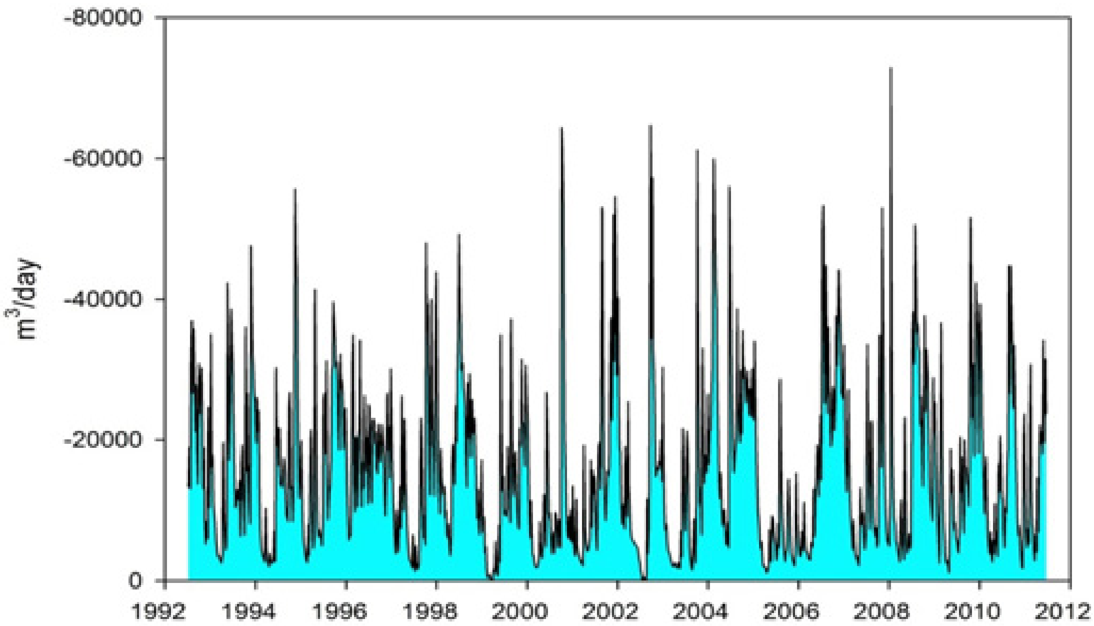

Figure B3: Simulated net natural surface water fluxes to the Mangaone Stream in the Te Horo zone when no groundwater abstraction is occurring. The negative fluxes represent flow from groundwater to the stream (i.e. gaining system). This plot shows the net gain over the entire reach of the Mangaone Stream.

Current abstraction

Current abstraction from the Te Horo zone was simulated for the 19-year transient model run and the water balance outputs were compared to the baseline (no-abstraction) simulation. The effects of groundwater abstraction on the surface water environment were then evaluated by comparing the two sets of water balance outputs.

(Figure B4) shows the modelled surface water depletion resulting from current abstraction in the Te Horo zone. Figure B5 shows a detailed portion of Figure B4 for the period 2004 to 2006 to illustrate the response of the groundwater system to abstraction. The scenario shows that seasonal abstraction has increased between 2001 and 2002 to peak at about 3,250 m^3/day. The total depletion of surface water is around 35 to 45% of the abstraction rate throughout the simulation period. The magnitude of the resulting total surface water depletion effect is calculated at 1,300 m^3/day which is approximately 49% of the 7-day MALF of the Mangaone Stream. However, it should be noted that total surface water depletion includes depletions from drains and part of the Kowhai Stream. Depletion effects on the Mangaone stream are discussed separately in the following sections.

Seasonal depletion peaks at the end of each irrigation season with a sharp reduction thereafter. However, there is residual depletion that occurs throughout the winter seasons.

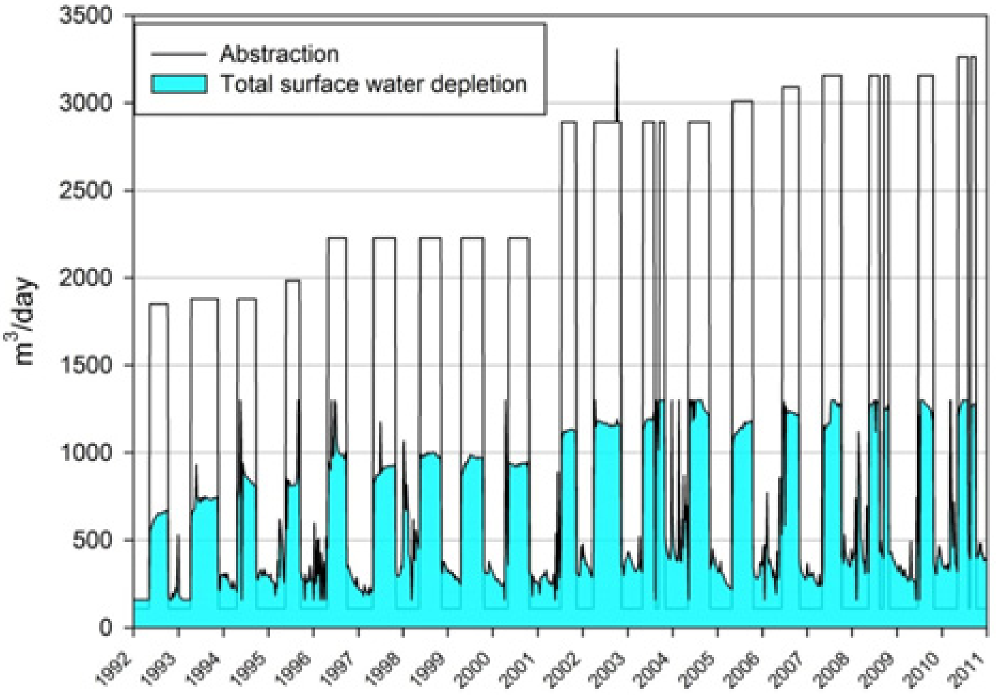

Figure B4: Simulated historic abstraction and associated surface water depletion in the Te Horo zone (1992-2012). A depletion equivalent to 35 to 40% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

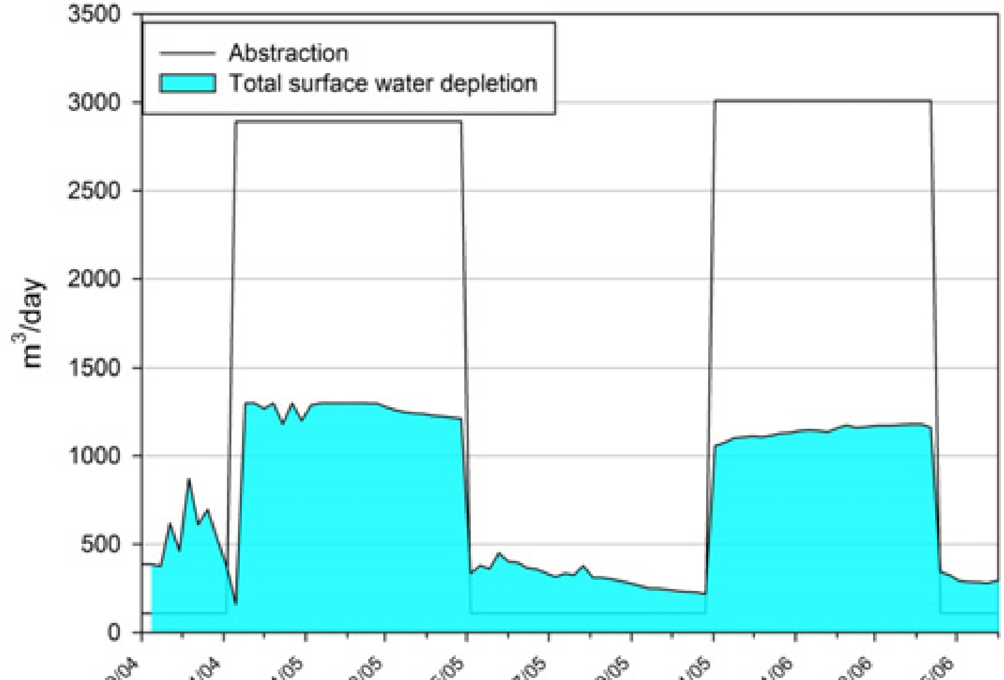

Figure B5: Details of Figure B3 – Simulated historic abstraction and associated surface water depletion in the Te Horo zone between 2004 and 2006. The plot demonstrates the lag between start and termination of seasonal pumping and surface water depletion. Surface water depletion responds almost immediately to pumping. There is a small residual depletion recession throughout the winter which is largely controlled by seasonal rainfall recharge.

Abstraction scenarios

The transient groundwater flow model for the Kapiti Coast was used to simulate 'synthetic' abstraction scenarios to further characterise the relationship between groundwater abstraction and the surface water environment that includes surface water depletion, wetland drawdown and coastal drawdown. For these scenarios, the transient run of 19 years was maintained in order to represent all climatic variations within this period.

The following scenarios were simulated:

- Scenario 1: A synthetic distributed abstraction from the deep aquifer (> 60m) pumping from both the higher and lower plains in the Te Horo zone. This scenario demonstrates the connection between the deep groundwater and surface water systems. The scenario also demonstrates the proportion of the Mangaone water depletion associated with abstraction from the coastal areas.

- Scenario 2: A synthetic distributed array of wells pumping from all aquifers throughout the Te Horo zone with abstraction rates of 7,500m^3/day. For this scenario abstraction occurs for 150 days each season. Abstraction bores are distributed through layers 2 to 6 and across the entire zone with each well pumping at 375m^3/day. Outputs for scenario 2 are shown in Figures C5 and C6.

- Scenario 3: The same as Scenario 2 except the pumping rate is increased to 15,000m^3/day and each well is pumped at 750m^3/day.

- Scenario 4: The same as Scenario 2 except the pumping rate is increased to 20,000m^3/day and each well is pumped at 1,000m^3/day.

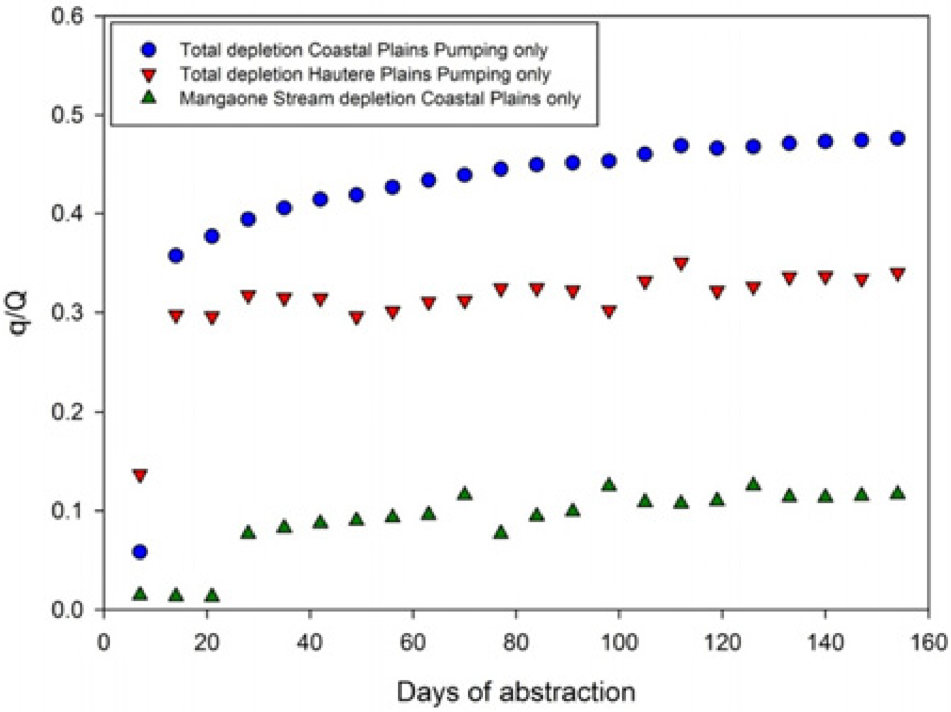

Figure B6: Scenario 1 – ratio of surface water depletion (q) to pumping rate (Q) when abstracting from deep aquifers of the Coastal and Hautere plains in the Te Horo Zone. The figure shows a fast response in stream depletion to abstraction from deep aquifers >60m for both the Hautere and Coastal zones.

Figure B6 shows the simulated surface water depletion from pumping from an array of synthetic bores in the semi-confined aquifers of the Hautere and Coastal areas of the Te Horo zone. The results of simulation are presented as the ratio between the depletion rate (q) and the average pumping rate (Q) which is termed the depletion factor (i.e. q/Q). The plot is useful since it is independent of the pumping rate which contributes to surface water depletion (the depletion factor). The data shown indicate that after about 7 days of pumping total depletion in the Hautere plains reaches about 30% of abstraction and remains constant throughout the abstraction period of 150 days. The data also shows a similar response when pumping from the Coastal plain, however depletion continues to increase and reaches about 50% of abstraction after 150 days. The figure indicates that deeper bores contribute to surface water depletion within a short period of abstraction commencing and are not abstracting from an isolated confined resource.

Figure B6 also shows the depletion factor of abstraction on the Mangaone Stream. Abstraction from deep groundwater has a delayed depletion effect on the Mangaone Stream. However the depletion factor (q/Q) reaches 0.13 within 30 days and remains constant throughout the simulation period of 160 days and it appears unlikely that the cumulative depletion on surface water would increase substantially over longer pumping durations.

Figure B7 and B8 relate to pumping Scenarios 2 to 4 in the three identified aquifers Q4 to Q6 in the upper and lower plains of the Te Horo catchment. Approximately 70% of current abstraction occurs within the three aquifers and it is important to assess the effect that groundwater takes from these aquifers may have on the surface water environment. The model scenarios predict that the effect on the Mangaone Stream is significant and the aquifers should be regarded as a single source.

Figure B8 shows that the depletion rate in the Mangaone Stream at the end of the irrigation season reaches a peak. When pumping ceases, there is a rapid recession in the depletion within a few days followed by a slow recession in depletion that continues through the winter period. Depletion responses indicate that regulation of these takes have immediate impact on the surface water depletion rate. Therefore, the regulation of these takes on the basis of the Mangaone low-flow triggers would provide an effective means to mitigate the effects of pumping during low flow periods.

Figure B9 shows the ratio of depletion to pumping rate for Scenarios 2 to 4 (abstracting at 7,500, 15,000 and 20,000 m^3/day respectively from the Q4 to Q6 aquifers). The plot demonstrates that the depletion factor is independent of pumping rate and that after 20 days of pumping, the depletion factor is about 11% of the total abstraction rate. The depletion factor increase slightly and levels off at 13% by 150 days and it appears unlikely that the cumulative depletion would increase substantially over longer pumping durations. The depletion factor for the Mangaone Stream is relatively low, however the rapid response of depletion to pumping and also the low MALF conditions in the Mangaone Stream necessitates regarding groundwater and surface water as connected and should not be regarded as a C Category.

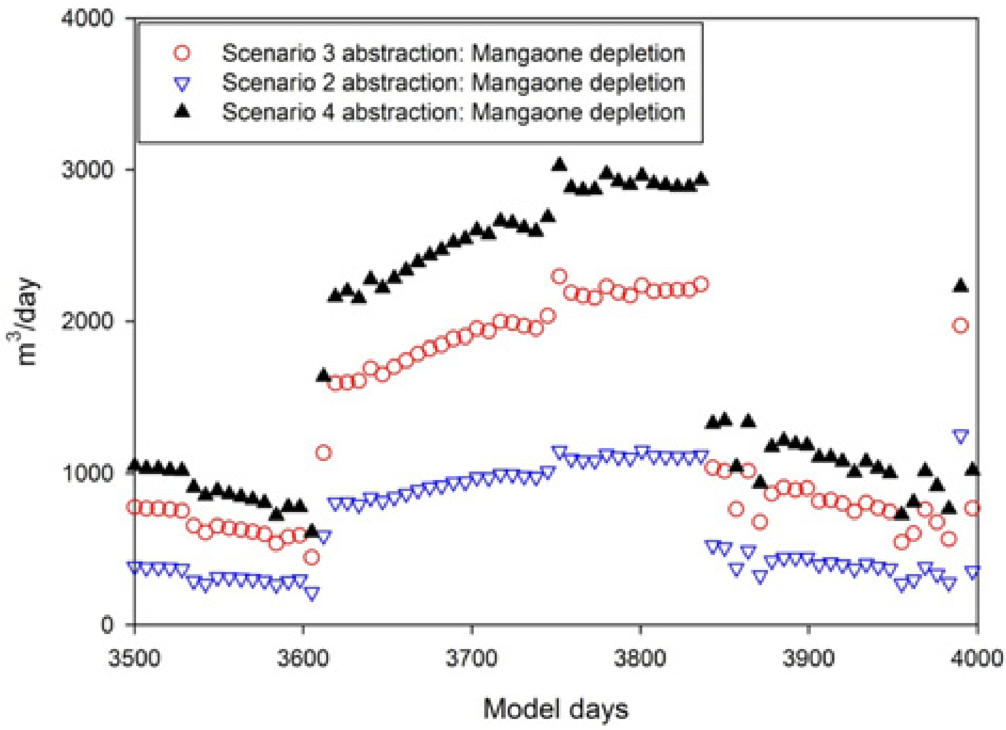

Figure B7: Scenarios 2 to 4 surface water depletion in the Mangaone Stream resulting from pumping an array of synthetic bores located in the three identified aquifers of the Te Horo zone. Abstraction from the aquifer at 7,500m³/day (Scenario 2), 15,000m³/day (Scenario 3) and 20,000m³/day (Scenario 4) extracted from model days 3500 to 4000 from 19 years (6930 days) simulation.

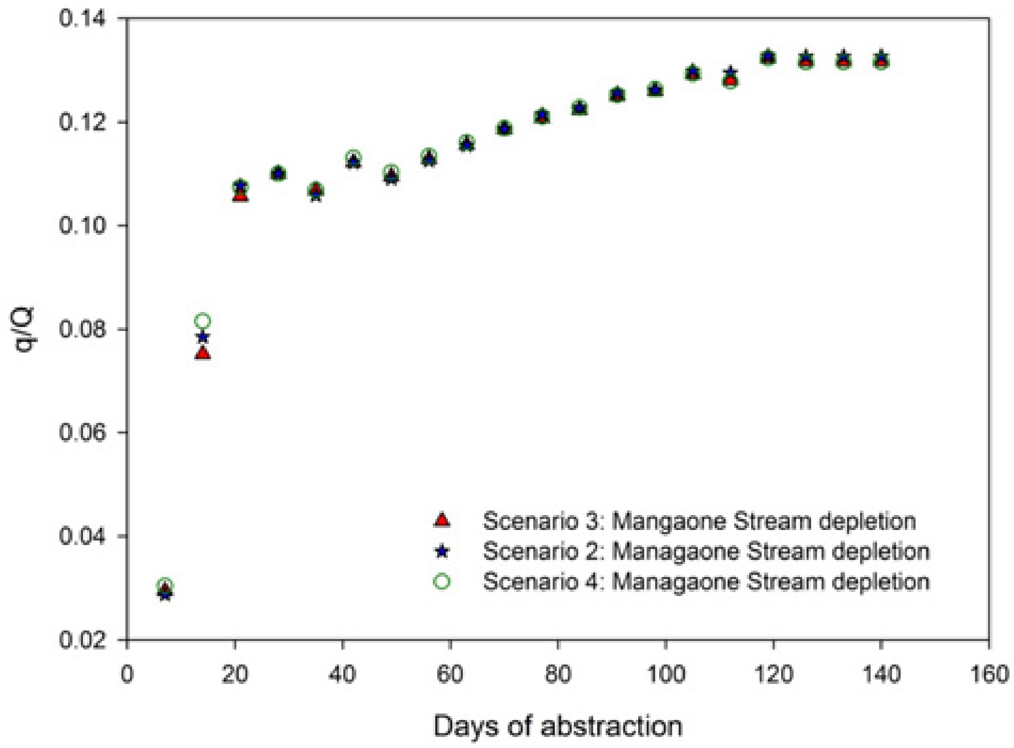

Figure B8: Scenarios 2 to 4 – ratio of surface water depletion (q) to pumping rate (Q) for the Mangaone Stream – abstracting from all the aquifers at 7,500 m³/day (Scenario 2), 15,000 m³/day (Scenario 3) and 20,000 m³/day (Scenario 4)

Figure B9 relates to pumping Scenarios 2 to 4 in the three identified aquifers Q4 to Q6 in the upper and lower plains of the Te Horo catchment with regard to wetland drawdown. Approximately 70% of current abstraction occurs within the three aquifers and it is important to assess the effect that groundwater takes from these aquifers may have on temporal and long term drawdowns on the Te Hapua wetland complex. The model scenarios predict that the effect on the Te Hapua wetland complex is significant and the aquifers should be regarded as a single source that is connected to the surface environment.

Figure B9 shows that the drawdown magnitude of the wetland complex reaches a peak at the end of the irrigation season. When pumping ceases, there is a slow recession in depletion that continues through the winter period until a new abstraction cycle. Simulations indicate that wetland levels do not recover fully and there are long term drawdown effects whose magnitude is dependent on the seasonal abstraction rate. It can be observed from the wetland drawdown to cumulative groundwater abstraction that regulation of pumping to control wetland drawdowns is unlikely to be an effective means of mitigating potential wetland drawdowns. The whole aquifer responds as a single unit such that abstraction from deeper Q4 to Q6 water bearing layers and away from the immediate margins of the Te Hapua wetlands is unlikely to be an effective means of mitigating potential wetland drawdowns. However, abstraction in the shallow Holocene sands further away from immediate margins of the Te Hapua wetland complex is likely to be effective in reducing wetland drawdowns.

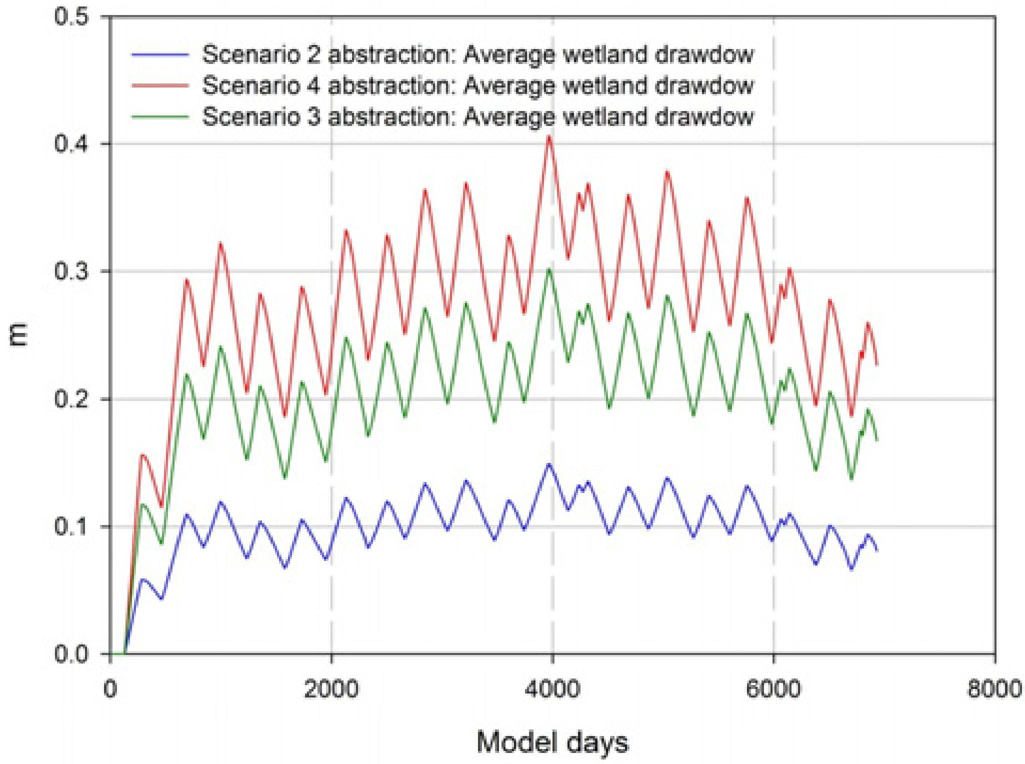

Figure B9: Scenarios 2 to 4 – Wetland drawdown averaged over the six wetlands in the Te Hapua wetland complex. Wetland drawdown when wells are abstracting from all aquifers at 7,500 m³/day (Scenario 2), 15,000 m³/day (Scenario 3) and 20,000 m³/day (Scenario 4).

Groundwater management options for the Te Horo zone

Groundwater-surface water interaction zones

- It is recommended that the Te Horo zone should be classified as Category B to all aquifer depths in recognition of the rapid responses of the Mangaone Stream to starting and ceasing pumping in both shallow and deep aquifers.

Groundwater allocation

- Aquifers in the proposed Te Horo zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.

- These effects are then compared (as a ratio) to the maximum permissible drawdown or depletion, specified as:

- **Stream flow depletion: 30% of Mangaone Stream 7-day MALF**: The groundwater allocation criterion for this zone should be referenced to the 7-day MALF for the Te Horo Groundwater Management Zone. The estimated 7-day MALF for the zone is 203 L/s (17,540 m^3/day). A stream flow depletion factor of 0.4 should be adopted for the Te Horo water management zone.

- **Average wetland drawdown: 0.20m**. The groundwater allocation criterion for this zone should also be referenced to the temporal and long term drawdown in the Te Hapua wetland complex. A maximum long-term drawdown of 200mm (0.20m) due to abstraction effects is adopted for this zone. Depletions of discharges to other surface environments such as drains are not considered in the allocation criteria.

- Annual Allocation should be based on a pumping duration of 180 days.

- Daily allocations should be based on weekly averages.

Table C2 outlines options for groundwater allocation in the Te Horo water management zone based on the potential cumulative effect of groundwater abstraction on baseflow in the Te Horo zone, on drawdown in the Te Hapua wetland complex and drawdown at the coast. Options 1 to 9 represent results of further modelling by varying the abstraction rates. The optimal scenario for maximising resource availability while minimising negative environmental effects is option 5. Under this scenario the maximum abstraction rate is calculated at 9,000 m^3/day (1.62×10^6 m^3/year). The annual volume is calculated over 180 days. The cumulative Te Horo zone depletion is 41.7 L/s that is equal to 15% of 7-day MALF depletion (Maximum allowable MALF depletion = 30%). Drawdowns at the coast are relatively small when compared to wetland drawdowns and zone surface water depletion effects and have not been discussed in detail in this report.

Figure B10 presents allocation envelope curves that have been developed to assess various scenarios for abstraction and related consequential effects on the surface environment.

Table B2: Groundwater allocation options for the Te Horo water management sub-zone

Options	Cumulative Depletion of Te Horo Zone % MALF (203) l/s	Allocation m3/day	Allocation m3/year X10^6	Cumulative Depletion l/s	Wetland Drawdown mm (Max.200mm)	Coastal Drawdown m (Max. 1m)	LSR %
1	5.1	2250	0.41	10.4	32	0.04	7.3
2	8.9	3900	0.70	18.1	54	0.12	12.7
3	10.3	4530	0.82	21.0	62	0.20	14.7
4	13.3	5850	1.05	27.1	79	0.23	19.0
5	***20.1***	***9000***	***1.62***	***41.7***	***119***	***0.24***	***30***
6	22.9	10054	1.81	46.5	133	*0.27*	32.7
7	26.0	11400	2.05	52.8	150	0.52	37.1
8	27.7	12151	2.19	56.3	160	0.58	39.6
9	68.4	30000	5.40	138.9	389	0.62	97.7

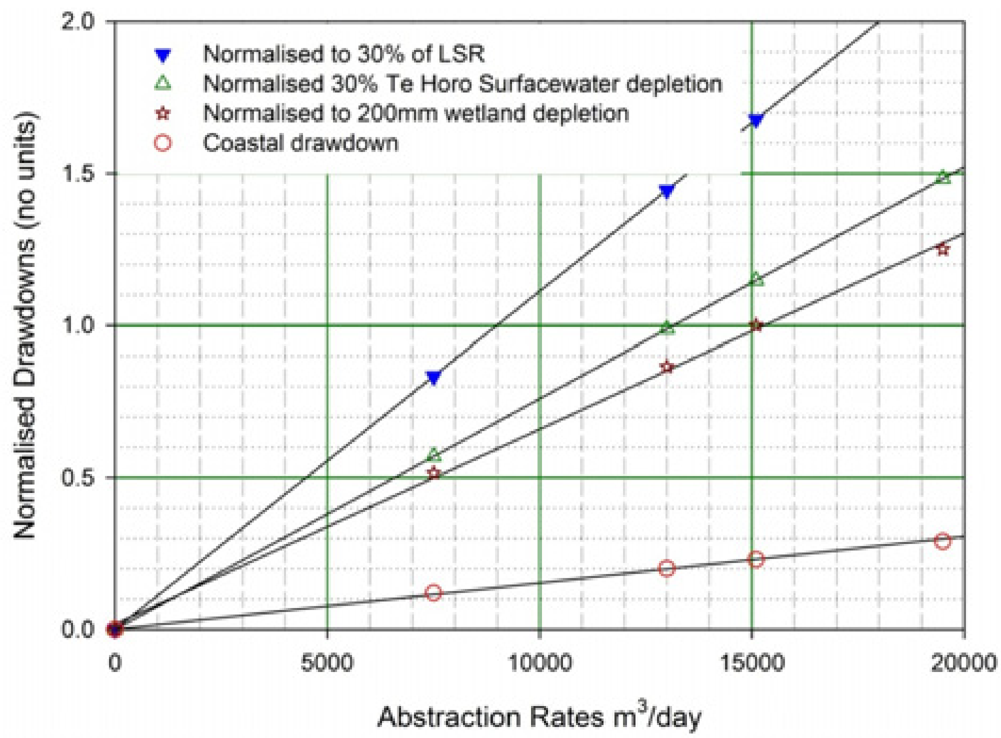

Figure B10: Allocation envelopes abstracting from all three aquifers in the Te Horo zone. Lower Quartile surface recharge is normalised to 30% LSR, Wetland drawdown is normalised to 0.20m, stream depletion is normalised to 30% of MALF for the zone (60.9 L/s) and drawdown at the coast is normalised to 1m. The normalisation values are the maximum allowable depletions or drawdown to limit adverse environmental effects. A normalised LSR of 1.0 intersects the abstraction rate at 9,000 m^3/day (i.e. the maximum abstraction rate equivalent to 30% LSR). The normalised stream depletion ratio at this abstraction rate is 0.7 or 70% of 60.9 L/s or 3,600 m^3/day. The coastal drawdown is approximately 0.3m. The normalised wetland drawdown at this abstraction rate is 0.6 (i.e. equivalent to 120mm drawdown).

Table B3: Te Horo Zone Summary Table: Groundwater Allocation Proposal

	Controlling factors	Proposed New Allocation	Current Allocation	Notes
Te Horo Zone	Wetland drawdown 1–allow maximum 200 mm MALF (203 L/sec)-allow up to 30% depletion. LSR allow up to 30% Coastal Drawdown- allow up to 1m	9,000 m^3/d $1.62x10^6$ m^3/yr	6,530 m^3/d 33% allocated 1.134x106 m^3/yr (32% allocated)	Wetland drawdown:120mm MALF depletion:15% Coastal drawdown (deep):0.120m Coastal drawdown (shallow):0.05m LSR:30%

Appendix C: Assessment of allocation options for the Waikanae groundwater zone

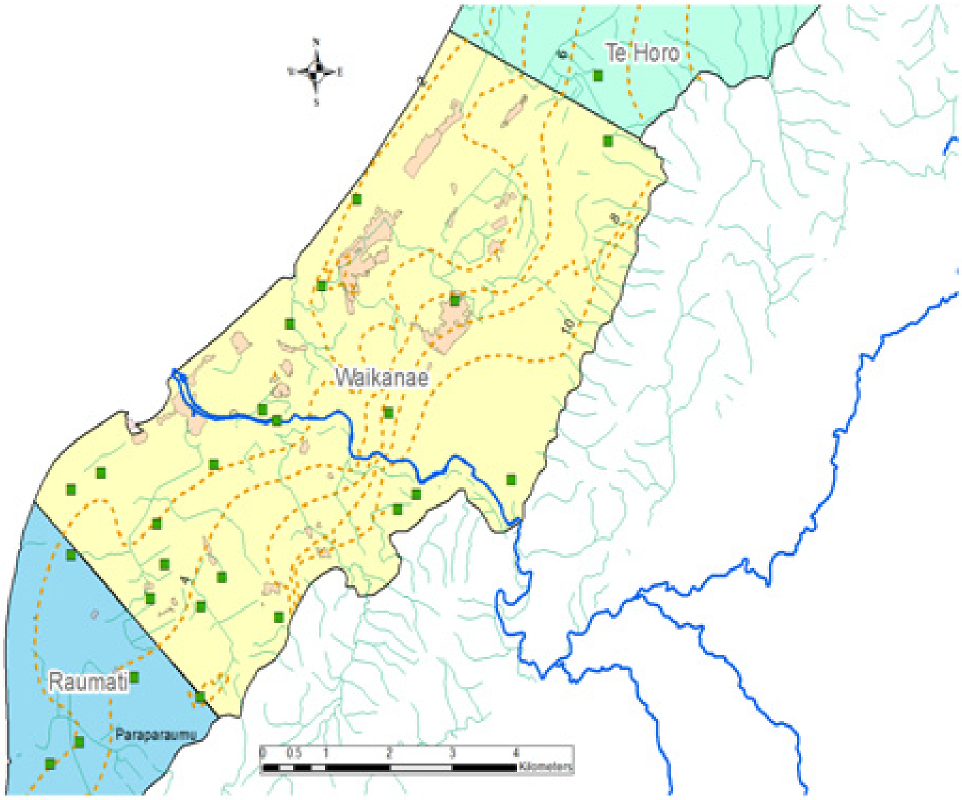

Figure C1: Waikanae Management Zone

Table C1: Summary of the Waikanae Groundwater Management Zone

Delineation	The Waikanae groundwater zone extends across the coastal plain from the Peka Peka Road in the north to Paraparaumu Beach in the south.
Area	42 km^2
Boundaries	Figure C1 shows the spatial extent of the zone including primary surface water features (streams and wetlands), groundwater level monitoring and concurrent flow gauging sites and the locations of bores recorded on the GWRC Wells database. The proposed Waikanae groundwater zone essentially remains the same as the current zone with relatively minor adjustments to the zone boundaries. These adjustments include: A slight shift and re-alignment of the northern boundary to finish at the greywacke exposure on the northern side of Hadfield Road to reflect the approximate southerly extent of the Otaki fan and better align with assumed groundwater flow directions (e.g. Kampman and Caldwell, 1983) rather than Peka Peka Road; Truncation of the groundwater zone boundary near the start of the Reikorangi Valley to reflect the exposure of greywacke basement in the bed of the Waikanae River near this location; and, movement and re-alignment of the southern boundary to better reflect the southerly extent of the Waikanae River alluvial fan (based on bore logs) and the alignment of the flow divide between Wharemakau Stream and Mazengarb Drain indicated by piezometric contours (GWRC, 2005);

Principal surface water systems	The major surface water feature of the Waikanae groundwater zone is the Waikanae River which drains from headwaters in the Tararua Range to the coast at Otaihanga. The Waikanae River loses appreciable flow in the upper reaches and also gains flow in the lower reaches towards the coast. Smaller streams draining the coastal plain include the Waimeha Stream, Wharemauku Stream, Mazengarb Drain and Ngarara Stream, all of which receive baseflow from the unconfined Holocene sand aquifer. Significant wetlands in the area include the Te Harakeke, Nga Manu, El Rancho, Ngarara and Tini Bush.		
Aquifer sequences:	Groundwater resources in the Waikanae groundwater zone are hosted in a succession of alluvial gravel materials accumulated on the alluvial fan of the Waikanae River over the late Quaternary period. These materials form a complex geological and hydrogeological environment reflecting the accumulation of sediments on an active alluvial fan during successive climate cycles during the late Quaternary Period. A simplified conceptual model for the area comprises two deeper semi-confined aquifers overlain by a shallow unconfined aquifer in the Holocene sand deposits accumulated along the coastal margin. Recent (Q1) alluvium forms a narrow highly permeable riparian aquifer along the margins of the Waikanae River and Waimeha Stream.		
Allocation Sustainability Criteria	Cumulative depletion of surface water discharge Drawdown in unconfined aquifer in the vicinity of significant wetlands Drawdown at the coastal margin		
Allocation categories	The Category A classification is applied to the unconfined aquifer hosted in Q1 alluvium adjacent to the Waikanae River and Waimeha Stream to a depth of 20 m bgl. Groundwater takes from within this classification will be included in the allocation for the relevant surface waterway (either Waikanae River or Waimeha Stream) and subject to relevant minimum flow regulation. The Category B classification is applied to the remainder of the Waikanae groundwater zone. Allocation criteria for groundwater takes from Category B are: • Assessment of stream depletion effects on adjacent surface waterways. Where q/Q > 0.6 or 10 L/s (10% of MALF in the case of small streams) the takes will be subject to pumping regulation based on the relevant surface water minimum flow. This assessment is likely to be most relevant to shallow takes along the margins of the Waikanae River flood plain or located in relatively close proximity to smaller streams on the coastal plain. • Cumulative drawdown at the coastal margin. Groundwater takes likely to result in a cumulative reduction in piezometric head to more than 1m asl at the coast will be classified as non-complying activities. • Drawdown in the shallow unconfined aquifer adjacent to significant wetland areas (including the Te Harakeke, El Rancho and Ngarara wetlands). Groundwater takes likely to result in cumulative reduction in piezometric head of 0.2 m around the wetlands will be classified as non-complying activities.		
	Average annual recharge is 13.4x10^6 m^3 with a lower quartile recharge of 9.94x10^{6}m^3. Average daily recharge is 36,714m^3 with a lower quartile of 27,234m^3		
Existing NRP zones	Waikanae zone		
Current consented Allocation as at December 2013	No of groundwater takes	m^3/day	x10^6 m^3/year
	20	41,140	2.98

Hydrogeology summary

The Waikanae groundwater zone is a single layered leaky aquifer system within which four productive water-bearing horizons are recognised:

- The Holocene (Q1) sand and gravel deposits form an extensive unconfined aquifer system which is recharged by local rainfall as well as flow loss from the Waikanae

River. Piezometric contours indicate groundwater flow is generally concordant with the gradual seaward slope of the coastal plain indicating discharge is likely to occur along the coastal margin (Jones and Gyopari, 2005). This formation is also hydraulically connected to numerous wetlands and streams on the coastal plain.

- Q2 (late last glacial) gravels form the terrace surface to the east of the Holocene marine terrace and extend under the Holocene (Q1) sand deposits to the coast. To the east these materials may inter-finger with locally derived colluvium accumulated at the base of the Tararua foothills. However, across the majority of the coastal plain these materials form a laterally continuous, unconfined/semi-confined aquifer extending between 30 to 40 metres below ground[12].

- Q4 (early last glacial) gravels - a relatively poorly defined semi-confined aquifer horizon hosted by permeable gravel materials accumulated during early stages of the Otira glacial period. These materials nominally occur between 50 to 60 metres below ground across the coastal plain; and

- Q6 and older materials (Waimea Gravels) - A poorly defined layer of heterogenous sand and gravel) extending below 70 metres. This unit (previously referred to as the 'Waimea Gravels') appears to be highly heterogeneous comprising channelized deposits of more permeable gravel materials separated by low permeability silts and sands. As a consequence, description of this layer as a single water-bearing unit may be a generalisation as significant variations in sediment texture and associated hydraulic properties are likely to occur both spatially and with depth.

The late Quaternary alluvial materials (certainly the Q2 and Q4 materials) lap onto a basement high underlying Waikanae. URS (2004) noted the influence of the basement high on the overall groundwater potential of the Waikanae groundwater zone marking a transition from a thinner (possibly lower permeability) sedimentary sequence in the east to a thicker, better sorted, laterally continuous geological sequence to the west.

At a regional-scale, the materials separating the primary water-bearing units (i.e. Q3 sand, silt and gravel and the Q5 sand and silt respectively) can be considered as aquitards which impede the vertical flow of water, but are not impermeable. At a local scale these materials may exhibit significant variation in hydraulic properties. For example, in the Waikanae area, the basal part of the Q5 unit appears to locally form a viable aquifer. The aquifer system in the Waikanae Groundwater Zone is therefore best described as a heterogeneous stratified system comprising multiple, leaky water-bearing intervals which become increasingly confined at depth, rather than hosting discrete 'aquifers' in the conventional sense.

Hydrology summary

The Waikanae River drains the western slopes of the Tararua Range and flows across the coastal plain in the vicinity of Waikanae Beach. Other streams draining the Waikanae groundwater zone include the Ngarara Stream which drains wetland areas on the coastal plain north of Waikanae, the spring-fed Waimeha Stream originating on the palaeochannel of the 'Waimeha River' and the Mazengarb Drain which drains the coastal plain south of the Waikanae River.

[12] This unit essentially corresponds with the upper part of the 'Parata Gravels' referred to by WRC (1994) and PDP (1996 a and b)

The Waikanae River is characterised by appreciable flow loss over the reach between Transmission Lines and Jim Cooke Memorial Park[13]. During periods of low flow (MALF about 850 L/s) gauged losses over this reach are generally of the order of 300 L/s (25,000 m^3/day) which may account for between 40 to 60 percent of the upstream flow. The flow loss over this reach is approximately 550 L/s (~50,000 m^3/day) at median flow. Baseflow discharge to lower reaches of the river from the surrounding unconfined aquifer may be in the order of 300 L/s.

A proportion of the flow loss from the Waikanae River appears to flow along the former channel of the 'Waimeha River' and emerge in headwater springs in the Waimeha Stream which carries a discharge of approximately 150 L/s. Appreciable baseflow discharge also occurs in the lower reaches of the Waikanae River (possibly of the order of 300 L/s) as well as the Mazengarb Drain (~50 L/s) and Ngarara Stream (30 L/s). An unknown component of groundwater throughflow is discharged offshore, although the observed reduction in piezometric gradient along the coastal margin may suggest that vertical leakage in this area may be a more important component of the water balance in the Q6 and Q2 aquifers.

Waikanae groundwater zone hosts a number of significant wetland areas on the coastal plain both north and south of the Waikanae River. Jones and Gyopari (2005) note that these ecosystems are largely sustained by groundwater inflow in areas where the water table in the Holocene (Q1) sand aquifer intersects (or lies close to) the land surface, particularly in interdunal depressions. In localised areas, evaporation from open water and evapotranspiration from wetland vegetation may comprise a relatively small component of the overall water budget in the unconfined aquifer which increases in significance during extended periods of low rainfall.

Zone management objectives

The principal management objective in the Waikanae zone is to ensure the sustainable allocation of groundwater resources with respect to protecting the ecological values of freshwater ecosystems and preventing intrusion of saltwater into the aquifers. The protection of instream values of the Waikanae River, Waimeha Stream, Ngarara Stream, Mazengarb Drain, wetland systems and prevention from saltwater intrusion from cumulative effects of groundwater abstraction and baseflow depletion are the primary criteria for developing sustainable allocation options in this zone.

Numerical modelling

The numerical groundwater flow model for the Kapiti Coast was used to assess the sustainability of the current groundwater abstractions and to develop allocation options for the Waikanae groundwater management zone. Full details of the model and the calibration process are provided by Gyopari, Mzila and Hughes (2012). The model has been principally used to evaluate the cumulative effects of abstraction on the surface water environment and coastal drawdown in developing options.

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[13] Both sites located downstream of KCDC water supply intake so observed flow variation not affected by abstraction

Zone water budget

The numerical groundwater flow model has enabled a temporal characterisation of the natural water balance for the Waikanae zone using a version of the 18-year calibration simulation (1993-2011) which has no groundwater abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated (by comparing the no-abstraction and abstraction scenarios). Of particular relevance to assessing the sustainability of abstraction, the model enables quantitative assessment of the potential cumulative depletion effects resulting from groundwater pumping on the surface water environment in the Waikanae water management zone.

The principal water balance components for the Waikanae zone are rainfall recharge and surface water/groundwater fluxes. Figure C1 shows the modelled annual rainfall recharge for the Waikanae zone for the period 1992 to 2010. The average annual recharge for this period is 13.4x106 m3 with a lower quartile recharge of 9.94x106 m3. This translates to an average daily recharge of 36,714 m3 with a lower quartile of 27,234 m3.

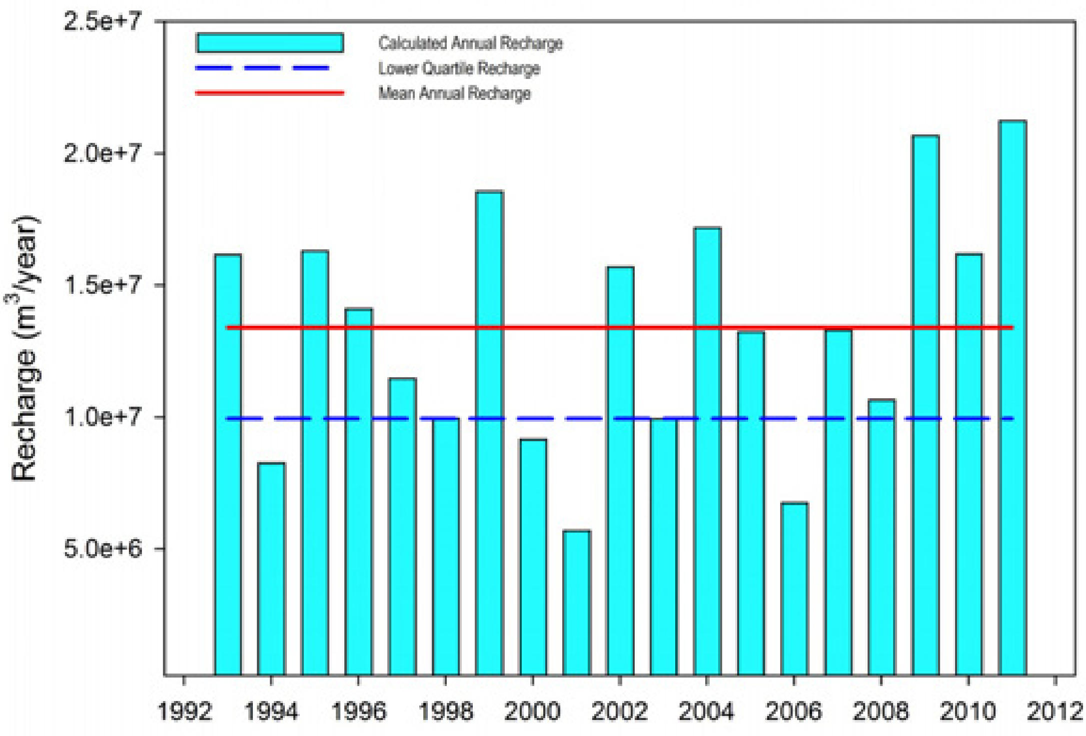

Figure C2: Modelled annual rainfall recharge (1993-2011) for the Waikanae zone between 1992 and 2012. A mean recharge 13.4x10^{6}m^3/year is indicated as is the lower quartile value of 9.94x10^{6}m^3/year (dashed line).

Modelled abstraction effects 1992-2012

Abstraction from the Waikanae zone was simulated for the 19-year transient model run (Figure C3). Seasonal abstraction in this area has increased significantly since 1993 and peaked at approximately 29,000 m^3/day over the 2003/04 and 2008/09 summer period. The high abstractions were due to the KCDC takes for municipal supply. KCDC reverts to groundwater for municipal supply when flows in the Waikanae River are at or near prescribed low flows. KCDC routinely abstracts water for system maintenance; typically these abstractions are for short durations of up to 2 weeks. KCDC had a consented groundwater take of a maximum 23,000 m^3/day which has since been increased to approximately 30,700 m^3/day for the Waikanae River Recharge Project. Other users are consented to abstract approximately 10,000 m^3/day.

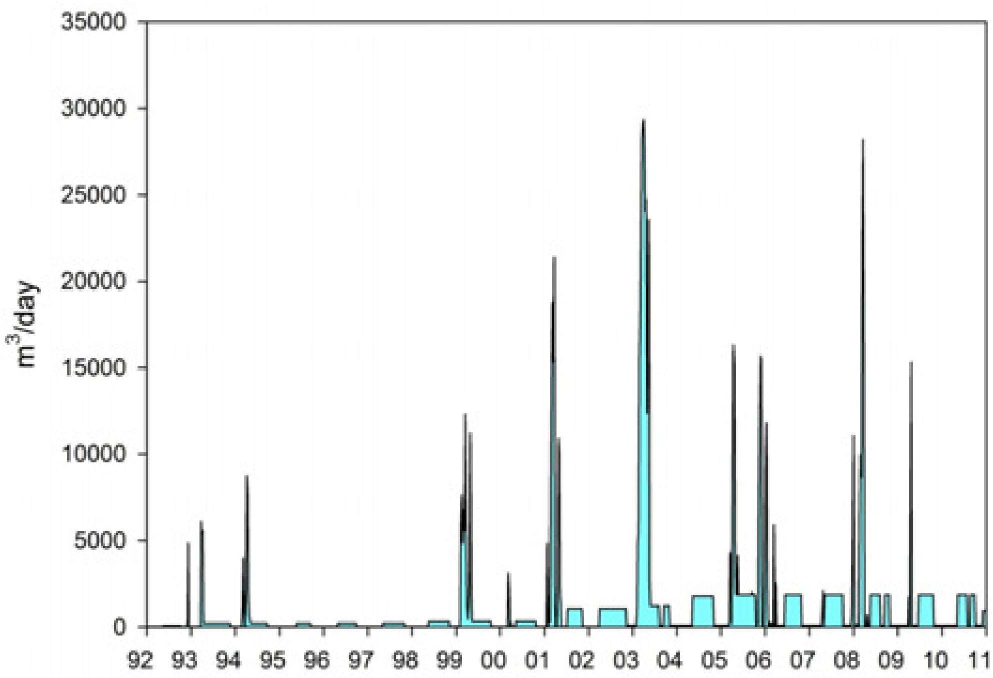

Figure C3: Modelled abstraction in the Waikanae water management zone between 1992 and 2012. The peaks represent the activation of the Waikanae bore field either for water supply or maintenance of the bore field.

The modelled depletion effects of estimated abstraction on the surface water environment are shown in Figure C4. This plot shows simulated depletion of the Waikanae River and total depletion including other streams and the Mazengarb drain resulting from historical abstraction from all consented bores in the Waikanae zone. The simulated maximum surface water depletion is 7,180 m^3/day.

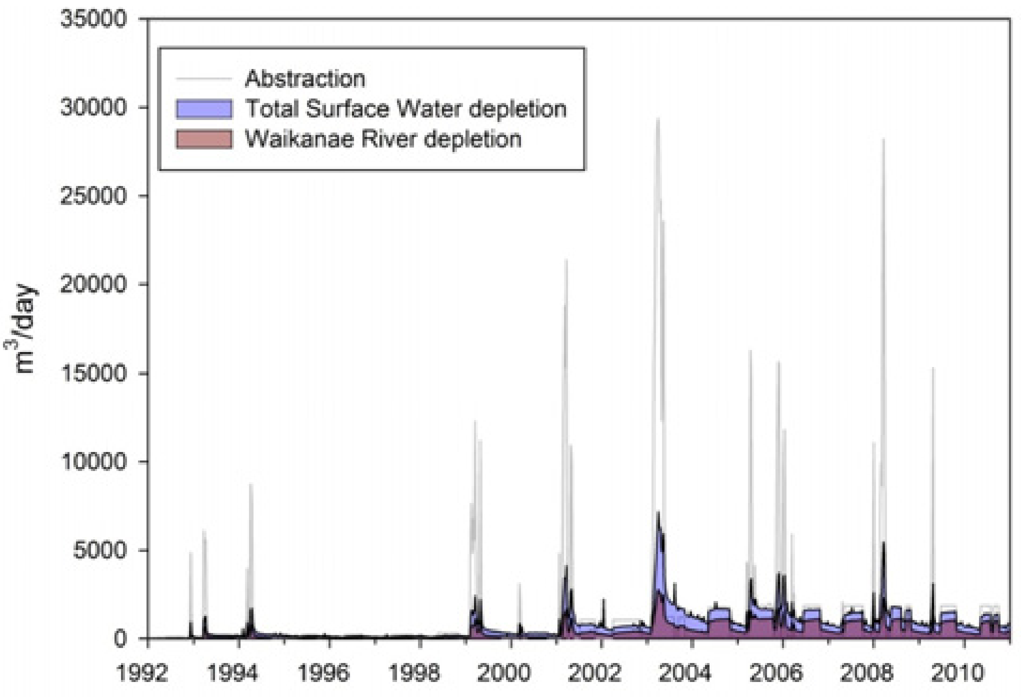

Figure C4: Simulated total surface water depletion resulting from abstraction in the Waikanae zone from all consented bores between 1992 and 2012. The relatively low surface water depletion when compared to groundwater abstraction was due to the short period of high abstractions.

Wetland and coastal drawdowns

Current (estimated) abstraction was simulated for the 19-year transient model run and wetlands levels were compared to the baseline (no-abstraction) simulation. The effects of groundwater level abstraction on the wetlands drawdown were then evaluated by comparing the two sets of groundwater levels. A similar analysis was carried out for coastal groundwater level drawdowns. Coastal groundwater level drawdowns were used as indicators of potential saltwater intrusion risk. A maximum coastal drawdown of 1m is deemed appropriate which is estimated to move the saltwater freshwater interface upwards by approximately 33 to 40m.

Figures B4 and B5 show the modelled wetland and coastal drawdowns resulting from current abstractions in the Waikanae management zone. This scenario shows that the wetland and coastal drawdowns respond to temporal and long term increases in abstraction. Figure C5 shows that wetland drawdowns do not fully recover during the winter seasons and winter wetland levels have declined by approximately 40mm between 1992 and 2012. The Nga Manu and Ngarara RDD wetlands were selected for analysis due to national significance and also were identified to be highly sensitive to cumulative abstractions from the Waikanae zone. During the peak abstraction season of 2003/04, the modelled drawdown in the Ngarara RDD wetlands reaches approximately 250mm with significant drawdown extending across the majority of wetlands. The current maximum allowable drawdown from abstraction is 200mm (Beca, 2008). The simulation would indicate that the current allocated abstraction does result in higher than acceptable wetland drawdown.

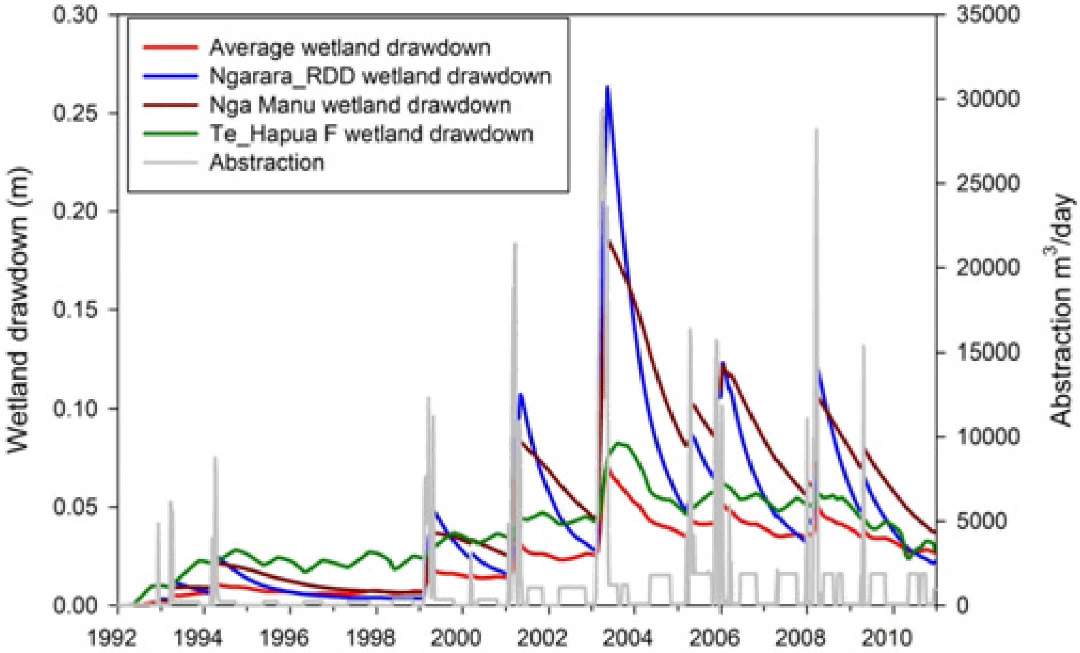

Figure C5: Simulated wetland drawdown resulting from abstraction in the Waikanae zone from all consented bores between 1992 and 2012. The quick response in wetland drawdown and un-complete recovery in wetland levels indicates that a continued increase in abstraction may not be sustainable in this zone.

The simulation is consistent with groundwater level monitoring data for the 2013/14 season were wetland levels declined by between 400mm to 1200mm in the Waikanae zone (Figure C6). The decline in wetland levels is attributed to the increased volume and duration of groundwater abstraction during this period.

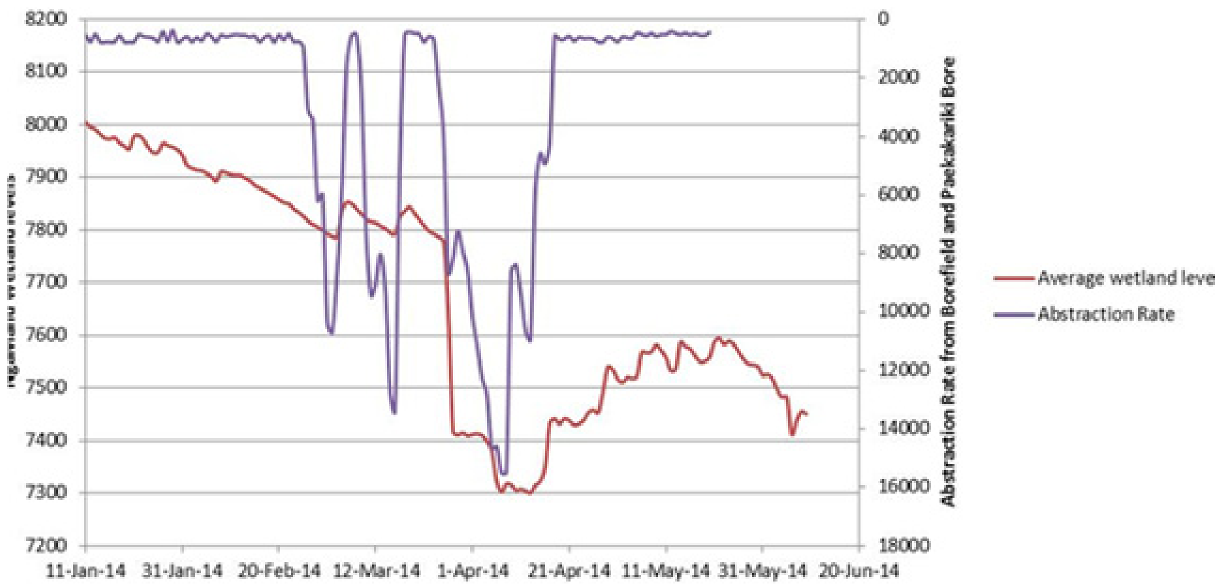

Figure C6: Effects of KCDC borefield groundwater abstraction on shallow groundwater levels in the NgaManu wetlands during the 2013/2014 summer season

Figure C7 shows the modelled coastal aquifer drawdown for both the deep and shallow groundwater during the transient 1992-2012 simulation. The modelled drawdown in the coastal deep aquifer reaches approximately1.3m and 0.08m for the shallow aquifer. The simulation is consistent with groundwater level monitoring data for the current 2013/14 summer season. Groundwater levels have declined more than 200mm for coastal shallow aquifers and more than 3m for deep aquifers located about 1km from the shoreline.

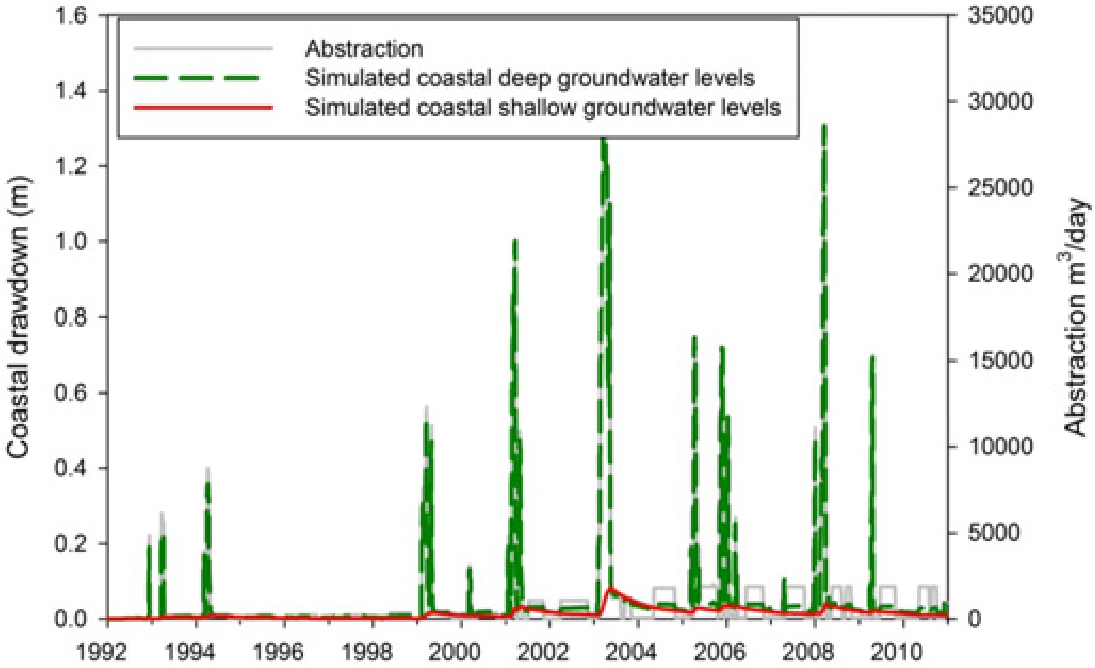

Figure C7: Simulated coastal drawdown resulting from abstraction in the Waikanae zone from all consented bores between 1992 and 2012. The quick response in coastal drawdown and complete recovery in deep groundwater levels indicates that although the potential for saltwater intrusion is high, deep coastal aquifers have quick recovery to re-establish the seaward discharge of groundwater. The shallow coastal groundwater behaviour is similar to wetland responses and do not recover completely from high groundwater abstractions.

Abstraction scenarios

The transient flow model for the Kapiti Coast was used to simulate a number of abstraction scenarios to further characterise the relationship between groundwater abstraction from different parts of the Waikanae water management zone, surface water depletion, wetland and coastal aquifer drawdowns. Abstraction from deep groundwater was limited to the current and proposed KCDC groundwater abstractions bores. However, abstraction scenarios for water-bearing layers below the Q1 gravels was also undertaken to evaluate groundwater-surface water connectivity. The transient run time for all the scenarios was 19 years in order to achieve a broader climatic representation.

The following scenarios were simulated:

- Scenario 1: Abstraction from the unconfined and semi-confined aquifer from twenty hypothetical bores in higher permeability Q1 and Q2 gravels (model layers 1 and 2) located along the Waikanae River and Waimeha Stream. The bores were evenly distributed in this zone and each bore was pumped at 289 m^3/day for a total abstraction rate of 5,770 m^3/day.

- Scenario 2: Abstraction from current KCDC borefield wells located in the Q6 deep aquifer only (model layers 6 and 7) at a rate of 26,825 m^3/day (75% of current daily consented abstraction) for a period of 180 days (Nov-May).

- Scenario 3: As in Scenario 2, but with abstraction from the semi-confined leaky aquifer (Q4) (i.e. well screens moved into layer 4 of the numerical model). The wells were pumped for the 19-year transient model run (the calibrated model).

For all scenarios, the water balance outputs were compared to baseline (no-abstraction) simulations so that the effects of abstraction on the surface water environment, wetland and coastal drawdown could be derived by comparing the two sets of water balance outputs. Flux balances for the Waikanae River were extracted from the model for the abstraction and no-abstraction scenarios. Wetland and coastal drawdowns levels were also extracted for Scenarios 2 and 3.

Scenario 1 - The bores are located between 75 to 300m from the river channel and screened to a depth of 20m (model layer 1) and 20 to 30m (model layer 2) below ground surface. Two model runs were undertaken using the same pumping well configuration. For the first run wells in layer 1 (Q1) were pumped at a rate of 5,770 m^3/day. For the second run the well screens were moved to layer 2 to simulate a condition when only layer 2 (Q2) wells are pumping at the same rate of 5,770 m^3/day. No other abstraction in the Kapiti catchment is occurring in this scenario. The overall objective of this scenario is to quantify the likely magnitude and characteristics of surface water depletion effects associated with abstraction from unconfined and semi-confined aquifers in the higher permeability area. The bores were pumped for the 19-year transient model run (the calibrated model).

Figure C8 shows the results of Scenario 1 in terms of surface water depletion effects when pumping only from Q1 or Q2 gravels along the Waikanae and Waimeha channels. The figure indicates the total surface water depletion effect is about 5,220 to 5,510 m^3/day. Pumping from the Q2 semi-confined aquifer (layer 2) results in surface water depletion of approximately 3,850 m^3/day. Figure C9 shows the same information in terms of the ratio between the depletion rate (q) and the synthetic pumping rate (Q) which is termed the ‘depletion factor’ (i.e. q/Q). This plot is useful since it is independent of the pumping rate which contributes to surface water depletion. The data shown indicate that after 20 days pumping from Q1 (layer 1) gravels the total depletion from surface water is equivalent to 85% of the overall abstraction rate. The depletion rate reaches about 95% after 60 days. Therefore, virtually all the abstraction is derived from surface water depletion when pumping occurs from unconfined Q1 gravels. Surface water depletion due to abstraction from Q2 (layer 2) semi-confined aquifer reaches 60% of the abstraction rate within 20 days and reaches a maximum of 63% after 60 days and remains constant thereafter.

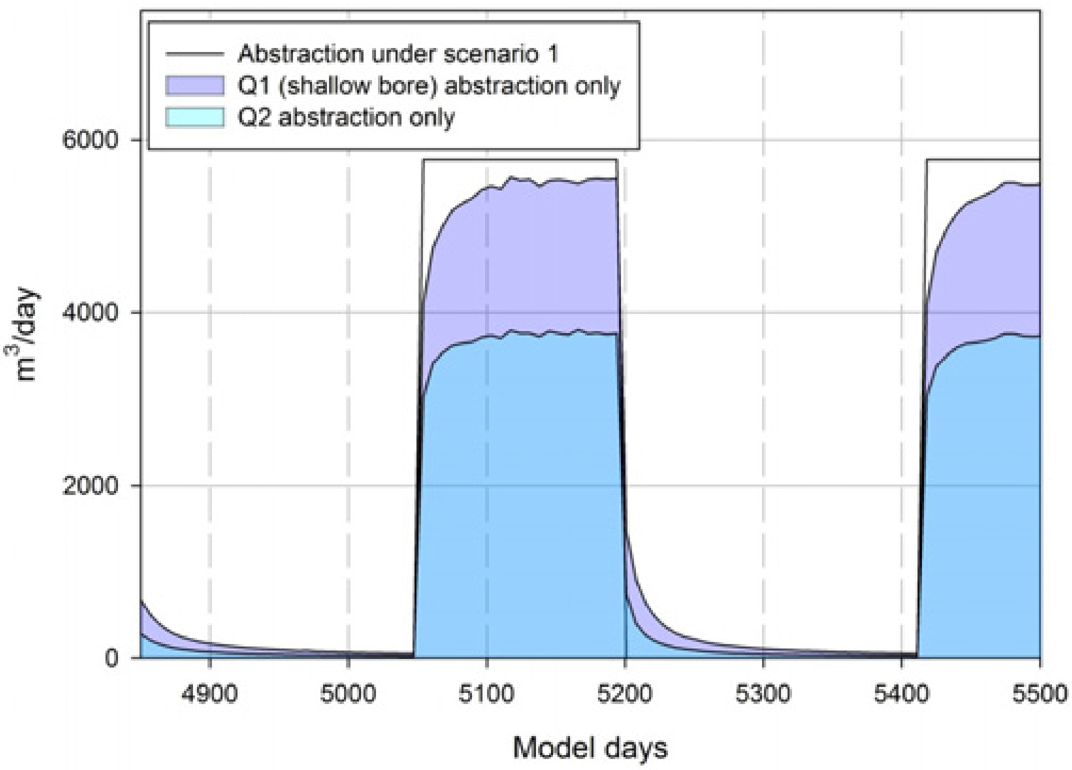

Figure C8: Scenario 1 output – total water depletion in the Waikanae zone from pumping an array of synthetic bores located in the shallow unconfined and semi-confined aquifers in Q1 (ground surface to about 20 m depth) and Q2 (between 20 m to 30 m depth) gravels

Surface water-groundwater fluxes are sensitive to groundwater abstraction and respond virtually instantaneously even to pumping from the semi-confined (Q2) aquifer. Based on this assessment it is recommended that this area should be assigned to the Category A hydraulic connectivity zone to a depth of 20 m. This scenario also shows that the semi-confined aquifer (Q2) also exhibits significant connectivity with surface water but is attenuated with the maximum depletion factor of approximately 63% (0.63) of the abstraction rate. This scenario indicates that abstraction from the semi-confined (Q2) aquifer should be classified as a Category B hydraulic connectivity zone.

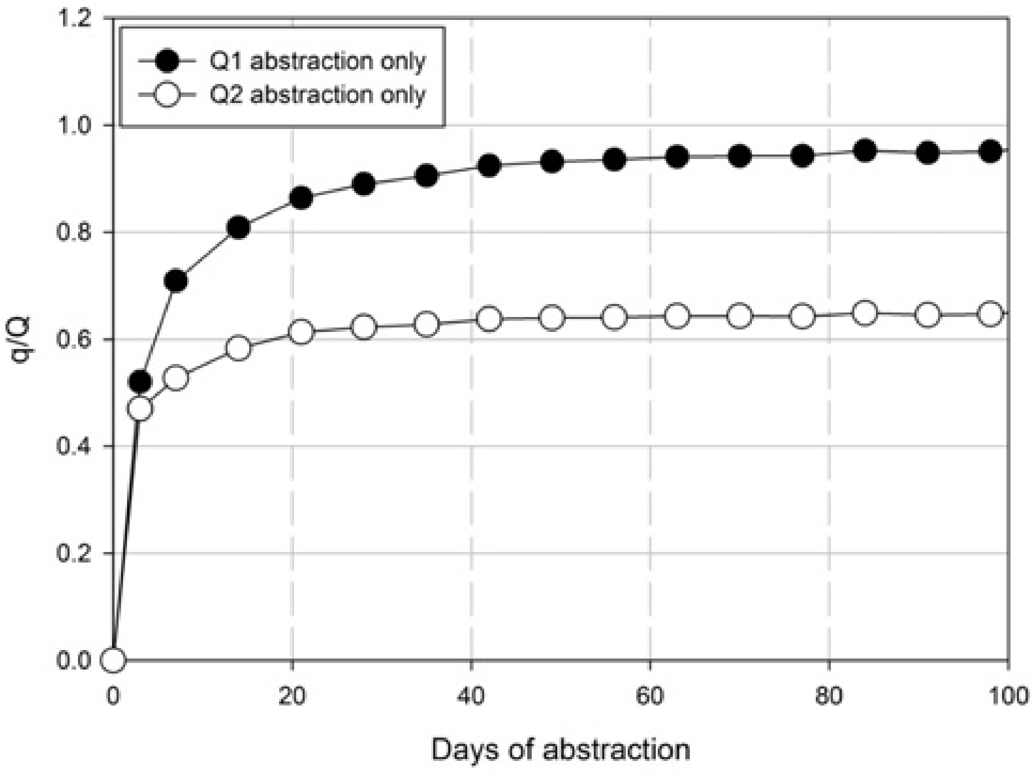

Figure C9: Scenario 1 – ratio of surface water depletion (q) to pumping rate (Q) from pumping an array of synthetic bores located in the shallow unconfined and semi-confined aquifers in Q1 (ground surface to about 20 m depth) and Q2 (between 20 m to 30 m depth) gravels

Scenario 2 - This scenario uses the current and proposed municipal bore locations and depths and well screens (located at depths greater than 60m below ground level). No other abstraction in the Kapiti Catchment is occurring in this scenario. The overall objective of this scenario is to quantify the likely magnitude of surface water depletion effects associated with abstraction from the deep productive aquifer (Q6 aquifer). Effects on wetland and coastal drawdown are also considered. Wetland drawdowns are referenced to the average maximum drawdowns in the zone and also the maximum wetland drawdown for the Nga Manu wetlands. The Nga Manu wetlands were selected due to national significance and also were identified to be highly sensitive to cumulative abstractions from the Waikanae zone. The bores are pumping for the 19-year transient model run (the calibrated model).

Figures C10 to C11 relate to pumping scenarios 2 and 3 abstractions. Scenario 2 relates to abstraction from the deeper semi-confined (Q6) aquifer in current consented wells in the Waikanae zone. Approximately 95% of current abstraction occurs from this deeper more productive aquifer system and it is therefore important to assess the effect that groundwater takes from this aquifer may have on the surface water environment. Only consented wells (including the KCDC wells) were used to test this scenario. These deeper bores are mostly used for augmenting municipal supply when Waikanae River flows are low.

The model scenarios predict that the effect is significant drawdown in the shallow aquifer and, as a consequence, the deeper aquifers in this area should not be regarded as a separate resource. The depletion ratio (q/Q) reaches 0.3 or 30% (Figure C9) within 40 days from the start of abstraction. The magnitude of the stream depletion effect is calculated at 10,000 m^3/day which is approximately 13 % of the 7-day MALF for the Waikanae zone. The magnitude of depletion of the Waikanae River is 4,200m^3/day (approximately 6.5% of MALF). It is significant to note here that by starting or ceasing pumping there is an immediate impact on the surface water depletion rate followed by a slow recession in the depletion throughout the following months. Therefore, the regulation of these takes on the basis of surface water low-flow triggers should provide an effective means to mitigate the effects of this pumping during low flow periods. This scenario indicates that due to the immediate impact of abstraction on surface water depletion, abstraction from the semi-confined (Q6) aquifer should be classified as a Category B hydraulic connectivity zone.

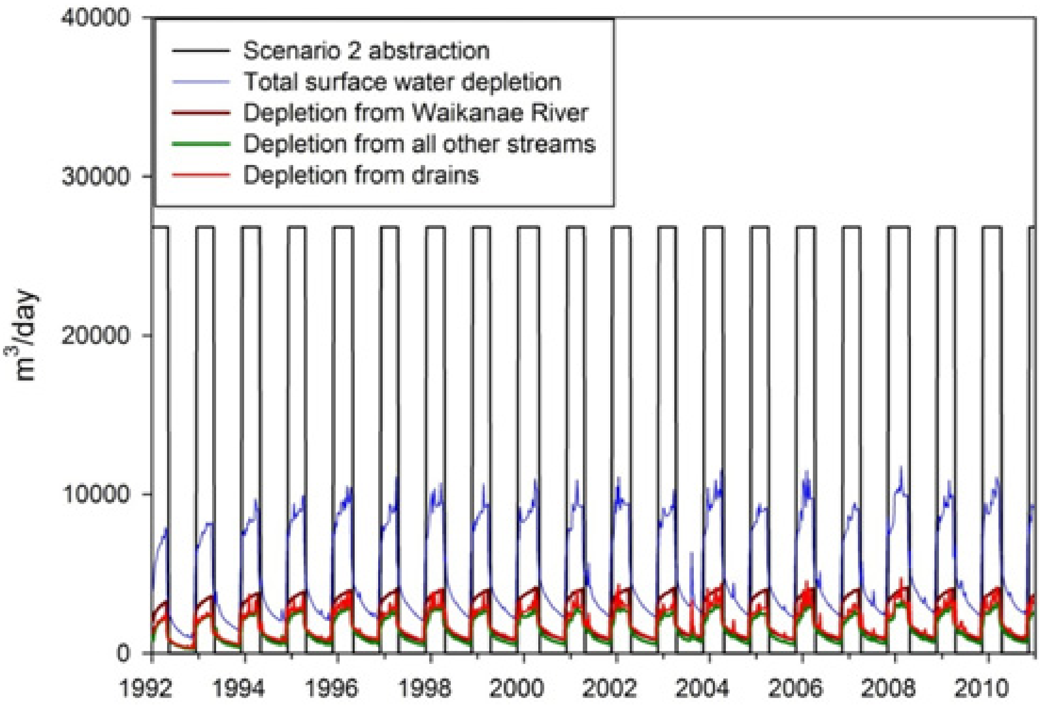

Figure C10: Scenario 2 output – surface water depletion when pumping from Q6 (layers 6 and 7) only of the of the Waikanae zone. Pumping from current consented bores located in the Q6 (> 60m deep) at an abstraction rate of 26,826 m³/d.

Scenario 3 - Scenario 3 relates to abstraction from the deeper semi-confined (Q4) aquifer in current consented wells in the Waikanae zone. Figure C11 shows the magnitude of surface water depletion due to pumping under scenario 3. The magnitude of the stream depletion effect is calculated at 13,000 m^3/day which is approximately 17 % of the 7-day MALF for the Waikanae groundwater zone. The magnitude of depletion of the Waikanae River is 6,000m^3/day (approximately 9.3% of MALF). The depletion ratio (q/Q) reaches 0.32 or 32% (Figure C12) within 40 days from the start of abstraction. The maximum depletion ratio reaches approximately 0.45 after 130 days of pumping.

It is significant to note here that by starting or ceasing pumping there is an immediate impact on the surface water depletion rate followed by a slow recession in the depletion throughout the following months. Therefore, the regulation of these takes on the basis of surface water low-flow triggers should provide an effective means to mitigate the effects of this pumping during low flow periods. The model scenarios predict that the leakage due to abstraction from this aquifer system is significant and that abstraction from the Q4 aquifer should not be regarded as a separate resource. This scenario indicates that due to the immediate impact of abstraction on surface water depletion, abstraction from the semi-confined (Q4) aquifer should be classified as a Category B hydraulic connectivity zone.

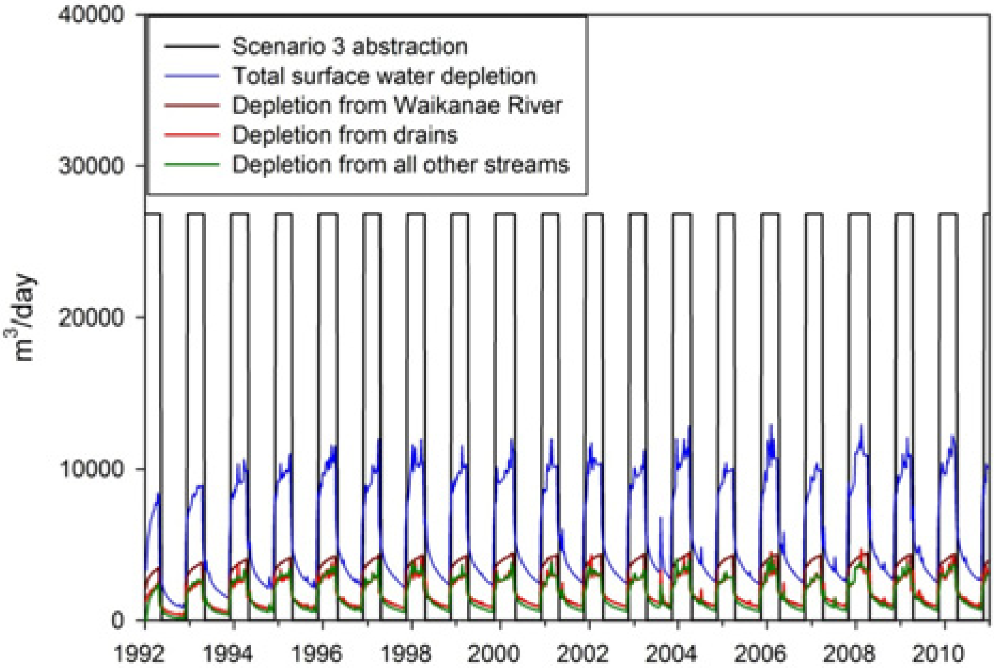

Figure C11: Scenario 3 output – surface water depletion when pumping from Q6 (layers 6 and 7) only of the of the Waikanae zone. Pumping from current consented bores located in the Q4 (50 to 60m deep) at an abstraction rate of 26,826 m^3/d.

It can be observed from the response of the groundwater system to cumulative groundwater abstraction that although abstraction from the deeper aquifer results in lesser depletion than from both the shallower and deeper aquifer. The difference in magnitude is not large enough to classify deeper (Q6) abstraction differently. A quick response in depletion due to start and stop of abstraction indicates a strong connection of deep groundwater through vertical leakage. The depletion continues through the winter months through delayed leakage. The model results indicate that the Waikanae zone aquifers act as a single unit connected to surface water through vertical leakage as discussed in the groundwater modelling report (Gyopari et al, 2012).

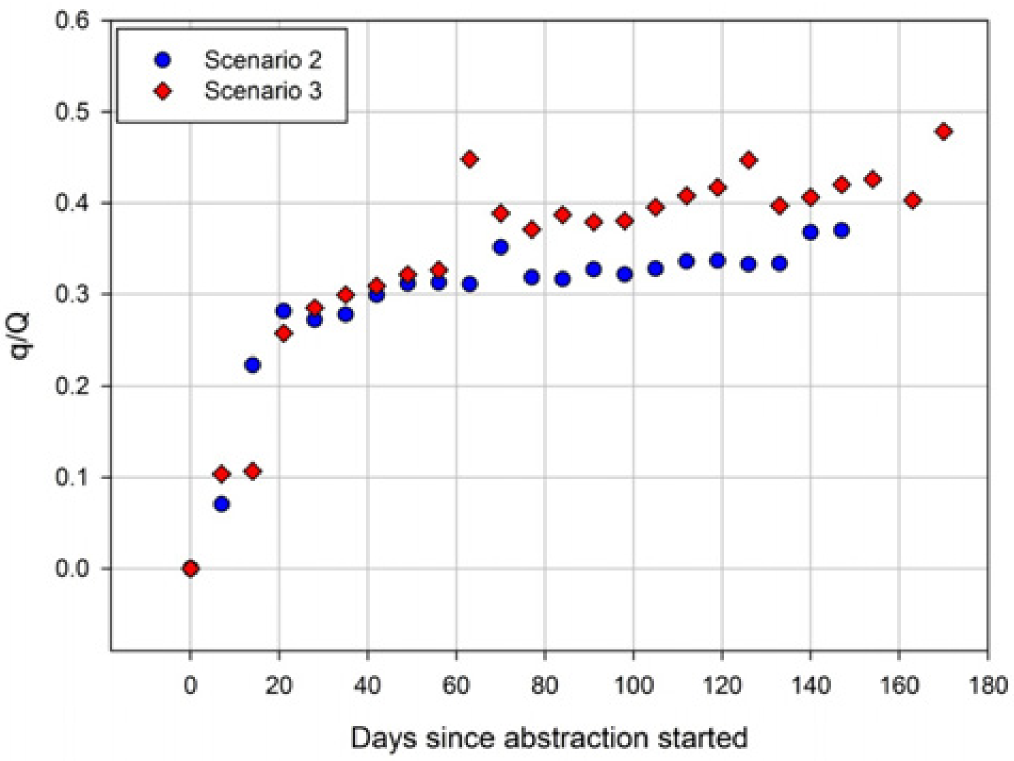

Figure C12: Scenario 2 and 3 – ratio of surface water depletion (q) to pumping rate (Q) for the Waikanae zone

Figures C13 and C14 show the effects of abstractions from scenarios 2 and 3 on wetland depletion and coastal groundwater level declines. The drawdown predicted in wetlands (Figure C13) of about 0.23m average and 0.4 to 0.6m for the Nga Manu wetland at a pumping rate of 26,960 m^3/day suggests that the Waikanae deep aquifers Q4 and Q6 could not sustain a significantly higher abstraction rate without causing adverse effects on wetlands. It is suggested that a maximum wetland drawdown of 0.2m should be maintained. The simulations show progressive wetland drawdowns that do not recover from seasonal groundwater abstraction until a new equilibrium in wetland levels is reached. The equilibrium is reached in about 7 years under Scenarios 2 and 3 abstractions.

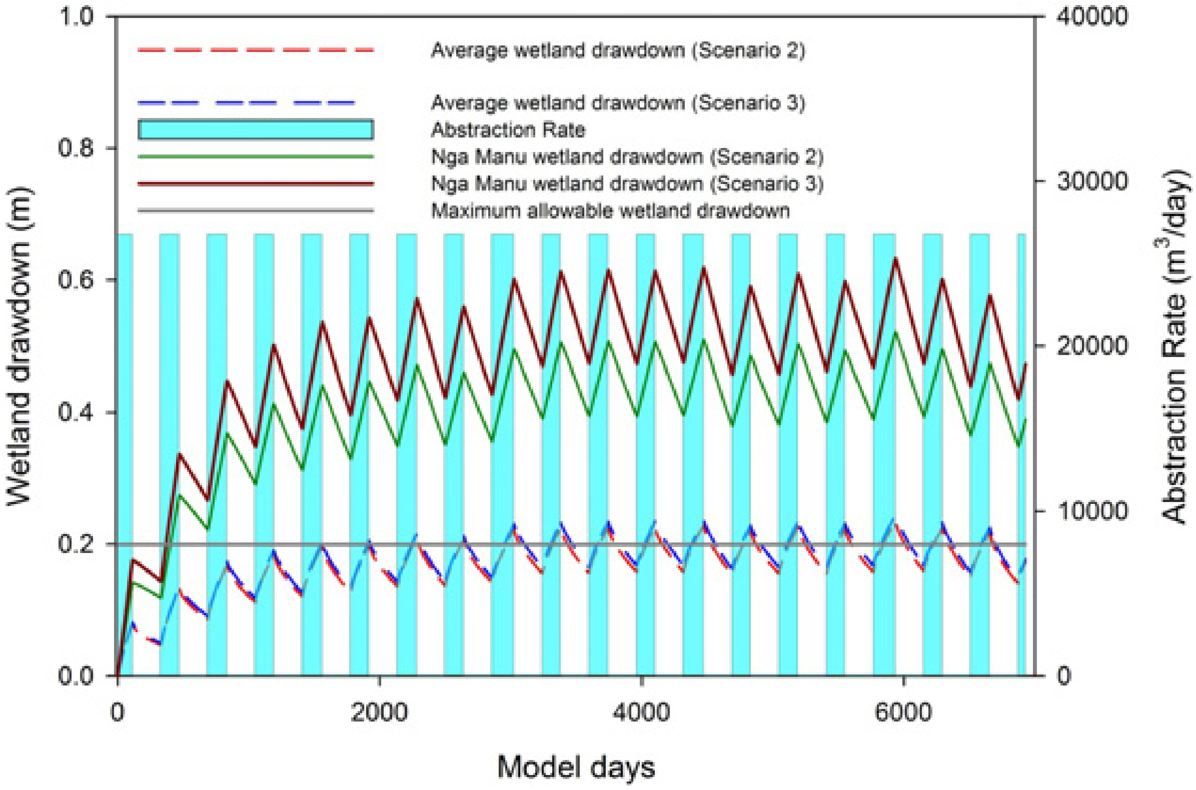

Figure C13: Scenarios 2 and 3 – Simulated wetland drawdown for the Waikanae zone for 19 years of simulation at a seasonal pumping rate of 26,960 m^3/day for scenarios 2 and 3. Plots show wetland drawdowns (average of 24 wetlands) and drawdown in the nationally significant Nga Manu wetland for the simulation period. The recommended maximum allowable abstraction effect on wetlands is a drawdown of 0.20m.

Figure C14 shows the effects of abstractions from scenarios 2 and 3 on deep groundwater at the coast. The predicted maximum drawdown due to pumping from the deep (Q6) aquifer is about 1.4m. The maximum drawdown predicted from abstracting from the Q4 aquifer (Scenario 3) is about 1.0m. Both scenarios indicate an almost immediate response to start and stop of abstractions. It is suggested that a maximum drawdown of 1m should not be exceeded at the coast in order to prevent saltwater intrusion. However, the quick and complete recovery in groundwater levels after pumping has ceased re-establishes groundwater heads and this indicates that the risk of saltwater intrusion is comparatively lower.

The higher confinement in the lower aquifer results in higher magnitudes of drawdown compared to abstracting from both the shallower and deeper groundwater.

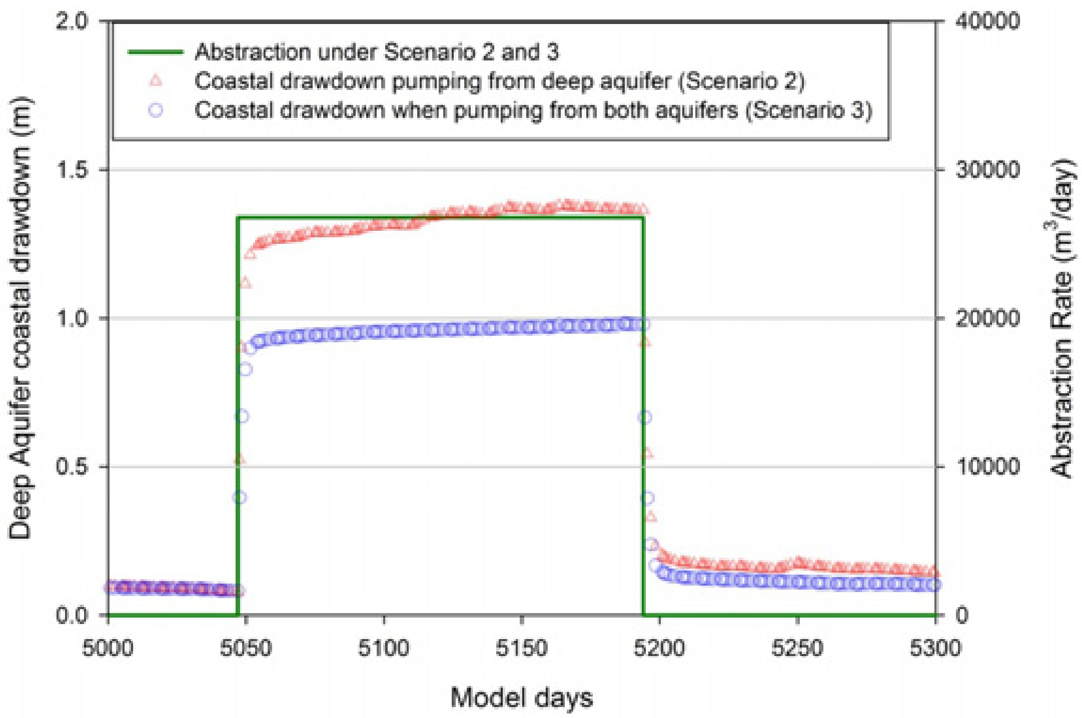

Figure C14: Scenarios 2 and 3 – coastal drawdown to pumping rate (Q) for scenarios 2 and 3 pumping. Abstractions from the deep Q6 aquifer > 60m bgl (Scenario 2) and Q4 (Scenario 3).

The overall groundwater allocation objective is to maximise groundwater resources allocation. The criteria for this objective are referencing groundwater allocation to 7-day MALF for the Waikanae River and the sum of MALFs for all streams in the zone. Groundwater allocation should also be referenced to maximum wetland drawdown of 0.2m (Beca, 2008) and maximum coastal drawdown of 1m.

Groundwater Management options for the Waikanae zone

Groundwater-surface water interaction zones

- Recent alluvium (Q1) associated with the Waikanae and Waimeha rivers should be classified as Category A to a depth of 20m to reflect the direct hydraulic connection with the two rivers.

- Beneath Category A, Category B should extend from 20m to the full depth of the aquifer.

- Elsewhere, it is recommended the Waikanae zone should be classified as Category B to all depths in recognition of numerous wetlands and small streams in the catchment.

- There is no defined Category C as modelling indicates that surface water system respond within a short period to abstractions from all depth zones.

Groundwater allocation

Aquifers in the Waikanae zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.

Groundwater allocation should be based on consideration of stream depletion, wetland drawdown and coastal groundwater level drawdown. Results from various scenario model runs at different abstraction rates are presented in Table C2 and Figure C15. For each model run, the effects on cumulative surface water depletion, wetland drawdown and coastal aquifer drawdown are presented. These effects are then compared (as a ratio) to the maximum permissible drawdown or depletion, specified as:

- **Streamflow depletion: 10% of combined 7-day MALF.** The groundwater allocation criterion for this zone should be referenced to the combined 7-day MALF for the Waikanae River (average of three sites) and the Waimeha stream (since the other streams are tributaries to these surface waterways). This flow incorporates groundwater baseflow to surface water for the entire zone. The estimated 7-day MALF in this zone is 934 L/s (80,700 m^3/day). A maximum allowable depletion of 10% of MALF is recommended since surface water is fully allocated in this zone. A depletion factor of 0.4 should be adopted for the Category B components of the Waikanae management zone to reflect the dominance of the more productive semi-confined aquifer to surface water depletion.

- **Average wetland drawdown: 0.2m.** The groundwater allocation criterion (daily and annual) for this zone should also be referenced to maximum wetland drawdown of 0.2m that should be adopted for the Waikanae management zone to reflect wetland drawdown effects from deep groundwater abstractions. Abstractions from the shallow Holocene sands should be located not less than 150 m from identified wetlands to limit any direct effects on wetland levels.

- **Coastal aquifer drawdown: 1m.** The reference coastal aquifer drawdown to cause saltwater intrusion is estimated at 1m which is calculated to move the saltwater freshwater interface upwards by approximately 33-40m. The current location of the coastal saltwater/freshwater interface is about 70m deep. Shallow and deep aquifer drawdowns have been considered for the Waikanae zone due to the layering and higher abstraction rates in this zone.

Annual allocation should be based on a pumping duration of 180 days and maximum daily abstractions should be based on weekly averages.

Figure C15 is a plot of normalised drawdowns of effects to the maximum permissible against incremental abstraction rates. In this case the normalised wetland drawdown controls the maximum permissible abstraction. The abstraction rate at a normalised wetland drawdown of one (unity) is approximately 15,000m^3/day. At this abstraction, the normalised stream depletion rate be approximately 0.7 and coastal aquifer drawdown will be 0.75 for the deep aquifer and 0.15 for the shallow aquifer. Drawdown in in the shallow aquifer is shown in brackets (Table 2).

Table B2 also shows the allocation options based on model scenarios. Scenario 1 meets all the criteria for total surface water depletion, wetland level drawdown and coastal drawdown. Wetland level drawdown is calculated as an average for all identified wetland drawdowns in the Waikanae zone. Table B2 also shows the abstraction rates as a percentage of annual lower quartile surface recharge (LSR). Scenario 1 shows that the abstraction is approximately 53% of LSR. The high proportion LSR is considered appropriate since most of the recharge into the deep (Q6) productive layer is derived from the Waikanae River losses.

- Further considerations on allocation should also be referenced to the envelope curves (Figure C15)
- It is recommended that the takes from this zone are regulated according to wetland drawdown and stream depletion effects.

Table C2: Summary of Scenario model results

Scenario	Cumulative Depletion %MALF (934) l/s)	Allocation m^3/day	Allocation m^3/yearx10^6	Cumulative Depletion L/s	Wetland Drawdown mm (Max. 200mm)	Coastal Drawdown m (Max. 1m)	LSR % Max (100%)
1	5.9	13,520	2.43	4,732	180	0.58 (0.12)	24
2	8.5	19,630	3.53	6,871	250	0.81(0.14)	36
3	11.2	25,900	4.66	9,065	370	0.85(0.15)	47
4	15.6	35,970	6.47	12,600	440	1.53(0.25)	65

*Nga Manu Wetland drawdown

** Depletion of the Waikanae River

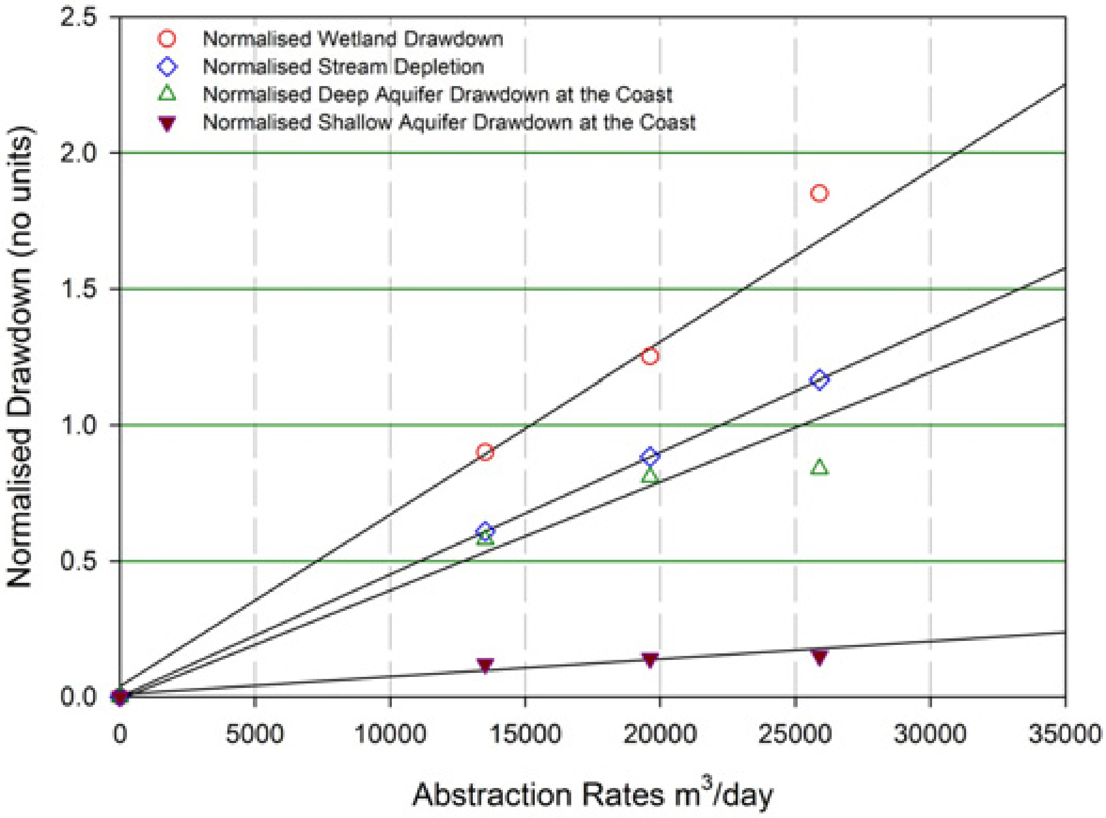

Figure C15: Allocation envelopes abstracting from Q4 and Q6 deep aquifers only. Wetland drawdown is normalised to 0.2m, stream depletion is normalised to 10% of MALF (90L/s) for the entire zone and drawdown at the coast is normalised to 1m. The normalisation values are the maximum allowable depletions or drawdown to limit adverse environmental effects. A normalised wetland drawdown of 1.0 intersects the abstraction rate at 15,000m^3/day (this abstraction will result in a stream depletion of 0.7 of maximum allowable normalised MALF depletion).

Table C3: Waikanae Zone Summary Table: Groundwater Allocation Proposal

	Controlling factors	Proposed new Allocation	Current Allocation	Notes
Waikanae Zone	Wetland drawdown 1–allow maximum 200 mm MALF (750 l/sec)-allow up to 30% depletion. LSR allow up to 30% Coastal Drawdown- allow up to 1m	15,000 m^3/d 2.7x10^6 m^3/yr	Over allocated on daily abstraction and fully allocated on annual basis. *Main current allocation is for KCDC abstraction annual allocation is over 75 days of abstraction.*	MALF depletion:7.5% Maximum? Wetland drawdown:200mm Maximum? Coastal drawdown (deep):0.75m Coastal drawdown (shallow):0.15m LSR:27%

Beca, 2008. *Executive Summary and Recommendations from: Draft Guidelines for the Selection of Methods to Determine Ecological Flows and Water Levels l*, Wellington: Ministry of Forestry and Environment.

Appendix D: Assessment of allocation options for the Raumati groundwater zone

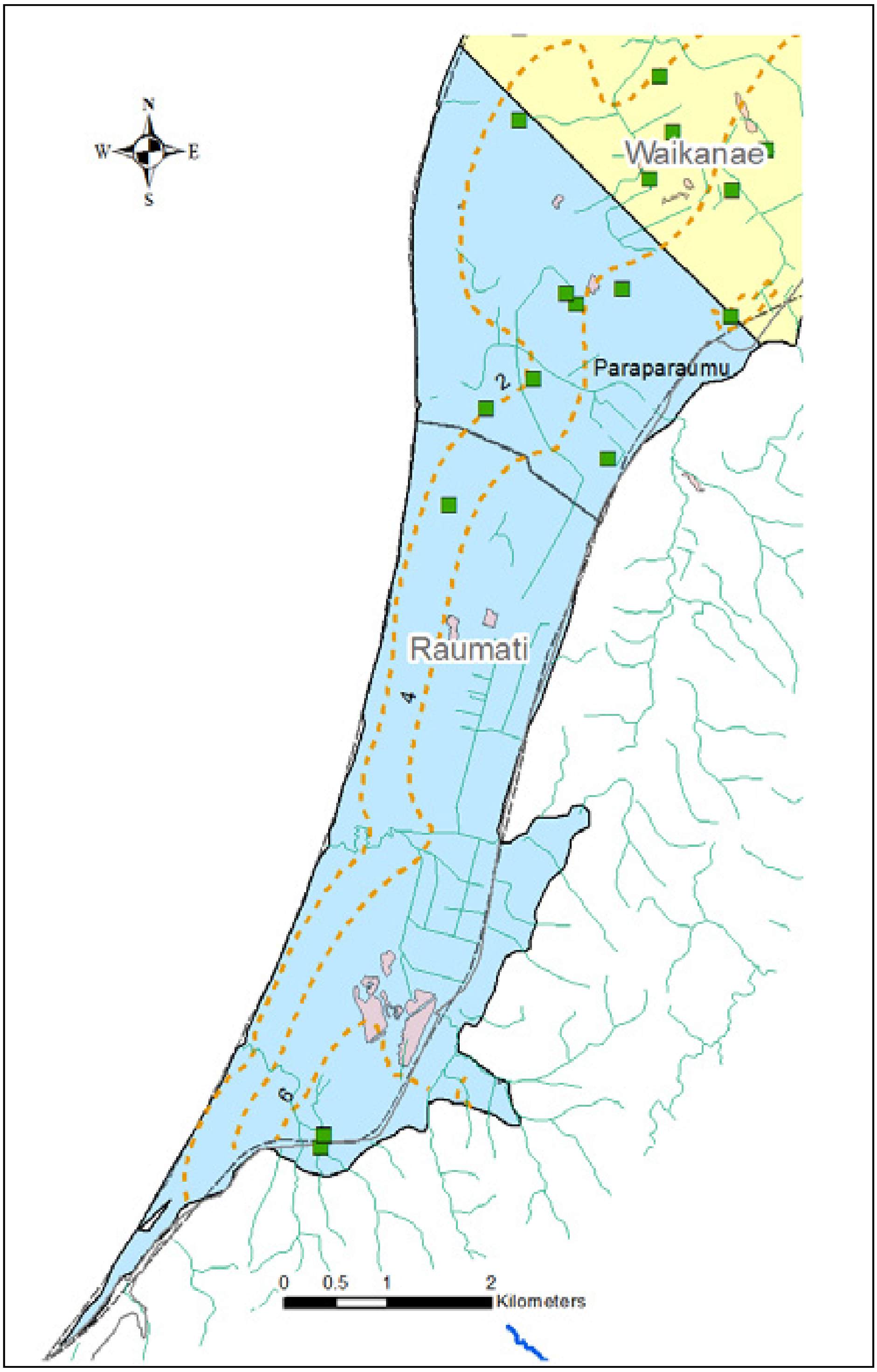

Figure D1: Spatial extent of the Raumati groundwater management zone

Table D1: Summary of the Raumati Groundwater Management Zone

<table>
<tr><td>Delineation</td><td colspan="3">The Raumati groundwater zone occupies the southernmost part of the Kapiti Coast coastal plains between Paekakariki and Paraparaumu.</td></tr>
<tr><td>Area</td><td colspan="3">22.3 km^2</td></tr>
<tr><td>Boundaries</td><td colspan="3">Figure D1 shows the spatial extent of the zone including primary surface water features (streams and wetlands), groundwater level monitoring and concurrent flow gauging sites and the locations of bores recorded on the GWRC Wells database.
The northern boundary runs NW-SE across the coastal plain and Paraparaumu Beach. This ‘boundary’ is really a transition zone approximating the southern extent of the Waikanae River fan. Laterally continuous gravel layers in the Waikanae area are replaced by a thick sequence of sand to the south. The boundary also corresponds with a flow divide between the Mazengarb and Wharemakau catchments - identified from piezometric surveying (Jones and Gyopari, 2005).</td></tr>
<tr><td>Principal surface water systems</td><td colspan="3">The Raumati groundwater zone is drained by three primary surface water catchments. The Wharemakau Stream flows westward across the coastal plain reaching the sea at Raumati Beach, Whareroa Stream drains the middle section of the Raumati groundwater zone to the north of QE Park, while the Wainui Stream flows from the foothills to the coast immediately north of Paekakariki.</td></tr>
<tr><td>Aquifer sequences:</td><td colspan="3">A single unconfined to semi-unconfined sand dominated stratified aquifer system containing multiple, discrete water-bearing sand and gravel intervals interspersed with lower permeability silt and organic/peat layers.</td></tr>
<tr><td>Recharge</td><td colspan="3">Average annual recharge is 8.94 x 10^6 m^3 with a lower quartile recharge of 6.5 x 10^6 m^3. Average daily recharge is 24,490 m^3 with a lower quartile of 17,982 m^3</td></tr>
<tr><td>Existing NRP zones</td><td colspan="3">Paekakariki/Raumati and southern part of the Waikanae zone.</td></tr>
<tr><td rowspan="2">Current consented Allocation as at December 2013</td><td>No of groundwater takes</td><td>m^3/day</td><td>x10^6 m^3/year</td></tr>
<tr><td>12</td><td>2647</td><td>0.6</td></tr>
</table>

Hydrogeology summary

The Raumati Zone is dominated by a thick succession of unconsolidated medium to fine sands containing isolated lenses of gravel and fine-grained/organic materials. This is the principal aquifer unit. These sediments merge with coarse-grained, poorly sorted alluvial sediments at the base of the Tararua foothills.

Groundwater occurs throughout the stratigraphic succession and the sand deposits form a relatively low-yielding aquifer system which becomes increasingly confined with depth. Higher yielding horizons occur in isolated gravel lenses which are likely to be associated with either former channels of streams draining the Tararua foothills, or represent beach deposits.

The aquifer system is recharged by infiltration of rainfall on the coastal plain augmented by infiltration of runoff from the foothills to the east. Groundwater discharge occurs via baseflow to the main streams draining the coastal plain as well as from evapotranspiration in wetland areas where the water table intersects the land surface. Given the relatively limited baseflow discharge observed (~100 L/s) and the relatively modest rates of evapotranspiration, particularly in areas of urban or agricultural development, it is inferred that outflow to the coast may be a significant component of the overall aquifer water balance in the Raumati groundwater zone.

Hydrology summary

The Raumati groundwater zone is drained by three primary surface water catchments. The Wharemakau Stream flows westward across the coastal plain reaching the sea at Raumati Beach, Whareroa Stream drains the middle section of the Raumati groundwater zone to the north of QE Park, while the Wainui Stream flows from the foothills to the coast immediately north of Paekakariki.

The Wharemauku stream gains between 30 to 50 L/s between Coastlands and Raumati Beach, the Whareroa gains approximately 20 Ls between SH1 and the coast and the Wainui gains approximately 25 L/s between SH1 and the mouth. The observed total baseflow discharge for the zone is approximately 100 l/s. The total mean annual low flow (MALF) for the zone is estimated at 75 L/s.

Zone Management Objectives

The principal management objective in the Raumati zone is to ensure the sustainable allocation of groundwater resources with respect to freshwater ecosystems and prevention of saltwater intrusion. The protection of instream values of the Wharemauku, Whareroa and Wainui streams, wetland systems and prevention from saltwater intrusion from cumulative effects of groundwater abstraction and baseflow depletion are the primary criteria for developing sustainable allocation options in this zone.

Numerical modelling

The numerical groundwater flow model for the Kapiti Coast was used to assess the sustainability of the current groundwater abstractions and to develop allocation options for the Raumati groundwater management zone. Full details of the model and the calibration process are provided by Gyopari, Mzila and Hughes (2012). The model has been principally used to evaluate the cumulative effects of abstraction on the surface water environment and coastal drawdown in developing options.

Zone water budget

The numerical groundwater flow model has enabled a temporal characterisation of the natural water balance for the Raumati zone using a version of the 18-year calibration simulation (1993-2011) which has no groundwater abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated (by comparing the no-abstraction and abstraction scenarios). Of particular relevance to assessing the sustainability of abstraction, the model enables quantitative assessment of the potential cumulative depletion effects resulting from groundwater pumping on the surface water environment in the Raumati water management zone.

The principal water balance components for the Raumati zone are rainfall recharge and surface water/groundwater fluxes. Figure D2 shows the modelled annual rainfall recharge for the Raumati zone for the period 1992 to 2010. The average annual recharge for this period is 8.94×10^6 m^3 with a lower quartile recharge of 6.5×10^6 m^3. This translates to an average daily recharge of 24,490 m^3 with a lower quartile of 17,982 m^3.

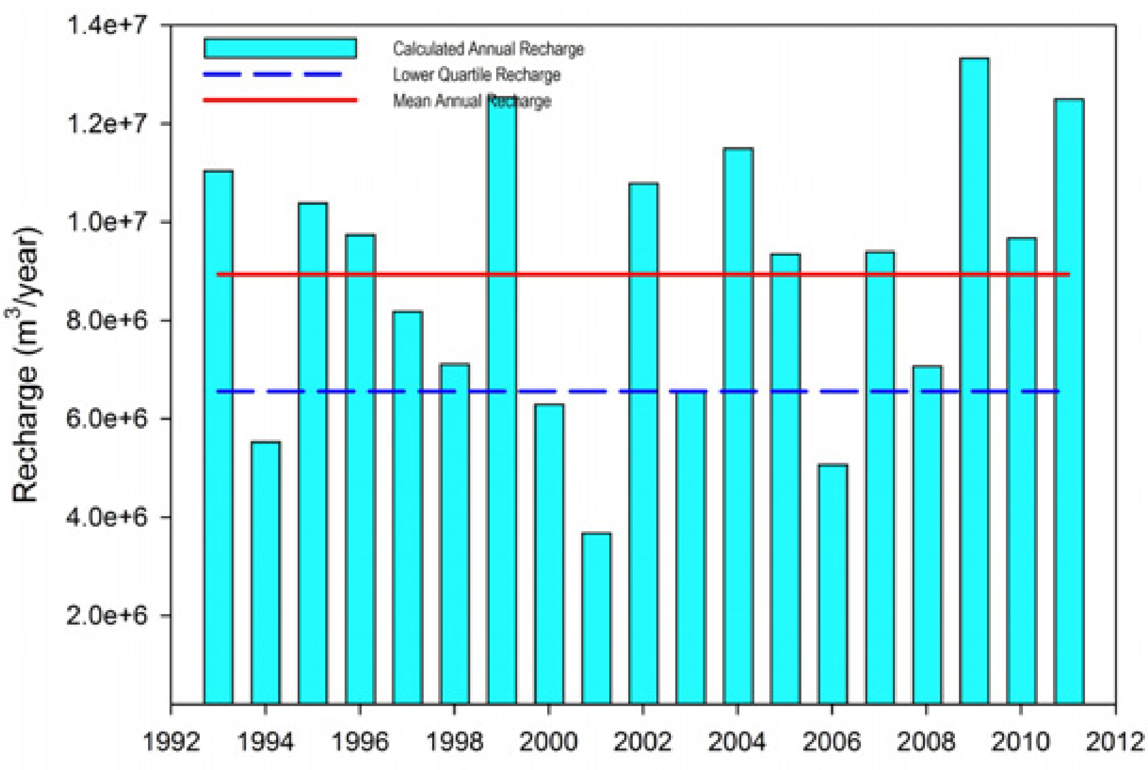

Figure D2: Modelled annual rainfall recharge (1993-2011) for the Raumati zone (mean recharge 8.94 x 10^6 m^3/year)

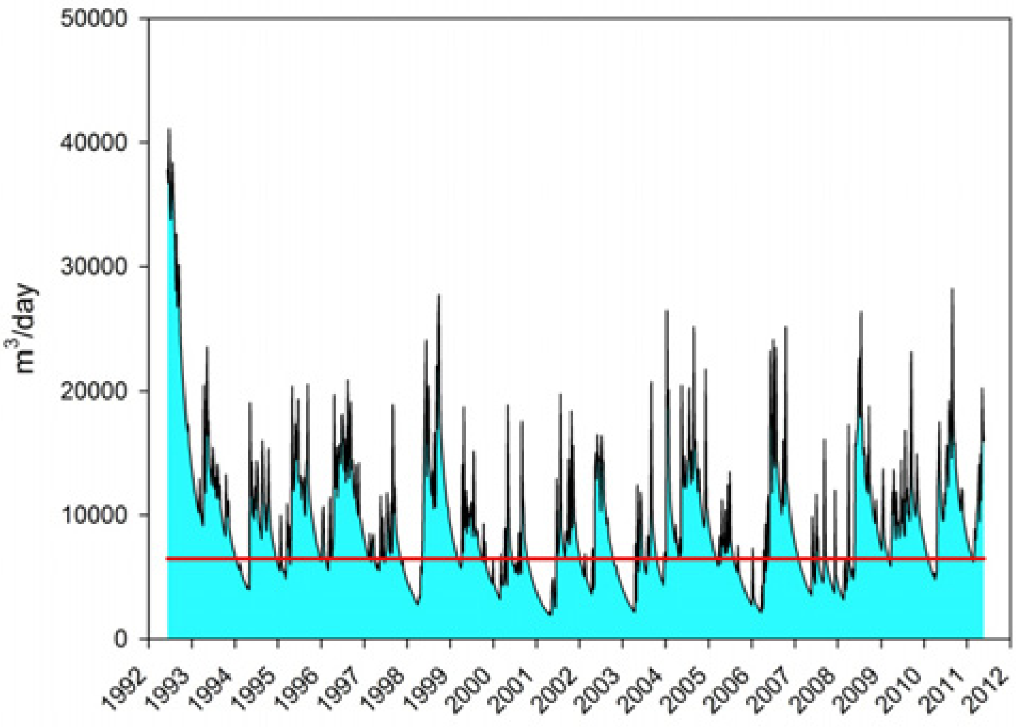

Figure D3: Simulated groundwater discharge to surface water (All streams in the Raumati Catchment) when there is no groundwater abstraction in the Raumati water management zone (1992-2011). Note the modelled summer baseflow is closely related with the 7 day MALF although less than MALF in some years. The extra contribution to MALF comes from drains and upstream discharges.

Current abstraction

Current (estimated) abstraction was simulated for the 19-year transient model run and the water balance outputs were compared to the baseline (no abstraction) simulation described above. The effects of abstraction on the surface water environment were then evaluated by comparing the two sets of water balance outputs. Further, the effects of abstraction on wetland drawdowns and coastal drawdown were also evaluated.

Figure D4 shows the modelled surface water depletion resulting from current abstraction in the Raumati management zone. Figure D5 shows a detailed portion of Figure D4 for the period 2002 to 2004 to illustrate the response of the groundwater system to abstraction. The scenario shows that seasonal abstraction increased from approximately 400 m^3/day in 2000 to reach a peak of approximately 1,350 m^3/day from 2008. The modelled surface water depletion is around 50 to 70% of the abstraction rate and occurs within the timeframe of seasonal abstraction. It is noted that abstraction for municipal supply also occurs over the winter months (2004 -2011) so some degree of surface water depletion occurs on a continuous basis (compared to the largely seasonal abstraction and associated surface water depletion occurring in other Kapiti groundwater zones).

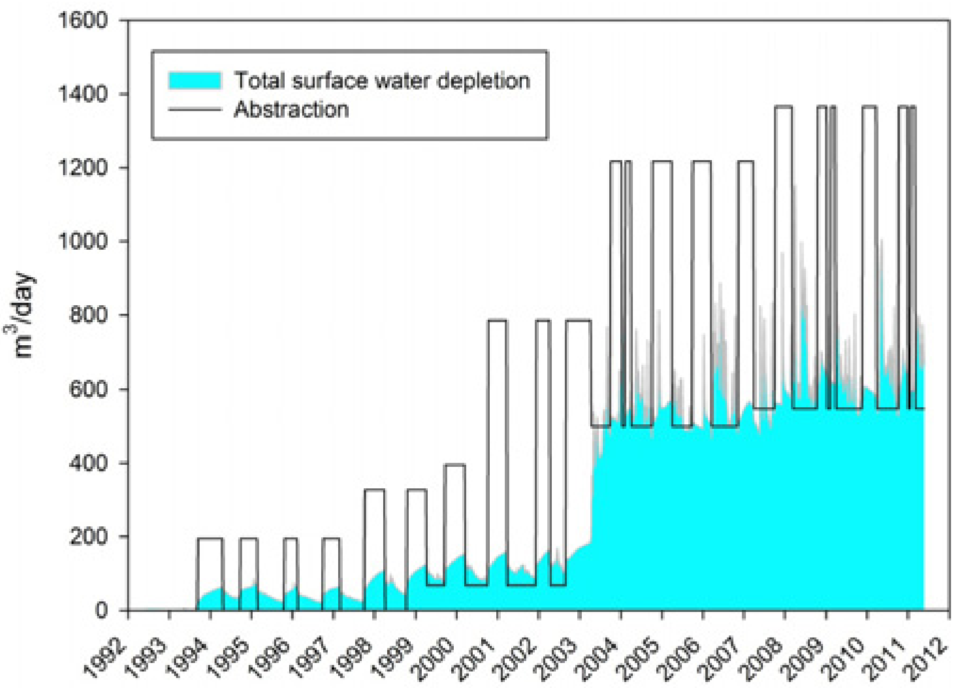

Figure D4: Simulated historic abstraction and associated surface water depletion in the Raumati zone (1992 – 2012). A depletion equivalent to 50 to 70% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

Figure D5 shows the modelled streamflow depletion occurring during the May 2002 to May 2004 period. The plot shows surface water depletion effects in the Raumati zone increase from 200 m^3/day in September 2002 to peak around 1,000 m^3/day January 2004, with little reduction during the 2003 winter due to continuous abstraction for municipal supply over this period.

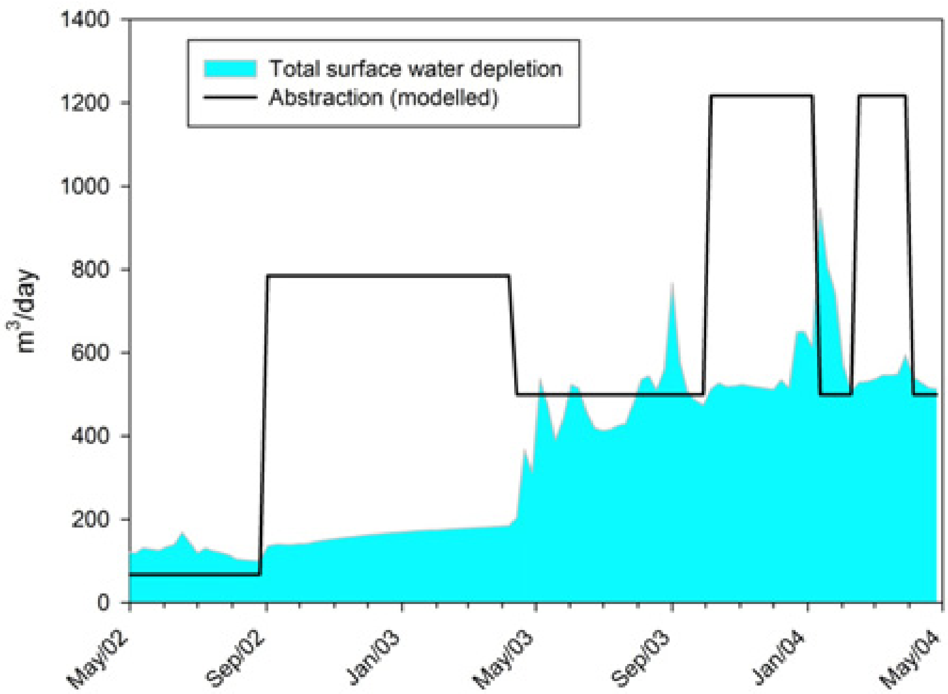

Figure D5: Simulated surface water depletion resulting from groundwater abstraction in the Raumati zone between May 2002 and May 2004

Current (estimated) abstraction was simulated for the 19-year transient model run and wetlands levels were compared to the baseline (no-abstraction) simulation. The effects of groundwater level abstraction on the wetlands were then evaluated by comparing the two sets of groundwater levels. A similar analysis was carried out for coastal groundwater level drawdowns.

Figure D6 and Figure D7 show the modelled wetland and coastal drawdowns resulting from current abstractions in the Raumati management zone. This scenario shows that the increasing abstraction resulted in both wetland and coastal drawdown effects. The drawdowns do not fully recover during the winter seasons. However, drawdowns from current abstraction are relatively small and the effects of current abstraction could be regarded as relatively minor. The maximum average wetland drawdown is 0.038m. The maximum allowable wetland drawdown for this zone is 0.2 m. This scenario results in a maximum average coastal drawdown of 0.06 m. The maximum allowable drawdown to prevent saltwater intrusion is 1 m.

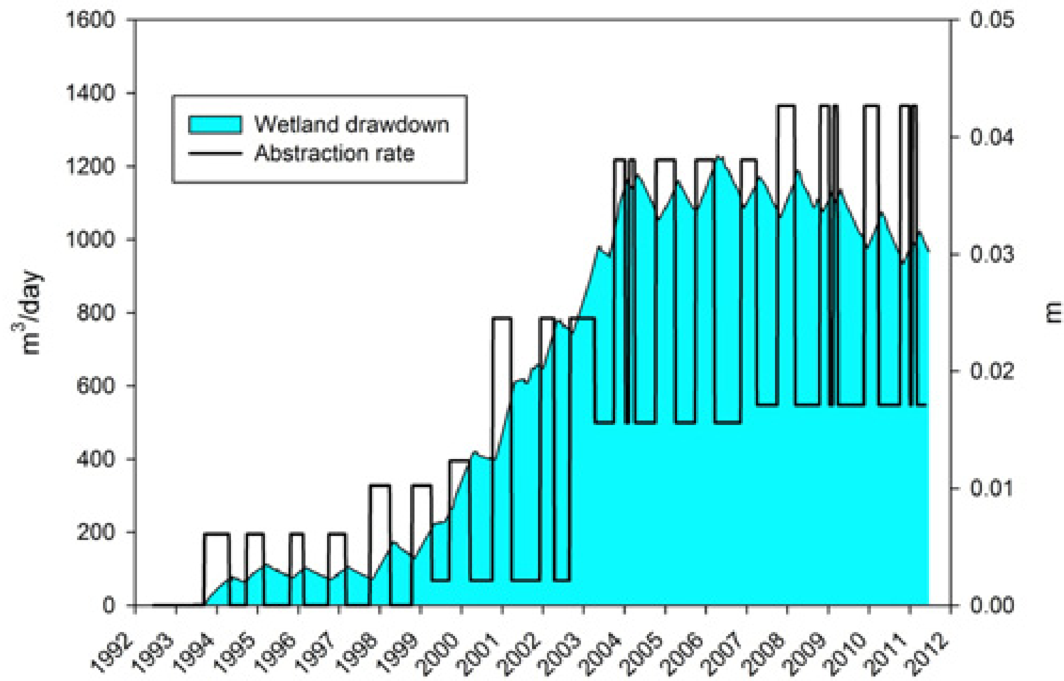

Figure D6: Simulated historic abstraction and associated shallow (Holocene sands) groundwater level drawdown in the vicinity of wetlands in the Raumati zone (1992-2011). A maximum average wetland drawdown of 0.038 m occurs within the timeframe of seasonal abstraction. Abstractions for municipal supply also occur over the winter months (2004-2011) and wetland shallow groundwater levels do not recover completely from cumulative abstractions.

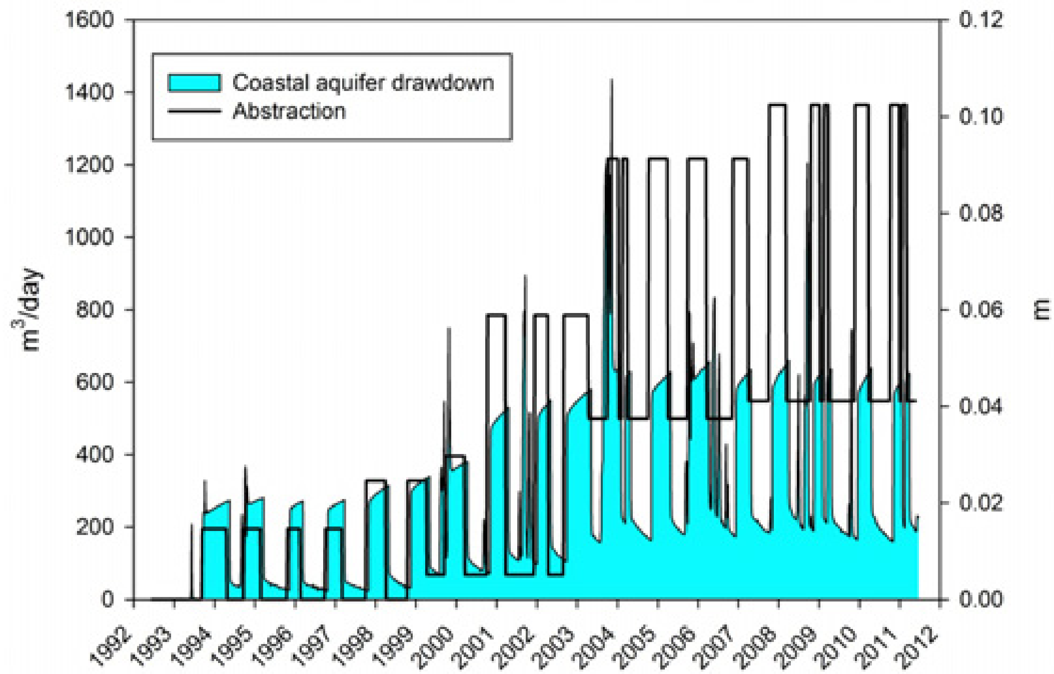

Figure D7: Simulated historic abstraction and associated coastal aquifer groundwater level drawdown. A maximum average coastal drawdown of 0.06 m occurs within the timeframe of seasonal abstraction. Abstraction for municipal supply also occurs over the winter months (2004-2011) and coastal aquifer groundwater levels do not recover completely from cumulative abstractions.

Figures A5 and A6 show that groundwater levels drawdown towards the end of each seasonal summer period but the depletion does not cease or completely recover over the winter periods.

Abstraction scenarios

The transient groundwater flow model for the Kapiti Coast was also used to simulate synthetic abstraction scenarios to further characterise the relationship between groundwater abstraction and surface water depletion. The model was also used to study the effects of groundwater abstraction on wetland level drawdown and also coastal aquifer drawdown. There are no Category A or Category C areas identified in the Raumati groundwater management zone. The whole zone is modelled as Category B to reflect the strong relationships between groundwater abstraction, stream flow depletion, wetland drawdown and coastal drawdowns.

The following scenarios were simulated:

- Scenario 1: Abstraction from the shallow Holocene sands aquifer only at a rate of 4,500 m^3/day from a distributed array of 45 bores each pumping at 100 m^3/day. The bores were assigned to model the top 2 layers with a maximum well depth of 20 m. The pumping rate was held constant over a 180 day pumping period (Nov-Apr) for each of the 19 years of simulation.

- Scenario 2: Abstraction from fully screened wells at the same rate as for shallow bores (4,500 m^3/day) from the same distributed array of 45 bores and at the same rate of 100 m^3/day. The bores were assigned to all model layers. The pumping rate was held constant over a 180 day pumping period (Nov-Apr) for each of the 19 years of simulation.

- Scenario 3: Abstraction from deeper aquifer layers at the same rate as for shallow bores (4,500 m^3/day) from the same distributed array of 45 bores and at the same rate of 100 m^3/day. The bores were assigned to model layers 4-8 with a minimum depth of 30m bgl. The pumping rate was held constant over a 180 day pumping period (Nov-Apr) for each of the 19 years of simulation.

- Scenario 4: As for Scenario 2 except that the abstraction continued during the winter period albeit at half the summer abstraction rate. The current abstraction for in winter is approximately 50% of the total summer abstraction rate.

Figure D8 shows results of Scenarios 1, 2 and 3 in terms of cumulative surface water depletion effects. The plots show that the largest depletion occurs when the unconfined shallow Holocene aquifer only is pumped (Scenario 1). The lowest depletion occurs when the deep aquifer >30m is pumped only (Scenario 3).

The stream depletion of approximately 3,000 m^3/day predicted when abstracting at a pumping rate of 4,500 m^3/day from the shallow Holocene sands only is equivalent to 42% of MALF for the catchment (i.e. greater than the 30% allowable). A cumulative depletion of 2,000 m^3/day (i.e. approximately 30% of MALF) is calculated for fully screened wells pumping at a combined rate of 4,500 m^3/day (Scenario 2). This decreases to approximately 1,350 m^3/day (30% of MALF) when abstraction is simulated from deeper water-bearing layers only (Scenario 3). These results suggest that the shallow Holocene sands cannot sustain a significantly high abstraction rate without causing adverse effects on surface water.

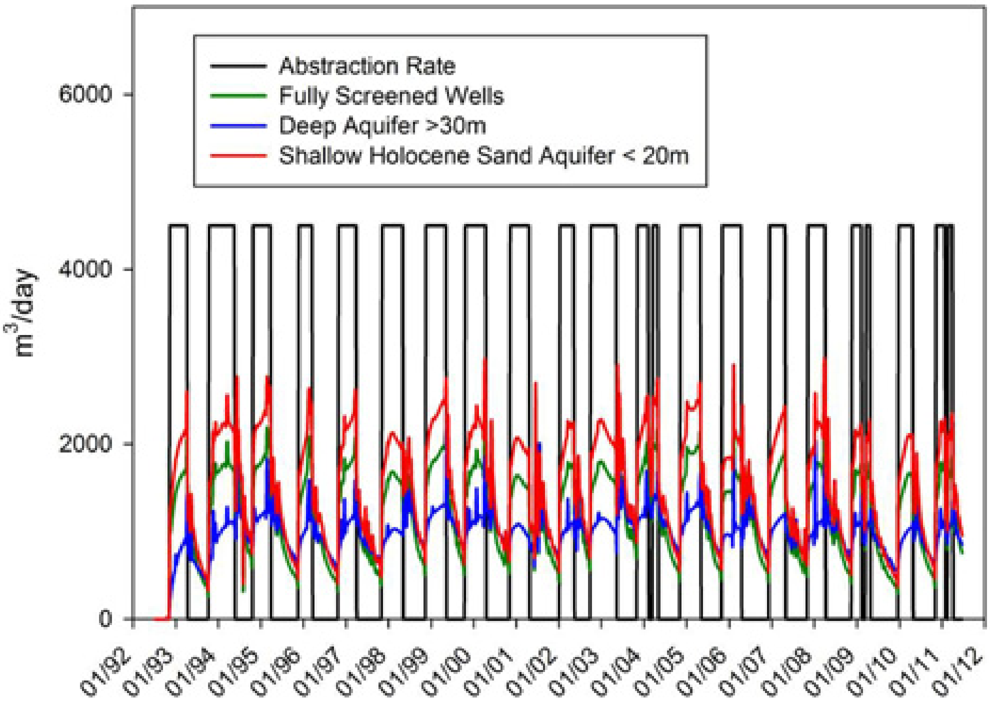

Figure D8: Comparison of cumulative stream depletion resulting from Scenario 1 (abstraction from the shallow Holocene sands), Scenario 2 (abstraction from fully screened bores) and Scenario 3 (abstraction from deeper bores)

Figure D9 shows a detailed plot of stream depletion effects under scenarios 1, 2 and 3 for the 2004/2005 period. The plot again shows the relative difference in the magnitude of stream depletion effects between simulated abstraction from the Holocene sands (Scenario 1) and deeper water-bearing layers (Scenario 3). The plot also shows stream depletion effects decline at a similar rate over the winter period for all three scenarios.

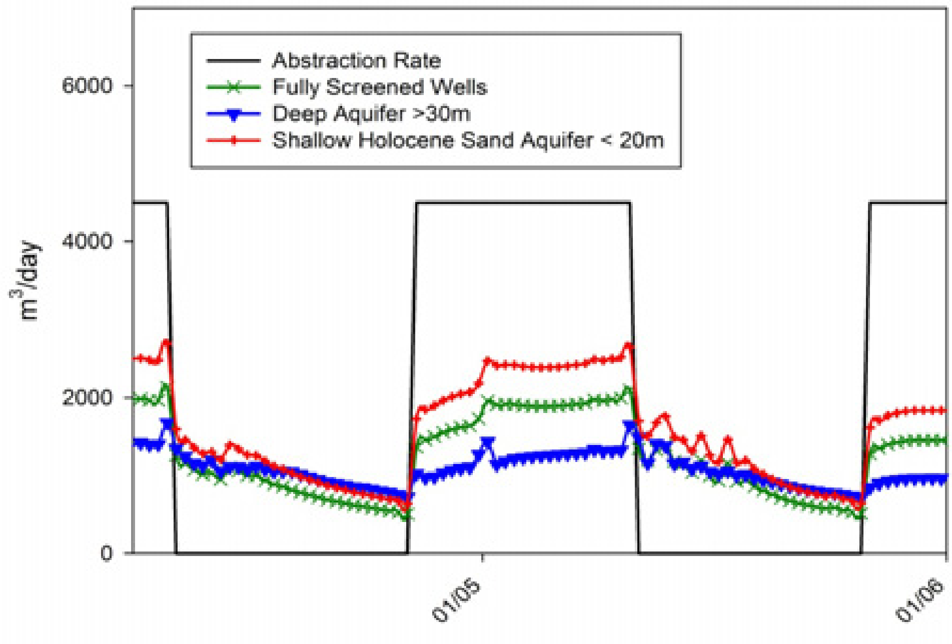

Figure D9: Comparison of cumulative stream depletion resulting from Scenario 1 (abstraction from the shallow Holocene sands), Scenario 2 (abstraction from fully screened bores) and Scenario 3 (abstraction from deeper bores) over the 2004 to 2006 period

The surface water depletion effects resulting from Scenarios 1, 2 and 3 are also represented in Figure D10 as the ratio between depletion rate (q) and pumping rate (Q). The plots show that the depletion factor (q/Q) depends on the pumping depth. The largest depletion ratio occurs when pumping from shallow Holocene sands where the maximum depletion factor q/Q reaches 0.6. When abstraction occurs only in the deep aquifer the surface water depletion effects are smaller than when pumping occurs from shallow Holocene sands. The plot shows that after about 180 days of pumping, the surface water depletion ratio is equivalent to about 0.3. Depletion effects when fully screened wells or combination of deep and shallow wells to represent abstraction from the whole aquifer results in a stream depletion ratio of 0.45.

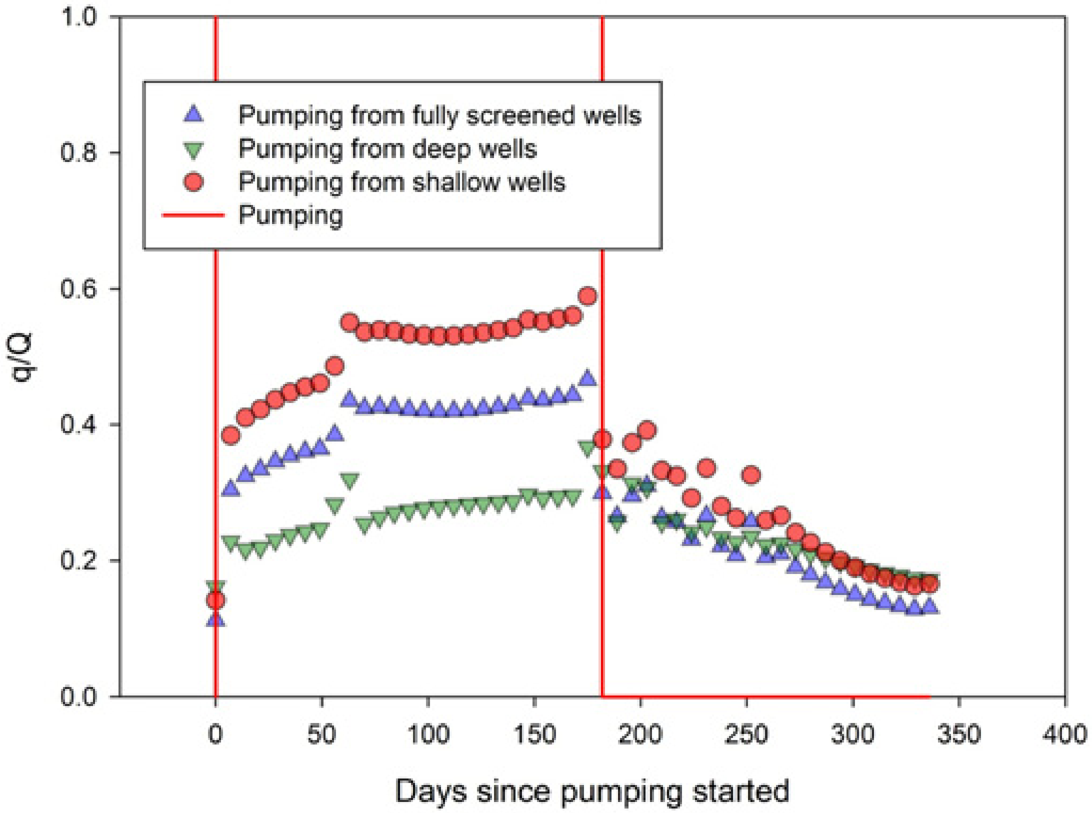

Figure D10: Simulated surface water depletion after 180 days pumping at 4,500 m³/day from the deep aquifer >30m, from shallow Holocene sands <20m and from fully screened wells in the Raumati zone expressed as the ratio of depletion rate (q) and pumping rate (Q)

The drawdown magnitude in the shallow Holocene sands is also an important management consideration. The shallow Holocene sands in the Raumati host a number of wetlands of national and regional significance that may potentially be adversely affected by drawdown in the Holocene sand aquifer.

In order to evaluate potential wetland drawdown simulations were assuming seasonal abstraction (180 day duration) distributed across a network of 45 wells pumping at 100 m^3/day (cumulative abstraction rate of 4,500 m^3/day) from the shallow and deep aquifers respectively. As illustrated in Figure D11 and D12, results of these scenarios indicate a maximum wetland drawdown of 0.25m resulting from abstraction from the Holocene sand aquifer and a 0.1m drawdown in response to abstraction from deeper water-bearing layers.

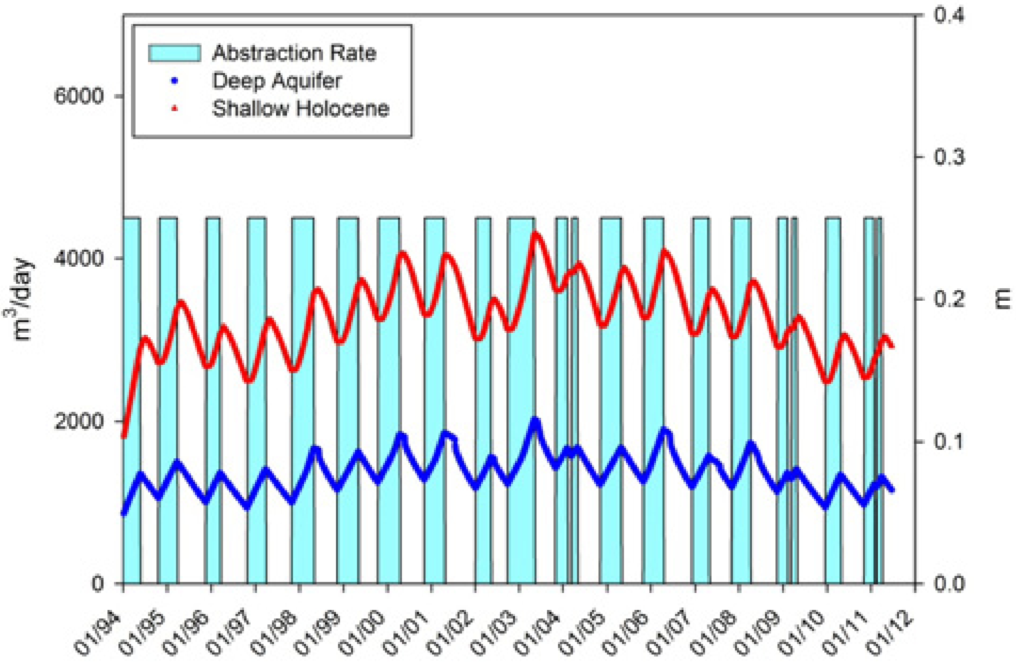

Figure D11: Simulated drawdown resulting from seasonal abstraction at a rate of 4,500 m³/day from the shallow Holocene aquifer and deep aquifer respectively between 1994 and 2012

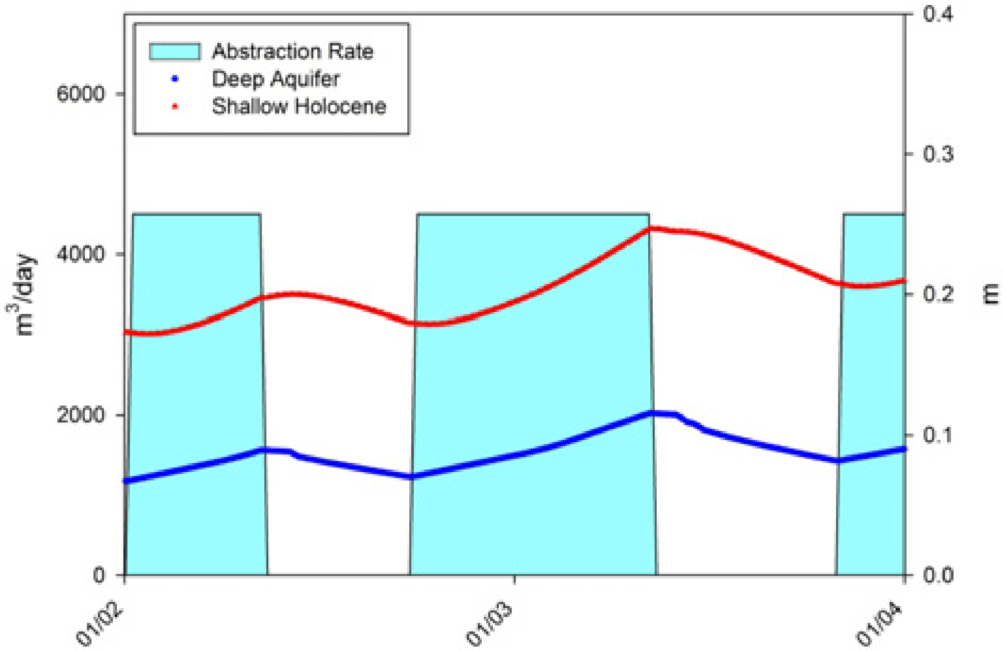

Figure D12: Simulated drawdown associated with seasonal abstraction at 4,500 m³/day from the shallow Holocene aquifer and deep aquifer respectively over the 2002/03 period

The graphs show a synchronous response of wetland levels to abstraction from either the deep or shallow aquifer indicating that the whole aquifer acts as a single unit. The graphs further confirm that pumping from the shallow Holocene sand aquifer only cannot sustain significantly higher abstraction rates without causing adverse water level effects to the wetlands. A maximum drawdown of 0.25 m at the end of the 2003 simulation year is greater than the maximum allowable wetland drawdown of 0.2 m.

Current consented groundwater use data for the Raumati zone shows that groundwater abstraction occurs throughout the year with seasonal peaks during the summer. The seasonal peaks are approximately two times the winter abstraction rates (refer Figure D14). In order to illustrate drawdown in response to semi-continuous abstraction, Scenario 4 simulates summer abstraction from fully screened bores pumping for 180 days at 4,500 m^3/day and the remainder of the year to 2,250 m^3/day. Results of this scenario are shown in Figure D13 and Figure D14 below and, as expected, show surface water depletion continues throughout the year with peaks during the summer period.

Figure D14 shows that seasonal surface water depletion peaks in summer but does not cease when the abstraction rate is reduced to 50% of the summer take during the winter months. The peak surface water depletion rate is approximately 2,300 m^3/day which recedes to a minimum of about 1600 m^3/day during winter. The peak and minimum depletion rates represent 35 and 25 percent of MALF, respectively. The MALF depletion under this scenario is greater than that in Scenario 2 and more than the permissible cumulative MALF depletion of 30%. This scenario represents the most likely groundwater abstraction pattern for this The Raumati groundwater zone.

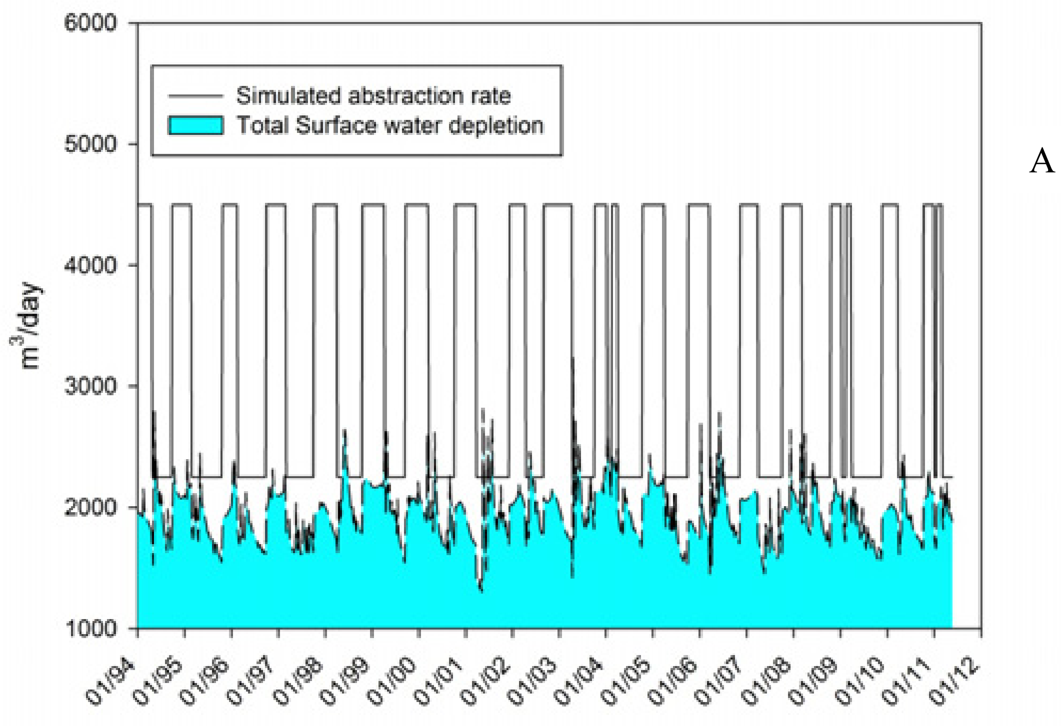

Figure D13: Scenario 4 results – simulated cumulative stream depletion resulting from continuous abstraction (4,500 m^3/day summer, 2,250 m^3/day winter) over the 1994 to 2012 period

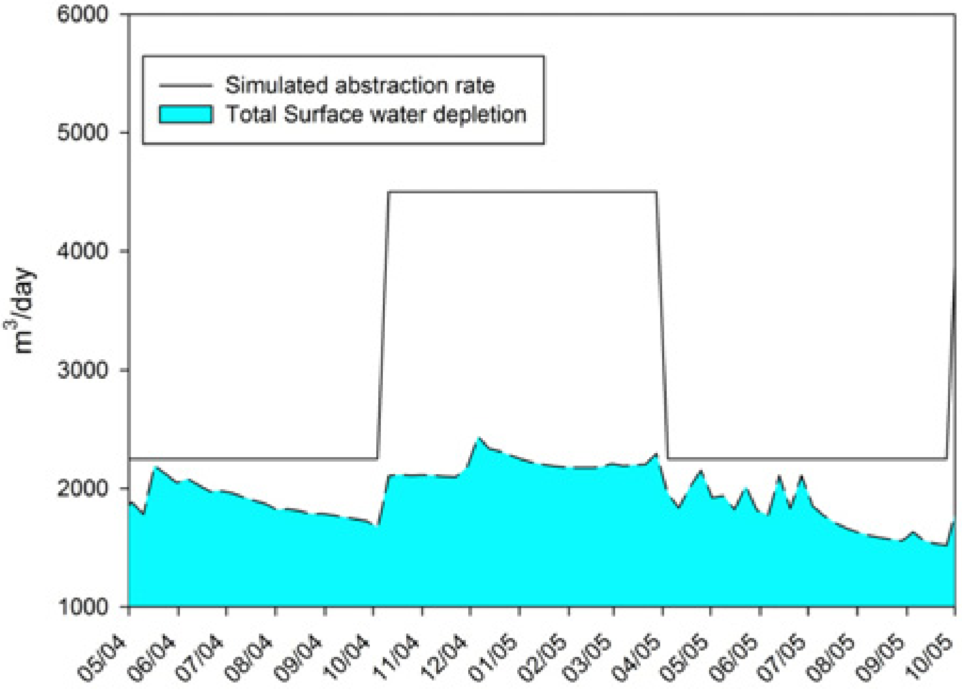

Figure D14: Scenario 4 results – simulated cumulative stream depletion resulting from continuous abstraction (4,500 m^3/day summer, 2,250 m^3/day winter) between May 2004 and October 2005

Figure D15 shows the results of Scenario 4 in terms of surface water depletion effects. The plot shows that the largest stream depletion occurs when the shallow Holocene aquifer only is pumped. This scenario is represented as the ratio between depletion rate (q) and the pumping rate (Q). This abstraction scenario is modelled to result in direct effects to surface water depletion effects (i.e. q/Q>0.6). The results also show that abstractions from the deep aquifer and through fully screened wells are likely to result in relatively indirect effects (i.e. q/Q<0.5).

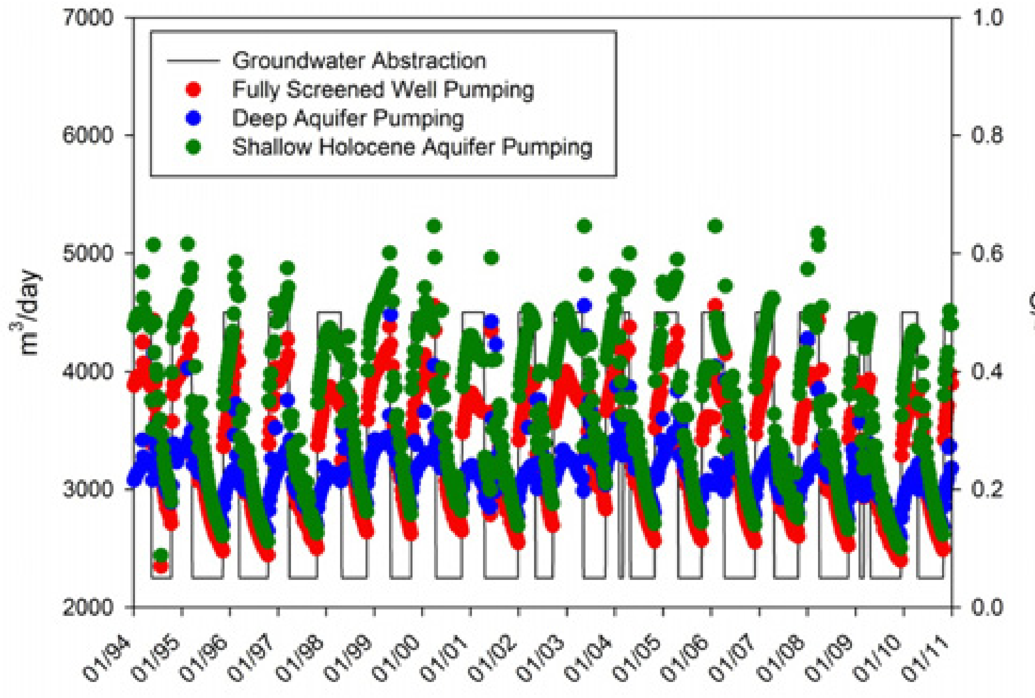

Figure D15: Scenario 4 – surface water depletion resulting from groundwater abstraction from the shallow Holocene sands, deep aquifer and from fully screened wells in the Raumati zone, 1994 to 2012

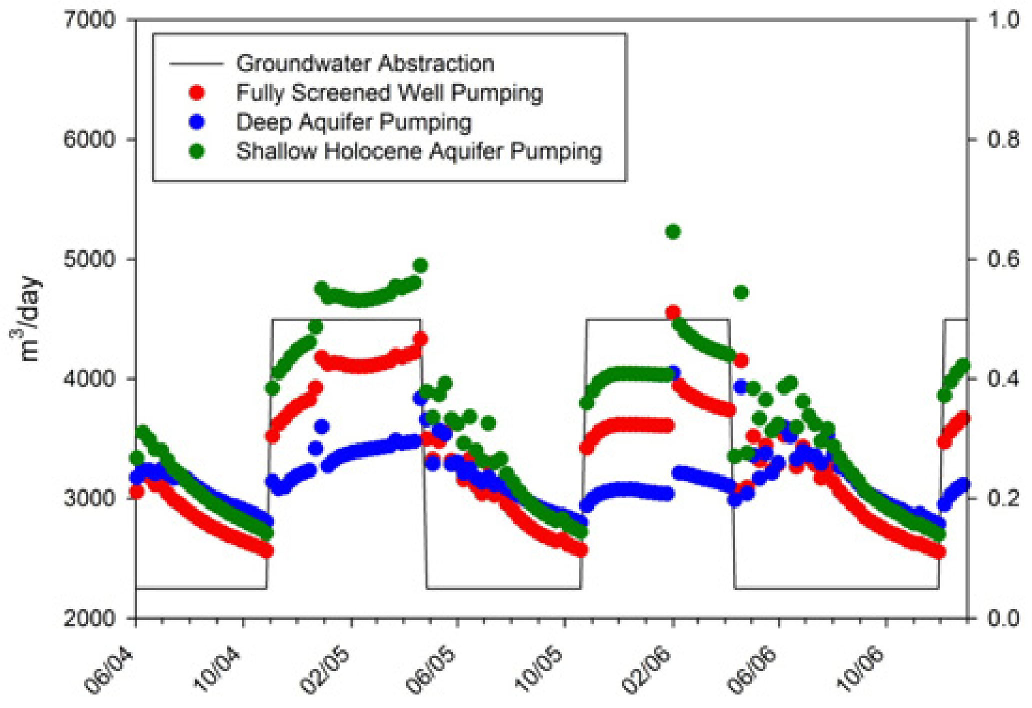

Figure D16: Scenario 4 – surface water depletion resulting from groundwater abstraction from the shallow Holocene sands, deep aquifer and from fully screened wells in the Raumati zone, May 2004 to October 2006

The surface water depletion effects resulting from Scenario 4 is also represented in Figure D17 in terms of a percentage of MALF (the maximum permissible surface water depletion is 30% of MALF). The plot shows that abstraction from the shallow Holocene sand only, will result in more than 45% depletion of MALF. Abstraction from fully screened wells will result in a cumulative depletion of about 35% and 25% for abstraction from deeper water-bearing layers.

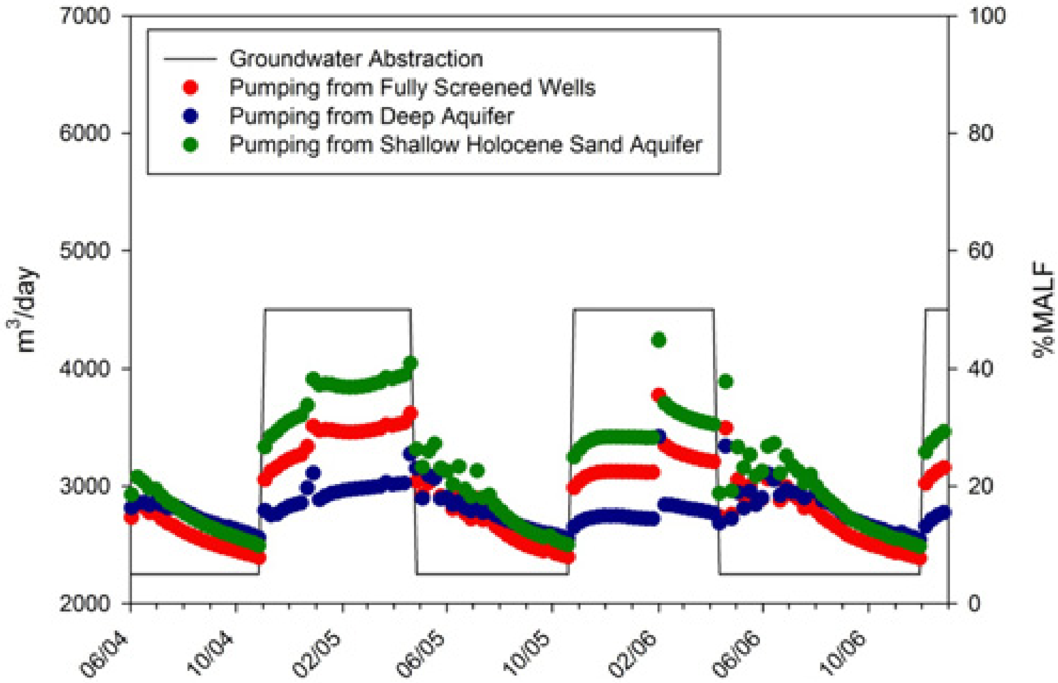

Figure D17: Scenario 4 – surface water depletion (%MALF) resulting from groundwater abstraction from the shallow Holocene sands, deep aquifer and from fully screened wells in the Raumati zone (2004-2006)

Figure D18 shows the results of Scenario 4 in terms of wetland and coastal drawdown effects resulting from abstraction from the Holocene sand aquifer. The plot shows that wetland drawdown remains high throughout the year (i.e. above the maximum permissible threshold of 0.2m) reaching a maximum of 0.3 m in late autumn. Shallow groundwater abstractions result in a relatively minor coastal aquifer drawdown of less than 0.1 m (maximum permissible drawdown of 1m).

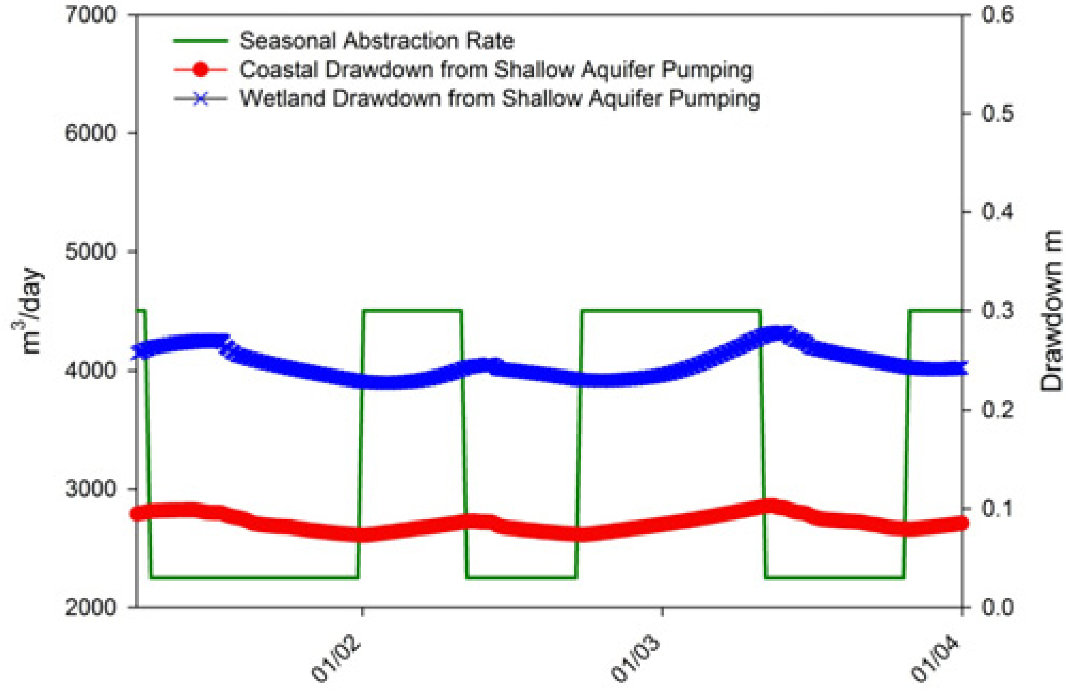

Figure D18: Scenario 4 outputs – simulated wetland and coastal drawdowns when abstraction is from shallow Holocene sands only after pumping at 2,250 m³/day (winter) and 4,500 m³/day (summer)

The drawdowns predicted from abstraction from the deep aquifer (Figure D19) at a seasonal pumping rate of 4,500 m^3/day (summer) and 2,250 m^3/day (winter) suggests that the deep aquifer could sustain these rates. The maximum wetland drawdown from this scenario is less than 0.2 m and the maximum coastal drawdown is less than 0.4m.

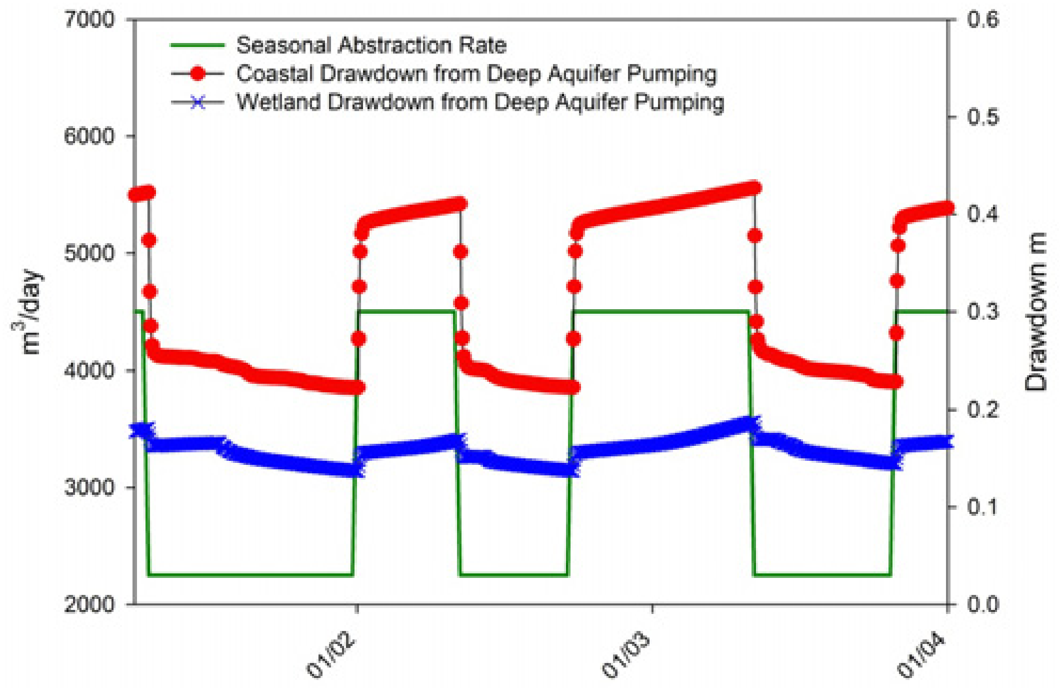

Figure D19: Scenario 4 – simulated wetland and coastal drawdown resulting from abstraction from the deep aquifer at a rate of 2,250 m³/day (winter) and 4,500 m³/day (summer)

Overall, results of Scenario 4 show that abstraction from only the shallow and only the deep aquifers have opposing effects on wetland and coastal aquifer drawdown. Deep aquifer abstractions will result in larger drawdown at the coastal margin but have less effect on wetlands. Shallow aquifer abstraction will result in larger wetland drawdown but less coastal drawdown. Results of Scenario 4 indicate that no further increase in abstraction from either aquifer could be sustained (from the abstraction rate simulated) either in terms of wetland drawdown levels and/or cumulative stream depletion at MALF conditions.

Groundwater Management Options for the Raumati zone

Groundwater-surface water interaction zones

- It is recommended the groundwater system across the entire Raumati water management zone should be assigned Category B status. This recognises the effects of both shallow and deep aquifer abstractions on surface water depletion and water level drawdowns on numerous wetlands with various local, regional and national significances. Both shallow and deep groundwater abstractions result in almost immediate depletion of surface water. Abstractions from deep groundwater result in marginal drawdown of coastal aquifer groundwater levels. Wetland levels, stream depletion and coastal drawdown do not completely recover from higher abstraction rates during the summer.

Groundwater allocation

Groundwater allocation should be based on consideration of cumulative stream depletion, wetland drawdown and coastal groundwater level drawdown. Results from various scenario model runs at different abstraction rates are presented in Table 2 and Figure D20 below. For each model run, the effects on cumulative surface water depletion, wetland drawdown and coastal aquifer drawdown are presented. These effects are then compared (as a ratio) to the maximum permissible drawdown or depletion, specified as:

- **Stream flow depletion: 30% of 7-day MALF**. The reference surface water flow should be the sum total of all stream flows in the water management zone. The estimated 7-day MALF for the Raumati water management zone is 75 l/s and the maximum allowable depletion is 30% of MALF i.e. 22.5 l/s, thus allowing all surface water depletion to be apportioned to groundwater abstraction effects i.e. no direct surface water takes. The equivalent groundwater allocation for a 30% depletion of 7-day MALF is approximately 4,500 m^3/day (Table 2) and Figure D16.

- **Average wetland drawdown: 0.2m.** Average wetland drawdown effects due to abstraction should be limited to 0.2m. Modelling indicates that this drawdown would occur at a seasonal pumping rate of 4,500 m^3/day.

- **Coastal aquifer drawdown: 1m.** The reference coastal aquifer drawdown to cause saltwater intrusion is estimated at 1m which is calculated to move the saltwater freshwater interface upwards by approximately 33 to 40m. The current location of the coastal saltwater/freshwater interface is about 70m deep. All pumping scenarios evaluated show a coastal drawdown of less than 0.4m.

Figure D20 is a plot of normalised drawdowns of effects to the maximum permissible against incremental abstraction rates. In this case the normalised total surface water depletion controls the maximum permissible abstraction. The abstraction rate at a normalised total surface water depletion of one (unity) is approximately 4,500 m^3/day. At this abstraction, the normalised wetland drawdown would be approximately 0.6 and coastal aquifer drawdown will be 0.2.

Table 2 shows the allocation options based on model scenarios. Scenario 5 meets all the criteria for total surface water depletion, wetland level drawdown and coastal drawdown. Wetland level drawdown is calculated as an average for all identified wetland drawdowns in the Raumati zone. Table 2 also shows the abstraction rates as a percentage of annual lower quartile surface recharge (LSR).

Table D2: Summary Table of effects of abstraction on surface water depletion, wetland drawdown and coastal aquifer drawdown (recommended option in bold)

Scenario	Cumulative Depletion %MALF (75 l/s)	Allocation m^3/day	Allocation m^3/year x 1000	Cumulative Depletion L/s	Wetland Drawdown mm (Max. 200mm)	Coastal Drawdown m (Max. 1m)	LSR %
1	10	1500	409.5	7.5	44.6	0.12	8.4
2	13	2000	546	9.9	60	0.16	11
3	20	3000	819	14.9	90.5	0.24	17
4	26	4000	1,092	19.9	120	0.32	22
5	**30**	**4500**	**1,229**	**22.3**	**135**	**0.36**	**20**
6	33	5000	1,365	24.8	151	0.40	28
Current	*17*	*2647*	*723*	*13*	*80*	*0.21*	*15*

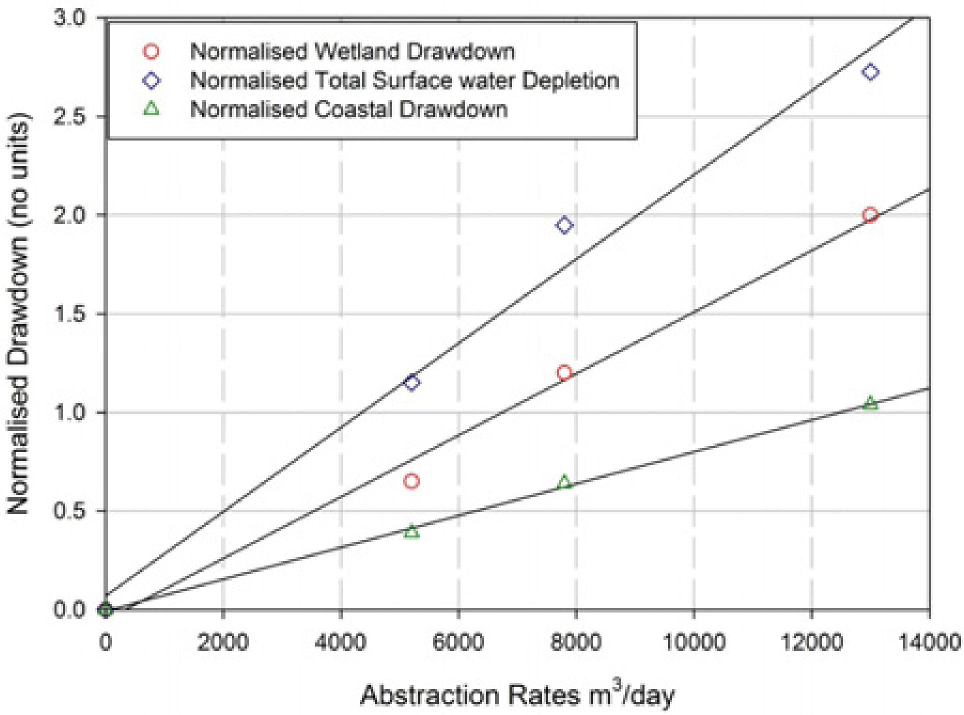

Figure D20: A plot of normalised drawdown/depletion to maximum permissible total surface water depletion, wetland drawdown and coastal drawdown effects against incremental daily abstraction rates

Table D3: Raumati Summary Table: Groundwater Allocation Proposal

	Controlling factors	Proposed new Allocation	Current Allocation	Notes
Raumati Zone	(1) Wetland drawdown - allow maximum 200 mm (2) MALF (75 l/sec) - allow up to 30% depletion. (3) LSR allow up to 30% (4) Coastal Drawdown- allow up to 1m	4,500 m^3/d *1.229 x 10^6 m^3/year	2,647 m^3/d (59% allocated) 0.723x10^6 m^3/year (59% allocated)	Allocation is capped at 4500 m^3/d Wetland drawdown 135mm 30% MALF depletion LSR:19% Coastal drawdown 135mm