Conjunctive water management recommendations for the Hutt Valley

greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Conjunctive water management recommendations for the Hutt Valley

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GW/ESC-T-15/77
ISBN-978-1-927217-78-8 (online)
ISBN-978-1-927217-77-1 (print)

July 2015

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The report may be cited as:

Gyopari M. 2014. *Conjunctive water management recommendations for the Hutt Valley* Greater Wellington Regional Council, Publication No. GW/ESCI-T-15/77, Wellington.

Executive summary

The groundwater resources of the Wellington Region form an integral component of the overall 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 management of groundwater and surface water resources in the Wairarapa Valley. This framework enables management of groundwater abstraction in a manner consistent with environmental flows and water levels established for hydraulically connected surface water resources. The management framework proposed by Hughes and Gyopari (2011) involves delineation of three hydraulic connection categories:

- Category A: areas where groundwater has a direct hydraulic connection with surface water where stream depletion effects may be mitigated by application of minimum flow or level cut-offs for relevant rivers, streams or lakes. Category A takes are essentially managed as equivalent surface water abstractions based on the average weekly abstraction rate (as opposed to the instantaneous abstraction rate for surface water takes);

- Category B: areas where groundwater abstraction effects on surface water may be significant and can potentially be managed through 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 for the aquifer system.

It is proposed in this report that the same conceptual approach is taken to manage the groundwater resources of the Hutt Valley.

Geological, hydrogeological and hydrological information are utilised to develop a conceptual model of groundwater/surface water interaction for the Hutt Valley. This conceptual model is then used to provide recommendations for the application of the proposed hydraulic connection categories to the Upper Hutt and Lower Hutt groundwater management zones. Groundwater modelling has also been used to assess the sustainable groundwater allocation limits for the zones.

Recommendations for the conjunctive management of water resources for these two zones are:

Upper Hutt Groundwater Management Zone

The principal management objective for groundwater allocation in the Upper Hutt groundwater zone is to ensure that instream values of hydraulically connected surface water ecosystems - the Hutt River and small spring fed streams, are protected.

Productive groundwater resources occur within the upper 50m and show a strong connectivity to the Hutt River and spring-fed streams. Modelling indicates that within about 1km of the river, groundwater abstractions have a significant and rapid depletion effect on the river and spring-fed streams. The western side of the valley is therefore designated as hydraulic connection Category A, whilst the eastern side of the valley is assigned to Category B, both to 50m depth. Category C is assigned to aquifers greater than 50m deep.

Groundwater allocation in this zone is referenced to an acceptable depletion of the 7-day mean annual low flow (MALF) of the Hutt River at Taita Gorge. A depletion factor of 0.5 should be adopted for Category B abstractions.

The following groundwater allocation options have been identified for the Upper Hutt groundwater zone. Option 1 is recommended.

Option	Cumulative depletion effect on Hutt River 7-day MALF at Taita Gorge (including spring-fed streams)	Allocation m^3/day	Allocation m^3/year
1	1% MALF	4,300	770,000
2	2% MALF	8,700	1,560,000
3	3% MALF	13,000	2,340,000

Lower Hutt Groundwater Management Zone

The principal management objective for groundwater allocation in the Lower Hutt groundwater zone is to manage the effects of abstraction on the Hutt River, minimise the risks of saltwater intrusion and optimise groundwater resource availability for public water supply. The impacts of maximising the groundwater resource on the Hutt River are taken into consideration in the designation of core allocation from the lower reach of the Hutt River.

The Waiwhetu Aquifer and its upstream unconfined zone extension and mergence with the Taita Alluvium are assigned allocation Category B. Taita Alluvium to a depth of up to about 15m over the confined aquifer area (south of Boulcott) is assigned Category A.

Annual, mean daily and peak daily allocation limits are recommended. However, saline intrusion risk management criteria will take precedence over these limits (i.e. saltwater intrusion controls may restrict abstraction to lower rates), but the limits shall not be exceeded. The maximum daily allocation limit should also be guided by the groundwater level in the unconfined aquifer at the Taita Intermediate monitoring site.

A total allowance of 600 L/sec from the core allocation of the lower reach of the Hutt River is needed to enable maximum allocation of the groundwater resource.

The following groundwater allocation options for the Lower Hutt groundwater zone are recommended:

Aquifer	**Allocation**
Waiwhetu Aquifer + Taita Alluvium unconfined zone	100,000 m^3/day (mean) 140,000 m^3/day (peak) 36,500,000 m^3/year

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1. Introduction

1.1 Background

In May 2011 Greater Wellington Regional Council (GWRC) published a technical report (Hughes and Gyopari, 2011, revised in 2014) 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 allocation is integrated with surface water allocation to ensure the cumulative effects of water use are consistent with environmental flows and water levels established for hydraulically connected surface water resources such as rivers, streams, lakes and wetlands.

The proposed framework for conjunctive water management in the Wairarapa Valley was the outcome of five years detailed of investigation and modelling, particularly in terms of the potential nature of groundwater/surface water interaction in response to groundwater abstraction. The proposed management framework included criteria for the application of pumping regulation to mitigate direct effects of groundwater abstraction on stream flows and established cumulative effects on surface water as a primary criterion for determining sustainable groundwater allocation limits.

1.2 Report objectives

The objective of this report is to provide recommendations for the application of the proposed framework for conjunctive water management to aquifer systems in the Upper and Lower Hutt groundwater management zones.

The report also provides recommendations for groundwater allocation volumes based upon recent groundwater modelling investigations. The models have also been used to help delineate hydraulic connectivity zones and quantify river flow depletion effects resulting from groundwater abstractions.

2. Conjunctive management framework

The groundwater resources of the Wellington Region form an integral component of the overall 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.

As described in the following sections, groundwater and surface water resources throughout the Wellington Region commonly exhibit a high degree of interconnection, particularly within the recent gravel deposits (denoted as Q1) along the riparian margins of the main river systems. Managing both localised and cumulative effects of groundwater abstraction on hydraulically connected surface waters is therefore a key component of a framework for managing surface and groundwater allocation to ensure environmental values can be maintained at or above thresholds established by the community through the Regional Plan review process.

2.1 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.* 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).

In this report, 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 in certain hydrogeological environments 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 Proposed conjunctive management framework

The proposed conjunctive water management framework comprises two main components:

1. Management of groundwater abstraction which has a direct or immediate effect on the surface water environment through application of allocation limits and pumping controls based on environmental flows and water levels established for hydraulically connected surface water bodies; and

2. Determination 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 stream flow depletion effect.

Hughes and Gyopari (2011) utilised the concept of '*hydraulic connectivity*' to differentiate areas where groundwater abstraction has the potential to result in direct and immediate effects on surface water from those where there is a considerable lag between pumping and resulting effects on surface water[1]. In order to implement the conjunctive water management framework, a three-tier management approach was proposed for managing groundwater abstraction as follows:

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 water bodies.

Category B: High Hydraulic Connectivity

Category B includes those areas of the hydrogeological system where groundwater abstraction may potentially result in significant impacts on surface water but where pumping regulation does not always provide an effective option for mitigating direct stream depletion effects. Category B represents the transition between indirect and direct stream depletion effects where it may be appropriate to manage groundwater takes in terms of either surface water or groundwater allocation policies depending on localised factors (e.g. local aquifer hydraulic parameters, abstraction rate and location of pumping with respect to surface water bodies).

Category C: Moderate Hydraulic Connectivity

The Category C classification applies to those areas of the hydrogeological system where, although groundwater abstraction may contribute to an overall cumulative reduction in base flow at a catchment scale, active regulation of pumping does not provide effective mitigation of potential effects on surface water.

[1] Appendix C of Hughes and Gyopari (2011) provides a detailed background outlining the potential effects of groundwater abstraction on streamflow. This material is not repeated in this report as, although hydraulic properties may vary between individual aquifers systems, the factors influencing groundwater/surface water interaction have universal applicability.

Specification of the spatial and depth distribution of the various hydraulic connection categories is therefore a key component of the overall conjunctive management framework. In both the Wairarapa Valley and Kapiti Coast areas, this process involved detailed investigations and analysis of the regional hydrogeological setting assisted by the development and application of numerical groundwater models. For this report, application of the proposed hydraulic connection categories has largely been approached through the development of a conceptual model of groundwater-surface water interaction the Upper and Lower Hutt groundwater zones which is informed by results from the application of numerical modelling for resource management.

2.3 Management of groundwater / surface water interaction

Under the proposed conjunctive management framework, in 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 proposed 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 encompasses the portion of the hydrogeological system which exhibits a direct and immediate hydraulic connection with surface water. In these areas groundwater abstraction is proposed to be managed as part of the environmental flow and water level regime established for relevant hydraulically connected surface water bodies.

Spatial Definition	Generally limited to the Q1 gravel aquifers along the riparian margins of the major river systems.
Application	All groundwater takes which require resource consent (i.e. excludes permitted uses under RMA s14(b) and takes permitted under the Regional Freshwater 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 surface water management policies. However, all takes will be assessed in terms groundwater Policies relevant to environmental effects such as well interference effects and saline intrusion.

Category B

Category B includes those areas 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 proposed 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 or is greater than **10 L/s** calculated using the average seasonal abstraction rate[2]. This q/Q threshold of 0.6 is arbitrarily defined as the point where pumping controls have a net positive benefit on stream flows (i.e. cessation of pumping will result in a reduction in the overall rate of stream depletion at a rate faster than natural flow recession so there is a net positive effect on stream flow).

[2] Average seasonal abstraction rate is defined as the seasonal volume divided by the duration of abstraction defined by resource consent conditions. Where the duration of abstraction is not specified in resource consent conditions, a nominal figure will be applied based on application of the seasonal volume calculation methodology.

Allocation	The 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 Category C classification includes those areas 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. In such areas groundwater allocation will be managed in terms of criteria relating to cumulative effects of groundwater abstraction (e.g. cumulative effects on stream flows, saline intrusion, drawdown or well interference effects).

3. Hutt Valley

3.1 Introduction

The original name given to the Hutt River by the Ngāi Tara is Te Awa Kairangi. 'Te Awa' meaning river, and 'Kairangi' meaning esteemed or precious. The river's high mountainous catchment and the coastal plains were originally forested and the swampy plains and waterways associated with the main river and the Waiwhetu Stream were a particularly rich source of food. In the late 19th century, with the arrival of European settlers, the valley floor was completely cleared of natural kahikatea and rimu forest, which affected the rainfall runoff and hydrological characteristics of the valley. Uplift associated with the 1855 earthquake also had a dramatic impact on the hydrology of the Lower Hutt valley. The landscape and hydrological system have therefore undergone radical changes in response to both natural and human influences in recent times. The lower plain of the catchment (Upper and Lower Hutt) is now extensively urbanised.

The Hutt Valley typically experiences between 1,100 and 1,300 millimetres of rain per year. However, in the upper mountainous Tararua catchment of the Hutt River, annual rainfall can exceed 5,000 millimetres (WRC, 1995). While rainfall in the Hutt Valley is usually relatively evenly distributed throughout the year, extended periods of low rainfall often occur during the summer and autumn resulting in periods of low river flow. Such periods of low rainfall and river flows can be particularly pronounced during La Niña weather patterns.

The water resources of the Hutt catchment (both surface and groundwater) are extensively utilised for municipal supply both within the Hutt Valley and across the greater Wellington area. Increased demand during periods of low rainfall commonly results in significant pressure on both surface water and groundwater resources

3.2 Geological setting

The Wellington Fault is the dominant geological feature of the Hutt Valley and defines the catchment of the Hutt River through the foothills of the Tararua Range and Western Hutt Hills. Tilting and warping of the basement block bounded by the Wellington Fault to the west and Wairarapa Fault to the east over the last two million years (Begg and Johnston, 2000) has resulted in the formation of a series of fault-bound basins which were in filled with a sequence of alluvial gravels deposited and reworked by the Hutt River during late Quaternary (Otira and Waimea) glacial and associated interglacial periods.

The main alluvial basins in the Hutt Valley are the Lower Hutt Basin, between Taita Gorge and extending southwards beneath Wellington Harbour, and the Upper Hutt Basin extending upstream from Taita Gorge to Birchville (Figure 1). Other smaller alluvial basins include the Pakuratahi Basin and the Mangaroa Valley which lie north-east and east of Upper Hutt respectively, and the Akatarawa Valley which follows the narrow gorge of the Akatarawa River to the north of Upper Hutt. The basement rocks underlying the Hutt Valley and forming the surrounding hills comprise compact mudstone and sandstone sequences (collectively termed greywacke). These rocks are deformed by folding and faulting and often exhibit well developed bedding, jointing and fracturing.

The effects of Late Quaternary (<125,000 years) cyclic changes in sea level are evident in the Lower Hutt basin where marine sediments extend inland from the present-day coast forming laterally continuous layers of fine-grained sediment within a thick alluvial gravel sequence. Asymmetric basin geometry in both Lower and Upper Hutt is the product of subsidence along the Wellington Fault restricted the Hutt River to the western side of the valley for extended periods, resulting in a predominance of fine-grained and organic-rich sediments toward the shallower eastern basin margins.

3.3 Hydrogeology

The principal groundwater resources of the Hutt Valley are found within alluvial gravel sediments infilling the various sedimentary basins formed along the Wellington Fault. Groundwater within the basins occurs within two primary hydrogeological settings:

- Shallow, highly permeable unconfined aquifers hosted in young postglacial (Q1) alluvial gravels; and,

- Semi-confined to confined aquifers hosted in deeper water-bearing gravel layers (Q2, 4, 6 +) which are confined by overlying layers of fine-grained silt, sand and organic materials. The confining layers represent fine-grained sediment deposition in swamp or wetland environments (inland basins), or marine silt and sand deposits associated with high sea level periods.

A limited groundwater resource also occurs in the greywacke basement rocks in areas where sufficient secondary permeability occurs within joints, fractures, bedding planes and other discontinuities within the rock mass.

For the purposes of resource management WRC (1995) divided the Hutt Valley into the groundwater management zones illustrated in Figure 3.1. These zones define areas of similar hydrogeological characteristics and are utilised as the primary units for groundwater allocation in the Regional Freshwater Plan (WRC 1999).

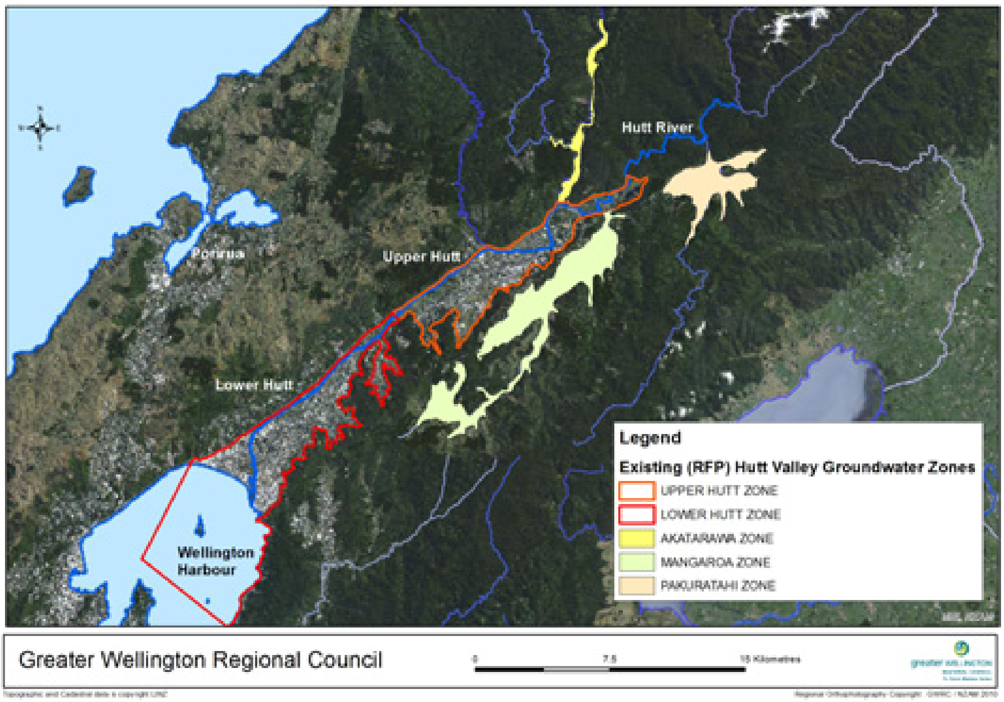

Figure 3.1: Groundwater Management Zones in the Hutt Valley as defined in the Regional Freshwater Plan (WRC 1999)

3.4 Groundwater / surface water interaction

The Hutt River and tributaries exhibit a significant degree of interaction with the underlying groundwater resource in many parts of the Hutt Valley. The following report sections utilise current hydrogeological information to develop a conceptual model of groundwater / surface water interaction for the Upper Hutt and Lower Hutt groundwater zones and provide recommendations for the management of potential effects of groundwater abstraction on surface water.

3.5 Other groundwater zones in the Hutt Valley

Due to the limited information available to describe the likely nature of groundwater/surface water interaction, the remaining groundwater zones in the Hutt River catchment (Mangaroa, Pakuratahi and Akatarawa groundwater zones) are not included in this report. Management of groundwater allocation in these areas will follow a generic methodology being developed by GWRC for areas outside of defined groundwater management zones in the Wairarapa Valley and Kapiti Coast areas (at the time of writing this report the methodology had not been finalised).

4. Upper Hutt Groundwater Management Zone

The Upper Hutt groundwater zone extends from Taita Gorge/Silverstream in the south to Te Marua in the north. Figure 4.1 shows the extent of the zone and GWRC river flow and groundwater level monitoring sites together with consented bores.

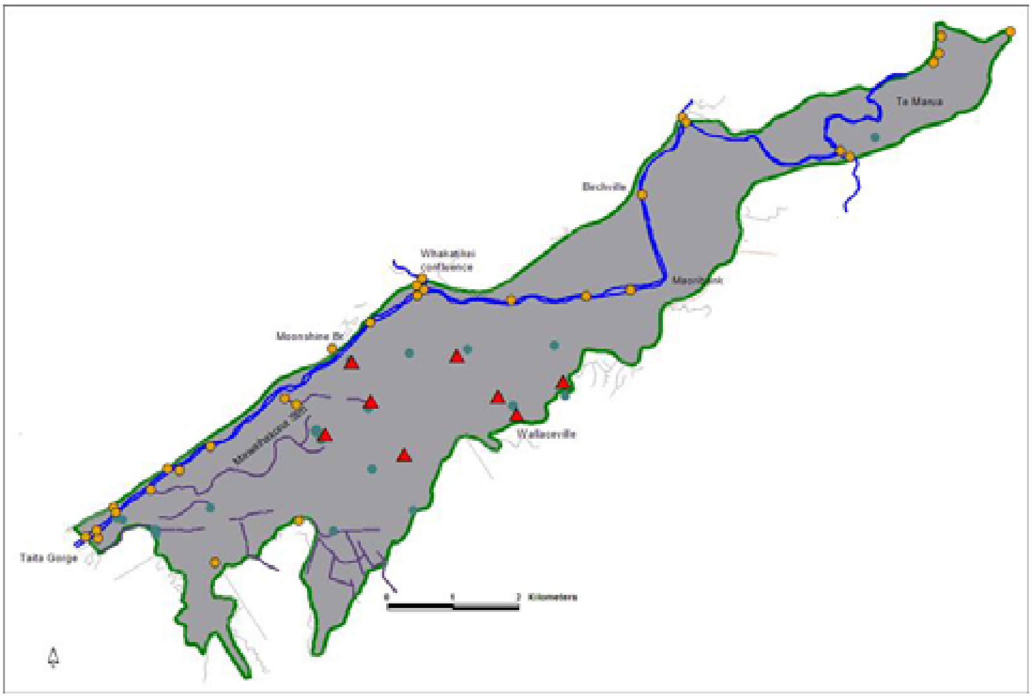

Figure 4.1: Upper Hutt groundwater zone showing groundwater monitoring sites (red triangles), existing bores (green circles) and surface water monitoring sites (orange circles)

4.1 Geology

The formation of the Upper Hutt sedimentary basin is associated with displacement of greywacke basement along the Wellington Fault which forms the linear north-western valley boundary. The basin is sub-rectangular (approximately 9km long and 3km wide) and estimated to be more than 200m deep. It is filled with a heterogeneous sequence of unconsolidated alluvial and swamp sediments. The Hutt River has locally reworked the deposits to create more localised permeable, channelized aquifers, particularly within the upper 20-30m of so of the sequence.

Greywacke basement is exposed in the bed of the Hutt River at Maoribank, near Birchville and at Taita Gorge at the southern end of the basin – all groundwater flow is therefore forced back into the river before Taita Gorge. Structure contours of the greywacke basement, derived from geological and geophysical data (Begg, 1993), show an asymmetrical basin geometry with sedimentary infill increasing adjacent to the middle section of the Wellington Fault and gradually shallowing to the north, south and eastern basin margins.

Bore logs show that the valley is underlain by alluvial gravels and sand. The thickness of the sedimentary infill near the central section of the basin is illustrated by the geological log of an investigation bore drilled at Trentham

Memorial Park which encountered 200m of sediment before weathered greywacke basement was intersected (Figure 4.2). The basin fill deposits are inferred to represent materials deposited and reworked by the Hutt River during the late stages of the Otiran glaciation (approximately 10,000 to 25,000 years ago) and subsequent interglacial period (nominally referenced as Q2 gravels). Logs from the few bores penetrating deeper levels of the Upper Hutt basin record a variable sequence of weathered silty gravels containing frequent layers of fine sand and organic sediments (Q4 and older alluvial deposits). These sediments are likely to represent deposition during the Waimea and early stages of the Otiran glaciations when appreciable erosion occurred from the Tararua Range. Intervening layers of finer-grained sediment and organic material may represent periods when drainage from the Upper Hutt basin was impeded by uplift and subsidence along the Wellington Fault resulting in sediment accumulation in extensive wetland areas.

In the Te Marua area at the northern end of the Upper Hutt groundwater zone, the subsurface geology comprises an uplifted section of greywacke basement surrounded by an elevated alluvial terrace. This terrace represents a remnant of the extensive fluvioglacial outwash deposits that infilled the Upper Hutt basin during the last (Otiran) glaciation which has been reworked by postglacial entrenchment of the Hutt River across the middle and lower sections of the basin.

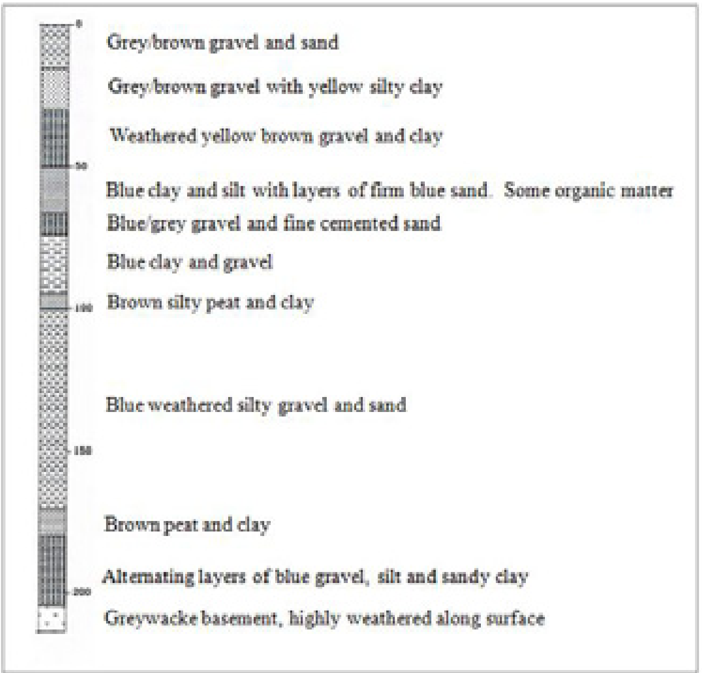

Figure 4.2: Bore log for Trentham Memorial Park (WRC, 1995). Numbers on the graphic log indicate metres below ground level.

4.2 Hydrogeology

Figure 4.1 shows a relatively small number of consented bores across the Upper Hutt groundwater zone reflecting the limited utilisation of the groundwater resource for industrial and park/golf course/race course irrigation supply. However, the groundwater resource of the Upper Hutt basin has been recently investigated to assess its suitability for supplementing the Greater Wellington municipal water supply (MWH, 2008).

Available bore log information suggests the presence of a shallow unconfined aquifer system, and a series of very low permeability confined aquifers at greater depth. Existing bores suggest the existence of an unconfined (to semi-confined) aquifer system to a depth of up to 50m which exhibits a strong hydraulic connection to the Hutt River. This shallow zone, constituting the productive and dynamic part of the groundwater basin, is a highly heterogeneous sequence of coarse water-bearing alluvial gravels alternating with gravel layers containing varying proportions of sand and silt. The aquifer is recharged by a combination of flow loss from the Hutt River between Maoribank and the Whakatikei confluence, and infiltration of rainfall and runoff from the surrounding hills.

Groundwater level monitoring provides evidence that the water balance in the shallow alluvial aquifer across the central and western parts of the Upper Hutt groundwater zone is dominated by fluxes to and from the Hutt River, while rainfall recharge appears to be more significant toward the eastern margin. Figure 4.3 shows a piezometric map constructed using monitoring data collected in July 2007 (MWH, 2008) showing a south-westerly groundwater flow. The map depicts flow loss to the aquifer between Maoribank and the Whakatikei confluence, with return flow from the aquifer to the river occurring between about Moonshine Bridge and Taita Gorge.

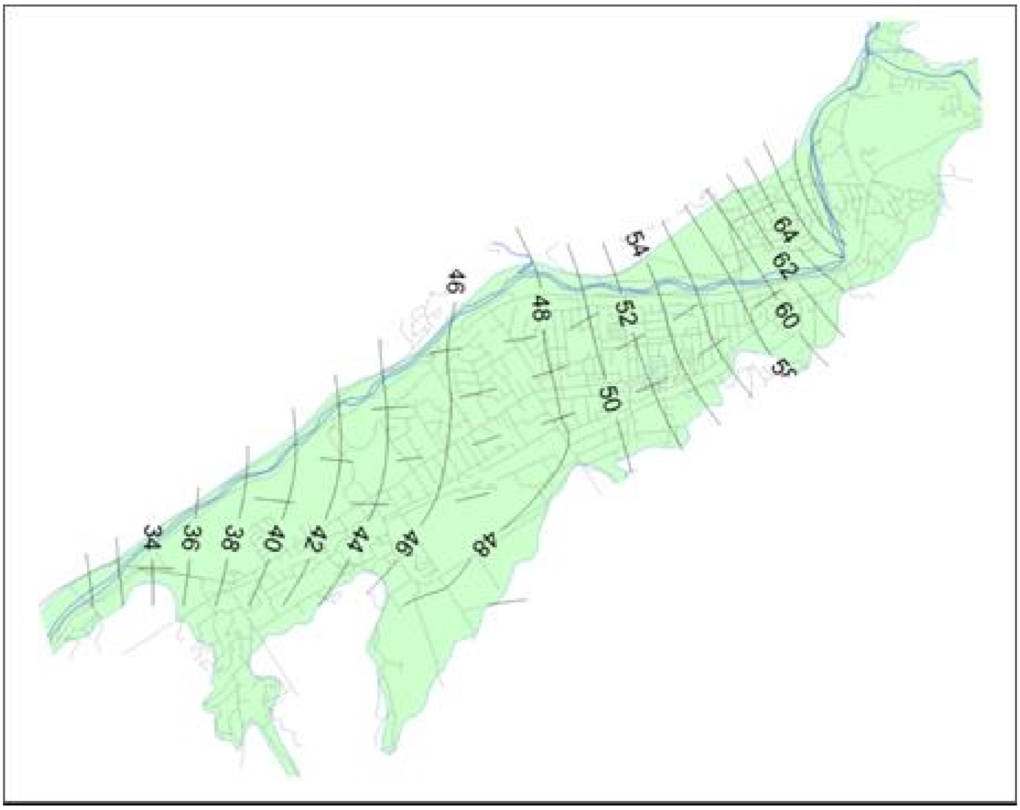

Figure 4.3: Water table map for the Upper Hutt Groundwater Zone – July 2007. Contours indicate the height of the water table in metres above mean sea level at 2m intervals (MWH, 2008). Dashed lines depict the approximate groundwater flow direction (perpendicular to the contour lines).

The groundwater resource at depths greater than about 30 metres is poorly characterised since few bores penetrating to this depth and saturated strata below about 30-50m depth appears to contribute little to groundwater circulation. Information from the deep exploratory bore at Trentham Memorial Park shown in Figure 4.2 (drilled in 1968 to 213m depth - R27/7012) and other deeper bores, show that the deeper confined aquifers comprise relatively low-yielding compact gravels with a high proportion of sands, silts and clays. In the central part of the valley, the confined aquifers are also overlain by a spatially variable, dense silt and swamp deposits between about 50 and 65m depth. Together with the poor water quality encountered with depth, the shallow unconfined aquifer is considered to be the only viable groundwater source in the Upper Hutt Valley being dynamically connected to the Hutt River and receiving rainfall recharge. Overall, due to the geometry of the surrounding greywacke basement, the Upper Hutt groundwater zone effectively comprises a 'closed' groundwater flow system. Under natural conditions, all groundwater is forced back into the Hutt River and spring tributaries to the Hutt River upstream of Taita Gorge.

Deeper levels of the Upper Hutt groundwater zone (>30-50 m depth) appear to form a confined aquifer system which is relatively isolated from short-term variations in recharge flux and which appear to have limited interaction with the shallow alluvial aquifer.

4.3 Hydraulic properties

Odlin (1972) described a series of aquifer tests undertaken by the HVUWA on three investigation bores screened approximately 30m depth at Trentham Memorial Park in the late 1960's. Data from these tests show a consistent pattern of drawdown in response to abstraction with the rapid stabilisation of water levels (as illustrated in Figure 4.4 attributed to the interception of a recharge boundary (in this case the nearby Mawaihakona Stream) shortly following commencement of pumping. While there may be some uncertainty with regard to the interpretation of the observed leakage boundary[3], test results indicate moderate permeability and semi-confined conditions in the alluvial gravel aquifer.

WRC (1994) summarised the results of five aquifer tests undertaken in the Upper Hutt groundwater zone. Again these data suggest semi-confined conditions (storativity 0.002 to 0.003) and moderate to high aquifer permeability (1,500 to 17,500 m^2/day)[4].

MWH (2008) described aquifer testing undertaken on two investigation bores installed near Heretaunga College at Wallaceville. Results of this analysis indicate the highly permeable, heterogeneous nature of the shallow alluvial gravel aquifer in this area with transmissivity estimated to be in the order of 23,000 to 28,000 m^2/day in one production bore, and between 6,000 to 7,000 m^2/day in the nearby second test bore.

[3] Given the location of the test bores with regard the Mawaihakona Stream, depth of the screened interval (~26 to 30m deep) screen depth and duration of pumping

[4] With one exception (R27/7025) exhibiting anomalously low permeability

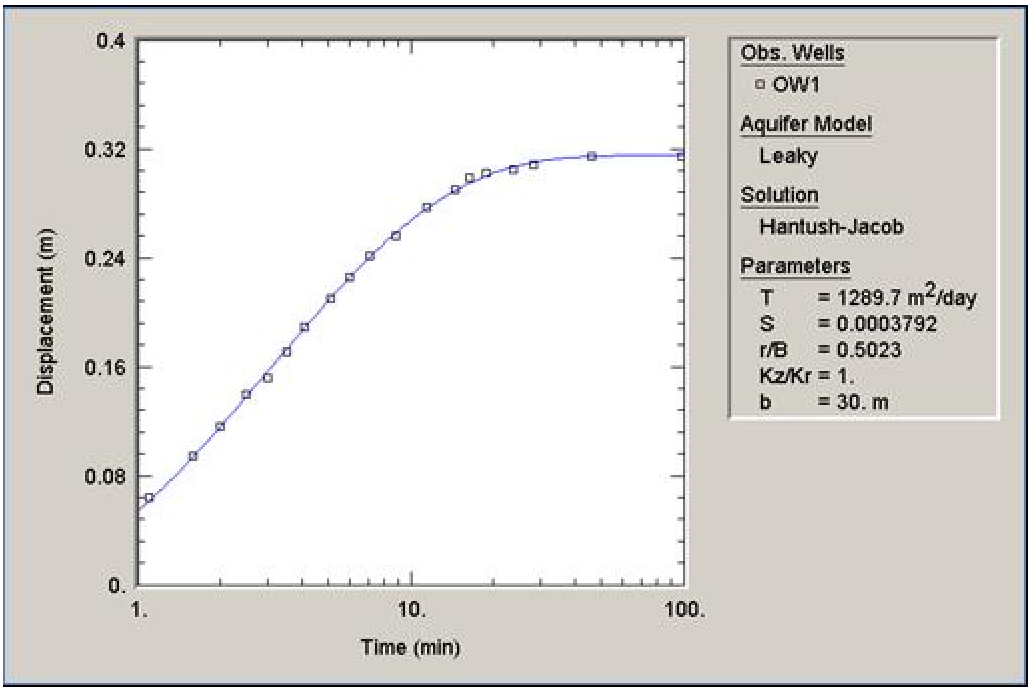

Figure 4.4: Aquifer test data from HVUWA investigations at Trentham Memorial Park fitted to Hantush-Jacob type curve

4.4 Surface water – groundwater connectivity

Flowing along the base of the Western Hutt Hills in close proximity to the Wellington Fault, the Hutt River controls the hydrogeological functioning of the Upper Hutt groundwater zone. A number of spring-fed streams emerge along the margins of the Hutt River over the reach between the Whakatikei River confluence and Silverstream Bridge. The largest of these springs is the Mawaihakona No.1 Stream which flows from the Trentham Memorial Park area through the Heretaunga golf course and discharges to the Hutt River immediately upstream of Silverstream Bridge. Other significant spring-fed streams include the Mawaihakona No.2 Stream and Hulls Creek. No significant wetland areas are recorded in the Upper Hutt groundwater zone reflecting the intensely modified and urbanised landscape.

Figure 4.5 shows a plot of concurrent gauging data from the Hutt River between Birchville and the Silverstream Bridge which shows a consistent pattern of flow loss between Maoribank and the Whakatikei River confluence, then a flow gain between Moonshine Bridge and Taita Gorge (allowing for flow inputs from the Whakatikei River). The measured flow loss over the upstream reach ranges between 470 to 930 L/s, while the corresponding gain between Moonshine Bridge and Taita Gorge ranges between 1,000 and 1,700 L/s. The net surplus in downstream flow gain over upstream flow loss is attributed to drainage of groundwater storage derived from a combination of rainfall recharge and flow loss from the Hutt River during high stage events (see Section 4.5).

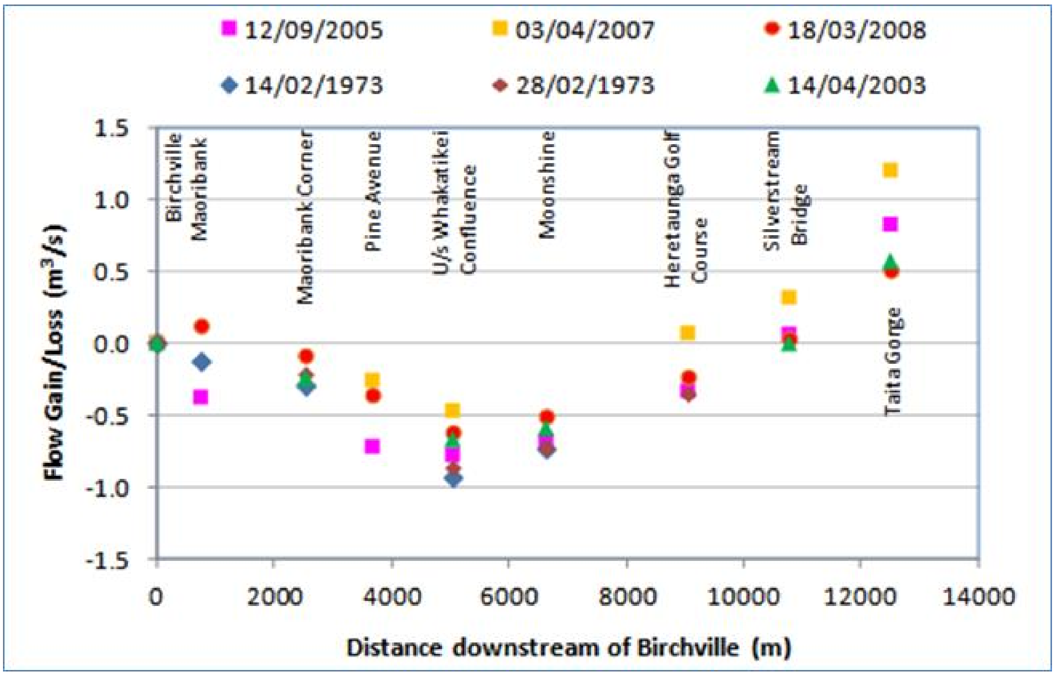

Figure 4.5: Concurrent gauging data from the Hutt River between Birchville and Taita Gorge

Figure 4.6 shows the correlation between measured Hutt River flow at Birchville and Moonshine Bridge. Based on the observed relationship, flow loss from this reach is estimated to be of the order of 600 L/s (52,000 m^3/day) which is similar to the magnitude of flow loss estimated by WRC (1995) and MWH (2008).

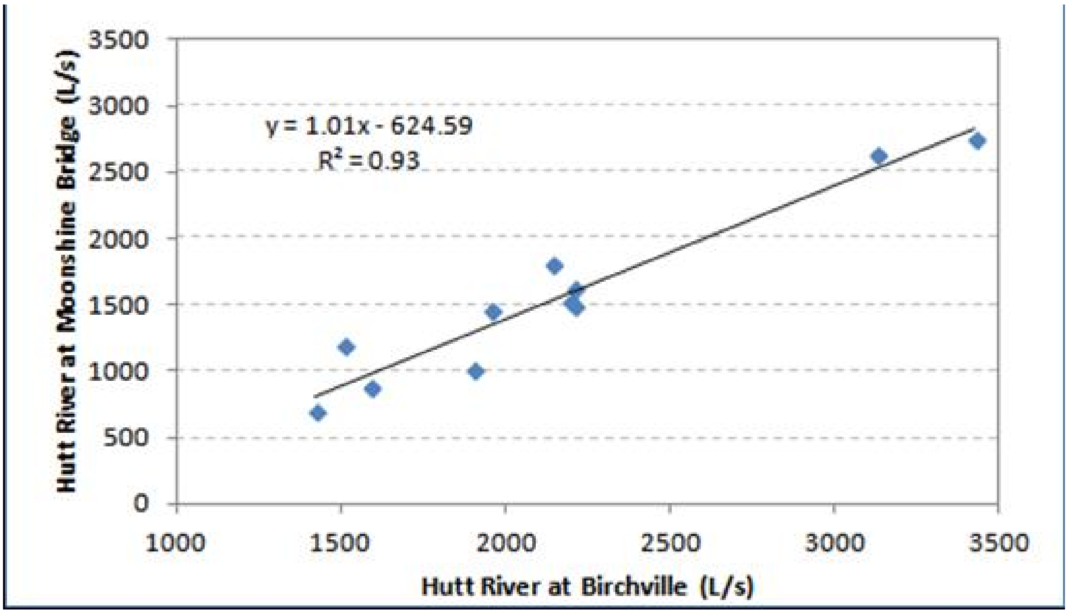

Figure 4.6: Correlation between Hutt River flow at Birchville and Moonshine Bridge (allowing for Whakatikei River inflows)

Appreciable flow occurs in spring-fed streams draining the southern section of the Upper Hutt groundwater zone. Based on gauging results, MWH (2008) estimated the combined flow from these streams at around 100 L/s (8,640 m^3/day) during stable summer baseflow conditions. In late 2006, a continuous flow recorder was installed on the Mawaihakona No.1 Stream at the Royal Wellington Golf Club. Although data from this site is of variable quality (due in part to excessive macrophyte growth), monitoring indicates river flow in the range of 70 to 1,000 L/s. Stream flow monitoring data are shown in Figure 4.7 together with stage in the Hutt River measured at Birchville. The strong correlation between river stage and spring flow illustrates the high degree of connectivity between the shallow aquifer and the river.

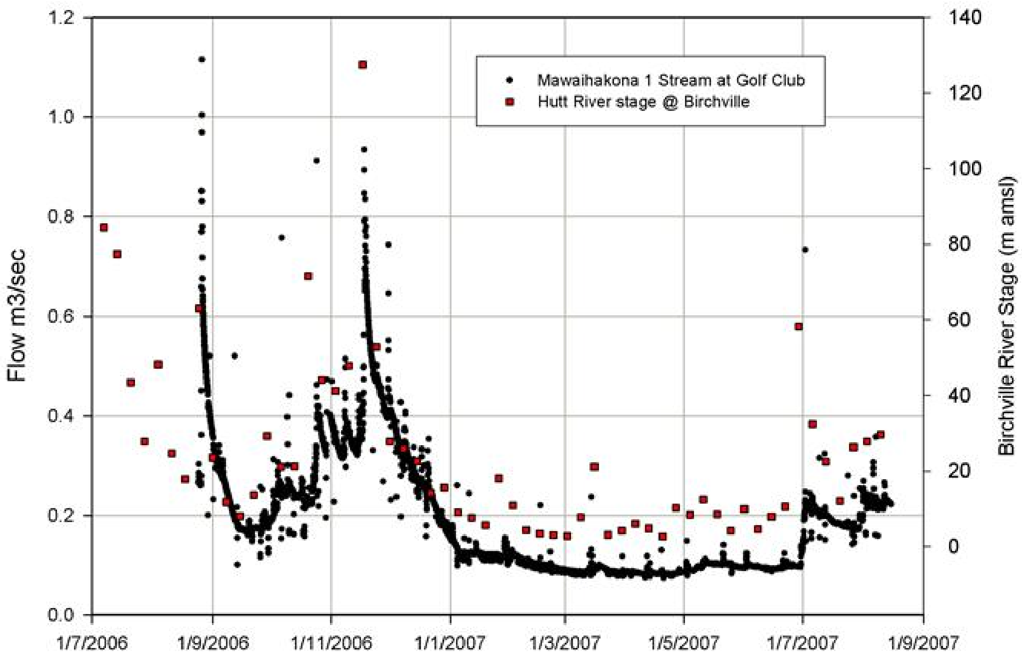

Figure 4.7: Mawaihakona Stream monitoring 2006/7 and concurrent Hutt River stage at Birchville (MWH, 2008)

Overall, the observed data indicate a high degree of hydraulic connection between shallow groundwater and surface water in the Upper Hutt groundwater zone. The Hutt River provides significant recharge flux to the unconfined alluvial gravel aquifer upstream of the Whakatikei River confluence and, in turn, drainage of groundwater across the southern section of the basin provides appreciable discharge to spring-fed streams and the Hutt River between Moonshine Bridge and Taita Gorge.

4.5 Temporal groundwater level patterns

Groundwater level monitoring data are available from a number of sites distributed across the Upper Hutt groundwater zone. However, with the exception of a 32 metre deep bore located at Trentham Memorial Park (R27/7004), the monitoring records are generally relatively short and/or intermittent. Figure 4.8 shows a plot of groundwater levels in the Upper Hutt groundwater zone recorded in a network of monitoring bores maintained by the HVUWA during the 1970s. Groundwater levels in a shallow bore adjacent to the Hutt River (R27/7005) and at Maidstone Intermediate (R27/7009) in the central area of the Upper Hutt Basin exhibit a rapid response to changes in stage height in the Hutt River. A similar, although much reduced response is observed in R27/7004 located at Trentham Memorial Park (possibly reflecting the semi-confined nature of the aquifer in this area as discussed in Section 4.3) while no response to variations in river flow is observed in a shallow bore at Trentham Racecourse (R27/7041), approximately 1.7 kilometres from the river.

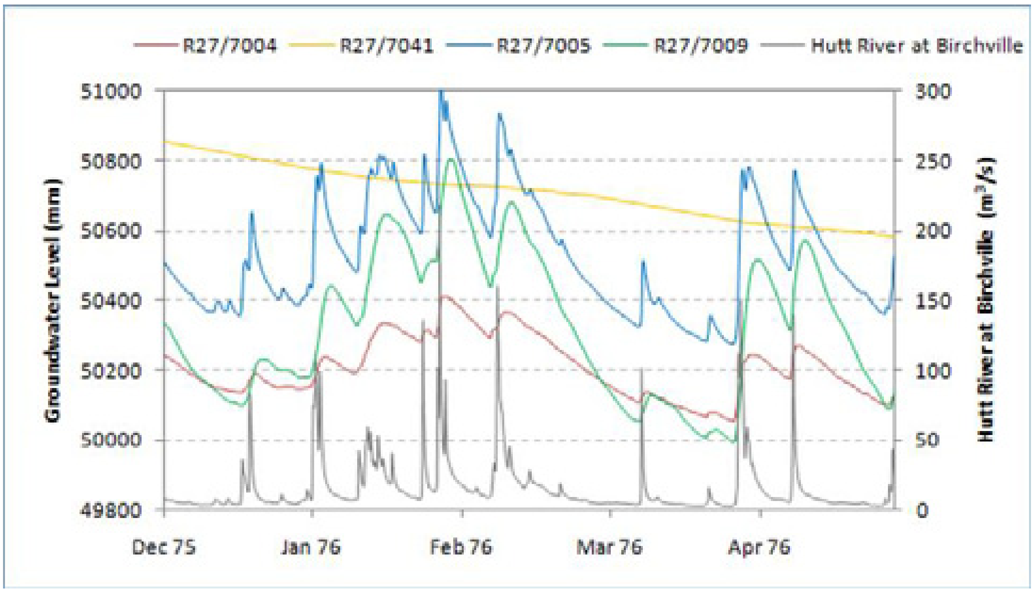

Figure 4.8: Groundwater levels in the Upper Hutt groundwater zone and flow in the Hutt River at Birchville, December 1975 to May 1976[5]

Figure 4.9 illustrates observed groundwater level variations in the Upper Hutt groundwater zone in response to a single high stage event in the Hutt River in December 1976. The data suggest the rapid propagation of a pressure wave, associated with increased river stage, through the aquifer system with the magnitude and delay in groundwater level response reflecting both the distance of individual bores from the river as well as local hydraulic properties of the aquifer system. Although the data show a rapid rise in groundwater level in response to increased river stage, the subsequent recession is appreciably slower than in the river (also evident over a longer timescale in Figure 4.8) suggesting recharge 'pulses' associated with high river flow events are stored in the unconfined aquifer system and slowly released back to the river via baseflow occurring across the downstream section of the aquifer system (i.e. bank storage).

[5] Note: The reduced levels from individual bores have been adjusted to allow presentation on a single axis

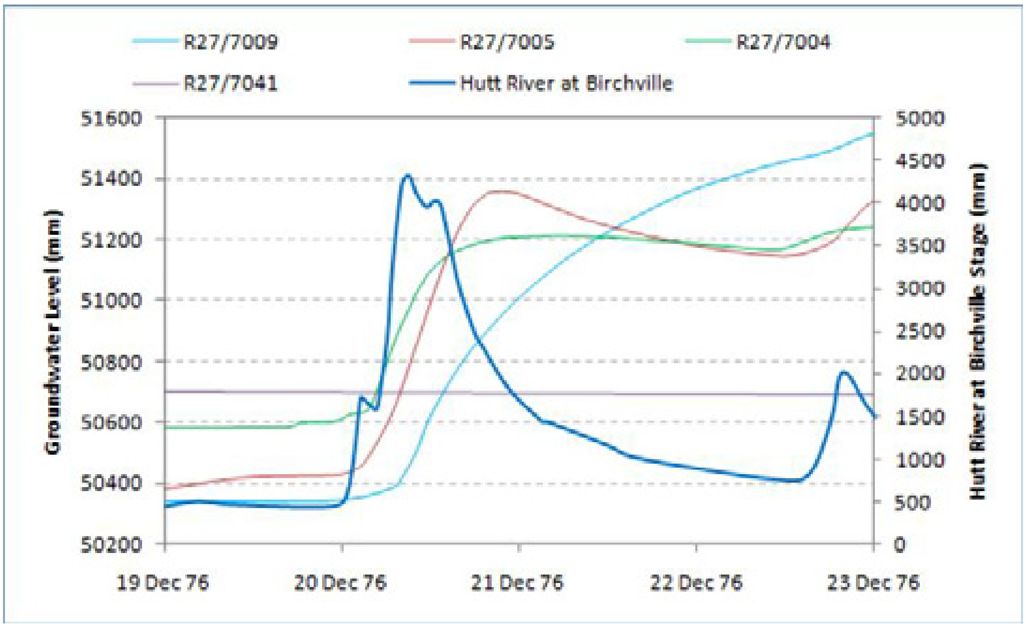

Figure 4.9: Groundwater level response in the Upper Hutt groundwater zone to a single high stage event in the Hutt River, December 1976

Although local rainfall recharge during high stage events[6] may contribute recharge to the aquifer system, both the timing of the observed groundwater level rise and the lack of groundwater level response observed in R27/7041 at Trentham Racecourse suggest that river recharge is the major factor controlling temporal variations in groundwater level across a majority of the Upper Hutt groundwater zone. The hydrograph from R27/7041 indicates groundwater levels toward the eastern side of the valley are influenced more strongly by seasonal variations in rainfall recharge rather than river losses. This spatial variation in temporal groundwater level response variations is attributed to the extensive reworking and chanelisation of the alluvial materials in central and western parts of the Upper Hutt Basin due to restriction of the active river channel to the western side of the valley.

4.6 Conceptual model of groundwater / surface water interaction

The Upper Hutt groundwater zone is characterised by tightly coupled groundwater and surface water environments. Temporal variations in aquifer storage (i.e. groundwater levels) show a rapid propagation of recharge flux associated with high stage events in the Hutt River through the highly permeable alluvial gravel materials comprising the upper 30-50 metres of the stratigraphic sequence. In turn, progressive drainage of groundwater storage contributes to base flow discharge across the southern section of the Upper Hutt groundwater zone which is equal to the flow loss across the upstream section plus the volume of land surface recharge occurring across the Upper Hutt basin. Groundwater level monitoring data shows that the shallow aquifer exhibits a strong connectivity to the river along the north-western side of the valley up to about a kilometre from the river. The eastern side of the valley does not exhibit a rapid response to river conditions and may be equally influenced by rainfall recharge.

[6] High stage events in the Hutt River are typically associated with widespread heavy rainfall across the contributing catchment, including the Upper Hutt basin.

Due to the geometry of the surrounding greywacke bedrock the Upper Hutt basin effectively forms a closed groundwater system with all outflow occurring via the reach of the Hutt River upstream of Taita Gorge. As a consequence, groundwater abstraction from the unconfined alluvial gravel aquifer (c. <30-40 m) has the potential to affect surface water either by inducing additional flow loss from the upstream section of the Hutt River (Birchville to the Whakatikei River confluence) or contributing to reduced baseflow discharge (spring-fed stream discharge or diffuse leakage to the Hutt River) over the downstream section between Moonshine Bridge and Taita Gorge.

4.7 Numerical modelling of the Upper Hutt groundwater basin

4.7.1 Summary model description and calibration

A numerical model for the Upper Hutt groundwater basin was developed in 2008 to assist in the assessment of the sustainable groundwater resource and the feasibility for developing a public water supply wellfield in the Wallaceville area. The MODFLOW-based model incorporated the results of an extensive monitoring, drilling and pump testing programme carried out by GWRC in addition to a re-evaluation of existing data. The model has been employed in this study to assist in the groundwater allocation assessment described in Section 4.8. A brief summary of the model is provided here – for a full description of the model and the calibration process, the reader is referred to MWH (2008).

The 2008 Upper Hutt groundwater model simulates only the upper unconfined groundwater system as a single layer with a thickness range of 10-35m as shown in Figure 4.10 (this differs from previous modelling and interpretations which represented the groundwater system as an upper 50m thick layer and a lower - largely inactive - layer extending to basement). Underlying alluvial sediments are not represented as there appears to be very little interaction between deeper, less permeable aquifers with poor water quality and the shallow, dynamic unconfined system. The thickest part of the aquifer occurs beneath the central part of the valley floor between Trentham Memorial Park and Upper Hutt City (including the Wallaceville area). The unconfined aquifer thins considerably towards Taita Gorge as basement rises towards the surface.

Rainfall recharge is a major component of the water balance for the unconfined aquifer systems in the study area and quantification was undertaken using a recharge model based upon a soil moisture balance method described by Rushton et al (2006). The model estimates recharge from a daily soil moisture balance using daily rainfall, evapotranspiration and soil properties. The Rushton model was adapted for this study to take into account runoff using the USDA Soil Conservation Service (SCS) runoff curve number model. This method was also used to account for the high run-off characteristics in urban areas.

Table 4.1 provides a summary of the recharge model output showing that the soil moisture balance model calculates an annual recharge of about 37% of rainfall in the urban areas, and about 44% in the non-urban areas. Recharge peaks at about 70% of rainfall during the winter months when soil moisture deficits are low and losses to evapo-transpiration are minimal. This is consistent with other recharge studies around New Zealand. Figure 4.11 shows the modelled annual rainfall recharge for the Upper Hutt groundwater zone for the period 1991 to 2006 (the 2008 model was calibrated up to 2006). The annual average rainfall recharge for this period is $12x10^6m^3$.

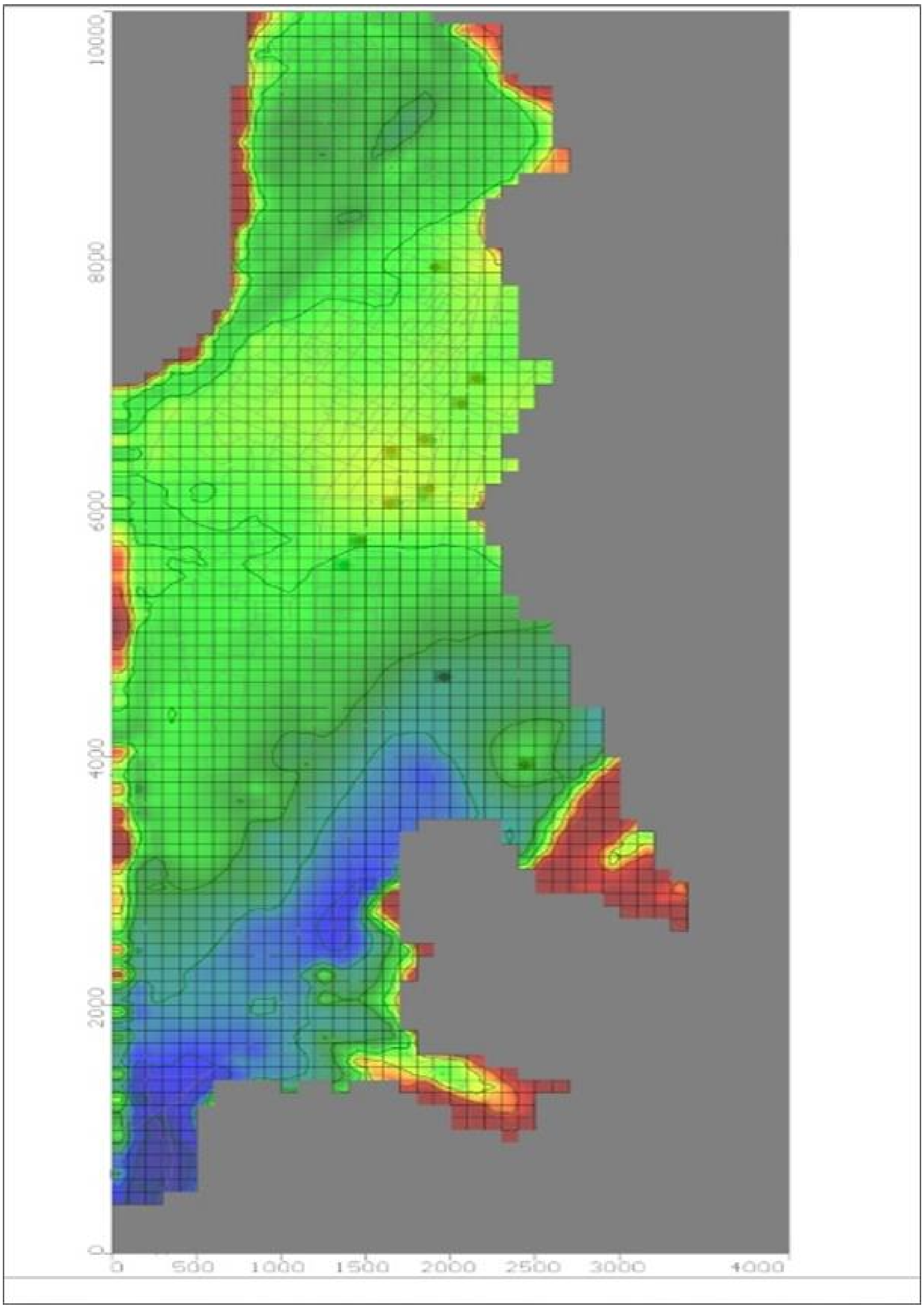

Figure 4.10: Upper Hutt groundwater zone modelled aquifer thickness (shallow unconfined system) – deepest part of the aquifer is shaded yellow beneath the Upper Hutt city/Wallaceville area (35m); blue shows thinner, shallower areas (10-15m)

Table 4.1: Mean monthly and annual rainfall recharge to the Upper Hutt groundwater zone derived from soil moisture balance modelling

	Urban recharge (mm)	Non-urban recharge (mm)	Mean rainfall (mm)	Urban %rainfall	Non-urban %rainfall
Jan	4.5	8.3	92.0	4.9	9.0
Feb	11.5	22.0	64.0	18.0	34.4
Mar	1.4	2.9	98.0	1.4	3.0
Apr	10.3	14.2	98.0	10.5	14.5
May	48.0	55.8	138.0	34.8	40.4
Jun	96.0	106.6	142.0	67.6	75.1
Jul	99.2	107.0	140.0	70.8	76.4
Aug	80.4	88.0	132.0	60.9	66.7
Sept	50.5	54.8	111.0	45.5	49.4
Oct	60.8	83.3	117.0	52.0	71.2
Nov	25.4	35.0	104.0	24.5	33.7
Dec	10.0	14.7	119.0	8.4	12.4
Annual tot	498.1	592.6	1355.0	36.8%	43.7%

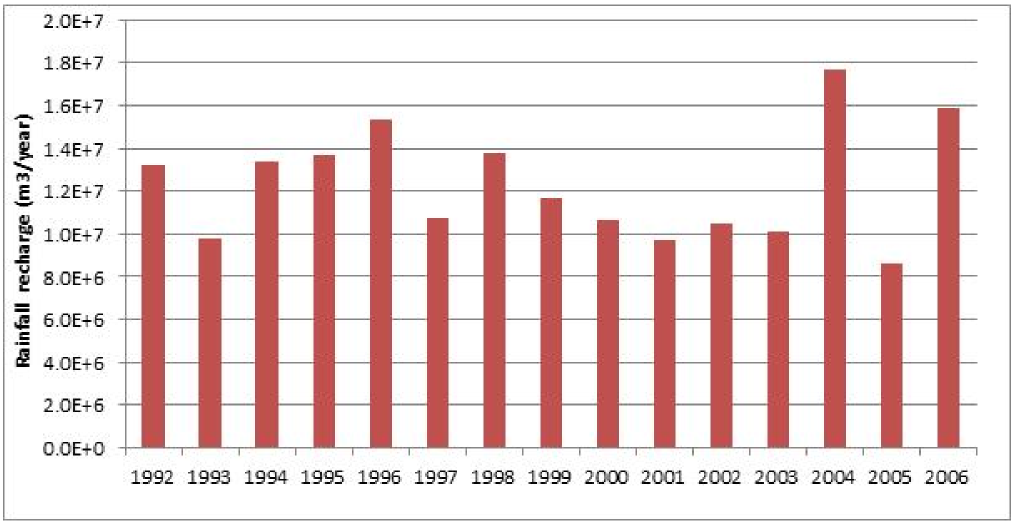

Figure 4.11: Modelled rainfall recharge (1992-2006) for the Upper Hutt groundwater zone (mean recharge is $12x10^6$ m^3/year).

Transient model calibration was performed using both groundwater level and water balance data - in particular, concurrent gauging data for the Hutt River and spring flow gaugings were used to ensure that the model accurately represented groundwater – surface water connectivity. The transient simulation was carried out for the 15 year period of 1/1/1992 to 1/7/2006.

Table 4.2 shows the simulated seasonal water balances derived from the calibrated model for two time instances – the dry summer of 2001 (one in 5 year return period), and the winter of 2006.

Table 4.2: Transient Water Balances, Upper Hutt Aquifer

Flow Component	**IN** m³/day	**OUT** m³/day	**IN** m³/day	**OUT** m³/day
	Winter July 2006		**Summer March 2001**	
Hutt River:				
Maoribank – Whakatikei Conf	20,600	-	37,400	-
Whakatikei Conf – Taita Gorge	-	57,500	-	37,500
Springs (Spring-fed streams)	-	12,200	-	7,300
Rainfall recharge	63,700	-	6,200	-
Wells (existing consents)	-	4,400	-	4,400
Storage change	-	10,500	5,600	-
Totals	**84,300**	**84,400**	**49,200**	**49,200**

Table 4.2 shows that during the winter, rainfall recharge is the dominant recharge process, and consequently, groundwater 'drainage' into the Hutt River below the Whakatikei Confluence by far exceeds the losses from the river to groundwater in the higher reaches. The 2001 summer water balance shows that river leakage (recharge) input component to the aquifer system increases since the head gradient between the river and the water table is greater. Recharge from the river, and discharge from the aquifer back to the river are about equal. Rainfall recharge during the summer is negligible.

The modelling results show that the groundwater and surface water systems interact in complex ways and should effectively be considered a single system and managed as such. It is also evident from the modelling that fluxes between the river and aquifer are highly sensitive to the relative groundwater and river levels. Therefore, groundwater abstractions in some areas are expected to result in significant effects on connected surface water environments. Using the model, identification of sensitive areas of the aquifer within which groundwater abstractions have a significant effect on the river, is provided in the following section to assist in the management of the Upper Hutt groundwater system.

4.7.2 Characterisation of surface water depletion effects of groundwater abstraction using the groundwater model

Hydrogeological information and the numerical model have shown that surface water systems interact strongly with the shallow aquifer and therefore consideration of the effects of groundwater abstraction on them is a primary consideration in the sustainable allocation of the groundwater resource. The numerical groundwater flow model been used to characterise and quantify the relationship between groundwater abstraction and surface water depletion.

The numerical model was initially used to quantify the water balance for the groundwater zone in the absence of groundwater abstraction using a baseline scenario in which all abstraction bores were turned off. Various abstraction scenarios could then be compared to the baseline run to quantify the effects of groundwater pumping on the Hutt River and spring-fed springs.

Figure 4.12 shows the simulated flow from the Hutt River into the shallow aquifer between Maoribank and the Whakatikei confluence, the discharge from the aquifer to the Hutt River downstream of the Whakatikei confluence to Taita Gorge, and discharge to the spring-fed streams. The discharge of groundwater to the Hutt River below the Whakatikei confluence and to spring fed streams exceeds the loss from the river to the aquifer (Maoribank to Whakatikei confluence) because rainfall recharge also provides an input to the aquifer (mean daily recharge is 33,000m^3).

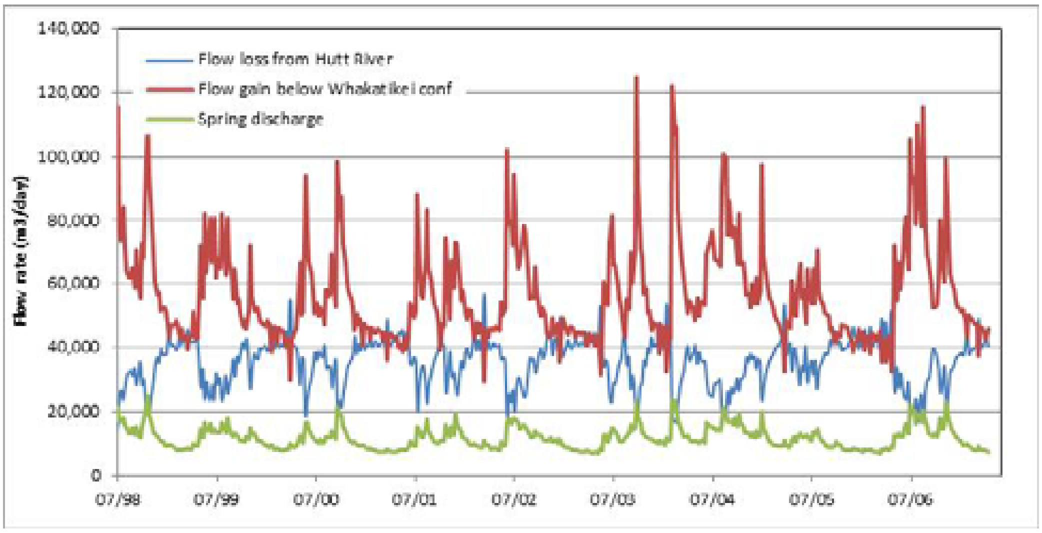

Figure 4.12: Simulated fluxes from and to the Hutt River and spring discharge for a representative period between 1998 and 2006 in the Upper Hutt groundwater zone

Abstraction scenarios

Figure 4.13 shows the results of an abstraction scenario equivalent to the full existing RPF 'safe yield' for the upper aquifer of 48,000m^3/day. The depletion effect on the Hutt River is equivalent to about 90% of the abstraction rate which is reached relatively quickly after about 100 days of pumping. This scenario was set up using a number of low yielding abstraction bores distributed across the Upper Hutt valley. The depletion of about 43,000m^3/day (90% of the take) is about 15% of the 7-Day MALF for the Hutt River at Birchville (3,430 L/sec - 50% of which is currently allocated) and 13% of the MALF at Melling downstream (3,776 L/sec). A groundwater allocation of 48,000m^3/day (17.7x10^{6}m^3/year) is clearly not sustainable for this zone. Note that the average annual rainfall is only 12x10^{6}m^3/year, significantly less than the current allocation limit for the upper/shallow aquifer.

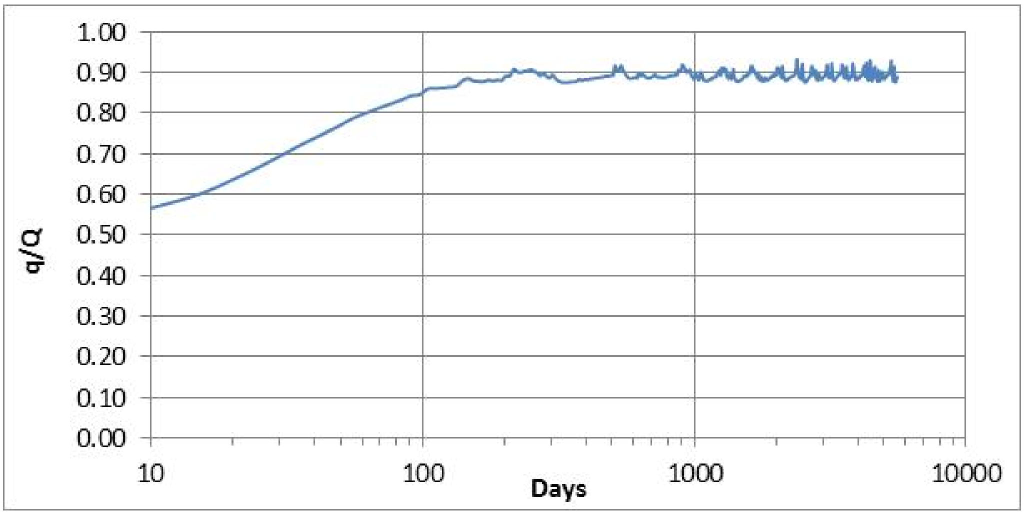

Figure 4.13: Surface water depletion in the Upper Hutt groundwater zones as a result of abstracting the old RPF 'safe yield' quantity of 48,000m^3/day. Vertical axis is surface water depletion rate (q) divided by total pumping rate (Q).

An additional set of abstraction scenarios was used to investigate the degree of hydraulic connectivity between the shallow aquifer and the Hutt River, and to define the limit of Category A abstractions (refer to Section 2.2). Category A abstractions are defined by a rapid and large stream/river depletion effect at more than 60% of the pumping rate. They are also characterised by a rapid dissipation of depletion effects once pumping stops rendering them amenable to low (river) flow regulation of pumping rate. As a consequence, a high proportion of the overall volume of groundwater pumped from Category A areas effectively represents immediately induced flow loss from local surface waterways. Due to the immediacy of the effect, 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 water bodies.

Pumping scenarios used to demonstrate the degree of river flow depletion were based upon a single well screened in the upper aquifer pumping at a rate of 2,500m^3/day (30 L/sec) for 100 days. The well was moved from an initial distance of 200m from the river to a maximum of 1,500m. In effect this exercise attempts to define the distance at which abstraction transition from Category A to Category B in terms of hydraulic connectivity to the river. Figure 4.14 shows the results of the scenarios in terms of the depletion ratio (q/Q). In close proximity to the river (200m), the depletion effect immediatly rises to more than 60% of the pumping rate, and attains nearly 100% at the end of the 100 day pumping period. At a distance of 800m the effects is more buffered but a depletion effect of 60% of the pumping rate occurs relatively quickly after about 10 days, and rises to about 90% after 100 days of pumping. At both 200m and 800m a reduction in depletion rate occurs quickly when pumping stops indicating that groundwater takes within this distance can be effectively regulated at low river flows to reduce depletion effects. At greater distances on the eastern side of the valley (1,500m), the depletion effects rise more slowly and decays more slowly, with 60% depletion occurring after about 45 days at Trentham Race Course. This is consistent with groundwater level monitoring data at Trentham Racecourse which shows that short term fluctuations in river stage do not impact groundwater levels at this distance (Figure 4.8; R27/7041). By the end of 100 days pumping, the depletion effect reaches about 80-90% of the pumping rate. When the well is turned off, the reduction in depletion is not immediate, but tails off slowly and may take more than 20 days to drop to a depletion effect of less than 60%. The aquifer near Wallaceville seems to have a greater connection to the river, and it could be argued that the depletion response in Figure 4.14 is not too dissimilar to the 800m scenario.

In summary, the modelling indicates that within about 1km of the river, groundwater abstractions have a significant and rapid depletion effect on the river and spring-fed streams. This distance approximates the edge of a river terrace lying very close to the main road (Fergusson Drive and Main Street) through the valley.

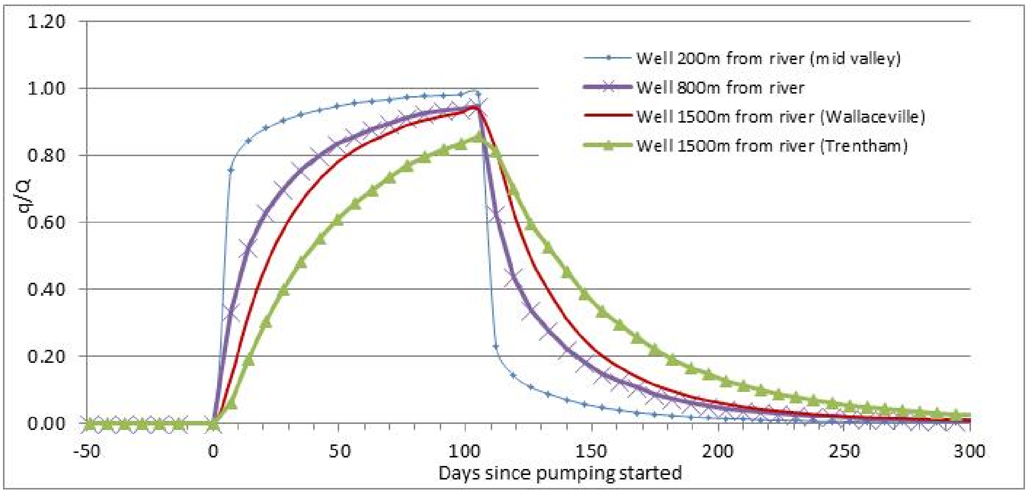

Figure 4.14: Results of pumping scenarios for a single well pumping at 30L/sec at different distances from the Hutt River

4.8 Recommendations for groundwater allocation from the Upper Hutt groundwater zone

4.8.1 Zone summary

Zone delineation: Figure 4.1 shows the boundaries of the Upper Hutt groundwater zone which covers an area of approximately 28.2km^2. The zone boundary remains unchanged from the GWRC 1999 Regional Freshwater Plan (RPF).

Principal aquifers: The principal aquifer in the Upper Hutt groundwater zone comprises shallow heterogeneous alluvial deposits to a depth of 30-50m. These deposits constitute an unconfined – semi-confined aquifer which exhibits a significant connectivity to the Hutt River, particularly within about 1km of the river. Deeper aquifer are known to occur (>c. 50m) but these have been proven to have a low yield and poor water quality. Therefore, all current abstraction and potential future abstraction is likely to occur in the upper 50m or so of the groundwater zone.

Existing RFP allocation: Upper aquifer (0-50m) – 17.7 x 10^6 m^3/year; lower aquifer (65-90m) – 9.2 x 10^6 m^3/year.

Current allocation: As of 2014, there are only five consented groundwater users in the Upper Hutt groundwater zone, four of which are used for golf course, the race course and park irrigation. The total consented volume is 348,500 m^3/year with a maximum total daily abstraction rate of 2,150 m^3. This equate to 2% of the existing RFP 'safe yield' for the upper aquifer.

4.8.2 Zone management objective

The principal management objective for groundwater allocation in the Upper Hutt groundwater zone is to ensure the sustainable use of water resources through protecting the instream values of hydraulically connected surface water ecosystems. The Hutt River is the primary freshwater ecosystem in the zone, but the instream values of small spring fed streams (Mawaihakona Stream and Hulls Creek) should also be considered.

4.8.3 Allocation categories (Figure 4.15)

Groundwater in the Upper Hutt groundwater zone should be managed as a single aquifer – the utilisable resource being less than 50m depth. The aquifer shows a strong connectivity to the Hutt River and spring-fed streams.

- The area to the west of Fergusson Drive/Main Street should be assigned Category A to a depth of 50m.

- The area to the east of Fergusson Drive/Main Street should be assigned Category B to a depth of 50m. This recognises the delayed depletion and depletion recovery characteristics at greater distance from the river. Under this classification, applications for large-scale abstraction (i.e. meeting the criteria for a weekly average abstraction rate >5 L/s) would have to be supported by aquifer test data and assessment of local hydrogeological conditions sufficient to characterise potential effects on the hydraulically connected surface water (the Hutt River and spring-fed streams).

- Category C underlies the entire catchment to a depth of greater than 50m. Category C also occurs at the surface in the Maoribank/Timberlea area where older less-permeable geological formations outcrop. Because limited information is available to characterise the hydraulic properties of waterbearing gravel layers deeper than 50 metres below ground, applications for abstraction from deeper than 50m would require sufficient aquifer test information and hydrogeological analysis to adequately characterise potential effects on hydraulically connected surface water.

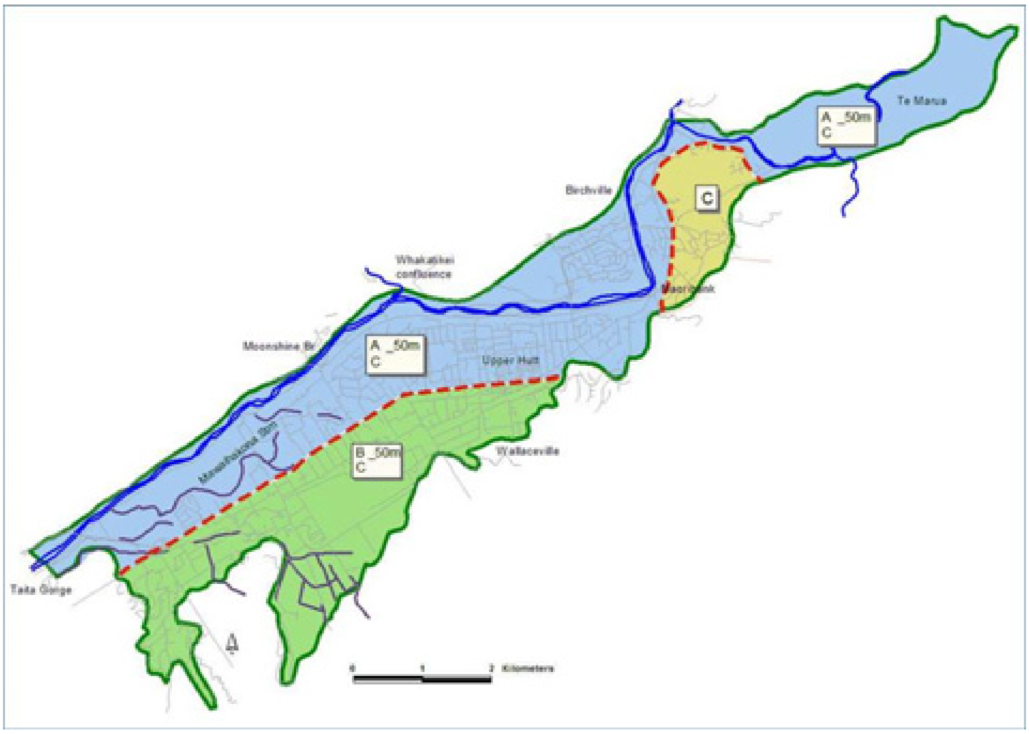

Figure 4.15: Delineation of Upper Hutt groundwater zones showing groundwater allocation categories

4.9 Summary – Allocation recommendations for the Upper Hutt Groundwater Management Zone

4.9.1 Allocation Category A

There is no groundwater allocation associated with Category A; allocation for this category is derived from the surface water allocation.

4.9.2 Groundwater allocation (Category C and B)

- Aquifers in the Upper Hutt groundwater zone should be managed as a single aquifer.
- The groundwater allocation in this zone should be referenced to the 7-day MALF of the Hutt River at Taita Gorge which is 4,505 L/sec (390,000m^3/day) – see Appendix 1. This flow incorporates groundwater baseflow to surface water for the groundwater zone.
- A depletion factor of 0.5 should be adopted for Category B abstractions (see Figure 4.14 – assuming 30 days continuous abstraction).
- Annual allocation should be based on a pumping duration of 180 days (to reflect the fact that seasonal rainfall recharge is a significant part of the aquifer water balance).
- Table 4.3 presents allocation options based upon a proportion of the 7-day MALF in the Hutt River at Taita Gorge.

Table 4.3: Groundwater allocation options for the Upper Hutt groundwater zone

Option	Cumulative depletion effect on the 7 day MALF in the Hutt River at Taita Gorge (including spring-fed streams)	Allocation m^3/day	Allocation m^3/year x 10^6
1	1% MALF	4,300	0.77
2	2% MALF	8,700	1.56
3	3% MALF	13,000	2.34

Option 1 is recommended as this represents an acceptable additional depletion of the Hutt River MALF. Adoption of this option would mean that the groundwater zone is currently about 10% allocated on an annual basis since most of the consented abstraction will be transferred to river core allocation.

5. Lower Hutt Groundwater Management Zone

The Lower Hutt - Port Nicholson sedimentary basin constitutes the Lower Hutt groundwater zone which extends southwards from Taita Gorge to the entrance of Wellington Harbour (Figure 5.1). Therefore, a large portion of this groundwater zone lies beneath the habour floor. Alluvial gravel sediments infilling the basin constitute a significant groundwater resource which is utilised to supply up to 40-50% of the municipal water demand for the Geater Wellington metropolitan area. There is no hydrogeological connection with the Upper Hutt groundwater basin since the two basins are separated by greywacke basement which is exposed in the river bed at Taita Gorge.

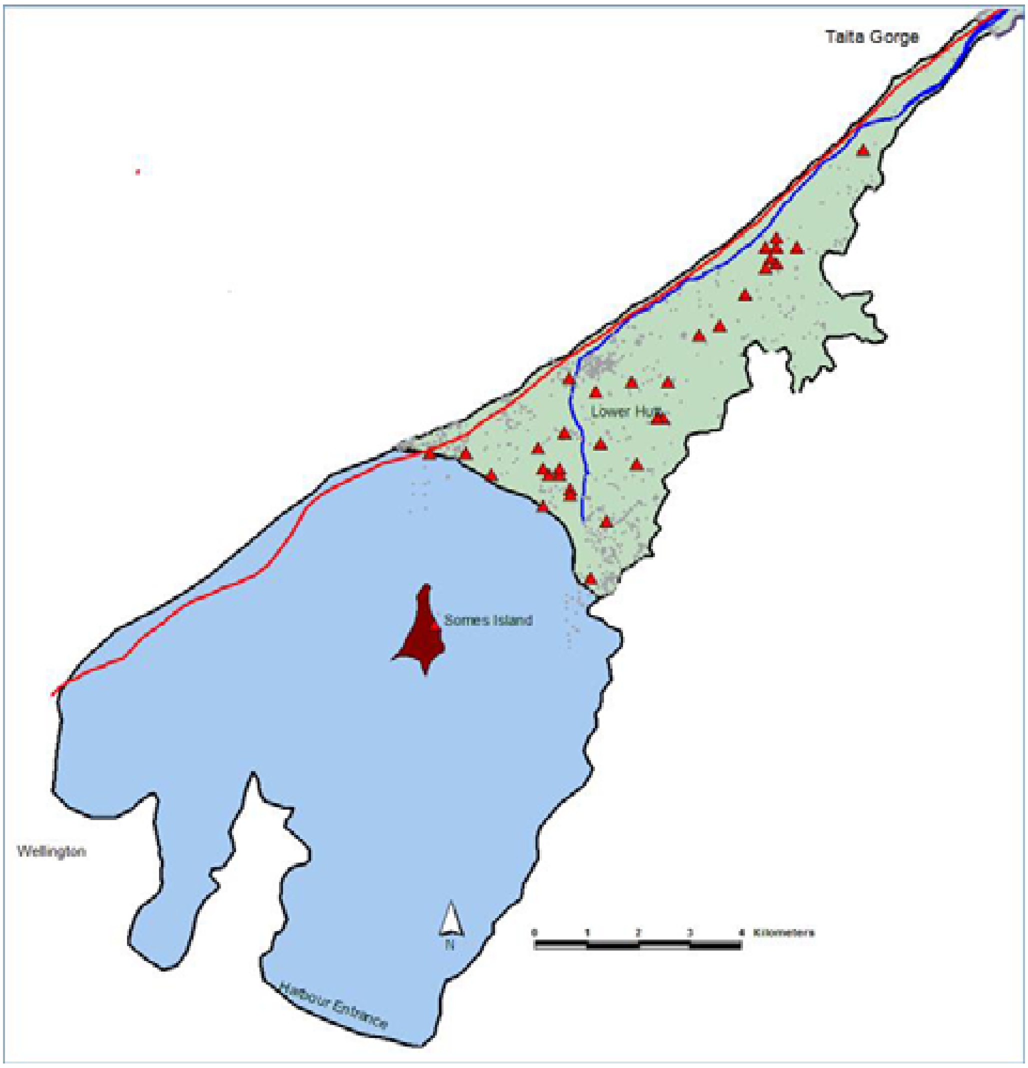

Figure 5.1: Lower Hutt groundwater zone showing onshore (green) and offshore (blue) sections. GWRC groundwater monitoring sites show (red triangles) and locations of historic bores (small grey circles).

5.1 Hydrogeology

5.1.1 Previous work

The Lower Hutt groundwater system has a history of geological and hydrogeological investigation extending over more than half a century and it is arguably one of the most studied groundwater systems in New Zealand. Principal geological and hydrogeological references are:

- Stevens (1956a,b) –the first interpretation of the geological history of the Hutt Valley and the artesian aquifer system.
- Donaldson and Campbell (1977) produced a seminal hydrogeological study entitled *Groundwaters of the Hutt Valley – Port Nicholson Alluvial Basin* which represented the most complete compilation and analysis of information at the time. It also presented a conceptual hydrogeological model which, with adaptations, remains valid.
- The 1:50 000 Geological map of the Wellington Area including memoir (Begg and Mazengarb, 1996).
- GNS (2010) in: It's our Fault – Geological and Geotechnical Characterisation and Site Class Revision of the Lower Hutt Valley (Boon et al., 2010). Incorporates recent geological modelling of the Hutt Valley upon which the new HAM3 numerical aquifer model is based.
- Wellington Regional Council (1995) – Hydrology of the Hutt Catchment, vol 2: Groundwater.
- Earth in Mind Limited (2014) – Lower Hutt Aquifer Model (HAM3) for GWRC. Includes a comprehensive review of previous work and available data, description of new investigations and numerical modelling of the groundwater zone, and sustainable resource management recommendations.

A summary of the hydrogeology of the Lower Hutt groundwater zone is presented here. The reader is referred to the above resources for more comprehensive information.

5.2 Numerical simulation: HAM3

A third generation Hutt Aquifer Model – HAM3 – was completed in 2014 (Earth in Mind, 2014) which incorporates the entire Lower Hutt groundwater zone. The purpose of developing the HAM3 was to facilitate the sustainable management of the Lower Hutt groundwater system. In particular, the mode was used to evaluate the risks associated with saline intrusion, to evaluate the sustainable yield from the Waiwhetu Aquifer and to assess the potential impacts of sea level rise. For these purposes a 'high confidence level' aquifer simulator is was developed in the form of the HAM3. A complete description of the model is provided in Earth in Mind (2014). The HAM3 forms the basis of recommended improvements to the sustainable management of the Waiwhetu Artesian aquifer (the principal aquifer in the Lower Hutt groundwater zone).

5.2.1 Basin morphology and hydrostratigraphy

The Hutt Valley – Wellington Harbour alluvial basin is the southernmost and largest of a series of basement depressions associated with the Wellington Fault system. The total length of the basin, from Taita Gorge to the harbour entrance, is approximately 23km. It is a broadly wedge-shaped structure tapering from its widest extent of around 9.5km in the harbour, to about 5km in width at the Petone foreshore, it then progressively narrows to only a few hundred metres at Taita Gorge.

The western and deepest side of the basin is controlled by Wellington Fault where subsidence has created a sub-vertical basin margin more than 300m deep in the foreshore area. It is probable that the Wellington Fault has disrupted and displaced the basin fill sediments adjacent to the fault. The Somes Island ridge is a notable basement high which is a fault-bounded horst structure that traverses the basin obliquely and displaces younger sediments (Begg et al., 2008).

The basin bedrock is indurated greywacke – a hard metamorphosed sandstone, siltstone and mudstone of Permian to Jurassic age (280-200 million years old). Although the greywacke is extensively fractured, it exhibits low permeability and does not significantly contribute to regional groundwater circulation (WRC, 1995).

The Hutt River has deposited sediment into the basin over at least the last 500,000 years - from about the middle and later Quaternary period. The sedimentary sequence is associated with the progradation of a delta into a subsiding basin centred on the harbour. Marine sediments were also deposited further up the valley during periods of higher sea level (interglacial periods) and as a result of tectonic subsidence. A c.350m thick wedge-shaped package of alluvial-deltaic-marginal marine sediments at the Petone coastline becomes thicker offshore where it exceeds 600m between Somes Island and the Wellington Fault.

The onshore basin fill succession was first characterised by Stevens (1956) using the large quantity of subsurface information available at that time. He called the fill sequence the 'Hutt Formation' which is comprised of six members:

- Taita Alluvium (Q1[7]) [*Aquifer-aquitard*]
- Melling Peat (Q1) [*Aquitard*]
- Petone Marine Beds (Q1) [*Aquitard*]
- Waiwhetu Artesian Gravels (Q2-4, last glacial) [*Main aquifer*]
- Wilford Shell Beds (Q5, last interglacial) [*Aquitard*]

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[7] 'Q' numbers refer to oxygen isotope age stages (Imbrie et al., 1984). ^{18}O (an oxygen isotope) is assumed to vary with climate and sea level - even values represent increasingly older cold periods (e.g. Q2, Q4, Q6), and odd numbers (eg Q1, Q5) represent warm periods of maximum sea level.

- Moera Basal Gravels (Q6-7, penultimate glacial) [*Aquifer*]

An older, undefined sequence of basal gravels (Q8-Q10?) is present in the deeper parts of the basin, and is associated with earlier glacial and interglacial cycles.

Figure 5.2 shows a three-dimensional representation of the sediments of the Lower Hutt basin from the Petone foreshore to Knights Road based on drillhole information (from Begg and Mazengarb, 1996).

Holocene sediments (Q1) - Taita Alluvium, Petone Marine Beds and Melling Peat

Taita Alluvium, Melling Peat and Petone Marine Beds are of postglacial Holocene age (<10,000 years old) and are semi-contemporaneous (they exhibit a degree of lateral equivalence in response to changing depositional environments). The Petone Marine Beds and Taita Alluvium continue to be concurrently deposited at the present time on the harbour floor and on the Hutt River floodplain respectively.

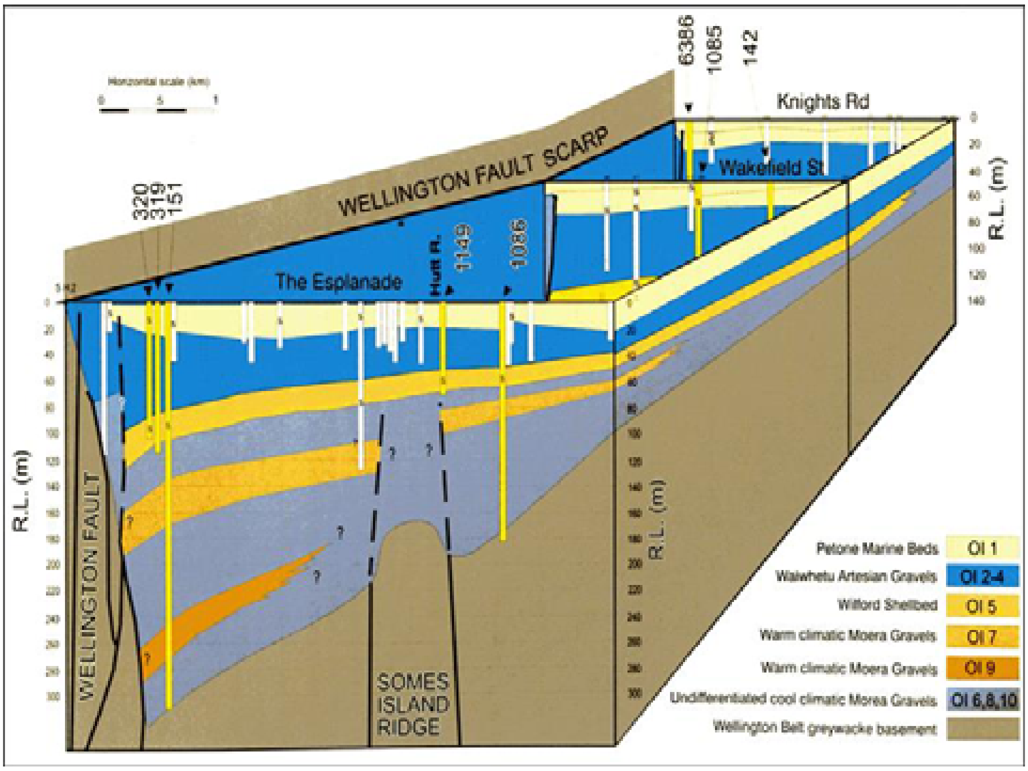

Figure 5.2: Three-dimensional representation of the sediments of the Lower Hutt basin from the Petone foreshore to Knights Road based on drillhole information (Begg and Mazengarb, 1996)

The Taita Alluvium consists mainly of buried river channel and fan gravel deposits but also includes sand, silt and clay deposited by the river as flood and over-bank deposits. Donaldson and Campbell (1977) interpreted an average thickness of 12m for this unit which dips gently to the southwest. The Taita Alluvium grades laterally into Melling Peat which represents a fossil forest. South of Melling Bridge, around Lower Hutt City, the peats grade laterally into the Petone Marine Beds which are dominated by clays, shelly silts and sandy silts. The marine beds are about 30m thick at the Petone foreshore and extend into the harbour where they continue to accumulate. The thickness of these deposits also thickens toward the western side of the basin reflecting greater subsidence along the Wellington Fault. Due to their fine-grained texture the Petone Marine Beds and Melling Peat exhibit low permeability and form a confining layer over the underlying Waiwhetu Artesian gravels.

Last Glacial Deposits – Waiwhetu Gravels (Q2-4)

Extensive cold-climate alluvial deposits known as the Waiwhetu Gravels underlie the Holocene sediments at a depth of around 20-30m below ground surface in the foreshore area. These gravels form the principal aquifer in the Lower Hutt valley and are confined by the younger Petone Marine Beds and Melling Peat. The confining beds pinch out between Ewen Bridge and Kennedy Good Bridge in the Mitchell Park area – further to the north the aquifer becomes unconfined.

The Waiwhetu Gravels extend from Taita Gorge to the Petone foreshore and under much of the harbour. Onshore, the formation attains a maximum thickness of about 55m on the western side of the Hutt Valley but elsewhere it is typically between 30m and 50m thick. Beneath the harbour the gravels are thicker in the north and west, and shallower in the south and east as a result of concentrated deposition in the deeper part of the basin along the Wellington Fault. Offshore geophysical interpretations (Davy and Wood, 1993) suggest that the gravels are around 20m thick on the eastern side of the harbour, thickening to as much as 70m alongside the fault in the west of the harbour. The gravels do not appear to outcrop on the floor of the harbour.

The water-bearing capacity of the Waiwhetu Gravels seems to decrease with depth and generally only the upper c.20-25m of the layer has a high flow capability. There is some evidence that the Waiwhetu Gravels comprise distinct upper and lower members, with an intervening thin aquitard.

Wilford Shell Bed (Q5)

The Wilford Shell Bed is a 15-30m thick marine, shelly, silty sand beneath the Waiwhetu Gravels. It is recorded at depths of 70 to 83m at the Petone foreshore, decreasing in depth and thickness inland – presumably onlapping the northern and eastern basin margins where it pinches out against older sediments. The inland extension of the unit appears to be around Knights Road about 4.5 km inland from the Petone foreshore A distinctive change in the hydraulic properties, hydraulic head and water chemistry recorded in bores screened above and below this unit is apparent. This suggests that the Wilford Shell Bed is continuous and acts as a low-permeability aquitard separating the Lower Waiwhetu Gravels from the underlying Moera Gravels.

Older sediments (>Q6) - Moera Gravels

Stevens (1956) termed the non-marine weathered gravels beneath the Wilford Shell Bed the 'Moera Basal Gravels'. Begg and Mazengarb (1996) identified this unit as being associated with the Waimea Glacial age (Q6, 130,000 - 180,000 years BP) and preceding interglacial period (Q7), and occurring between about 100 and 160m depth at the Petone foreshore. The term 'Moera Basal Gravels' is used here to refer to only these two units. Below this, Boon et al. (2010) postulate an older sequence of glacial and interglacial deposits (Q8-Q10) lying on top of the greywacke basement surface. Two groundwater units are identified within the basal gravels on the basis of hydrogeological and hydrochemical properties - an upper unit of between 16 and 60m thick and a deeper unit containing brackish or saline water.

5.2.2 Aquifer conditions and groundwater flow pattern

In the area to the north of Kennedy Good Bridge the Taita Alluvium and underlying older materials merge to form a single (though heterogeneous) unconfined aquifer zone which is recharged by flow loss from the Hutt River and local rainfall. South of this point, the Petone Marine Beds and Wilford Shell Beds separate the two main confined aquifer; the Waiwhetu Aquifer and the underlying Moera Aquifer. These become progressively deeper and more confined down the valley and become artesian (groundwater pressures are higher than the land surface) approximately 2 to 3 kilometres inland from the Petone foreshore.

Groundwater flows southward through the aquifer system from the Taita Alluvium recharge area following the natural topographic gradient. Near the inland margin of the aquitard layers, groundwater flows down-valley through the confined Waiwhetu or Moera Aquifers with the excess throughflow discharged back to the Hutt River to the south of the confined aquifer margin (i.e. downstream of Boulcott). On the eastern side of the Lower Hutt valley, discharge occurs along the inland margin of the upper confining layer (i.e. Petone Marine Beds) to the Waiwhetu Stream. Groundwater flowing through the Waiwhetu and Moera aquifers is discharged offshore via diffuse leakage through the confining layer materials which in places is sufficiently concentrated to form submarine springs on the harbour floor. The Waiwhetu Gravels remain under artesian pressure beneath the harbour (as evidenced by the Somes Island monitoring bore and submarine springs) indicating that the aquifer is not in direct hydraulic connection with the ocean.

Regional groundwater flow in the Lower Hutt Groundwater Zone occurs down-valley from the unconfined aquifer to the foreshore and continues offshore beneath Wellington Harbour. Figure 5.3 shows the piezometric contours for the Upper Waiwhetu Aquifer based upon monitoring data and the HAM3 simulation for summer conditions (January 2012). The drawdown associated with the Waterloo Wellfield is evident and the abrupt flattening of the hydraulic gradient downstream of the wellfield is evident.

Figure 5.3: Water table contours for the Upper Waiwhetu Aquifer simulated by HAM3 for January 2012 and based on available monitoring data. Contours in metres above mean sea level (note the contour intervals below 4.0m reduce from 1m to 0.1m). From Earth in Mind (2014).

5.3 Aquifer hydraulic properties

Available data indicate the alluvial materials comprising the Taita Alluvium and (Upper) Waiwhetu Aquifer are highly permeable.

Aquifer testing undertaken in the Taita Alluvium near Avalon Studios yielded a range of transmissivity values from 2,700 to 52,700 m^2/day, with an average value of 4,500 m^2/day. The significant variation in estimated aquifer permeability reflecting the heterogenous nature of the gravel deposits (WRC, 1995).

Several large-scale pumping tests were undertaken on the GWRC Gear Island and Waterloo municipal supply wellfields during the 1990's at rates of up to 600 L/s (50 MLD). Analysis of these tests show that the Waiwhetu Gravels exhibit a wide range of hydraulic properties. The mean aquifer transmissivity for the Upper Waiwhetu Aquifer is estimated to be approximately 28,000 m^2/day, locally increasing to between 35,000 and 40,000 around the Waterloo Wellfield. Assuming an average thickness of 20m for the gravels, this equates to a hydraulic conductivity of approximately 1,400 m/day. The pumping tests indicate a range for the confined aquifer storage coefficient of between $3x10^{-4}$ and $1x10^{-3}$ (Earth in Mind, 2014).

Hughes (1998) reported the results of a free-flow test undertaken on a bore screened in the Moera Aquifer at Hutt Park which indicated a transmissivity value of approximately 1,150 m^2/day and a storage co-efficient of 0.0002. Aquifer testing undertaken during installation of a investigation bore in the Melling area (Brown and Jones, 2000) indicated aquifer transmissivity in the Moera Aquifer in the range of 2,100 to 2,600 m^2/day with a storage co-efficient of between 0.00004 to 0.00008.

5.4 Recharge

The Taita Alluvium and the Waiwhetu and Moera aquifers receive recharge sourced from the Hutt River in the upper part of the groundwater catchment where the aquifers become unconfined upstream of Boulcott. The river has a complex recharge-discharge relationship with the shallow unconfined Taita Alluvium aquifer, but generally loses water to underlying aquifers in the area between Taita Gorge and Boulcott/Kennedy Good Bridge. Between Boulcott and the coastline in the area where the Waiwhetu aquifers are confined, the river generally gains groundwater.

A proportion of the river bed losses in the recharge zone remains in the highly permeable Taita Alluvium and flows southwards to the coast, or returns to the river in its lower reaches. The remainder of the loss reaches the deeper aquifers. The Upper Waiwhetu Aquifer receives vertically infiltrating water transmitted through the overlying Taita Alluvium which is in hydraulic continuity with the river bed. Aquifers below the Upper Waiwhetu Aquifer exhibit a relatively small throughflow because of significantly lower hydraulic conductivities (reducing with increasing depth and compaction) and lower hydraulic gradients. The aquifer recharge dynamics and river losses are, however, strongly influenced by the abstraction regime, river conditions and unconfined aquifer levels.

Quantification of river recharge relies upon a limited number of concurrent river flow gaugings, which out of necessity have been carried out mostly under low flow conditions when gaugings are more easily and safely undertaken and when the measurement errors are smaller. Concurrent gaugings carried out between 1969 and 2013 shows a flow loss between Taita Gorge and Kennedy Good Bridge of between about 800 and 1,500 L/sec. Further downstream flows either level off or start to increase. At higher river flows there also appears to be an apparent flow gain in the initial 2km or so downstream of Taita Gorge to about Taita Rock, below which flow losses occur (higher measurement errors associated with higher flows may however call this observation into question).

Infiltration of rainfall is a source of recharge to the Taita Alluvium but is considered to be a relatively minor component of the water balance for the Lower Hutt Groundwater Zone. Average annual recharge over the predominant Waikanae gravelly and silt loams is estimated to be around 36-45% of average annual rainfall (1140mm) by Earth in Mind (2014).

Under natural (i.e. non-pumping) conditions, an appreciable proportion of the recharge flux from the upstream section of the Hutt River is likely to have be discharged back to the river downstream via throughflow in the shallow Taita Alluvium south of the confined aquifer margin. A relatively small proportion (equal to the volume of water lost via diffuse leakage and submarine springs in the Wellington Harbour) flows southwards through the confined aquifers. However, under the current management regime, a significantly greater proportion of throughflow in the Taita Alluvium is likely to flow into the confined aquifer system to balance the volume of water abstracted for municipal and industrial supply from the Upper Waiwhetu Aquifer (up to 120,000 m^3/day at peak abstraction rates).

5.5 Aquifer discharge

The confined Waiwhetu Gravels and deeper aquifers naturally discharge through vertical leakage across overlying aquitards, both onshore and offshore.

The main confined aquifer discharge mechanism offshore is through widespread diffuse leakage across the Petone Marin Beds. However, discharge from the Upper Waiwhetu Aquifer is also known to occur offshore at discrete points in the form of submarine springs off the Hutt River mouth and around Somes Island (there is also some evidence that springs occur at other locations around the edge of the harbour). These are assumed to be discharging from the Waiwhetu Gravels where the artesian pressure has been breached or burst through the Petone Marine Beds aquiclude. The recent high-resolution and high-accuracy MBES bathymetry survey of the harbour floor (NIWA, 2010) is particularly useful for locating spring vents (Figure 5.4). Figure 5.5 also schematically shows the configuration of the spring vents around Somes Island. The total spring discharge has been estimated to be in the order of 1-2 ML/day through modelling work (Earth in Mind, 2014).

The Lower Hutt Groundwater Zone also provides baseflow to the Waiwhetu Stream which flows along the eastern margin of the Lower Hutt Valley. This stream has headwaters in the foothills to the east of the Lower Hutt Valley but receives appreciable baseflow discharge near the inland margin of the Petone Marine Bed aquitard.

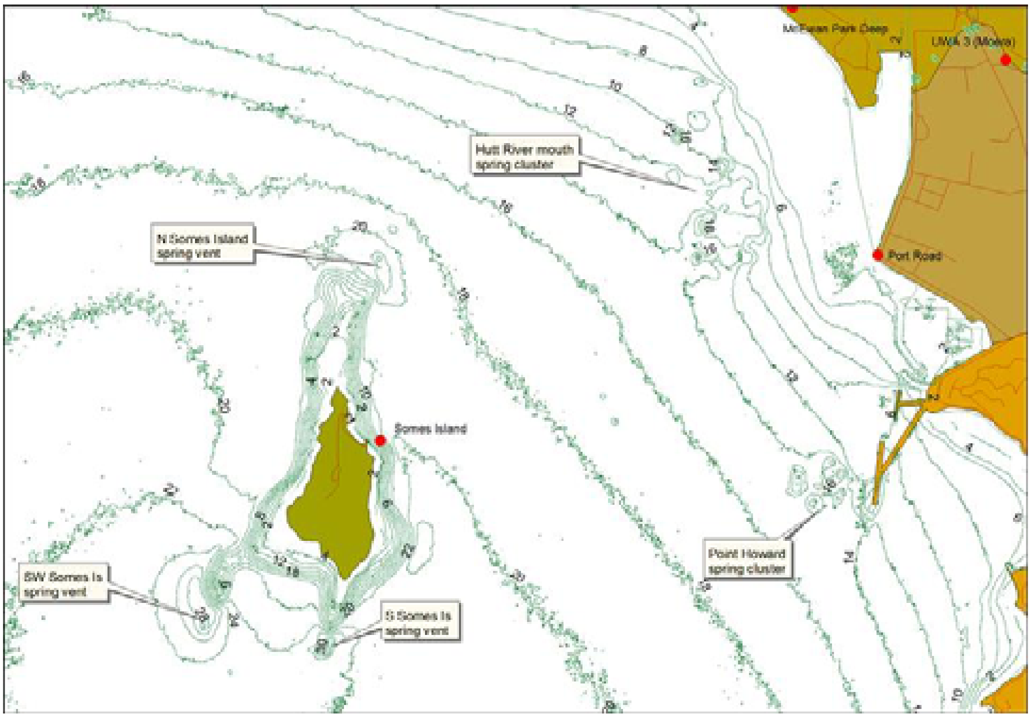

Figure 5.4: Location of submarine spring vents off the Hutt River mouth and around Somes Island based on multi-beam sonar bathymetry survey (NIWA, 2010). Contours are in metres below mean sea level. Red circles are monitoring bores.

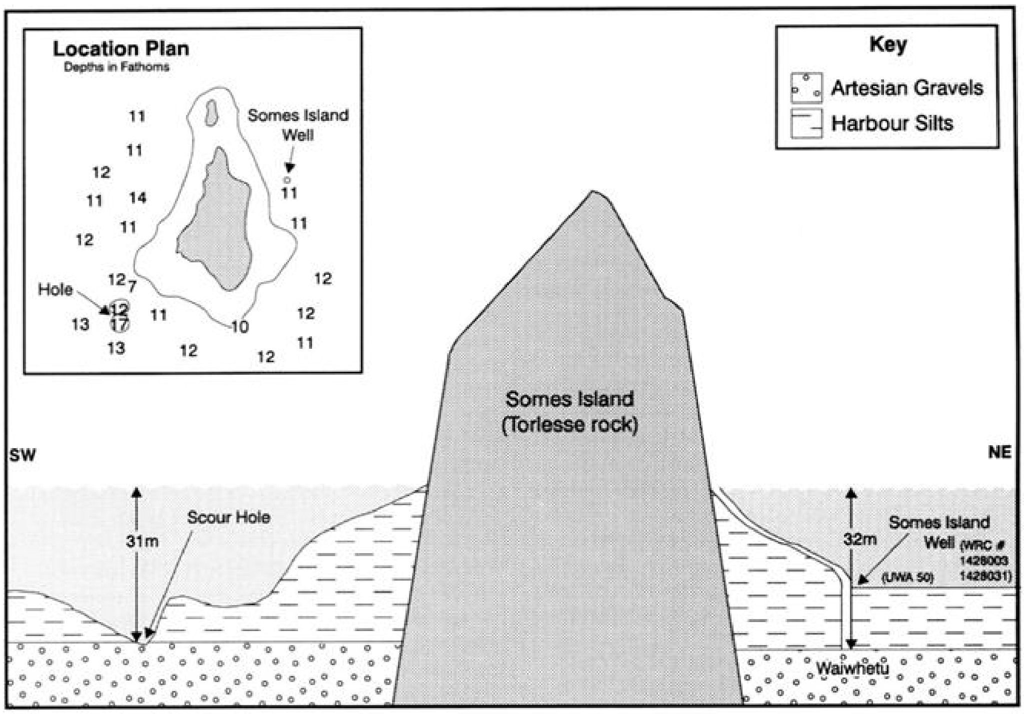

Figure 5.5: Cross-section of the Somes Island area showing the relationship between the Waiwhetu Aquifer and the spring vent (or scour hole) off the south-western tip of the island (from Begg and Mazengarb, 1996)

5.6 Groundwater levels and flow patterns

Groundwater levels in the Lower Hutt groundwater zone are influenced by a range of factors including river stage, rainfall recharge and abstraction along with tidal and barometric pressure variations in confined aquifers near Wellington Harbour.

GWRC maintains 29 groundwater level monitoring sites in the Lower Hutt groundwater zone comprising automatic and manually recorded observation bores (Figure 5.6).

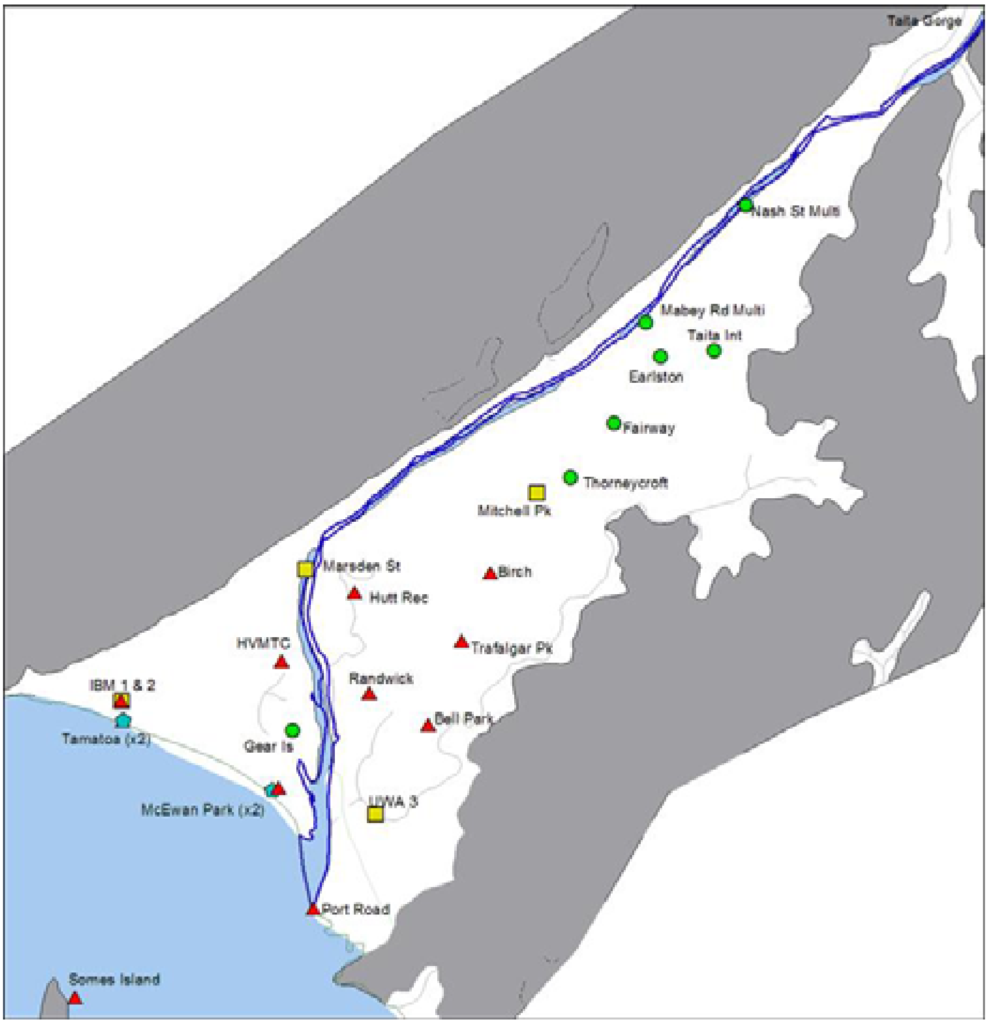

Figure 5.6: Locations of groundwater level monitoring sites in Lower Hutt. Green circles – Taita Alluvium; yellow squares – Moera Gravels; red triangles – Upper Waiwhetu Aquifer; blue hexagons – Lower Waiwhetu Aquifer.

Taita Alluvium

Groundwater level has been measured continuously at the Taita Intermediate site (R27/1117) since 1968. This is an important site as it enables characterisation of the storage state of the unconfined aquifer (Taita Alluvium) and recharge to the downstream Waiwhetu Aquifer. Long-term and short-term variations in groundwater levels in the Taita Alluvium are strongly influenced by the level in the Hutt River and, to a lesser extent, by localised rainfall. Figure 5.7 shows the long-term monitoring record for Taita Intermediate using

30-day and annual mean levels. The plot shows large amplitude fluctuations in mean groundwater level of about 0.7m. These long-term fluctuations can be related to changes in the Hutt River bed level which experiences cycles of degradation and aggradation.

The changes in the Hutt River bed and associated effects on the levels in the unconfined aquifer are of interest in terms of downstream effects on levels in the Waiwhetu Aquifer – particularly at the foreshore where management levels are set.

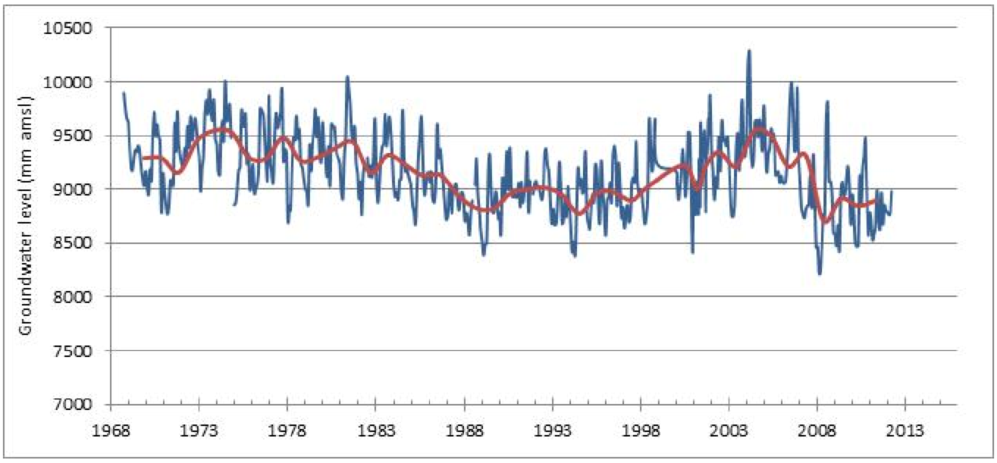

Figure 5.7: Long-term groundwater level record for Taita Intermediate site – 30 day (blue) and annual means (red) data are shown

The Hutt River also exerts both short-term and seasonal effects on the groundwater level in the Taita Alluvium as shown in Figure 5.8. The unconfined aquifer reaches a summer low between about February and April each year corresponding to low river levels and low rainfall. The groundwater level variation between summer lows and winter highs is 1-2m. Figure 5.8 also shows that the aquifer is very responsive to peaks in river flow illustrating a high degree of connectivity between the river and the aquifer.

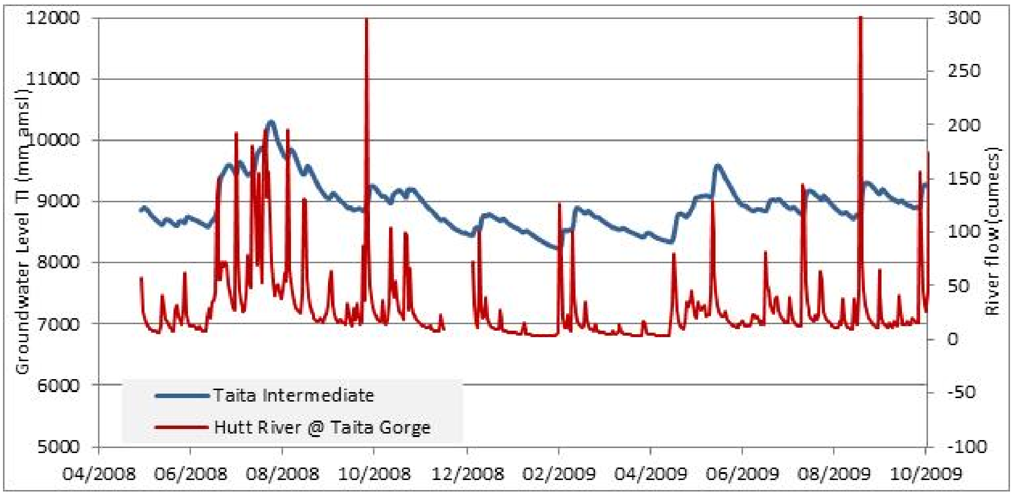

Figure 5.8: Seasonal groundwater level variation in the Taita Alluvium and correlation with flow in the Hutt River

Waiwhetu Aquifer

The Waiwhetu Aquifer has an extensive network of 11 permanent groundwater level monitoring stations including the Somes Island monitoring site some 3km offshore (Figure 5.6). Most of these sites are screened in the top 10m of the aquifer (Upper Waiwhetu Aquifer). New foreshore sites at McEwan Park Deep (R27/7153) and Tamatoa Deep (R27/7215) are screened in the Lower Waiwhetu Aquifer adjacent to counterparts screened in the Upper Waiwhetu Aquifer. McEwan Park Deep and Tamatoa Deep were constructed in 2008 primarily to enhance saline intrusion monitoring.

The important point to note in terms of groundwater levels in the Waiwhetu Aquifer is that they are significantly influenced by continuous abstraction drawdown effects which extend across the entire valley and propagate into the unconfined area (levels are also influenced by tidal effects as discussed in detail below). It is therefore difficult to assess the natural groundwater level variability of the Waiwhetu Aquifer.

Figure 5.9 shows the long-term monitoring record for the McEwan Park monitoring site (R27/0122) on the Petone foreshore (plotted as 7-day and 12-month means) and also the available abstraction record for the municipal supply wells (monitoring commenced in 1994).

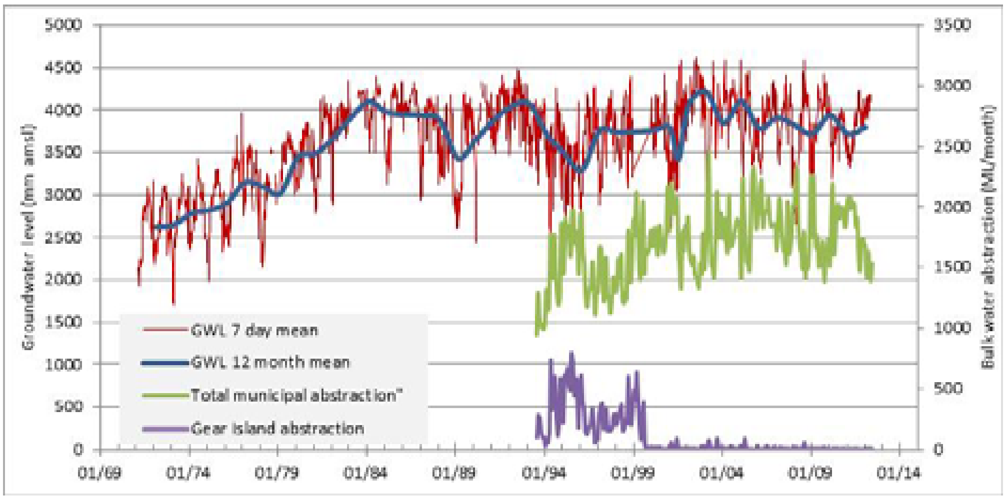

Figure 5.9: Piezometric levels at McEwan Park (R27/0122) and bulk water abstraction record, including Gear Island abstraction at the foreshore (plotted as monthly totals). Note private users are not included in the abstraction plots. GWL = groundwater level.

The gradual rise in levels between 1970 and 1982 is associated with a progressive decrease in abstraction from the Waiwhetu Aquifer. Since the early 1980s, consented abstraction has remained between about 113,000 and the 95,000m^3/day. In 1981 the municipal bulk water supply bores were moved from the foreshore area at Gear Island and Seaview almost 3km inland to Waterloo. Therefore, the continued rise in foreshore piezometric levels between 1981 and 1984 may be attributable to the inland shift in abstraction. Foreshore groundwater levels are sensitive to abstraction volume, particularly when the bores at Gear Island near the foreshore are operational. In 1999 public water supply abstractions near the foreshore (Gear Island and Buick Street) ceased and there is a noticeable recovery in foreshore groundwater levels despite increasing total municipal abstraction from the inland Waterloo Wellfield.

The effects of groundwater abstraction from the bulk water supply wellfield at Waterloo are illustrated in Figure 5.10 which shows wellfield abstraction and Waiwhetu Aquifer levels at McEwan Park on the foreshore during early 2013. There was concern during this time that the first saline intrusion warning level of 2.3m could be triggered. The plot shows the sensitivity of foreshore aquifer levels to abstraction 3km inland at Waterloo and that groundwater levels respond rapidly to adjustments in pumping rate.

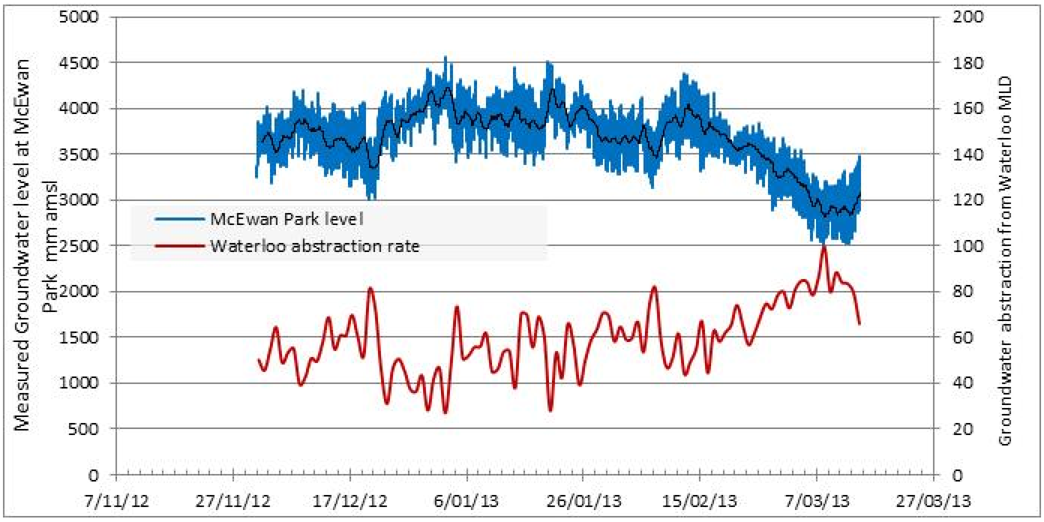

Figure 5.10: Relationship between groundwater abstraction at Waterloo and water level in the Waiwhetu Aquifer at the Petone foreshore (McEwan Park site). Black line is 24-hour mean level at McEwan Park.

Figures 5.9 and 5.10 show that the piezometric levels in the confined Waiwhetu Aquifer (and underlying Moera aquifer) are strongly influenced by tidal cycles, with the effect decreasing with distance from the foreshore. The time lag – or time taken for the piezometric level in the aquifer to peak after high tide –increases with distance from the foreshore. Figure 5.11 shows the tidal variations in groundwater level in the Waiwhetu Aquifer at the foreshore (McEwan Park Shallow well), where a maximum tidal range of about 850mm is evident. Table 5.1 summarises the observed tidal responses at four selected sites in the Waiwhetu Aquifer.

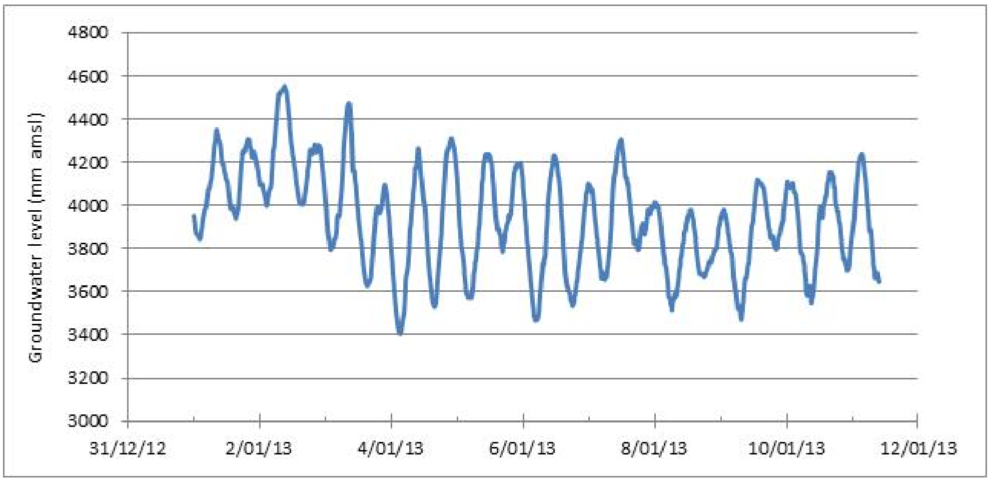

Figure 5.11: Tidally-induced groundwater level fluctuation in the Waiwhetu Aquifer at the Petone foreshore (McEwan Park, Shallow, R27/0122)

Table 5.1: Tidal responses at selected groundwater monitoring sites in the Waiwhetu Aquifer (from WRC, 1995)

Recording site	Distance from foreshore (km)	% of tidal range recorded	Average time lag (mins)
Somes Island	3km offshore	87	0
PCM	0	70	30
HVMTC	1.2	60	45
Hutt Rec	2.2	45	83

Moera gravel aquifer

Three monitoring bores are located in the main confined part of the Moera Aquifer – IBM1, UWA3 and Marsden Street (Figure 5.6). These all intersect the upper freshwater part of the deeper aquifer sequence, at just over 100m depth on the western deeper side of the basin (IBM1 and Marsden St), and at about 65m depth in the east (UWA3). Water levels in this aquifer are also tidally influenced showing an efficiency of about 45-50% (WRC, 1995).

Figure 5.12 shows that the Moera Aquifer groundwater levels vary seasonally by up to about 1m. A major influence on levels in this aquifer is abstraction from the overlying Waiwhetu Aquifer. Pumping effects have been documented by WRC (1995) by correlating pumping in the Waiwhetu Aquifer to water levels in the Moera Aquifer. However, pump testing of the Moera gravels in the Marsden Street well (Brown and Jones, 2000) did not result in any measurable response in the overlying Waiwhetu Aquifer – possibly due to the low pumping rate and short duration of the test. Figure 5.12 also illustrates the some difference in piezometric head between the Waiwhetu Aquifer (IBM2) and the Moera Aquifer (about 1m) indicating that the intervening Wilford Shell Bed is of relatively low permeability. The decline in levels between about 1994 and 1996 is evident in both aquifers and can be related to higher abstraction from the Waiwhetu Aquifer during this time.

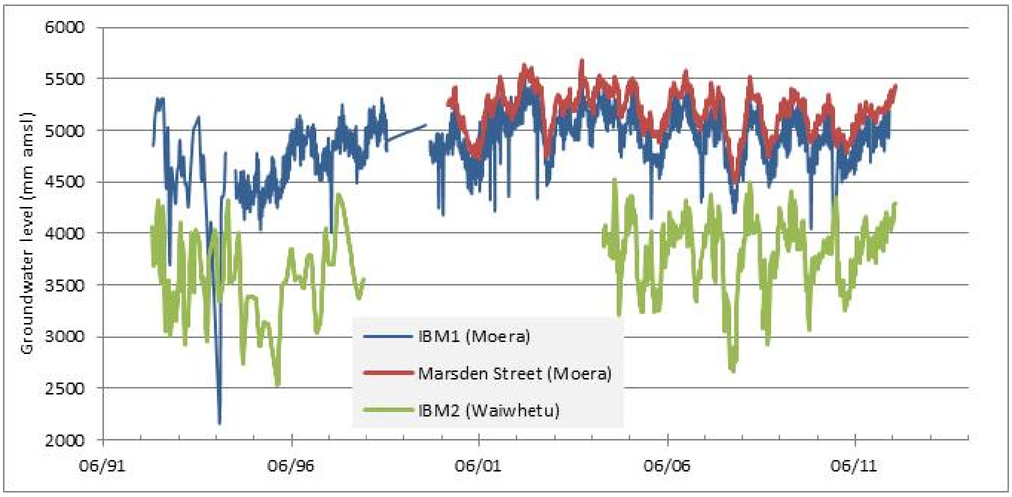

Figure 5.12: Groundwater level monitoring in the Moera Aquifer (IBM1 and Marsden Street) and Waiwhetu Aquifer (IBM2), 1992 to present (7-day means)

5.7 Resource utilisation

Development of the Waiwhetu Aquifer commenced over a century ago, but the past 50 years have seen a progressive increase in abstraction. It is estimated that as a result, the natural aquifer throughflow at the coast has reduced by between 80 and 90%. Groundwater usage in the Lower Hutt Groundwater Zone has not changed significantly over the past two decades. The current consented groundwater takes from the groundwater zone total 33.7 x10^6 m^3/year – 90% of which is associated with the GWRC public water supply take (the public water supply wellfield is located at Waterloo in Lower Hutt City). Metered annual volumes for the GWRC public water supply are shown in Figure 5.13 which shows that annual GWRC abstraction rarely exceeds 25 x10^6 m^3/year.

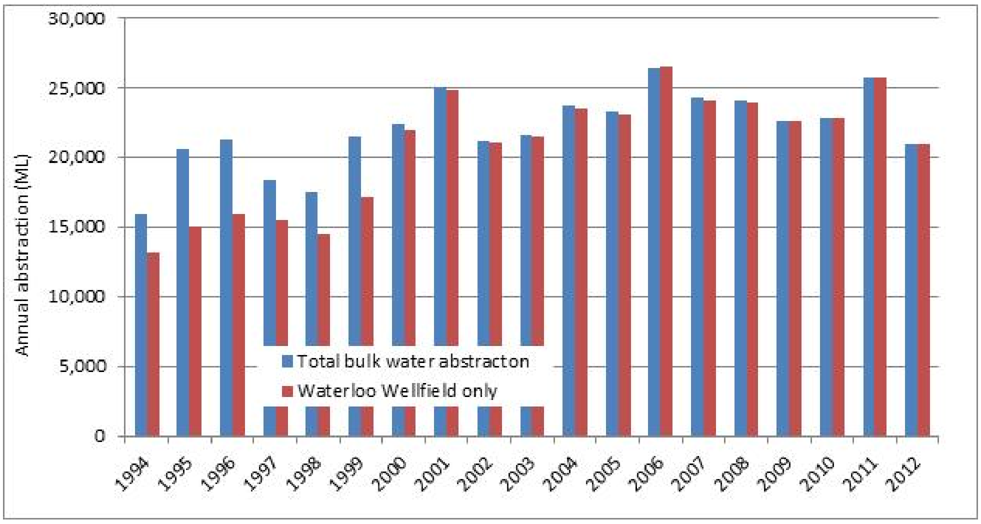

Figure 5.13: Metered GWRC annual bulk groundwater abstraction volumes between 1994 and 2012. The Gear Island wellfield near the foreshore provided some of the supply prior to 2001. The consented annual GWRC abstraction is 30,254ML.

Recent modelling (HAM3; Earth in Mind 2014) has been used to examine the impacts of abstraction on the wider groundwater environment. Figure 5.14 provides a snapshot of aquifer drawdown in April 2009 for the Upper Waiwhetu Aquifer, when abstraction from the wellfield was about 60ML/day. It is evident that abstraction from Waterloo results in significant drawdown (from simulated non-pumped conditions) across the entire groundwater system – the drawdown around the production wells in the middle of the valley is clearly visible. There is a marked flattening of the hydraulic gradient downstream of the wellfield in response to the reduction of the aquifer throughflow caused by the abstraction. The drawdown extends under the whole of Wellington Harbour where it exceeds 2m – reflecting the low aquifer storage, high transmissivity, reduction in throughflow, and the 'semi-blind' nature of the sub-harbour aquifer (i.e. it does not have an open connection with the ocean, except very locally at submarine spring sites). A steep drawdown gradient extends upstream of the wellfield beneath the Hutt River, inducing recharge through the river bed.

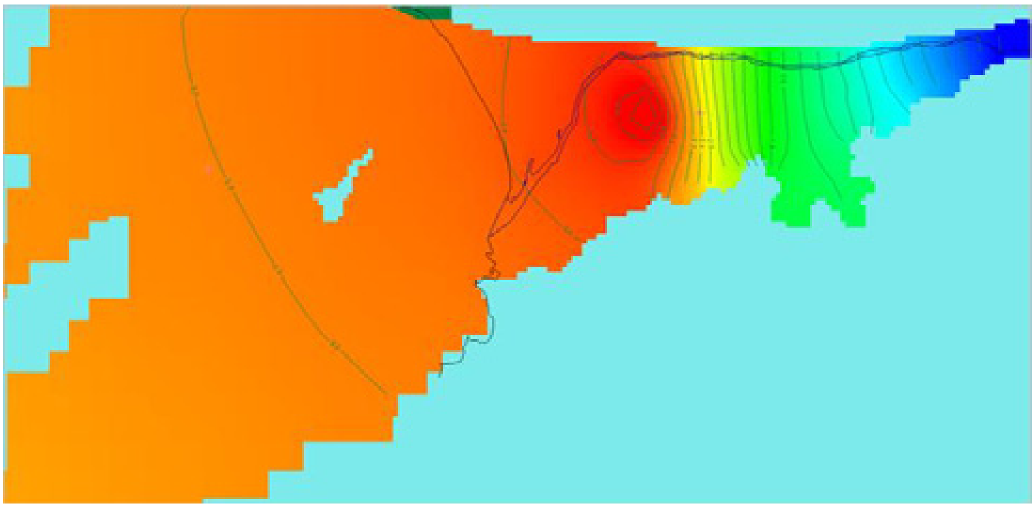

Figure 5.14: Simulated drawdown in the Upper Waiwhetu Aquifer (April, 2009). Waterloo Wellfield pumping rate is 60 ML/D. Note offshore drawdown exceeds 2m beneath the whole of Wellington Harbour.

Figure 5.15 shows the simulated drawdown at three critical monitoring sites – Taita Intermediate in the unconfined (recharge) zone, McEwan Park (on the Petone foreshore, Upper Waiwhetu Aquifer), and at Somes Island (Upper Waiwhetu Aquifer). The locations of these sites are shown on Figure 5.6. The aquifer drawdown at the foreshore and offshore ranges between about 2m and 3m and is clearly correlated to the pumping rate from the Waterloo Wellfield. Drawdown in the unconfined aquifer at Taita Intermediate is consistently around 1m.

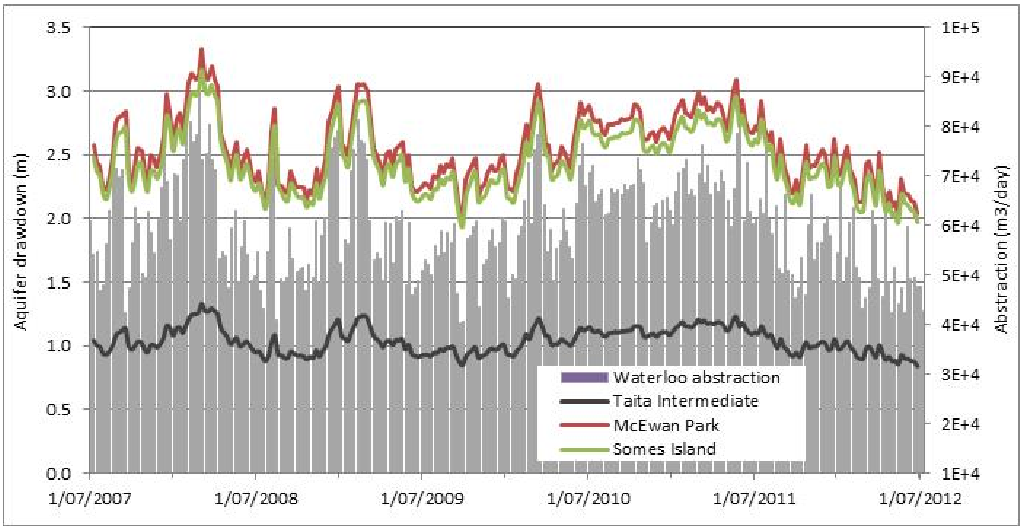

Figure 5.15: Simulated drawdowns at Taita Intermediate, McEwan Park (foreshore) and Somes Island from the HAM3 calibration run

Figure 5.16 shows the simulated effects of abstraction on river loss – the additional induced recharge from the river caused by the drawdown associated with pumping from the Waterloo Wellfield. Modelled induced recharge ranges from 25,000 to 40,000m^3/day (25–40MLD) which equates to about 45% of the total measured river losses of between 60 and 100 ML/day (section 5.4). The linear relationship between Waterloo abstraction and induced river recharge is show in n Figure 5.17 and is (in m^3/day):

*Induced river loss = 0.2498 * pumping rate (Waterloo) + 15,978* [Eq1]

The analysis shows that induced recharge constitutes about 40–60% of the pumping rate – the proportion being higher at lower pumping rates possibly because proportionally more water is drawn from storage at higher pumping rates.

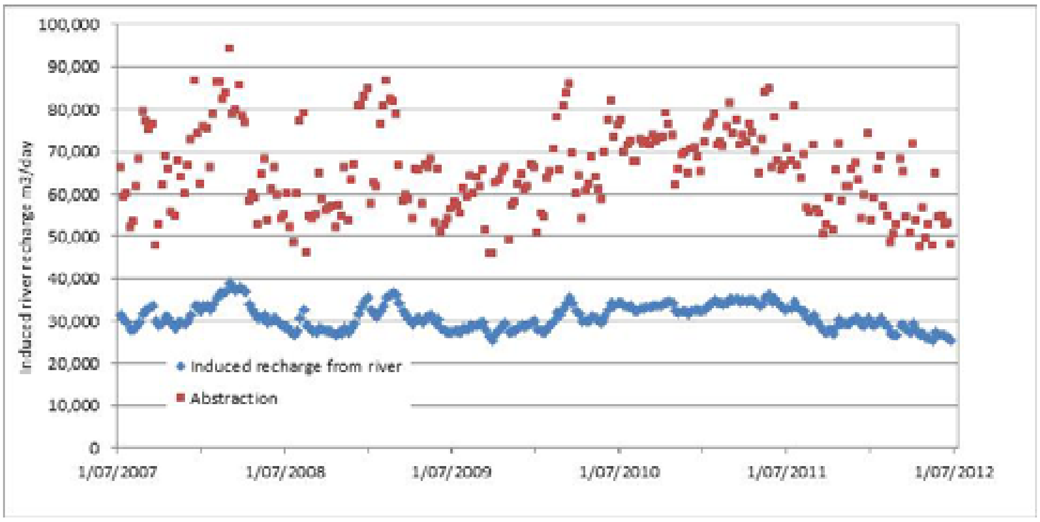

Figure 5.16: Relationship between daily groundwater abstraction and induced recharge from the Hutt River (derived from subtracting the pumping HAM3 scenario from the non-pumping scenario)

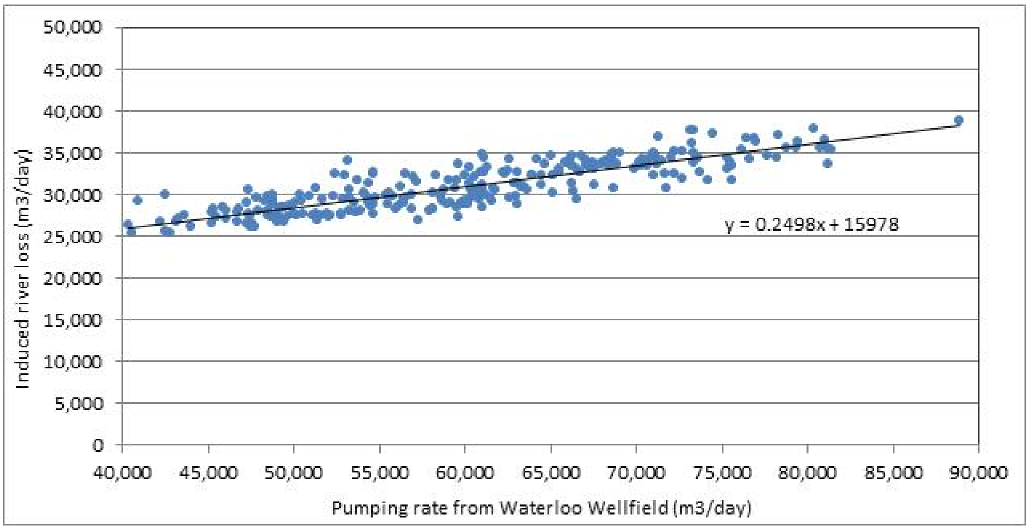

Figure 5.17: Relationship between daily abstraction from the Waterloo Wellfield and induced recharge from the Hutt River

5.8 Management of the Lower Hutt groundwater zone

5.8.1 Saline intrusion risk mangement

Being a critical water source for Wellington and a vulnerable coastal aquifer, the principal criterion for the management of the Waiwhetu Aquifer is saline intrusion risk. The GWRC saline intrusion risk management framework relies both upon theoretical minimum groundwater levels at the Petone foreshore, the maintenance of positive offshore gradients and upon a direct detection of water quality changes. The latter is considered particularly important since the Waiwhetu Aquifer potentially has a 'fast response' characteristic due to its exceptionally transmissive, confined nature and the presence of discreet saline intrusion access sites through near-shore submarine spring vents. In this context, a robust monitoring approach capable of rapidly detecting water quality, aquifer levels and flow gradients is therefore essential. The fast response characteristic of the Waiwhetu Aquifer also means that there is a negligible time lag between changes in pumping rate and the groundwater level response at the foreshore. Therefore changes in pumping rate can be confidently assumed to have an almost instantaneous effect on foreshore pressures in the Waiwhetu Aquifer thereby allowing fast mitigation of saline intrusion risk.

Figure 5.18 shows the components of a proposed revised saline intrusion monitoring strategy (Earth in Mind, 2014) showing the three elements of the framework – groundwater level thresholds, water quality (electrical conductivity) monitoring, and gradient maintenance. Three continuously monitored foreshore water level monitoring sites are central to the framework – Tamatoa, McEwan Park and Port Road. Except for Port Road, these sites have been operational for at least the past decade. These three sites also have continuous electrical conductivity monitoring. Groundwater flow gradients are determined using the three foreshore sites plus additional ones inland (HVMTC) and offshore (Somes Island).

The following three saline intrusion groundwater level thresholds for the Upper Waiwhetu Aquifer[8] are recommended:

Review Level:	2.5m amsl (24-hour mean)
Alert Level:	2.3m amsl (24-hour mean)
Minimum Level:	2.0m amsl (24-hour mean)

The Review and Alert levels provide a structured framework for stepping up from an increased state of awareness at 2.5m, to an intensification of monitoring at 2.3m. The 2.3m Alert Level signifies the onset of a low but rising saline intrusion risk as the offshore hydraulic gradient approaches a critical state. A two-tiered water quality monitoring response when the Alert Level is triggered is proposed.

Continuous monitoring of electrical conductivity (EC) at sentinel foreshore wells provides a good direct indicator of changes in water quality which may reflect the onset of saline intrusion. In addition to the two existing continuous dual-level EC monitoring sites at the Tamatoa and McEwan Park sentinel wells, development of a third foreshore site at Port Road is recommended (bringing the number of EC monitoring sites to five).

The following EC trigger levels are proposed to provide warning of the onset of significant water quality changes in the Lower and Upper Waiwhetu Aquifers:

Upper Waiwhetu Aquifer:	EC = 150 µS/cm
Lower Waiwhetu Aquifer:	EC = 250 µS/cm

[8] the terms ‘Upper’ and ‘Lower’ Waiwhetu Aquifer refer to a recognised subdivision of the Waiwhetu gravels into an upper highly productive part and a lower hydraulic conductivity basal unit separated by an interstadial aquitard. They are in hydraulic continuity however.

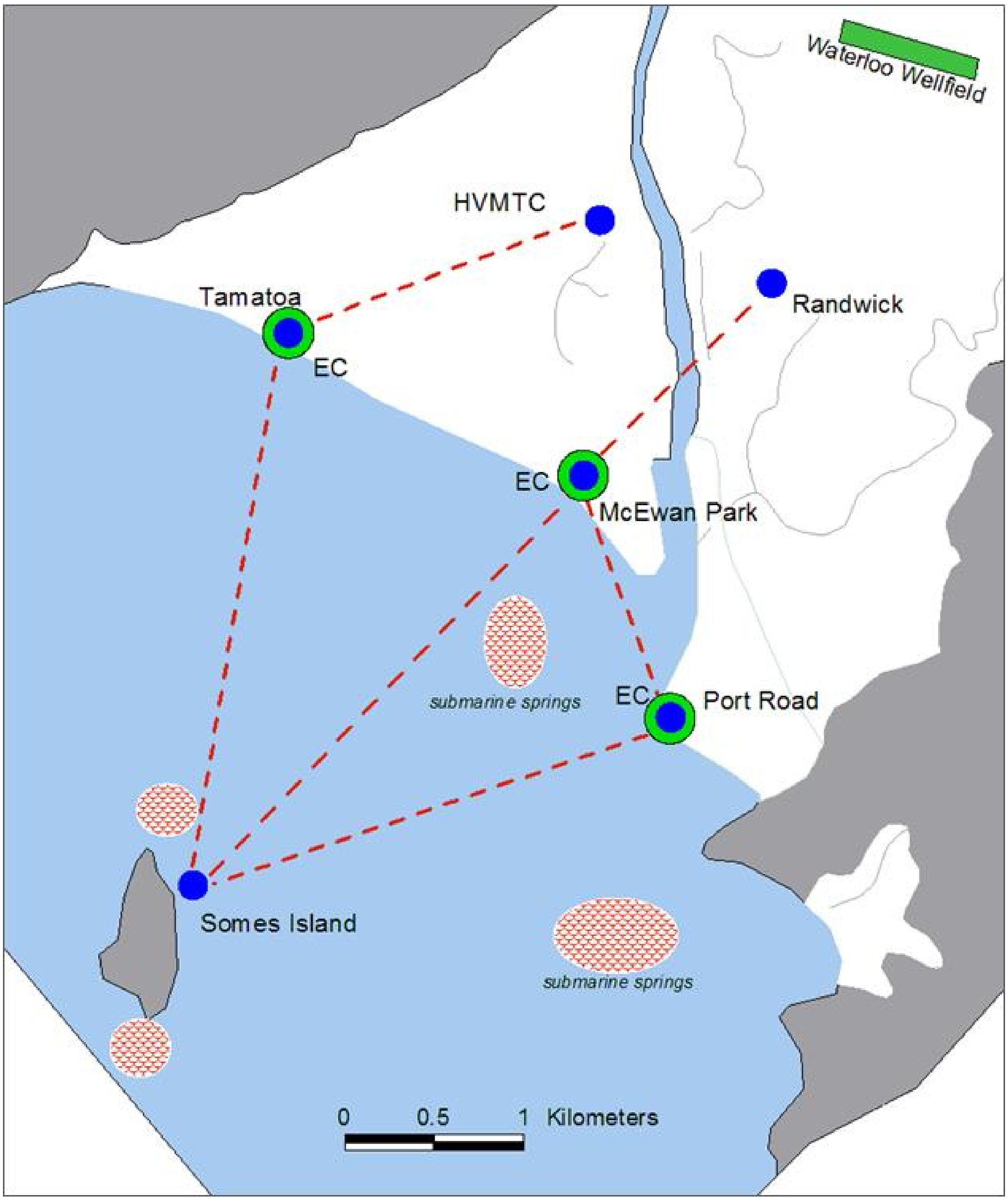

Figure 5.18: Components of a revised saline intrusion monitoring system for the Waiwhetu Aquifer, Lower Hutt. Blue circles are continuous groundwater level monitoring bores, green circles are bores equipped with continuous electrical conductivity probes, dashed red line are monitored hydraulic gradients.

Table 5.2 summarises the recommendations for the revision of the saline intrusion risk management framework for the Waiwhetu Aquifer. The table is divided into three saline intrusion risk categories – '*none*', '*low to increasing*' and '*elevated*'. These categories are based primarily upon foreshore level thresholds, but also incorporate hydraulic gradients (onshore and offshore) and water quality (EC) thresholds. Monitoring and abstraction management responses relevant to each risk category are also shown. The requirement to instigate a structured tiered water quality investigation in response to the breaching of EC thresholds, and/or when the foreshore levels drop below 2.3m amsl, and/or when all onshore gradients reverse is an important new component to the aquifer management framework.

Table 5.2: Saline intrusion risk management framework and risk categories for the Waiwhetu Aquifer, Lower Hutt

SI Risk	Indicators	Response(s)
None	**STANDBY LEVEL: 2.5m** McEwan Park or Tamatoa <2.5m (24 hr) and: All offshore gradients positive Randwick-MP onshore gradient positive and: EC < 150 µS/cm Upper Waiwhetu EC < 250 µS/cm Lower Waiwhetu	Wellfield operators on standby to actively manage foreshore levels through abstraction rate adjustment; Employ yield prediction tool (HADC).
Low to Increasing	**ALERT LEVEL: 2.3m** McEwan Park or Tamatoa < 2.3m (24 hr) and/or: Both onshore gradients negative or positive All offshore gradients positive and: EC < 150 µS/cm Upper Waiwhetu EC < 250 µS/cm Lower Waiwhetu	Instigate Alert Level water quality monitoring and perform weekly (Tier 1 protocol). Wellfield operators required to actively manage foreshore levels through abstraction rate adjustment. Employ yield prediction tool (HADC).
Elevated	**MINIMUM LEVEL: 2.0m** McEwan Park and/or Tamatoa < 2.0m (24hr) and/or: One or more offshore gradients negative and/or: EC > 150 µS/cm Upper Waiwhetu EC > 250 µS/cm Lower Waiwhetu (or consistently rising EC trends)	Reduce pumping rate to maintain minimum foreshore level above 2.0m, or until water quality improves. Instigate water quality investigation response (Tier 1 and, if necessary, Tier 2).

Summary of saline intrusion monitoring recommendations:

Sentinel groundwater level sites (continuous):

McEwan Park (Upper and Lower Waiwhetu), Tamatoa (Upper and Lower Waiwhetu), Port Road (Upper Waiwhetu)

EC monitoring sites (continuous):

McEwan Park (Upper and Lower Waiwhetu), Tamatoa (Upper and Lower Waiwhetu), Port Road (Upper Waiwhetu)

Hydraulic gradient monitoring sites:

Offshore, McEwan Park– Somes Island, McEwan Park – Port Road , Tamatoa Shallow – Somes Island, Port Road – Somes Island, Onshore , Randwick – McEwan Park, HVMTC – Tamatoa

Response water quality monitoring:

Upon breaching EC, gradient or level thresholds, the following two-tiered response is recommended:

Tier 1 response - within 24 hours or weekly when Alert Level triggered:

- Review all monitoring data;
- All monitoring wells equipped with EC probes should be flushed (at least 2 bore volumes by free-flowing) and the EC readings then checked against an independent portable meter.

Tier 2 response – within 48 hours:

- Should the rise in EC be confirmed in Tier 1, additional water quality sampling and chemical laboratory analysis from samples taken from all water quality sites must be carried out;
- Should additional water quality data confirm the likelihood of saline intrusion, the pumping rate from the Waterloo wellfield should be incrementally reduced if it has not already been, until an improvement in water quality or stabilisation of EC trend is observed.
- Resource managers at GWRC should be informed and involved in the assessment of the monitoring data.

For further detailed description of the saline intrusion risk management framework and background information on the calculation of the various threshold values see Earth in Mind (2014).

5.8.2 Sustainable aquifer yield and surface water depletion

Waiwhetu Aquifer (including unconfined zone Taita Alluvium[9])

Mean sustainable yield: HAM3 simulations indicate that the long-term mean yield for the Waiwhetu Aquifer is about 100 ML/day, or 36,500 ML/year. However, this is not the maximum aquifer yield at any point in time, but the maximum rate that would prevent the foreshore level dropping below the 2.0m saline intrusion level during an extreme drought period. During all other times, when the aquifer storage and recharge conditions are not stressed, significantly higher yields can be maintained within the same foreshore level constraints. The HAM3-derived mean daily yield of 100ML can be used for allocation policy and expressed as a 12-month moving mean and also expressed as an annual volume (36,500 ML). However, greater volumes can be safely taken from the aquifer contingent upon aquifer storage and recharge conditions as described below.

Maximum short-term aquifer yield: The maximum sustainable yield of the Waiwhetu Aquifer is constrained by saline intrusion risk and the maintenance of critical groundwater levels at the foreshore. Under this constraint, the maximum aquifer yield is dynamic and dependent upon storage/head conditions – particularly in the unconfined part of the aquifer – and the recharge potential from the Hutt River. A groundwater level in the unconfined aquifer at the Taita Intermediate monitoring site can be used to assess the maximum yield potential of the aquifer since this is regarded to be a suitable indicator of the aquifer storage and recharge state. The unconfined aquifer level influences the foreshore groundwater level in the Waiwhetu Aquifer. Simple level relationships have been derived between the two 'ends' of the aquifer and their response to pumping at the Waterloo wellfield using the HAM3.

To assess the maximum yield potential of the Waiwhetu Aquifer under a range of unconfined aquifer levels at Taita Intermediate, four 0.5m groundwater bands have been defined. The potential sustainable yield for each of the bands, together with the calculated induced recharge from the Hutt River (using correlations derived from the HAM3 are shown in Table 5.3.

Table 5.3: Guidelines for potential maximum sustainable yield band for the Waiwhetu Aquifer based upon groundwater level in the unconfined aquifer at Taita Intermediate and a minimum foreshore level of 2.0m amsl

Taita Intermediate level (24 hour mean level a msl)	Waiwhetu Aquifer Maximum yield ML/day	Induced recharge from the Hutt River (L/sec)
<8-8.4m	110	500
<9m >8.4m	120	530
<9.5m >9m	130	560
>9.5m	140	590

[9] The Taita Alluvium in the unconfined zone is in hydraulic continuity with the Waiwhetu gravels and is therefore considered to be part of the same resource.

The potential maximum yield from the aquifer based Table 5.3 is 140ML/day, which can be sustained when aquifer conditions permit. The yields associated with the groundwater level bands shown in Table 5.3 should however be used for operational guidance only – it is not recommended that they be incorporated into allocation policy.

In summary, it is recommended that the allocation from the Waiwhetu Aquifer for resource management policy is as follows:

- mean daily abstraction (12 month mean) of 100,000m^3
- annual allocation of 36.5x10^6m^3 (the current allocation is 33x10^6m^3/year).
- peak daily rate of 140,000m^3.

In reality, under stress conditions, the maximum yield from the aquifer will be governed by saline intrusion level constraints at the foreshore which will over-ride the rates specified above.

The induced loss from the Hutt River caused by groundwater abstraction should be taken into consideration by GWRC when assigning the core allocation from the river.

Moera Aquifer

The deeper Moera Aquifer is connected to the Waiwhetu Aquifer in the unconfined area – it also shares the same recharge source Significant abstraction from the Moera Aquifer is unlikely to occur due to the low-yielding nature of the sediments and poor water quality. There are currently no consents to abstract from this aquifer. Given these factors, especially the common recharge source, it is recommended that the Moera Aquifer is not assigned an allocation volume. Rather, allocation from this aquifer should be included within the volume allocated to the Waiwhetu Aquifer.

5.9 Recommendations for groundwater management from the Lower Hutt groundwater zone

5.9.1 Zone summary

Zone delineation: Figure 5.1 shows the boundaries of the Upper Hutt groundwater zone which covers an area of approximately 108km^2, of which 28.4km^2 occurs onshore. The onshore zone boundary remains unchanged from the Regional Freshwater Plan (WRC 1999), but the groundwater zone is now extended beneath most of Wellington Harbour.

Principal aquifers: The principal aquifer in the Lower Hutt groundwater zone are a shallow unconfined aquifer (Taita Alluvium), a highly productive confined aquifer (Waiwhetu Gravels) and a deeper confined aquifer (Moera Gravels). Overall, the aquifer sequence represents a leaky confined system. The Waiwhetu

	Aquifer provides up to 40% of Wellington's municipal supply.
Existing RFP allocation:	Waiwhetu Aquifer and Taita Alluvium – 33.3 x 10^6 m^3/year; Moera Aquifer – 1.5 x 10^6 m^3/year.
Current allocation:	As of 2014, there were 19 consented groundwater users in the Lower Hutt groundwater zone, with 90% of the total allocated volume being assigned to GWRC for public water supply. The total consented volume is 33.9 x10^6 m^3/year and 96.8ML/day (96,800m^3/day). This equates to 102% of the existing RFP 'safe yield'.

5.9.2 Zone management objectives

The productive aquifers in the Lower Hutt groundwater zone exhibit a tight hydraulic coupling with the Hutt River thereby requiring that these resources be managed conjunctively. There is also exceptionally high value placed on the groundwater resource in the Waiwhetu Aquifer for public water supply.

The following groundwater management objectives are therefore proposed for this zone:

- The principal management objective for groundwater allocation in the Lower Hutt groundwater zone is to maximise groundwater resource availability within the constraints of saline intrusion risk.
- The impacts of maximising the groundwater resource on the Hutt River must be taken into consideration in the designation of enduring core allocation limits for the lower reach of the Hutt River.

5.9.3 Allocation categories

The conjunction allocation framework described in the Section 2 of this report and the extensive analysis of the groundwater system and its response to abstraction using the HAM3, justify placing the the Waiwhetu Aquifer, and its upstream unconfined zone extension and merger with the Taita Alluvium, in allocation Category B. This category recongises a moderate to high degree of connectivity with surface water.

Taita Alluvium to a depth of up to about 15m over the confined aquifer area (south of Boulcott) should be assigned Category A in recognition of its connection to the river and minor streams, and its disconnection from the underlying Waiwhetu Aquifer. In the unconfined zone (north of Boulcott), the Taita Alluvium is assigned Category B since it constitutes part of the recharge and storage zone to the main Waiwhetu Aquifer and any abstraction that may affect it needs to be accounted for within the groundwater budget.

Deeper water-bearing layers beneath the Waiwhetu Aquifer (i.e. Moera Aquifer), are also recommended to be assigned to Category B in recognition of a common Hutt River recharge source.

Figure 5.19 contains a map of the proposed allocation categories for the Lower Hutt groundwater zone.

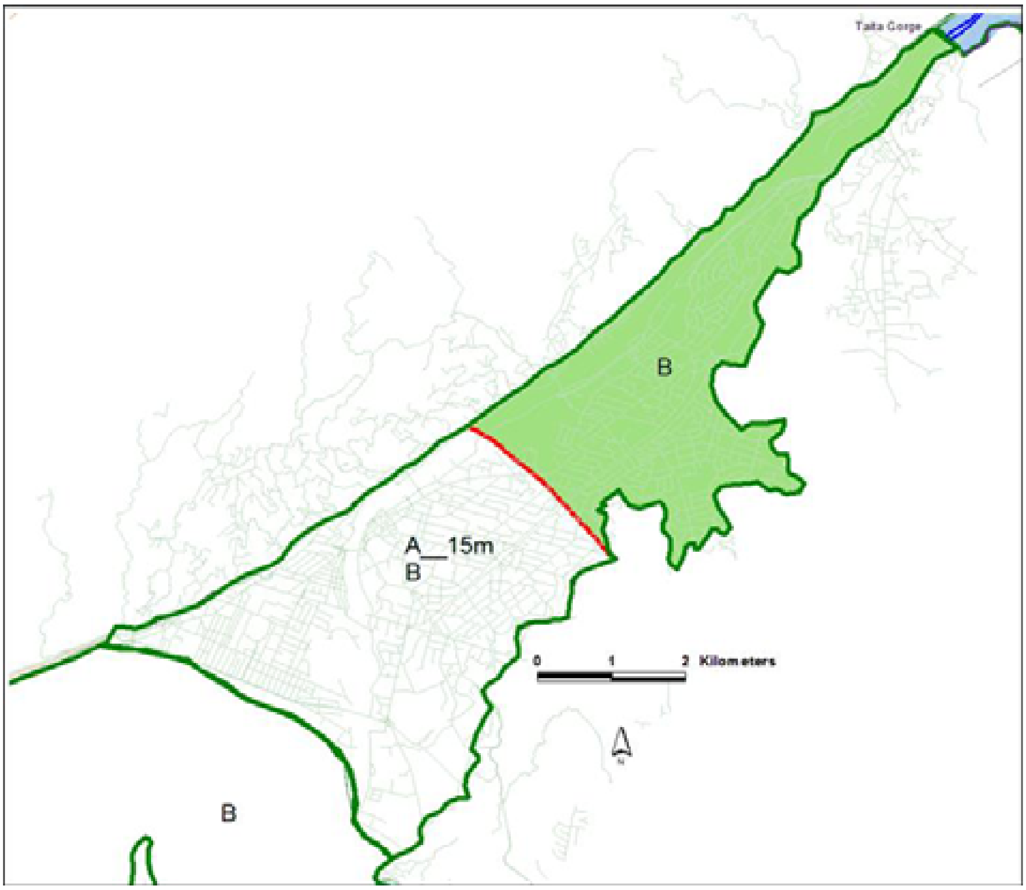

Figure 5.19: Lower Hutt groundwater zone showing proposed groundwater water allocation categories

5.10 River core allocation required to enable maximum aquifer utilisation

Simulations using the HAM3 show that, under average pumping conditions of 70-80 ML/day that the induced recharge from the river is about 50% of the abstraction rate, the proportion decreasing with increasing pumping rate (Figure 5.17 and Equation 1). At the recommended peak pumping rate of 140,000m^3/day the induced recharge from the river is predicted to be closer to 37% of the abstraction rate. Table 5.3 shows the change in induced recharge at different abstraction rates.

If the Waiwhetu Aquifer is to be fully utilised, the effect of maximum allocation on the river (i.e. induced recharge) will need to be allowed for. The maximum depletion effect on the river would occur during a peak abstraction of 140,000 abstraction which, using Equation 1 (represented in Figure 5.20), is around 600 L/sec. This is about 120 L/sec more than the existing level of maximum depletion under the current allocation regime.

In the Proposed Natural Resources Plan, GWRC are proposing an interim allocation limit for large rivers of 50% of 7d MALF. For the lower Hutt River (from the confluence with the Pakuratahi River to the Hutt River mouth), this equates to an allocation limit of 2,140 L/s (based on a 7d MALF of 4,275 L/s at Melling – see Appendix 1). A recent assessment of existing takes (both core surface water and hydraulically connected groundwater takes) showed that the total potential river flow depletion in the lower Hutt River is already 2,520 L/sec (ie, 59% of 7d MALF at Melling), and therefore exceeds the interim allocation limit being proposed. The implication of this is that any additional 'take' (to make up the full 600 L/sec depletion effect) between Taita Gorge and Boulcott to sustain maximum future pumping rates from the Waiwhetu Aquifer will not necessarily be readily available under the Proposed Natural Resources Plan. The importance of providing the necessary depletion allowance to maximise groundwater use will need to be considered further when interim allocation limits are finalised through the Wellington Harbour and Hutt Valley whaitua (catchment committee) process.

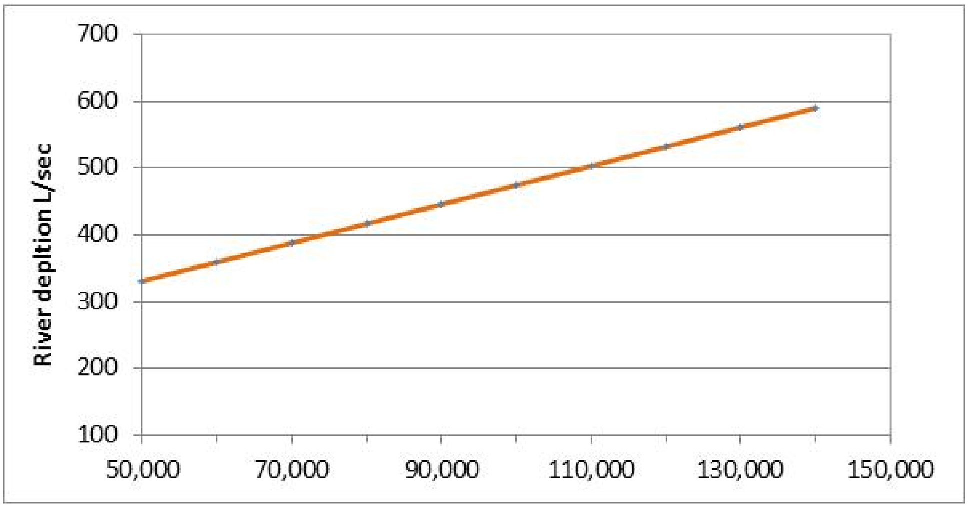

Figure 5.20: HAM3 simulated relationship between abstraction from the Waiwhetu Aquifer and induced recharge from the Hutt River

5.11 Summary – Allocation recommendations for the Lower Hutt Groundwater Management Zone

5.11.1 Allocation category A

Category A groundwater in the Lower Hutt Groundwater Management Zone extends to a depth of 15 m within the Taita Alluvium from south of Boulcott to the coast. There is no groundwater allocation associated with category A; allocation for this category is derived from the surface water allocation.

5.11.2 Allocation category B: Waiwhetu Aquifer, Taita Alluvium (unconfined zone) and deeper aquifers

- This zone has allocation limits (daily and annual) calculated using the HAM3 model and based on saline intrusion risk management criteria. Annual, mean daily and peak daily allocation limits are recommended. However, the saline intrusion risk management criteria will take precedence over these limits (i.e. saltwater intrusion controls may restrict abstraction to lower rates), but the limits shall not be exceeded. Table 5.4 summarises the allocation limits recommendations for the Lower Hutt groundwater zone.

- The maximum daily allocation is contingent on the groundwater level in the unconfined aquifer (i.e. the aquifer recharge and storage state). The groundwater level at the Taita Intermediate monitoring bore can be used as a guideline to predict the maximum sustainable aquifer yield potential whilst maintaining a minimum foreshore level of 2.0m masl for saltwater intrusion protection (Table 5.3). The recommended maximum daily allocation limit for the Waiwhetu Aquifer is 140,000 m^3/day.

- A total allowance of 600 L/sec from the core allocation for the lower reach of the Hutt River is needed to enable maximum allocation (140,000 m^3/day) of the groundwater resource.

- The saline intrusion risk management framework and methodology are detailed in Section 5.8.1. A minimum foreshore groundwater level in the Waiwhetu Aquifer of 2.0m amsl (24-hour mean) is recommended, in conjunction with electrical conductivity and hydraulic gradient criteria.

Table 5.4: Summary groundwater allocation recommendation for the Lower Hutt groundwater zone

Aquifer	Groundwater allocation	Total core allocation from Hutt River required to enable groundwater allocation
Waiwhetu Aquifer + Taita Alluvium unconfined zone + Moera Aquifer	100,000 m^3/day (mean) 140,000 m^3/day (peak) 36,500,000 m^3/year	600 L/sec

Acknowledgements

Brydon Hughes (formerly of Liquid Earth Ltd) is acknowledged for contributing material to an earlier version of this report.

Peer reviews of the Hutt Aquifer Model (HAM3) and aquifer management approach that underpin recommendations in this report were provided by Catherine Moore (ESR) and Peter Callander (PDP), respectively, as part of a project completed for GWRC in 2014.

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Appendix 1: Hutt River mean annual low flow (MALF) estimates

Mean annual low flow (MALF) has been used in this report as a reference index for baseflow against which groundwater allocation options have been assessed. MALF figures were provided by GWRC for key locations on the Hutt River and the basis for these figures is presented in the table below.

Mean annual low flow estimates

Location [location names in bold have automated flow recorders]	**7 day MALF*** (litres/sec)	**Comment / Basis for MALF**
Hutt River at **Kaitoke Weir**	1,435	This location is upstream of all abstraction so measured MALF is naturalised MALF. Figure reproduced from Keenan (2009) based on data from 1967 to 2008.
Hutt River at **Birchville**	3,430	Equates to measured 7d MALF of 2,670 L/s (Wilson 2006, Table 19) plus abstraction of 760 L/s to naturalise (following method of Hudson 2008).
Hutt River at just Upstream of Whakatikei River confluence	3,060	There is no flow recorder at this site. MALF estimated from concurrent gauging flow patterns. When un-naturalised flow at Taita Gorge is close to 7d MALF, flow upstream of Whakatikei River confluence is about 2,300 L/s. So naturalised 7d MALF estimated as 2,300 + 760 = 3,060 L/s
Hutt River at **Taita Gorge**	4,505	Equates to measured 7d MALF of 3,745 L/s (Wilson 2006, Table 19) plus abstraction of 760 L/s to naturalise (following method of Hudson 2008).
Hutt River at Melling	4,275	This is approximately the same location as Boulcott There is no flow recorder at this site. MALF estimated based on a correlation equation developed by Wilson (2006, Table 26); 7d MALF = Taita Gorge 7d MALF * 1.022 -828 The result from the correlation above (3,825 L/s) is then further naturalised to take account of the additional depletion effect of the existing groundwater abstraction in the Waiwhetu Aquifer (estimated to be about 500 L/s on average). Hence 3,775 + 500 = 4,275 L/s.

* Naturalised MALF (ie, with abstraction added back into measured record)

The Greater Wellington Regional Council's purpose is to enrich life in the Wellington Region by building resilient, connected and prosperous communities, protecting and enhancing our natural assets, and inspiring pride in what makes us unique

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