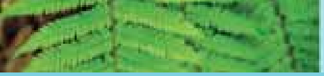




Freshwater allocation and availability in the Wellington region

State and trends

Quality for Life

greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao




Freshwater allocation and availability in the Wellington region

State and trends

L Keenan
M Thompson
D Mzila

Environmental Monitoring and Investigations Department

For more information, contact Greater Wellington:

Wellington
PO Box 11646

T 04 384 5708
F 04 385 6960
www.gw.govt.nz

Masterton
PO Box 41

T 06 378 2484
F 06 378 2146
www.gw.govt.nz

GW/EMI-T-12/141
ISBN: 978-1-927217-08-5 (print)
ISBN: 978-1-927217-09-2 (online)

May 2012

www.gw.govt.nz
info@gw.govt.nz

DISCLAIMER

This report has been prepared by Environmental Monitoring and Investigations staff of Greater Wellington Regional Council (Greater Wellington) and as such does not constitute Council policy.

In preparing this report, the authors have used the best currently available data and have exercised all reasonable skill and care in presenting and interpreting these data. Nevertheless, Greater Wellington does not accept any liability, whether direct, indirect, or consequential, arising out of the provision of the data and associated information within this report. Furthermore, as Greater Wellington endeavours to continuously improve data quality, amendments to data included in, or used in the preparation of, this report may occur without notice at any time.

Greater Wellington requests that if excerpts or inferences are drawn from this report for further use, due care should be taken to ensure the appropriate context is preserved and is accurately reflected and referenced in subsequent written or verbal communications. Any use of the data and information enclosed in this report, for example, by inclusion in a subsequent report or media release, should be accompanied by an acknowledgement of the source.

The report may be cited as:

Keenan L., Thompson M. and Mzila D. 2012. *Freshwater allocation and availability in the Wellington region: State and trends*. Greater Wellington Regional Council, Publication No. GW/EMI-T-12/141, Wellington.

Main cover photo: Centre-pivot irrigation (JR Milne)

Executive summary

Greater Wellington monitors the quantity of water resources across the Wellington region with an instrument network that includes 50 rainfall, 45 river level/flow and, 146 groundwater level sites. The region's water resources support a wide range of values including providing for consumptive water needs such as drinking water, irrigation and industrial use. Greater Wellington is also responsible for managing this abstraction of water. It does this through issuing resource consents, in accordance with regional plan policies that specify sustainable allocation limits and environmental flow regimes.

The rivers, streams, lakes and groundwater systems of the Wellington region support a wide range of values, including ecological, recreational, aesthetic and cultural values. These water resources also provide for our consumptive water needs, for example for drinking water, irrigation, and industrial use. Greater Wellington is responsible for managing the abstraction of water so that any adverse effects are avoided, remedied or mitigated. To help assist with this Greater Wellington monitors the quantity of water resources across the region with an instrument network that includes 50 rainfall, 45 river level/flow and, 146 groundwater level sites. This State of the Environment (SoE) monitoring network also assists with other aspects of water management, including responding to extreme events such as floods and drought.

This report provides an assessment of the current 'state' of, and trends in, freshwater allocation under operative resource consents in the Wellington region. Allocation trends are assessed for the period 1990–2010, with the current allocation status reported against limits set in Greater Wellington's existing Regional Freshwater Plan (RFP), and potential future management scenarios, to provide an indication of remaining water availability. The report also presents analyses of trends in hydrological factors that affect water availability, drawing primarily on results from a selection of the SoE rainfall, river flow and groundwater level monitoring sites. Rainfall and river flow assessments are focused primarily on the period 1980–2011 (although full site records were also assessed) and on summer conditions when water stress is highest. The groundwater assessment is focused primarily on the period 1994–2011.

As at the end of 2010, a total 414 million m^3/yr of freshwater was allocated via resource consents in the Wellington region. While there are twice as many groundwater consents as surface water consents, by volume most of the water is taken from rivers and streams. Two thirds of the region's total annual volume of allocated water is used in the Wairarapa, predominantly for irrigation. However, across the region as a whole, public water supply is the largest single use of allocated water (39.5%), followed closely by irrigation (35.6%).

Consented water allocation more than doubled in the past two decades in the Wellington region, primarily due to increased irrigation demand. The amount of water allocated for irrigation increased four-fold between 1990 and 2010 and almost three quarters of this increase was due to growth in dairy pasture irrigation.

Most rivers and streams are fully allocated and there is little remaining 'run of river' water available during times of low flow, especially in the areas where further irrigation growth is likely (ie, the Wairarapa Valley). While under existing RFP policies there is still significant remaining groundwater available, it is likely that these policies overstate the actual availability of groundwater in many areas, especially in shallow gravel aquifers in river corridors. This is largely because the depletion effect of groundwater abstraction on hydraulically-connected surface water bodies is not explicitly accounted for in existing aquifer safe yield estimates; allocation assessments in this report have shown that the estimated streamflow depletion caused by groundwater takes is nearly as high as, or even exceeds, direct surface water allocation in many catchments.

While there has been a tendency in the last 10–15 years towards slightly drier than normal conditions in the Wellington region, and lower rainfall and river flow minima, there is no evidence that patterns in the natural 'supply' of water have departed from historical ranges. Few statistically significant trends in several indicators of rainfall or river flow were found when assessed over the common period 1980–2011 or full length site records. Despite this, several groundwater aquifer systems – primarily the deeper aquifers in the Wairarapa Valley – showed declining trends in water levels and signs of storage depletion between 1994 and 2011. Notwithstanding considerable uncertainty about the exact causes of observed depletion trends or whether they will continue into the future, analysis in this report suggests that abstraction beyond sustainable limits is an issue for some aquifers.

Climate change is likely to alter the seasonal and annual average availability of water in the region. Most significantly, drought risk is likely to increase in the Wairarapa.

A new integrated groundwater–surface water management framework has been proposed for the Wairarapa Valley and work is underway to develop conceptually similar frameworks for managing water resources in other parts of the region (mainly the Hutt Valley and the Kapiti Coast). A key issue highlighted by this report is the potential impact these proposed frameworks will have on future water availability, if groundwater takes that result in streamflow depletion are to be managed under surface water allocation policies. A primary limitation with respect to understanding how much water remains available for allocation is a lack of agreed criteria for determining 'safe' limits. However, it is clear that more efficient use and accurate accounting of water is needed to maximise the utility of available resources. Mechanisms discussed in this report include 'free-ing up' unused (but currently allocated) water and flow-sharing between users. Harvesting and storage of higher river flows (ie, after freshes) also has the potential to alleviate pressure on catchments during times of water stress.

The report makes several specific recommendations relating to improving the accuracy of information on water resources in the region and undertaking further data analysis. Key amongst these are; better quantification of actual water use (as opposed to allocated volumes), improving our understanding of low flow characteristics in un-gauged river reaches (particularly downstream of major catchment abstractions), and further investigation of the cause of the most significant groundwater level declines and storage depletions.

Contents

1. Introduction

The rivers, streams, lakes and groundwater systems of the Wellington region support a wide range of values, including ecological, recreational, aesthetic and cultural values. These water resources also provide for our consumptive water needs, for example for drinking water, irrigation, and industrial use. Greater Wellington Regional Council (Greater Wellington) is responsible for managing the abstraction of water so that any adverse effects are avoided, remedied or mitigated. It does this through issuing resource consents to take and use water, in accordance with regional plan policies that specify sustainable allocation limits and environmental flow regimes.

This report assesses the current 'state' and recent trends in water allocated through resource consents in the Wellington region. The report also makes an assessment of 'water availability', and uses data collected as part of Greater Wellington's State of Environment (SoE) hydrological monitoring programme (ie, rainfall, river flow and groundwater levels) to analyse trends in hydrological factors that affect water availability. Monitoring the state of the environment is a specific requirement for regional councils under Section 35(2)(a) of the Resource Management Act (RMA) 1991.

In the context of this report, 'water availability' refers to the amount or flow of water in rivers, lakes and groundwater systems that may be allocated for use without compromising the life-supporting capacity of the water resource and other identified important instream values. Water availability is assessed in this report by comparing the amount of water allocated (as at the end of 2010) with established or potential future allocation limits.

1.1 Report purpose

This technical report is one of eight covering air, land and water resources prepared with the primary purpose of informing the review of Greater Wellington's five regional plans. These plans were established to sustainably manage the region's natural resources, including freshwater. The review of the regional plans follows the recently completed review of the overarching Regional Policy Statement (RPS) for the Wellington region (GWRC 2010).

The focus of the eight technical reports is on providing an up-to-date analysis of monitoring information on state and trends in resource health as opposed to assessing the effectiveness of specific policies in the existing RPS (WRC 1995) or regional plans. Policy effectiveness reports were prepared in 2006 following the release of Greater Wellington's last formal State of the Environment (SoE) report, *Measuring up* (GWRC 2005).

This report specifically aims to address the following questions:

- What is the current state of water allocation and availability in the Wellington region, and what have been the recent trends in allocation?
- Are there any background trends in hydrological factors (such as rainfall, river flows and groundwater levels) that may affect water availability, now and in the future?

This report is the first thorough analysis of water allocation and availability in the Wellington region. However, the analysis of hydrological trends affecting water availability follows on from the 2005 SoE technical reports on Greater Wellington's hydrological and groundwater monitoring (Watts 2005; Jones & Baker 2005)[1].

1.2 Report scope

This report focuses on the current status of consented water allocation in the Wellington region (as of the end of 2010) and trends during the 20-year period 1990 to 2010. The analysis of trends in rainfall and river flows largely focuses on the last 30 years (1980 to 2010) and on data that describes conditions during the time of highest water stress (ie, summer). Particular attention is given to the six years since the 2005 SoE technical reports. Groundwater trend analysis is focussed on the time period 1994–2010; this is shorter than the period assessed for rainfall and river flow because many groundwater sites were only established in the early 1990s.

The report does not make recommendations regarding actual allocation limits or 'environmental bottom-lines'. With respect to rivers and streams, the assessment of water availability is focussed on 'run of river' availability during summer periods of stable and/or low flow. The availability of additional surface water during higher flows periods has not been assessed.

1.3 Report outline

The report comprises six sections:

- Section 2 provides some background to the water resources of the Wellington region and how water allocation is managed in the region.
- Section 3 presents an analysis of water allocation and availability: current allocation statistics, trends in allocation over the last 20 years, and water availability under existing management frameworks and potential future water management scenarios.
- Section 4 presents an analysis of trends in key hydrological factors that affect water availability (rainfall, river low flows and groundwater levels).
- Section 5 discusses the results presented in the previous two sections, highlighting the key issues around water allocation and availability and what they mean in the context of resource management in the region. The discussion also provides some national context, covers some of the likely reasons for observed trends in water allocation and availability, and outlines primary knowledge gaps.
- Section 6 presents conclusions and recommendations, particularly relating to Greater Wellington's monitoring programmes and the review of the existing regional plans.

[1] Greater Wellington also prepares annual summary reports documenting SoE monitoring results obtained in the last financial year. Refer to Thompson and Gordon (2010) and Tidswell et al. (2010) for the most recent annual hydrology and groundwater monitoring reports, respectively.

1.4 Terms and definitions

Several technical terms and phrases are repeatedly used in this report. Meanings are given in Table 1.1.

Table 1.1: Meaning of terms and phrases commonly used in this report

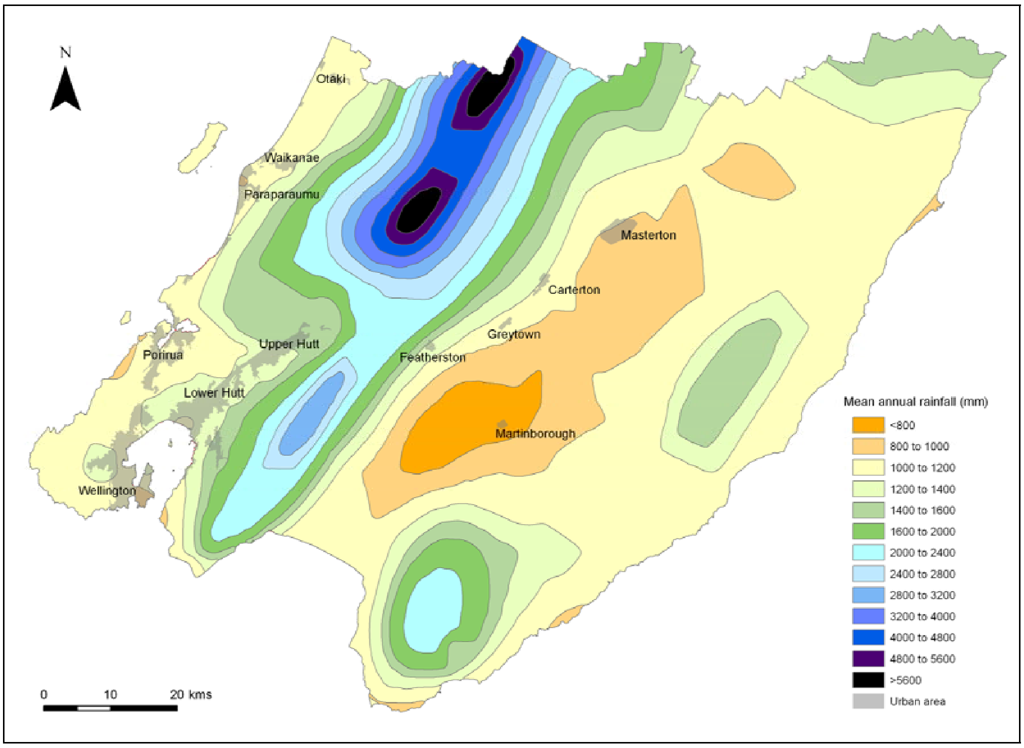
Term or phrase	Meaning
Abstraction / water take	The withdrawal of water from a river, stream, lake or groundwater aquifer by a consent holder.
Water availability	The amount of water that may be taken out of our rivers, streams, lakes and groundwater systems without compromising the life-supporting capacity and other identified critical values associated with individual water bodies. Water availability is determined by regional plan flow policies and rules.
Environmental flow	The amount of water in a river or stream that is deemed necessary to protect specified environmental values. The 'minimum flow' is an example of an environmental flow.
Minimum flow	A flow threshold specified for rivers and streams in a regional plan, below which all abstraction must cease. Minimum flows are commonly set as a proportion of a low flow statistic, such as mean annual low flow.
Mean annual low flow (MALF)	The average of the annual flow minima for a given river or stream. MALF is often used as a reference to set low flow policies.
Allocation (limit)	The amount of water that has been authorised by resource consent for abstraction from an aquifer or catchment. The allocation limit describes the maximum sustainable amount of water that can be abstracted.
Core allocation	The total amount of water in a catchment that has been authorised for abstraction at any time flow is above the minimum flow (but below the 'supplementary flow' (see definition below)).
Supplementary allocation / supplementary flow	'Supplementary allocation' is the total amount of water in a catchment (in addition to core allocation) that has been authorised for abstraction at times when flow exceeds the 'supplementary flow' threshold.
Summer	In the context of this report summer equates to the irrigation season, and unless otherwise stated refers to the months of November to April inclusive.
Run-of-river take	Abstraction occurring directly from a river or stream and that has no significant storage component. To achieve a high security of supply, run-of-river takes often continue during low flow conditions
Groundwater management zone	Discrete spatial units of similar hydrogeological type that have been defined in Greater Wellington planning and technical documents.
Safe yield	The estimated annual volume of water that can be abstracted from an aquifer or groundwater management zone without resulting in long-term depletion.

2. Overview of Wellington's freshwater resources

A brief hydrological overview of the water resources of the Wellington region, and management of water allocation, is given in this section to familiarise the reader with waterbodies, groundwater management zones and issues referred to later in this report.

2.1 Rainfall

Rainfall patterns affect river flows, lake levels, groundwater levels in rainfall-recharged aquifers, and soil moisture; all of these in turn affect water availability and demand. Within the Wellington region, mean annual rainfall varies from around 700 mm in the driest parts of the Wairarapa plains, up to over 6,000 mm in parts of the Tararua Range (Figure 2.1). The areas of lowest rainfall in the Wellington region are the Wairarapa plains, eastern Wairarapa coast and the Kapiti Coast.



(Source: NIWA, based on 1981–2010 data)

Figure 2.1: Mean annual rainfall in the Wellington region

The seasonal pattern of rainfall is important for determining water availability at critical times of the year. The Wellington region has a temperate climate, with rainfall generally highest in winter and spring and lowest in summer. The driest months are usually January to April. A more detailed description of seasonal and spatial rainfall patterns of the Wellington region can be found in Watts (2005).

Section 4 contains an assessment of trends in rainfall, with a focus on summertime patterns. Specific information on notable rainfall events and recent rainfall patterns across the seasons can be found in Greater Wellington's annual hydrology reports (eg, Thompson & Gordon 2010).

2.2 Rivers and streams

Figure 2.2 shows the main rivers and streams in the Wellington region.

Rivers and streams of Wairarapa include the Ruamahanga River and all its tributaries that drain the central Wairarapa Valley (including the tributaries of Lake Wairarapa), and all rivers and streams of the eastern Wairarapa hill country. The central and southwest part of the region includes the Hutt River and its tributaries, tributaries of Porirua Harbour, and the Wainuiomata and Orongorongo rivers. The Kapiti Coast area includes the Otaki River, Waikanae River, and smaller streams such as Waitohu, Mangaone, Waimeha and Wainui streams. All these waterways flow from their source (either in the Tararua Range, foothills or springs) directly to the coast.

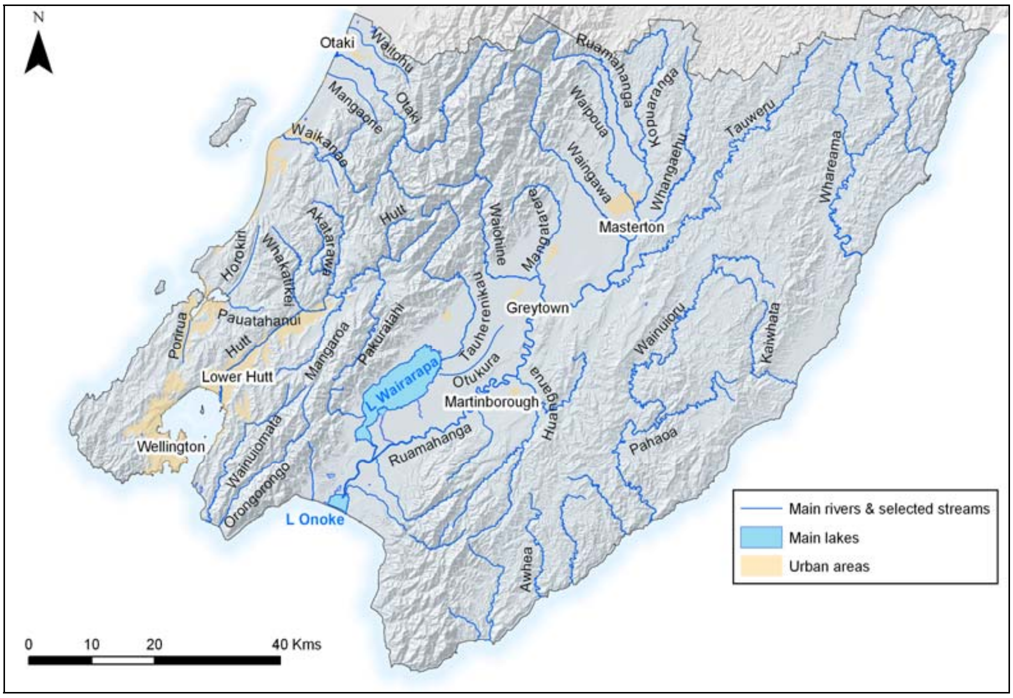


Figure 2.2: Main rivers and selected streams of the Wellington region

Seasonal variations in river flows are controlled by both rainfall and catchment characteristics. Most rivers and streams of the Wellington region tend to have their highest 'average' flows (such as mean monthly flows) during winter, although rivers with catchments in the Tararua Range tend to have a secondary flow peak during spring caused by prevailing westerly frontal rainfall events at that time of the year. The lowest flows for the year tend to occur during the period January to April.

The focus of this report is water resource availability, which is largely affected by low flows because most water takes from rivers in the Wellington region are 'run-of-river' takes (ie, there is no associated storage). To give an indication of how low flows vary across the region, mean annual low flows (the average of the lowest flow measured in each year of the monitoring record) at river mouths are shown in Figure 2.3[2]. Although some of the rivers of the eastern

[2] In this report, the 7-day mean annual low flow is generally used; that is, the annual lowest flow averaged over a 7-day period. In most cases, mean annual low flows have been extrapolated from monitoring site locations to the river mouths using flow gauging information.

Wairarapa hill country have large catchments, their mean annual low flows are very low; some of these waterways frequently dry up during times of low flow.

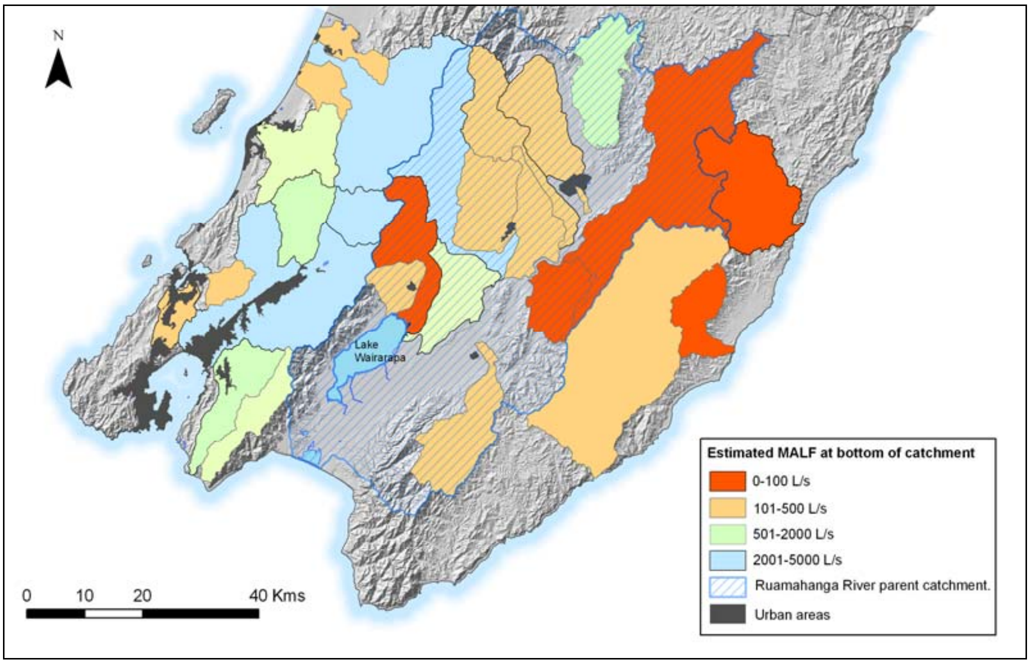


Figure 2.3: Mean annual low flow (MALF) statistics for the catchments of main rivers and streams in the Wellington region (based on estimated bottom of catchment flow statistics from Keenan 2009a and Thompson 2011a). Estimated MALF at the bottom of the Ruamahanga River parent catchment is 12,000 L/s

Water availability for high flow takes (such as for filling storage dams) is influenced by the frequency of freshes and floods. However, high flow takes currently make up a very small proportion of water allocation in the Wellington region, and so trends in flood magnitude and frequency are not analysed in this report.

An assessment of trends in river low flows during the last 30 years can be found in Section 4. Analysis of low flows during recent droughts, as well as descriptions of recent flood events, can be found in Greater Wellington's annual hydrology monitoring reports (eg, Thompson & Gordon 2010).

2.3 Lakes

Although there are a number of lakes in the Wellington region, only Lake Wairarapa is mentioned in this report. Lake Wairarapa is by far the largest lake in the region, and is the only lake from which water is allocated for use (although the abstractions are from connected drains and channels rather than directly from the open lake itself).

Lake Wairarapa is situated at the southern end of the Ruamahanga River catchment (Figure 2.2). It is a large (80 km^2) lake and its hydrological characteristics have been highly modified, with the outflow to Lake Onoke being controlled by barrage gates. The main inflows to the lake are from the Tauherenikau River, small streams, and groundwater, although work is currently commencing to quantify the importance of different inflow mechanisms and derive a water balance for the lake.

Lake Wairarapa levels tend to be highest in winter and spring, when inflows are highest. The operation of the barrage gates to control the water levels in the lake are largely driven by the need to maintain target lake levels, as defined in Greater Wellington's Regional Freshwater Plan (RFP, Wellington Regional Council 1999), and control floodwaters. Analysis of recent patterns in Lake Wairarapa water levels can be found in Greater Wellington's annual hydrology monitoring reports (eg, Thompson & Gordon 2010).

2.4 Groundwater

There are three principal groundwater areas in the Wellington region: Wairarapa Valley, lower Hutt Valley and Kapiti Coast. Secondary groundwater areas include upper Hutt Valley, Mangaroa Valley, Wainuiomata Valley and sections of the eastern Wairarapa coastline. For analysis of water allocation statistics in Section 3, the groundwater areas are grouped into three sub-regions: Wairarapa, Central and Kapiti Coast. The Central groundwater sub-region comprises the groundwater systems of the Hutt, Mangaroa and Wainuiomata valleys.

Detailed descriptions of the geological setting of each of the major groundwater areas can be found in Jones and Baker (2005), and Gyopari and McAlister (2010a, 2010b & 2010c); only a brief overview of the recharge mechanisms and productivity is given here.

The complex system of aquifers in the Wairarapa Valley may be classified into three broad categories: alluvial fan deposits, reworked river gravels and stratified lower valley deposits (Jones & Baker 2005). The alluvial fan deposits are poorly sorted gravel and sand that form low transmissivity aquifers predominantly recharged by rainfall. In the northern Wairarapa Valley these gravels are transversed by active faults, and springs are common at the base of the fault scarps. These springs supply a number of small streams in the valley.

The reworked river gravels are found alongside the large waterways of the Wairarapa Valley and form highly productive unconfined aquifers. These aquifers are in direct connection with surface water and loss of flow from the rivers (into the aquifers) is the dominant recharge mechanism.

The stratified deposits of the lower Wairarapa Valley comprise sand and gravel layers separated by fine-grained marine sediments. These thin sand and gravel layers form a series of productive confined aquifers. The recharge mechanism for these aquifers is thought to be a combination of rainfall and river losses – rainfall recharge from the Tauherenikau Fan to the north and the sides of the valley and river losses primarily from the Ruamahanga River. Discharge from the lower valley aquifers is thought to be limited as the degree of connection with the sea is likely to be constrained geologically (Hughes and Gyopari 2011)

The aquifers of the lower Hutt Valley were formed by the thick accumulations of gravel deposited by the Hutt River. The primary aquifer of the valley is found in the Waiwhetu gravels, and is separated into an upper and lower aquifer, recharged by the Hutt River. The upper Waiwhetu aquifer is highly productive with transmissivity values as high as 35,000 m^2/day (Jones & Baker 2005).

The Kapiti Coast groundwater area has three broad types of aquifers associated with different types of deposits: recent river gravels, glacial and interglacial deposits, and post-glacial beach and dune sand deposits. The aquifers present in the recent river gravels of the Otaki River, Waikanae River and Waitohu Stream are recharged by the surface waterways and are high-yielding. The confined aquifer system associated with glacial and interglacial deposits is predominantly rainfall-recharged and moderate-yielding. At the coast, aquifers associated with the dune sands are low-yielding and rainfall is the dominant recharge mechanism.

2.5 Monitoring water quantity

Greater Wellington operates State of the Environment (SoE) hydrological monitoring programmes that include 50 rainfall, 45 river level/flow and, 146 groundwater level sites, as well as several wetland level, lake level, and soil moisture sites. The information collected is important for:

- Detecting long and short-term trends in climate and water resources;
- Providing warning of floods and information during droughts;
- Regional policy and plan development and review; and
- Assessing resource consent applications and monitoring the effects of active resource consents.

The hydrological trend analysis in Section 4 of this report focuses on rainfall, river flows and groundwater levels using data collected from Greater Wellington's monitoring networks (supplemented with hydrological data from NIWA).

All of Greater Wellington's long-term SoE hydrological monitoring sites are shown in Figures 2.4–2.7 and site details are listed in Tables A1.1–A1.5 of Appendix 1. The specific monitoring sites used in the trend analyses are outlined in Section 4.

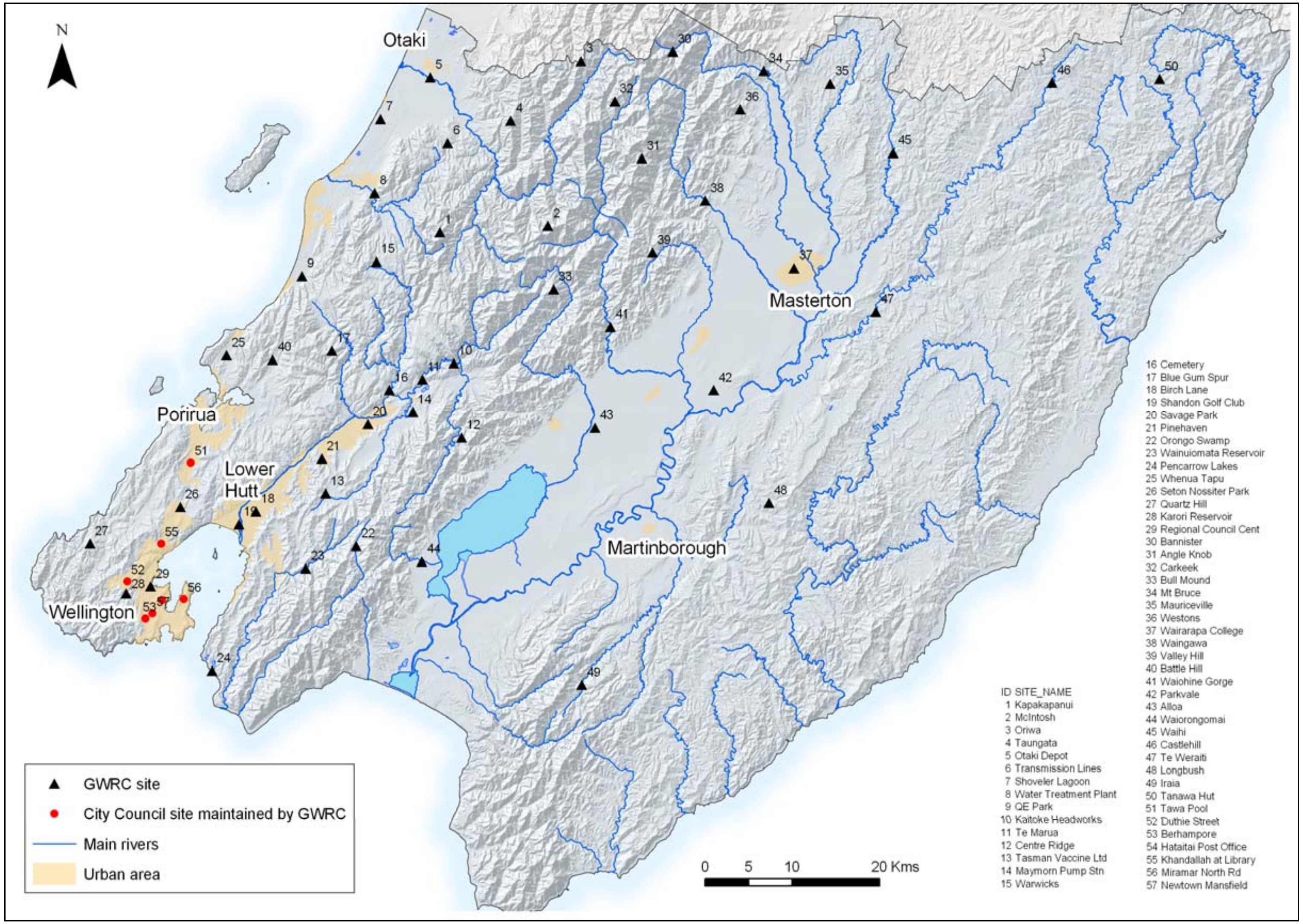
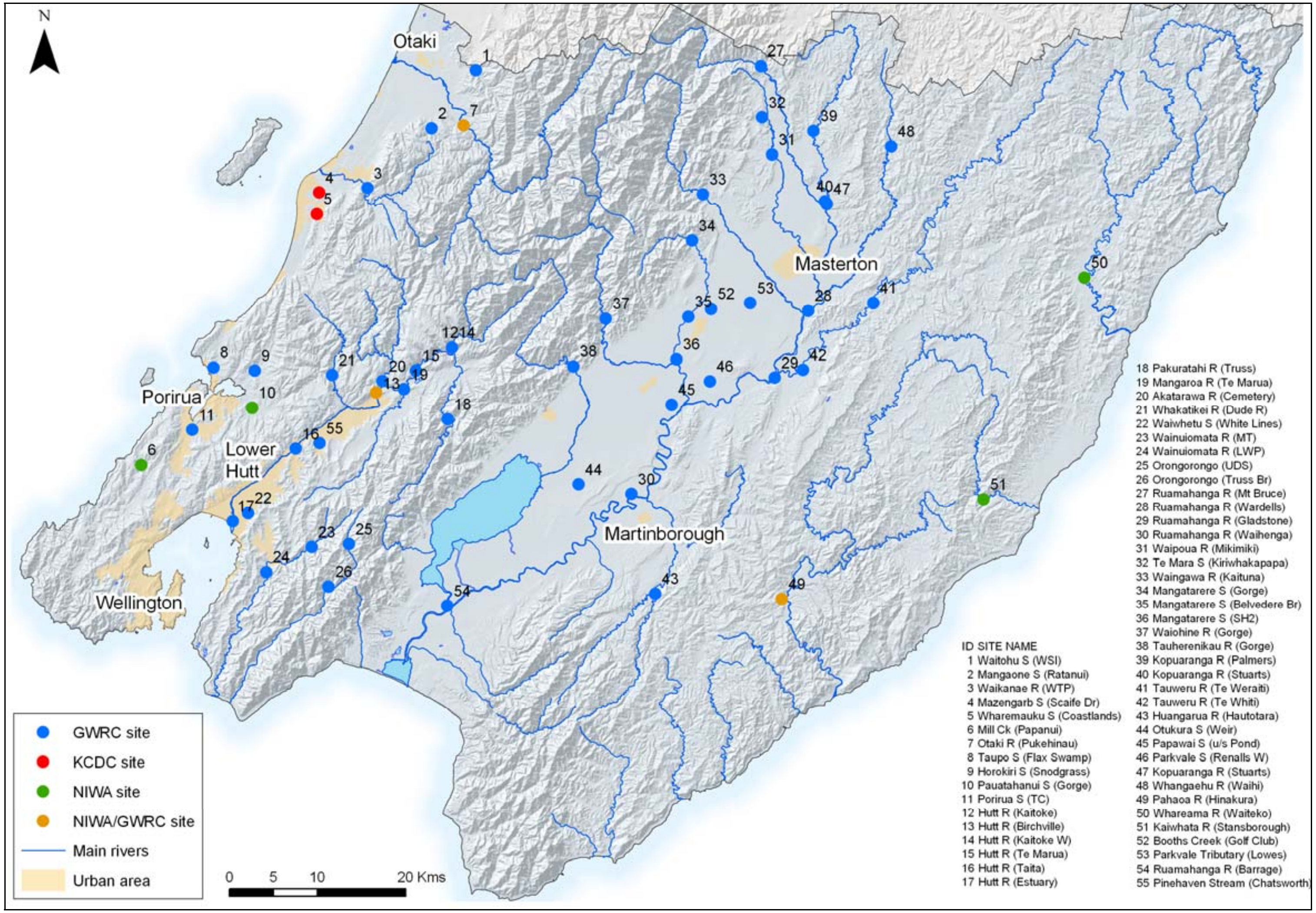


Figure 2.4: Location of Greater Wellington's (GWRC) automatic rainfall monitoring sites (as at December 2011)



Note: Only water level (stage height) is measured at sites Hutt River at Estuary (ID=17) and Ruamahanga River at Barrage (ID=54). Both these sites are heavily influenced by tides.

Figure 2.5: Location of automatic river level monitoring sites in the Wellington region (as at December 2011)

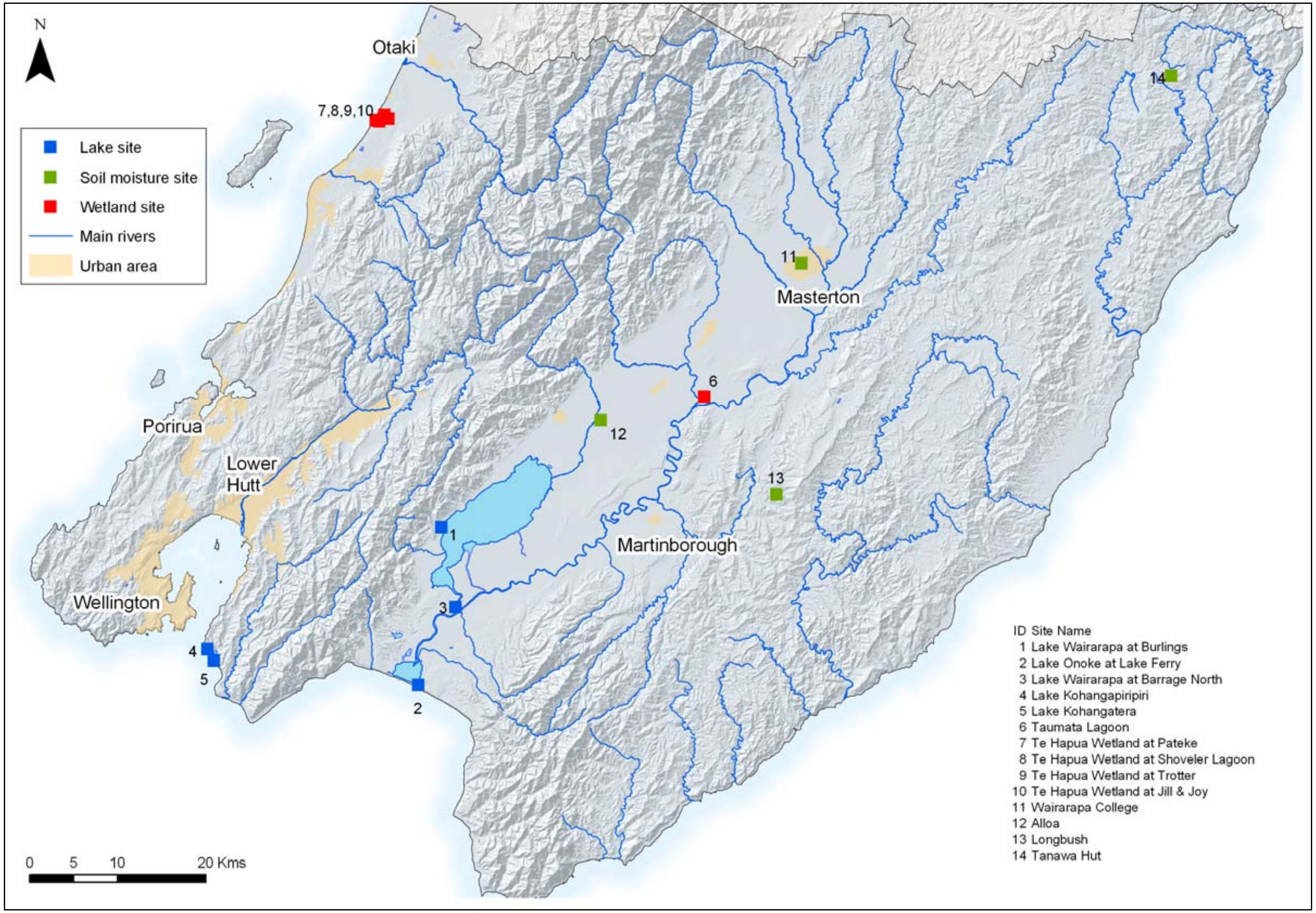


Figure 2.6: Location of Greater Wellington's automatic lake level, wetland level, and soil moisture monitoring sites (as at December 2011)

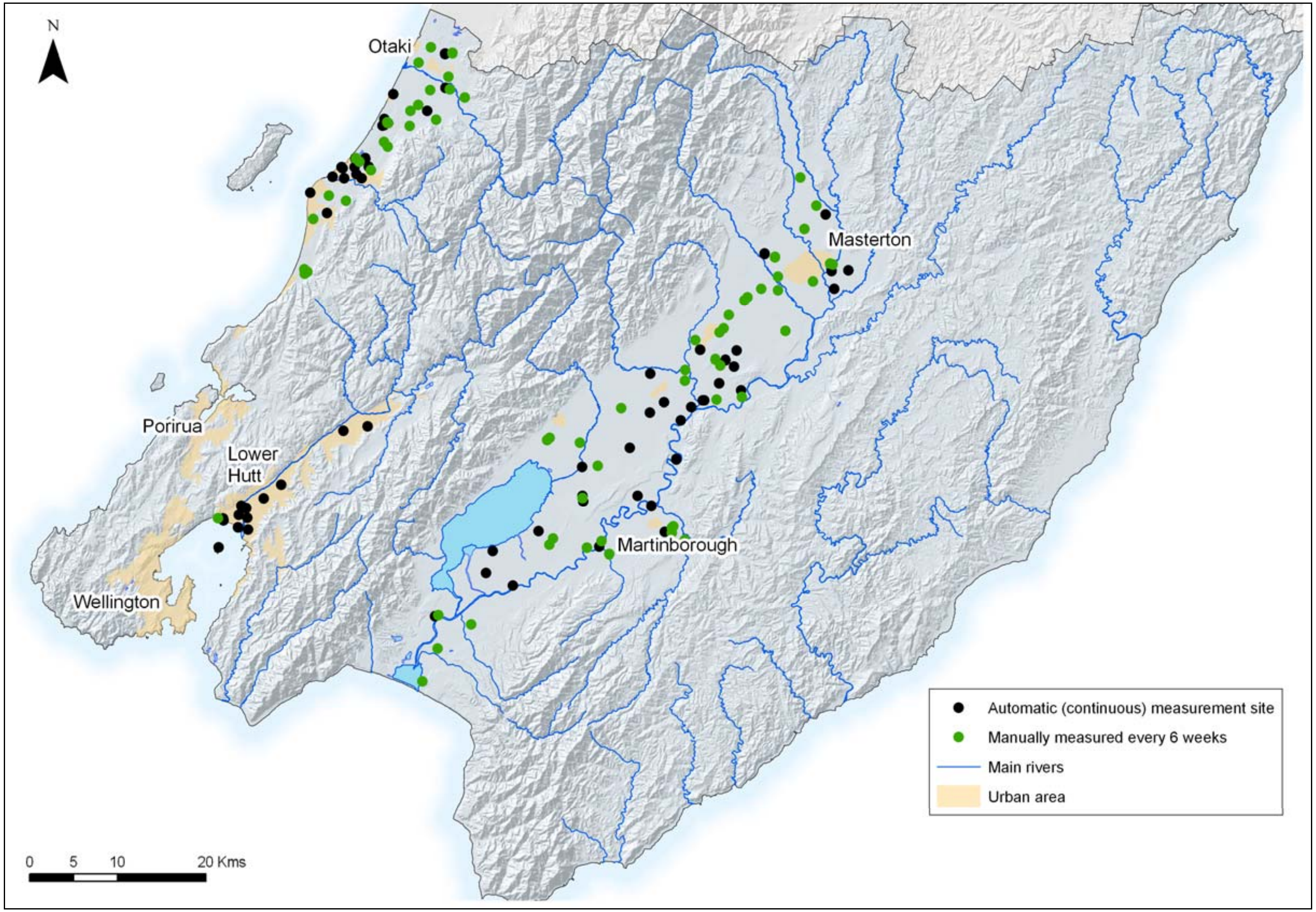


Figure 2.7: Location of Greater Wellington's groundwater level monitoring sites (as at December 2011)

2.6 Water allocation management in the Wellington region

2.6.1 General aspects of water allocation management

The basis of water allocation management for the Wellington region is Greater Wellington's RFP (WRC 1999), which became operative in 1999 with subsequent changes to allocation provisions becoming operative in September 2006 (Plan Change 2), March 2007 (Plan Change 1) and May 2009 (Plan Change 3). Rule 7 of the RFP specifies that 'minor abstractions' of less than 20,000 L/day of water (from rivers, streams, lakes or groundwater systems) are a permitted activity, provided some conditions are met (including that the abstraction occurs at a rate of less than 2.5 L/s). Water taken under permitted activity rules is primarily used for domestic purposes and stock drinking water. Any abstraction that does not meet permitted activity conditions must be authorised by a resource consent. This report focuses on water allocated through resource consents and does not make any analysis of quantities or effects of water abstracted under the RFP permitted activity rule.

Greater Wellington is required to assess resource consent applications to take water against the relevant policies of the RFP. These policies include allocation limits for water bodies and environmental flow regimes for surface waterways (eg, minimum flows and 'step down' flows); these are explained in Section 2.6.3 and 2.6.4.

2.6.2 Water allocation vs actual use

Resource consents to abstract water in the Wellington region have historically specified an instantaneous or maximum daily abstraction rate, as well as a maximum weekly and seasonal or annual allocation volume (in the case of groundwater takes). While resource consents to take water for irrigation purposes usually specify when during the year the take can occur (usually October to April), in general the daily and weekly maximum allowable rate of take is constant through this period. Similarly, most resource consents to take water for public water supply do not have variable rates of take through the year; therefore the annual allocation is generally related to the maximum rate of take required during the time of highest demand.

The actual amount of water abstracted under resource consents in the Wellington region is largely unknown, because not all water takes are metered. It is estimated, from resource consent records, that around two-thirds (64%) of consented takes have water meters. Historically, not all of the users have been required to send in abstraction records, nor have Greater Wellington staff been required to regularly check and read all meters – the focus has been in highly-allocated catchments or groundwater zones. However, Greater Wellington is currently taking steps to expand water metering in line with the national regulation for water metering (this regulation came in to force in 2010 – see Section 5.3.4).

A recent analysis of estimated and measured groundwater use for irrigation in the Wairarapa found that, over the period 2002 to 2008, most users took between only 10% and 30% of the seasonal allocation (ie, total for the irrigation season) specified on their resource consent (Gyopari & McAlister

2010c). However, a targeted study in 2006/07 (which was not a particularly dry irrigation season) found that in the dry peak of the irrigation season, the daily abstraction rate was up to 80% of that specified in the resource consent (Baker & King 2007). Overall, these findings indicate that water use for irrigation is likely to be significantly less on a seasonal or annual basis than the consented volume, but may be approaching (or reach) the consented maximum daily volumes in the peak of the irrigation season during particularly dry years. Similarly, brief assessment of consented public water supply abstraction records shows that during times of peak demand (ie, at the warmest and driest times of the year) water supply consent holders tend to abstract up to the maximum consented daily amount. However, on an annual basis the volumes abstracted are usually significantly less than the maximum consented volumes.

The inconsistency between actual use and consented water allocation in the Wellington region is important to bear in mind when reading the allocation and water availability analysis in Section 3 and the discussion presented in Section 5. All the analyses presented in this report relate to amounts of water *allocated* rather than the amounts actually abstracted.

2.6.3 Surface water quantity management

Policy 6.2.1 of the RFP specifies 'core allocations' for a selection of rivers and streams in the Wellington region. The core allocation is the amount of water that may be allocated for use during 'normal' (moderate to low) flow conditions. Core allocations and groundwater safe yields (explained in Section 2.6.4) are collectively referred to in this report as 'allocation limits'. Policy 6.2.1 also specifies flow-related abstraction thresholds for the selected rivers. These thresholds are:

- The step-down flow – this is the flow at which the core allocation must reduce (often by around half of the instantaneous rate) to reduce impacts on the instream environment during times of low flow;
- The minimum flow – this is the flow that Greater Wellington aims to retain in the river; often resource consents specify that the water take must cease or further reduce when this flow is reached.
- The supplementary flow – this is the flow above which the core allocation no longer applies; ie, Greater Wellington may allocate additional water beyond the amount specified by the core allocation (the aim of this part of the policy is to allow more takes to occur during higher river flow conditions).

Because high flow takes occur above the supplementary flow threshold, such takes are often referred to in this report as supplementary takes. Essentially, these are takes that are not counted as part of the core allocation, and are not allowed to operate during moderate to low flow conditions.

As noted above, Policy 6.2.1 covers a selection of rivers and streams only: generally those which had been the focus of environmental assessments prior to the time the RFP became operative in 1999. Policy 6.2.1A, which was added via a change to the RFP that became operative in May 2009, specifies capped allocation limits for a few highly-allocated streams in the Wairarapa (this policy essentially capped the allocation at the 2009 level). Water allocation for rivers and streams not covered by either Policy 6.2.1 or 6.2.1A is generally assessed on a case-by-case basis, in some cases by considering recently completed environmental assessments of sustainable allocation limits[3]. For a discussion of issues relating to allocation limits for rivers and streams see Section 5.3.1.

2.6.4 Groundwater quantity management

Policy 6.2.3 of the RFP sets out groundwater management zones for the Wellington region. There are seven groundwater management zones for the Kapiti Coast, three for Wainuiomata, seven for the Hutt Valley, and 29 for Wairarapa (Figure 2.8). Within some of the management zones there are sub-zones and/or aquifers of different depths. Policy 6.2.3 also specifies annual safe yields for each zone (or aquifer); this is the maximum amount of water that may be allocated from the aquifer on an annual basis. In most cases, the safe yield is based on a proportion of the estimated average annual recharge to the groundwater zone.

The groundwater management zones for the Wairarapa Valley that are referred to in the RFP are currently being reviewed and a draft management framework has been proposed (Hughes & Gyopari 2011) with new groundwater management zones (Figure 2.9). Hughes and Gyopari (2011) recommended a range of allocation limits for each management zone, and at this stage there have not been any decisions on which allocation limit to propose for each zone as part of the regional plan review process. Therefore, in Section 3, Wairarapa groundwater allocation and availability are assessed against both the existing safe yields in the RFP and the proposed range of allocation limits in Hughes and Gyopari (2011).

One of the objectives of the proposed Wairarapa groundwater management framework (Hughes & Gyopari 2011) is to ensure that the effects of groundwater abstraction on hydraulically-connected waterways (such as wetlands, spring-fed streams, and rivers and streams that discharge to or receive recharge from groundwater aquifers) is minimised – or at least is taken into account when resource management decisions are made. The proposed framework specifies categories of groundwater (A, B and C) which have different degrees of hydraulic connectivity with surface water. Category A represents direct connectivity (eg, shallow gravel aquifers alongside rivers), and groundwater abstraction from Category A areas are proposed to be managed under surface water allocation policy. Category B areas have moderate to high connectivity with surface water bodies, and it is proposed that a proportion of the take from these areas be managed as surface water allocation, with the remainder counted as part of the groundwater allocation limit. In general, all the allocation from Category C areas will be counted against the relevant groundwater allocation limit. To ensure regional consistency in groundwater management, work on proposals for surface water – groundwater management framework for other parts of the Wellington region is underway (Hughes in prep & Hughes et al. in prep).

---

[3] Greater Wellington has an instream flow assessment programme for progressively reviewing or assessing environmental flow requirements, and such assessments usually include an analysis of water allocation compared to hydrological characteristics. Recent examples of instream flow assessments are Keenan (2009b & 2009c) and Thompson (2011b).

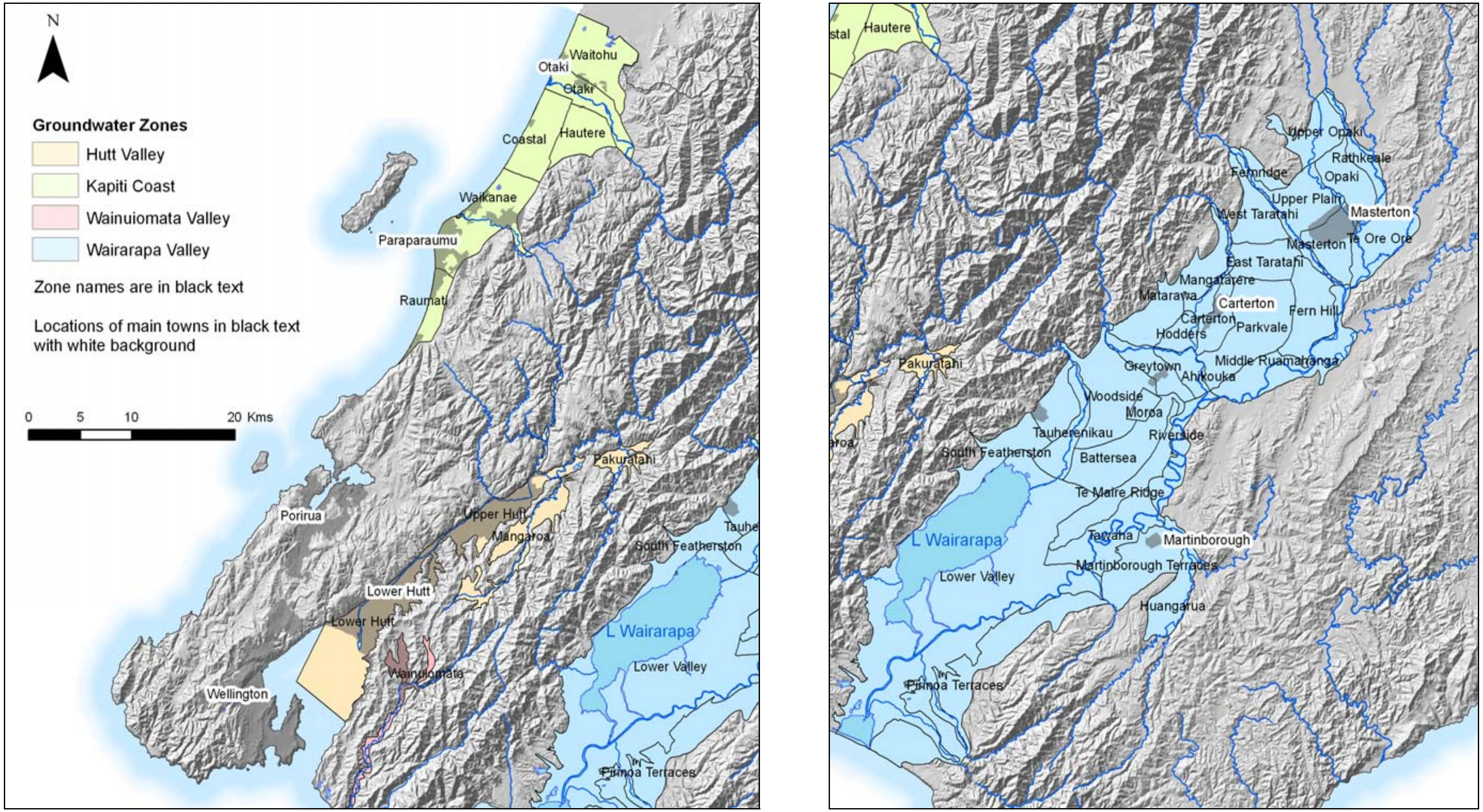


Figure 2.8: Existing groundwater management zones for the Wellington region (western zones in the left panel and Wairarapa zones in the right panel), as set out in the Regional Freshwater Plan (WRC 1999)

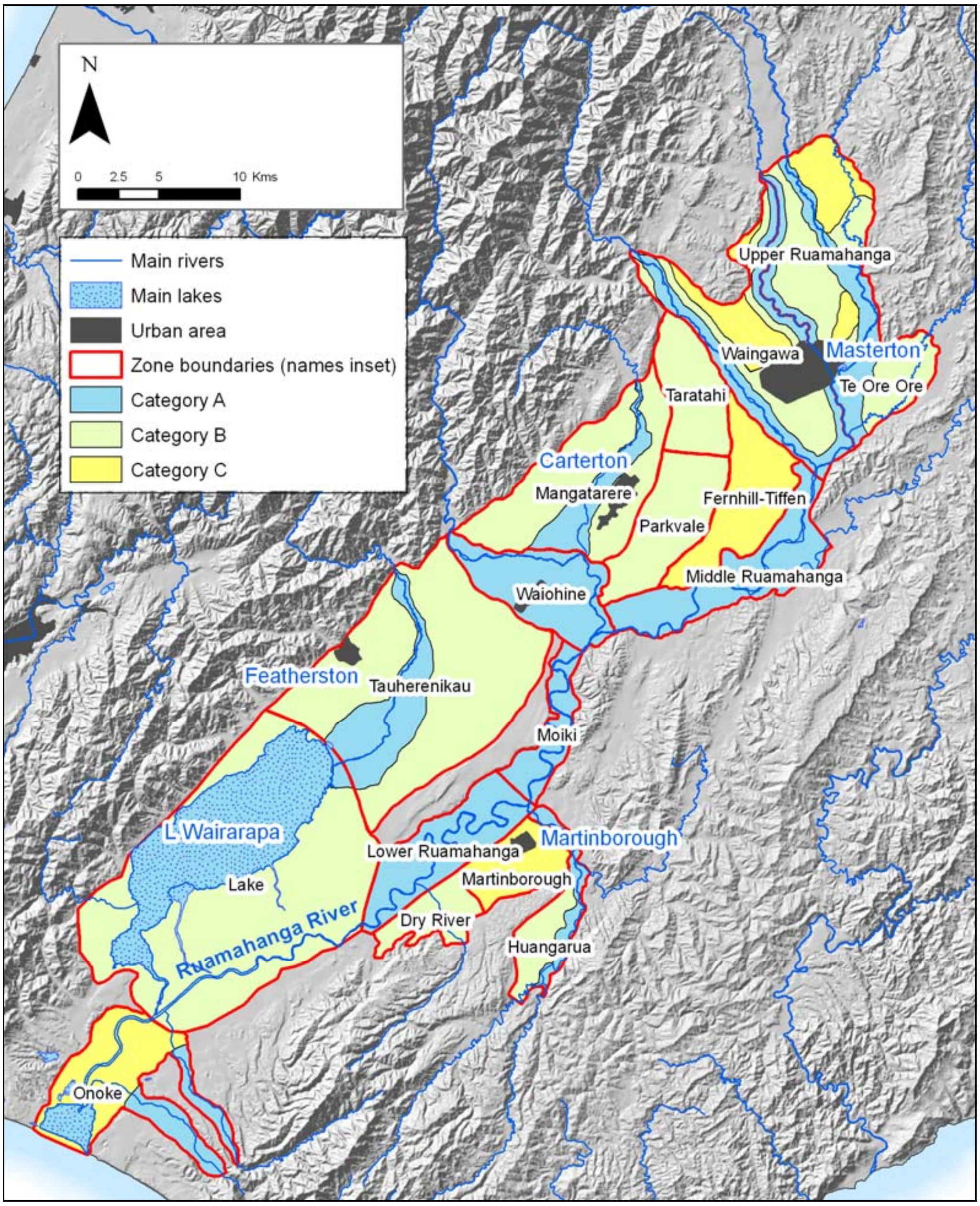


Figure 2.9: Proposed new groundwater management zones and abstraction categories (A, B, C) for the Wairarapa Valley (from Hughes & Gyopari 2011)

While the management of groundwater takes that affect surface water using the three categories described (A, B and C) is only proposed at this stage, the water availability analysis in Section 3.3 considers the effects of the proposal on future water availability – both from a surface water and groundwater management perspective.

3. State and trends in water allocation and availability

This section discusses the patterns in water allocation across the Wellington region and what the water is used for (Section 3.1), trends in water allocation over the last 20 years (Section 3.2), and remaining water availability (Section 3.3). Information is presented on a sub-regional basis according to the general division of area shown in Figure 3.1.

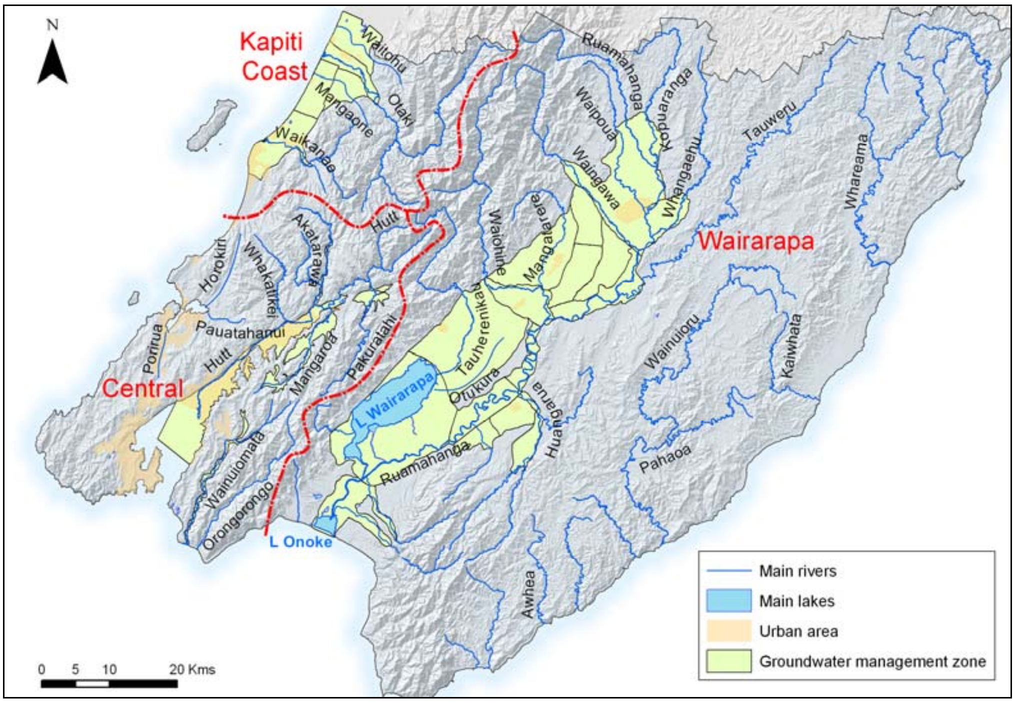


Figure 3.1: Sub-regions, main rivers and groundwater management zones of the Wellington region

3.1 Approach to assessment

Greater Wellington stores information on resource consents for taking water in the 'Ozone' database and in related water allocation spreadsheets. These information sources were used to determine the numbers of consents, water abstraction rates, and purpose for which the water is abstracted (although assumptions had to be made regarding abstraction purpose in some cases). Resource consents active at the end of 2010 were included in the analysis for this report.

Due to the configuration of Greater Wellington's resource consent database, the water allocation trend analysis in Section 3.3 contains two assumptions. Firstly, the analysis is of active resource consents only and it is assumed that there have been no surrendered or lapsed resource consents for taking water during the last 20 years. Although this will not actually be the case, anecdotal evidence suggests that resource consents for taking water are seldom surrendered or lapse and the total amount of water involved is likely to be very minor in relation to the total volumes in the analysis. Secondly, for replacement or 'renewed' resource consents, the date the water take was originally consented sometimes had to be assumed. Although it is unlikely that the assumptions have largely affected the accuracy of the water allocation data, it is suggested that the trends in consented abstraction presented in Section 3.3 are only *indicative* of the likely situation.

The approach taken to assess allocation levels in relation to water availability is described in Section 3.4.1.

3.2 Allocation and water uses across the region

In the Wellington region, as at the end of 2010, there were about 670 active resource consents for taking water, accounting for an annual water volume of approximately 414 million m^3/year. Of this amount, two-thirds (276 million m^3/year, 210 resource consents) is from rivers, lakes and streams, and the remaining third (137 million m^3/year, 460 resource consents) is from groundwater. Of the amount allocated from surface water sources, most (97%) is 'run-of-river'; ie, allocated from rivers, streams and lakes during 'normal' flow conditions, around 2% is high-flow (or 'supplementary') water allocation, and less than 1% is from storage dams.

3.2.1 General patterns in water allocation

Table 3.1 shows a breakdown of annual water allocation volumes and water take resource consent numbers by general source and sub-region. The Wairarapa has 67% of the groundwater and 61% of the surface water allocation for the Wellington region, and 78% of the resource consents to take water. In most parts of the region the annual volume of water allocated from surface water sources exceeds that from groundwater, except on the Kapiti Coast (Figure 3.2).

Table 3.1: Annual water allocation and water take consent numbers in the Wellington region as at December 2010, shown by sub-region

	Wairarapa		Central		Kapiti Coast	
	Annual allocation (million m^3/year)	Number of consents	Annual allocation (million m^3/year)	Number of consents	Annual allocation (million m^3/year)	Number of consents
Surface water	186.4	175	78.4	24	11.5	11
Groundwater	83.9	346	36.2	30	17.2	84
Total	*270.3*	*521*	*114.6*	*54*	*28.7*	*95*

Figure 3.3 shows the Wellington region's annual surface water and groundwater allocation divided into use types. Water supply accounts for around 41% of the surface water allocation and 36% of groundwater allocation; this includes public (municipal) water supplies and privatised community water schemes. Water allocation for irrigation is also significant, at about 24% of the total surface water allocation and 60% of the groundwater allocation. There are no other significant use types for allocated groundwater. However, other significant uses of surface water are the Wairarapa water races[4] (19% of the

[4] The Wairarapa has a network of six agricultural water races that were constructed in the first half of the 20th century for distributing water, primarily for stock drinking water purposes. The races have intakes from the upper reaches of rivers and discharge any remaining water at the

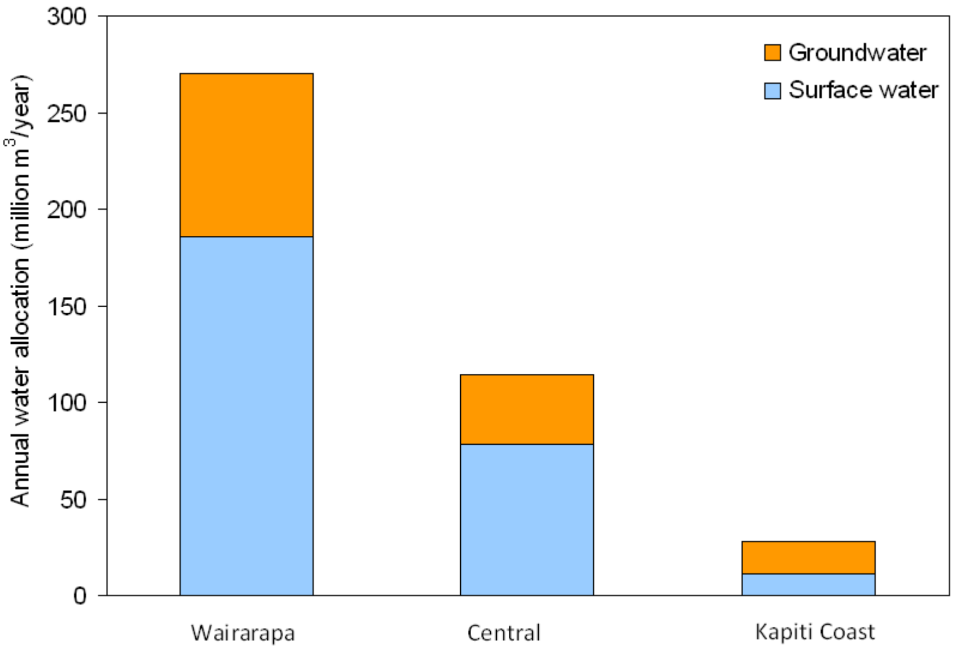


Figure 3.2: Annual (consented) allocation of groundwater and surface water in the sub-regions of the Wellington region, as at December 2010

total surface water allocation) and hydroelectricity generation (nearly 14% of the total surface water allocation)[5]. Surface water allocation for industry, frost protection and filling ornamental lakes (shown as 'Other' surface water use in Figure 3.3) accounts for less than 5% of the total annual allocation. There is also a small amount of consented water allocation for domestic use, which includes private water supply, stock drinking water and dairy shed washdown. Because water abstraction for these uses is usually classed as a permitted activity, the amount consented for domestic use is less than 0.1% of the annual surface water and groundwater allocation.

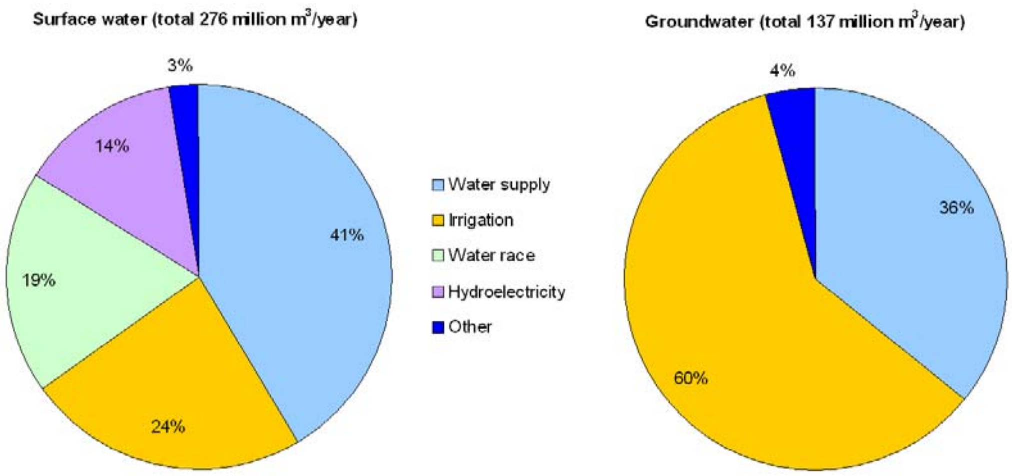


Figure 3.3: Break-down of consented surface water and groundwater allocation in the Wellington region by use type

bottom end of the network into various streams and rivers. However, the consented take at the intake is considered to be the total allocation for this assessment, because the discharge volumes vary significantly over time.

5 Nearly all of the hydroelectricity generation allocation is for the Kourarau Power Scheme, and is classed as 'non-consumptive' allocation because there is discharge back to the catchment. For this reason the Kourarau allocation is excluded from some of the analyses in this report.

Table 3.2 shows the water allocation divided into the major use types for the three sub-regions. For the Wellington region as a whole, water supply and irrigation are allocated similar volumes of water on an annual basis, accounting for about 40% and 36% of the total allocation respectively. However, in the Kapiti Coast and Central sub-regions, water supply is the dominant water use. Irrigation accounts for around one-fifth of water allocation on the Kapiti Coast but is not significant in the Central sub-region. Conversely, in the Wairarapa irrigation is the most significant use, accounting for just over half of the annual water allocation. The water races, water supplies and hydroelectricity use also have significant allocations. Frost protection accounts for less than 1% of the annual water allocation in the Wairarapa; there are no water take consents issued for this use in other parts of the region. Water allocation for industry is most significant in the Central sub-region, but overall makes up less than 2% of the annual water allocation.

Table 3.2: Annual consented water allocation in the Wellington region as at December 2010, grouped by major use type

Sub-region	Total allocation of groundwater and surface water (million m^3/year)	Water supply (%)	Irrigation (%)	Water races (%)	Hydro-electricity (%)	Industry (%)
Wairarapa	270.3	12.6	51.6	19.2	13.9	0.3
Central	114.6	94.0	1.9	-	-	4.1
Kapiti Coast	28.7	75.6	21.3	-	0.4	2.5
Total	*413.7*	*39.5*	*35.6*	*12.5*	*9.1*	*1.5*

Figure 3.3 and Table 3.2 are based on allocation of water on an annual basis. Assessing allocations on a daily basis (ie, the total of the maximum daily allowable limit for each consent) essentially indicates the proportion of water allocated to the major uses during the irrigation season because resource consents to take water for irrigation specify a season during which the water can be taken, usually from October to April. During the irrigation season, irrigation accounts for around half the water allocation for the region as a whole on a daily basis (Table 3.3), and water supply accounts for a further one-third. Note that frost protection also becomes more significant when the data are assessed on a daily basis; however, these takes only operate during spring frost conditions (which are unlikely to coincide with irrigation conditions) and are likely to only operate for a maximum of ten nights per year.

Table 3.3: Maximum consented daily water allocation in the Wellington region as at December 2010, grouped by use type

	Total allocation of groundwater and surface water (m^3/day)	Water supply (%)	Irrigation (%)	Water races (%)	Hydro-electricity (%)	Industry (%)	Frost protection (%)
Wairarapa	1,185,224	8.6	64.7	12.0	8.7	0.2	3.6
Central	342,172	92.3	3.3	-	-	3.8	-
Kapiti Coast	91,071	65.6	31.4	-	0.3	2.5	-
Total	*1,618,467*	*29.5*	*49.9*	*8.8*	*6.4*	*1.1*	*2.6*

Water allocation for irrigation can be further divided into the crop or land use type, although the statistics presented here are indicative only because the crop type is not always recorded in Greater Wellington's resource consent database. Currently around 70% of the total water allocated for irrigation in the Wellington region is for dairy pasture. A further 18% is for non-dairy pasture, 6% is for horticulture (including cropping but excluding viticulture) and 4% is for viticulture. Irrigation of recreational land (ie, sports fields and golf courses) and landscape gardens (ie, for aesthetic purposes) accounts for less than 2% of the total allocation for irrigation.

The dominant crop types, in terms of the amount of water allocated for irrigation, vary significantly between the three sub-regions (Figure 3.4). In the Wairarapa, nearly three-quarters of the water allocated for irrigation is for dairy pasture, with less significant proportions for non-dairy pasture, horticulture and viticulture. The irrigation of recreational land accounts for less than 1% of the Wairarapa's irrigation water allocation. However, in the Central part of the region, over half (58%) of the water allocated for irrigation is for recreational land uses (eg, golf courses); non-dairy pasture and dairy pasture irrigation are also relatively significant. On the Kapiti Coast, horticultural irrigation accounts for nearly half of the irrigation water allocation, and a further one-third is for dairy pasture.

The spatial variation in the use for which water is allocated across the region is a reflection of the population concentration in the major cities and towns (ie, in the Central and Kapiti Coast sub-regions) and location of agricultural activities – which are in turn a reflection of land availability, soil type and climate. A vast majority of the region's dairy farming occurs in the South Wairarapa and Carterton districts of the Wairarapa, nearly all of Wellington's vineyards are located in the Wairarapa, and there is significant horticulture around Greytown (in the Wairarapa) and on the northern Kapiti Coast. Information on how land use – particularly agriculture – varies across the region can be found in Sorensen (2012).

The spatial variation in the use for which water is allocated across the region is a reflection of the population concentration in the major cities and towns (ie, in the Central and Kapiti Coast sub-regions) and location of agricultural activities – which are in turn a reflection of land availability, soil type and climate. A vast majority of the region's dairy farming occurs in the South Wairarapa and Carterton districts of the Wairarapa, nearly all of Wellington's vineyards are located in the Wairarapa, and there is significant horticulture around Greytown (in the Wairarapa) and on the northern Kapiti Coast. Information on how land use – particularly agriculture – varies across the region can be found in Sorensen (2012).

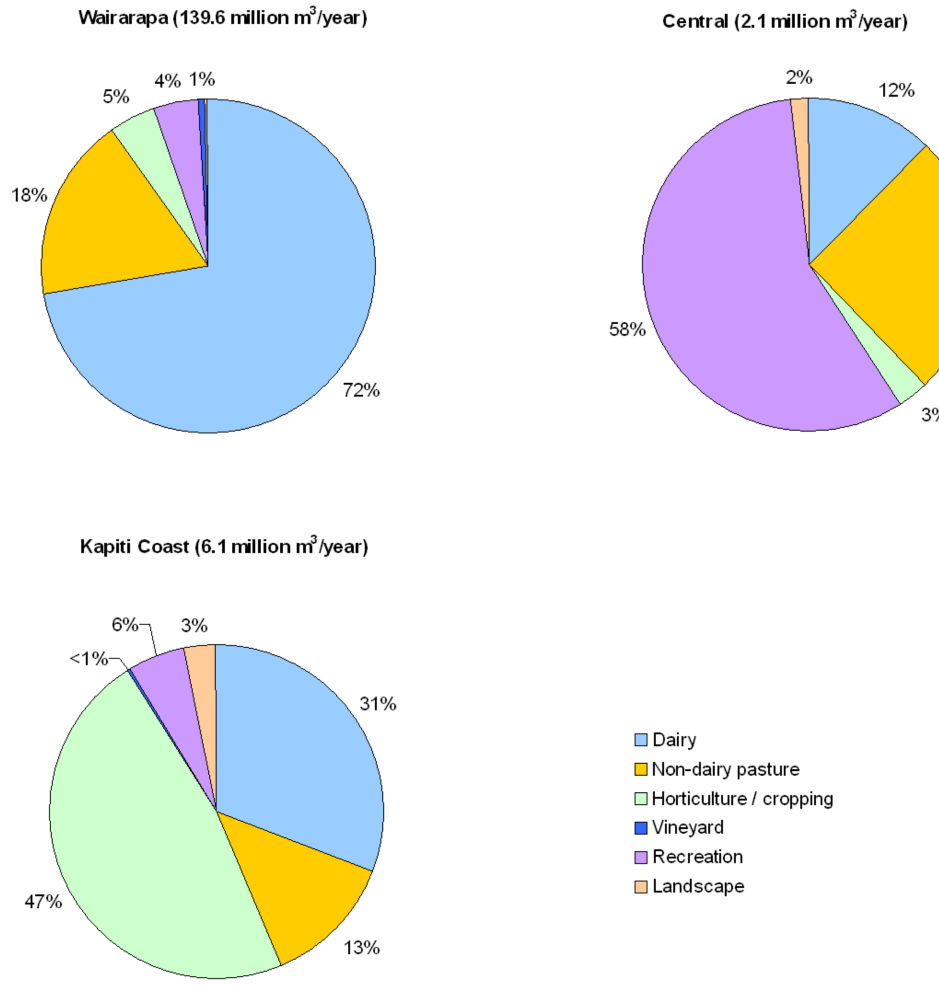


Figure 3.4: Annual water allocation for irrigation divided into crop or land use type, for the three sub-regions of the Wellington region

3.2.2 Water allocation from specific sources

Surface water sources supply around two-thirds of the Wellington region's total annual water allocation. On an instantaneous basis (which is the most appropriate way of assessing surface water allocation) the waterways with the highest allocation are the Ruamahanga River and its tributaries (7,501 L/s), Lake Wairarapa and its tributaries (1,735 L/s), the Hutt River (2,015 L/s), Wainuiomata and Orongorongo rivers (each with around 1,130 L/s) and the Waikanae River (463 L/s). The waterways most highly used within the Ruamahanga catchment are the Ruamahanga River itself (2,727 L/s), the Waingawa River (1,047 L/s) and the Waiohine River (1,042 L/s). Water allocation from the Hutt, Wainuiomata, Orongorongo and Waikanae rivers is almost exclusively for public water supply. Water allocation from the Ruamahanga River catchment is for a mix of public water supply, irrigation, water races and hydroelectricity, while allocation from the Lake Wairarapa catchment is mostly for dairy pasture irrigation.

The rivers and streams with the highest allocation are, as would be expected, those with the highest mean annual low flows (refer to Figure 2.3); the Otaki River is the only major river of the Wellington region that does not have a significant amount of allocation. However, the smaller rivers and streams are also important for providing water – particularly for irrigation. Tables of allocations from individual waterways can be found in Section 3.3.

Groundwater sources supply around one-third of the Wellington region's total annual water allocation. Groundwater is particularly important as a supply of water for irrigation, providing for 60% of the region's irrigation allocation, and 30% of the region's public and community water supply allocation.

The most highly-used aquifers are Lower Hutt, the shallow groundwater systems associated with the major Wairarapa rivers, and the deeper Wairarapa aquifers (in the lower Wairarapa Valley and Parkvale areas). A breakdown of groundwater allocation from individual management zones can be found in Section 3.3.

3.3 Trends in water allocation 1990–2010

Based on Greater Wellington's resource consent records, water allocation in the Wellington region increased from about 269 million m^3/year in 1990 to about 414 million m^3/year at the end of 2010, an increase of around 54%. Although water allocation increased throughout the 20 years, the most rapid increase was between the late 1990s and 2005 (Figure 3.5). The growth in water allocation was due to increased utilisation of both surface water and groundwater resources, although the increase in groundwater allocation was greater than the increase in surface water allocation over the 20-year period.

The following sections look at the activities that were the driving forces of the increase in water allocation over the 20 years (Section 3.3.1) and trends in water allocation from specific water sources across the region (Section 3.3.2).

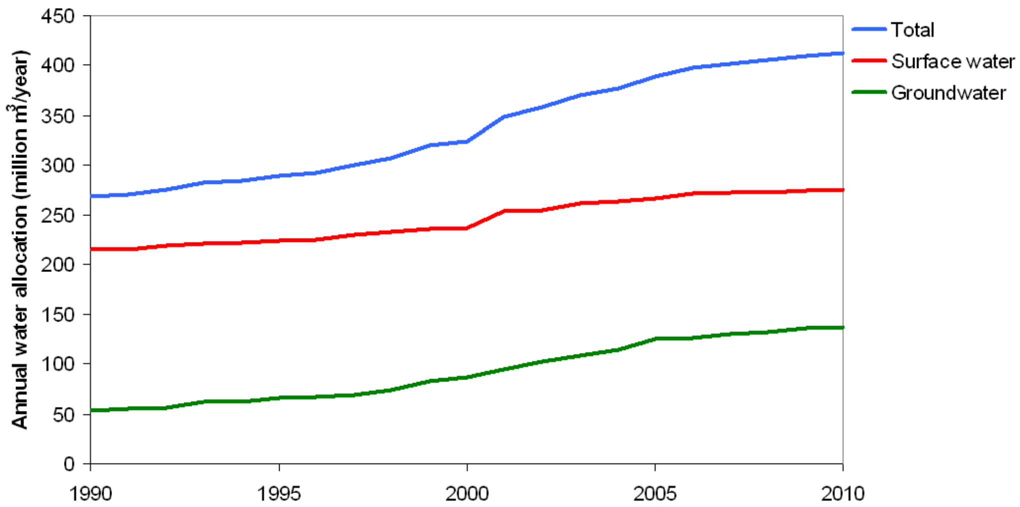


Figure 3.5: Annual consented water allocation in the Wellington region, 1990–2010

3.3.1 Trends in use types

While there was a significant increase in water allocated for public water supplies (20% of the overall increase in water allocation), the most rapid increase in water allocation between 1990 and 2010 was for irrigation (77% of the increase, Figure 3.6). Other uses were less significant in their contribution to the increase, with industry accounting for around 2% and the other uses combining to about 1% of the increase.

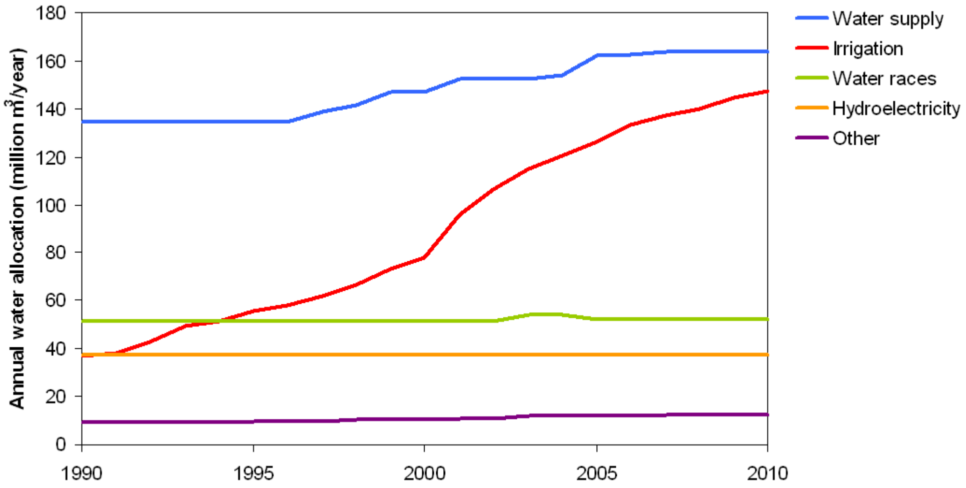


Figure 3.6: Wellington region's annual (consented) water allocation for major uses, 1990–2010

Because of the rapid increase in water allocation for irrigation, the proportions of total water allocation for different uses changed between 1990 and 2010, with a more significant proportion for irrigation in 2010 and smaller proportions for all other water uses (Figure 3.7).

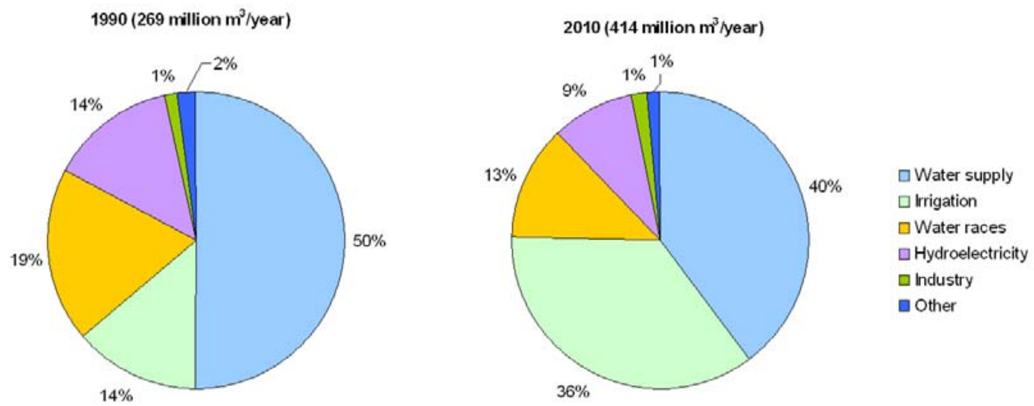


Figure 3.7: Proportions of the Wellington region's total consented water allocation for different uses in 1990 and 2010

The amount of water allocated for irrigation in the Wellington region increased four-fold over the 20-year period, from around 37 million m^3/year in 1990 to nearly 148 million m^3/year at the end of 2010. Water allocation for dairy pasture irrigation increased nearly five-fold over the twenty years (Figure 3.8), and accounts for most (73%) of the increase in water allocated for irrigation. Water allocation for non-dairy pasture irrigation also increased significantly (nearly three-fold), accounting for around 16% of the overall increase in water allocated for irrigation. Irrigation of other crop types (horticulture, viticulture, recreation and landscape) also increased, but because these have lower total allocations they contributed less to the overall increase in water allocation for irrigation. It is noteworthy that water allocation for vineyard irrigation (predominantly in the Wairarapa) increased eight-fold from around 0.8 million m^3/year in 1990 to 6.2 million m^3/year in 2010, with the most rapid increase being during the late 1990s to 2004. Linkages between these increases in irrigation and changes in agricultural activities in the region are made in Section 5.

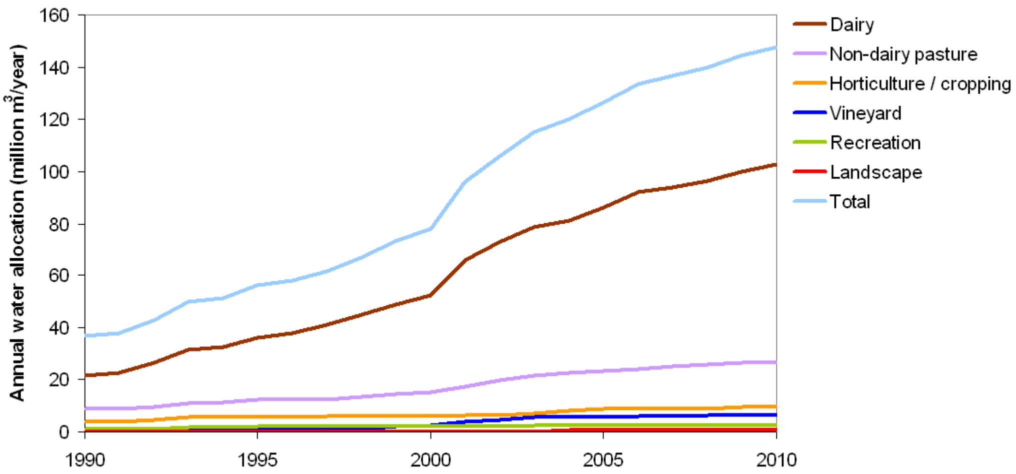


Figure 3.8: Annual consented water allocation for irrigation of different crop or land use types in the Wellington region, 1990–2010

The annual volume of water allocated for public water supply increased 22% between 1990 and 2010. Whilst there were subtle changes in the allocated volumes for many of the town and community water supplies throughout the period, three of the most significant increases occurred in 1997, 1999 and 2001 due to the re-consenting of the municipal water supply abstractions from the Waingawa, Waiohine, and Wainuiomata / Orongorongo rivers respectively, with the consents allowing for increased allocation to reflect actual or anticipated changes in demand (relating to population increases) and desired security of supply. There was also a significant increase in water allocation for water supply in 2005 due to the granting of a consent to Kapiti Coast District Council for the operation of the Waikanae borefield as a back-up water supply for Waikanae and Paraparaumu. Although this consent allows for an annual allocation of nearly 8.4 million m^3/year of groundwater, in reality it is generally only used when flows are too low for taking water from the Waikanae River.

The allocation of water for industrial use nearly doubled between 1990 and 2010 (a total increase of around 2.5 million m^3/year) although industry makes up a low proportion of the total water allocation for the region. There were only relatively small increases in the amount of water allocated for water races, hydroelectricity, ornamental lakes, frost protection and consented domestic use over the 20-year period. Although it didn't contribute significantly to the overall growth in water allocation, frost protection was a new water use in the 20-year period, with no water allocated for this use in 1990, and around 720 L/s[6] allocated from surface water sources by the end of 2010.

[6] Reported here as instantaneous rather than annual allocation, because most resource consents for this use specify a maximum instantaneous abstraction rate (usually during moderate or high river flow conditions) but no maximum annual allocation.

3.3.2 Trends across the region

Most of the increase in water allocation between 1990 and 2010 occurred in the Wairarapa (Table 3.4). In fact, during most years, the Wairarapa had more than 80% of the region's annual increase in water allocation, and over the 20-year period accounted for about 83% of the region's total increase; most of this can be attributed to the increase in irrigation, particularly of dairy pasture. Around 47% of the region's increase in allocation between 1990 and 2010 was from Wairarapa groundwater, and an additional 37% was from Wairarapa surface water sources. The increase in allocation from Kapiti Coast groundwater sources was also significant; this was mainly for public water supplies to either back-up or replace water supplies from surface water sources.

The surface waterbodies that had the largest increase in annual water allocation over the period 1990–2010 were the main stem of the Ruamahanga River, Lake Wairarapa, Wainuiomata / Orongorongo rivers[7], and Waingawa River. The increase in allocation from the Ruamahanga River alone (20.7 million m^3/year) accounts for around 35% of the region's increase in surface water allocation over the 20 years. Nearly all of the increase in allocation from the Ruamahanga River was linked to agricultural activities: 68% of the increase was for dairy pasture irrigation, 12% was for non-dairy pasture irrigation and a further 12% was increased allocation for the water races. The increased allocation from the Wainuiomata and Orongorongo rivers was for public water supply, as was most of the increase from the Waingawa River (which provides drinking water for Masterton). The individual waterbody that experienced the largest relative growth in water allocation (ie, increase in allocation relative to the amount allocated in 1990) was Lake Wairarapa, which had more than a 7-fold increase in allocation between 1990 and 2010. All of this increase was for dairy pasture irrigation.

Table 3.4: Increase in consented water allocation 1990–2010, listed by general sub-region and source

Sub-region and source	Increase 1990–2010	Proportion of the region's total water allocation increase 1990–2010
Wairarapa – surface water	52.8 million m^3/year (40% increase)	36.6%
Wairarapa – groundwater	67.4 million m^3/year (411% increase)	46.6%
Central – surface water	6.8 million m^3/year (10% increase)	4.7%
Central – groundwater	2.1 million m^3/year (6% increase)	1.4%
Kapiti Coast – surface water	0.7 million m^3/year (6% increase)	0.5%
Kapiti Coast – groundwater	14.8 million m^3/year (615% increase)	10.2%

The significance of the growth in surface water allocation from the Wairarapa Valley over the 20 years becomes even more apparent when annual surface water allocation trends are analysed on a catchment-basis (ie, combining allocation from tributaries). Surface waterbodies in the Ruamahanga catchment

[7] These two rivers are grouped together because the resource consent for Wellington's water supply specifies a maximum daily rate from all abstraction points in the two catchments combined.

upstream of Lake Onoke (ie, excluding Lake Wairarapa and its tributaries) had 60% of the region's increase in surface water allocation over the period 1990–2010 (Figure 3.9). The increase within the Ruamahanga catchment was largely due to increased allocation for dairy pasture irrigation (59%), public water supplies (20%) and non-dairy pasture irrigation (12%).

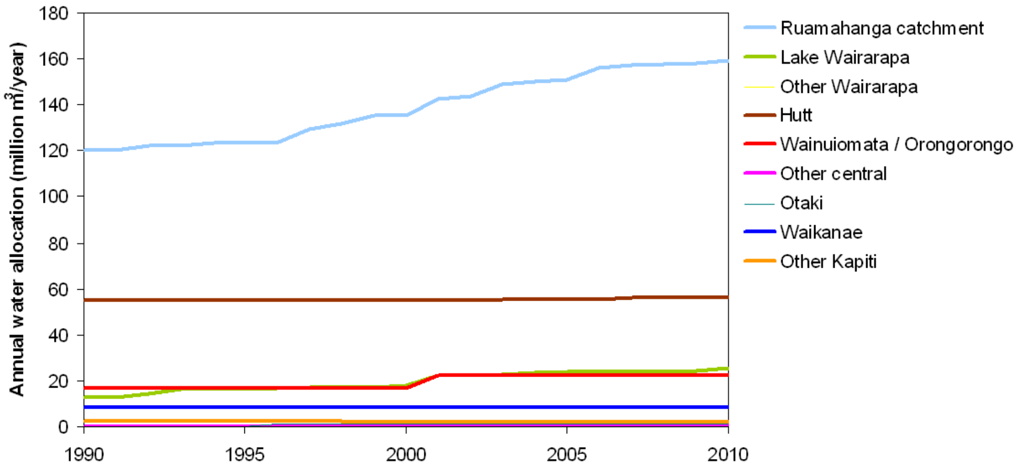


Figure 3.9: Consented surface water allocation by catchment, 1990–2010. Note Ruamahanga catchment refers to upstream of Lake Onoke (excluding the discharge from Lake Wairarapa)

Several streams and smaller rivers had significant relative increases in water allocation (ie, allocation at the end of the 20-year period compared to that in 1990), but didn't contribute significantly to the overall increase in surface water allocation (due to less flow available for allocation compared to in the major rivers). The Kopuaranga River (a tributary of the Ruamahanga River), and some of the tributaries of Lake Wairarapa (South Featherston Drains, Stonestead Creek and Otukura Stream) had 3- to 4-fold increases in allocation over the 20 years. Nearly all of the increase from these smaller rivers and streams was for dairy pasture irrigation.

Most (75%) of the region's increase in groundwater allocation during 1990–2010 was for irrigation in the Wairarapa, mainly for dairy pasture (70%), non-dairy pasture (17%) and vineyards (8%). A further 14% of the increase was for public water supply in the Kapiti sub-region. Other significant increases in groundwater allocation occurred for water supply in the Wairarapa (5% of the overall increase in groundwater allocation) and irrigation on the Kapiti Coast (3% of the overall increase in groundwater allocation).

Nearly all the groundwater management zones in the Wellington region (as defined in the RFP for Kapiti Coast and Central sub-regions, and proposed by Hughes and Gyopari (2011) for the Wairarapa) experienced at least a doubling of water allocation between 1990 and 2010, although many zones had no or very little allocation at the start of the period of analysis. The groundwater zones (or proposed zones) that had the largest increase in water allocation over the period 1990–2010 were the Lower and Middle Ruamahanga, Waiohine and Tauherenikau zones of the Wairarapa and the Waikanae groundwater zone on the Kapiti Coast. As shown in Figure 3.10, the groundwater areas with the largest increase in allocation over the 20 years are generally associated with major rivers. In fact, 61% of the Wairarapa's increase in groundwater allocation over the 20 year period came from proposed Category A groundwater areas; as explained in Section 2.6.4 (and shown on Figure 2.9) this is groundwater that is strongly connected with surface water and abstraction from these areas is likely to result in some degree of surface water flow depletion.

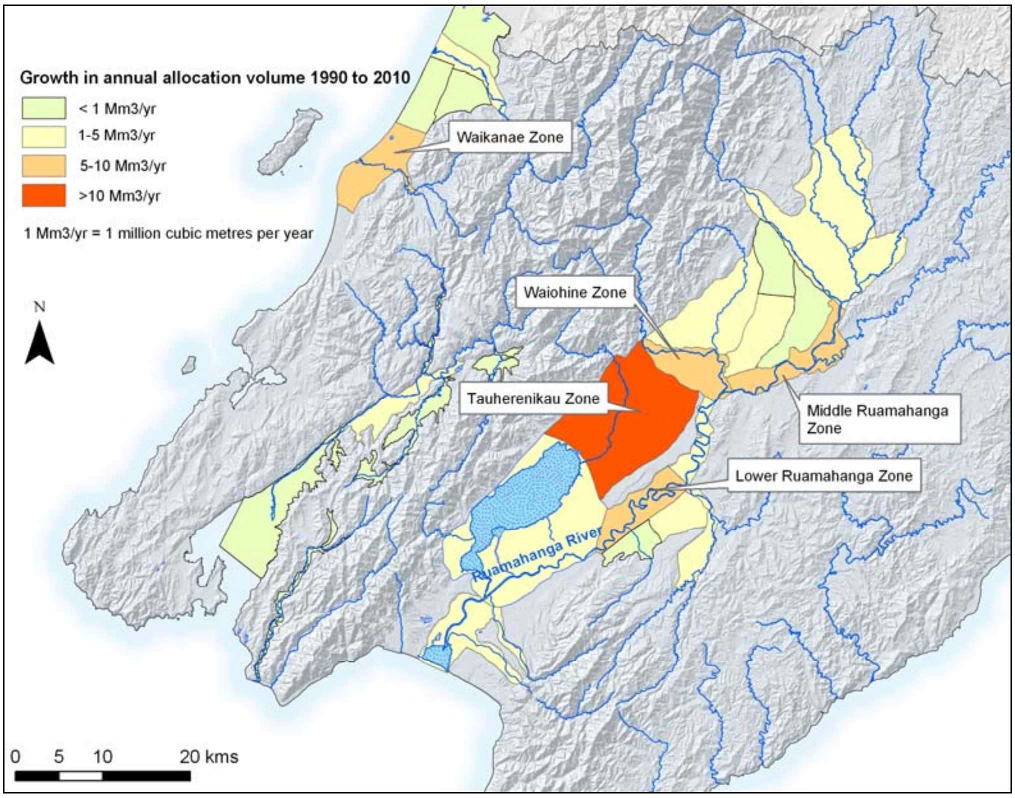


Figure 3.10: Growth in consented annual groundwater allocation volume between 1990 and 2010. Mapped units are the existing groundwater management zones for the Kapiti Coast and central regions and proposed groundwater management zones (Hughes & Gyopari 2011) for the Wairarapa Valley. Zones with the largest increase in allocation (>5 million m^3/yr) are labelled.

3.4 Allocation limits and water availability

Water availability, in the context of this report, refers to the amount of water that may be taken out of our rivers, streams, lakes and groundwater systems without compromising the life-supporting capacity and other identified critical values associated with individual water bodies. However, assessing the amount of water needed to sustain such values is often a subjective and arduous process. As outlined in Section 2.6, Greater Wellington has set allocation limits – known as safe yields for groundwater systems and core allocations for rivers and streams – for many of Wellington's waterbodies in the RFP[8]. At the time the RFP was made operative these limits were accepted as the amount of water that could be taken without compromising life-supporting capacity and other values, provided other relevant RFP policies are also adhered to. As described in Section 2.6.4, the safe yields for groundwater systems in the Wairarapa

[8] In addition to core allocation limits, the Regional Freshwater Plan also identifies minimum flows for rivers and streams to protect instream values from abstraction during times of low flow (refer Section 2.6.3).

Valley are currently being reviewed, and a new management framework has been proposed by Hughes and Gyopari (2011).

3.4.1 Approach to analysis

In this section, current remaining water availability is assessed by comparing the amounts of consented water abstraction (ie, allocated water) to allocation limits in the RFP and, in the case of the Wairarapa Valley, the new groundwater allocation limits proposed by Hughes and Gyopari (2011). For allocation from surface water bodies, a comparison is also made with estimated mean annual low flows. Note that surface water allocation is generally expressed in this section as an instantaneous rate (ie, litres per second, L/s) so that direct comparison with stream flows and core allocations is possible. Also, to assess remaining water availability it is assumed that all consented takes from a waterway or groundwater zone operate simultaneously (except where consent conditions specify flow-sharing regimes), and that all takes utilise the full amount (rate of take and hours of operation) specified in the resource consent.

There are no regionally or nationally agreed definitions for what amounts to a ‘high’ level of allocation or how allocation limits should be set. Therefore, for the purposes of drawing comparisons between water bodies in this report and interpreting the regional significance of results, the following criteria have been used to highlight where relatively ‘high’ levels of allocation occur:

- For rivers and streams, allocation levels equating to or exceeding 40% of MALF; and
- For groundwater, allocation levels equating to or exceeding 80% of aquifer safe yield.

The river and stream criteria are drawn from technical guidance (Beca 2008) accompanying the proposed National Environmental Standard for Ecological Flows and Water Levels (pNES, Ministry for the Environment 2008a). This guidance states that an allocation of more than 40% of MALF is considered a “high level” of hydrological alteration irrespective of the hydrological characteristics of the river or stream. Thresholds on either side of 40% (ie, >30% and >50% MALF) have also been used in this report to see how allocation levels might change under possible alternative policy scenarios. While largely arbitrary, 30% and 50% of MALF are suggested in the pNES as maximum allocation levels for small and large rivers, respectively.

The 80% of safe yield allocation threshold for groundwater is arbitrary.

3.4.2 Rivers and streams during ‘normal’ flows

In Section 2.6.2, the RFP policies relating to surface water allocation management are explained. In this section, allocation from rivers and streams that is consented to occur during ‘normal’ (medium to low) flow conditions is assessed. In reality this represents nearly all surface water allocation in the Wellington region at this time because most takes are run-of-river; the highest demand for these takes tends to be when soil moisture deficits and/or temperatures are high, which is usually when river flows are moderate to low.

The allocation from the rivers and streams covered by Policies 6.2.1 and 6.2.1A that is classed as 'core allocation' (ie, excluding supplementary takes which are only allowed to operate during higher flow conditions), is shown in Table 3.5. According to the two policies, the only Wairarapa waterways with

Table 3.5: Current consented water allocation, allocation limits and remaining allocation available during 'normal' flow conditions, for rivers and streams included in Policies 6.2.1 and 6.2.1A of Greater Wellington's existing Regional Freshwater Plan (WRC 1999) as at December 2010

Sub-region	River/stream	Total allocation classed as core allocation (L/s)[1]	Core allocation limit (Policy 6.2.1) or capped allocation limit (Policy 6.2.1A) (L/s)	Remaining available allocation under Policies 6.2.1 and 6.2.1A (L/s)
Wairarapa	Ruamahanga River – upper reach	796	800	4
	Ruamahanga River – lower reach	1,500	1,500	0
	Kopuaranga River	125	125	0
	Waipoua River	90	90	0
	Makoura Stream	42	40	0
	Waingawa River	1,056	1,040	0
	Tauweru River – upper reach	41	50	9
	Makahakaha Stream	41	50	0
	Parkvale Stream	135	160	25
	Booths Creek	97	100	3
	Mangatarere Stream – upper reach	176	180	4
	Mangatarere Stream – lower reach	140	140	0
	Waiohine River	727	740	13
	Papawai Stream	177	200	23
	Otukura Stream	56	60	4
	Stonestead Creek	212	210	0
	Tauherenikau River	272	405	133[3]
Central	Hutt River – upper reach	1,850	n/a[2]	n/a
	Hutt River – lower reach	165	300	135
	Wainuiomata River – upper reach	1,095	n/a[2]	n/a
	Wainuiomata River – lower reach	33	65	32
	Orongorongo River	1,132	n/a[2]	n/a
Kapiti Coast	Waitohu Stream	32	57	25.5
	Otaki River	68	2,120	2,052
	Mangaone Stream	24	25	1
	Waikanae River	463	n/a[2]	n/a

[1]Excluding supplementary (high flow) allocation and consents that have flow-sharing requirements.

[2]Included in Policy 6.2.1 but no core allocation limit is specified.

[3]Although recent hydrological analysis for the Tauaherenikau River (Thompson, in prep) indicates that the lower reaches of the river may not be able to support any further abstraction and the existing 'available' allocation (133 L/s) may need to be reduced.

While Policies 6.2.1 and 6.2.1A provide the current management framework for surface water allocation, it would be misleading to use these policies alone to assess future water availability and identify ‘stressed’ catchments in terms of water allocation. This is because:

- Not all surface water bodies which have water allocated are covered by the policies or have allocation limits specified;
- Policy 6.2.1 uses a ‘reach-based’ approach, and does not account for allocation from tributaries or upstream reaches if these are managed separately;
- The core allocation limits were derived in different ways (and represent different proportions of river flow). For example, some core allocation limits are based on a cap being placed on allocation at a past point in time, while others are set as a proportion of base flow (such as 30–50% of a one-in-10 year low flow). The consequence of this variation in methods for setting core allocation is that calculating remaining allocation is not a consistent indicator of water allocation stress; and
- Any non-utilised allocation from the streams covered by Policy 6.2.1A is due to takes being surrendered or reduced since the allocation from these streams was capped in 2007; because these streams are so highly used this water may in fact not be ‘available’ at low flows and the capped allocation limits may not be assessed as sustainable in the future.

In addition to the points above, we now have a better understanding of low flow characteristics and flow requirements to sustain instream values than when the core allocations were originally set. It is therefore likely that the core allocations will be reviewed and may be changed (and allocation limits added for more rivers incorporated) as part of Greater Wellington’s regional plan review.

To provide a regionally-consistent and holistic picture of surface water allocation stress and enable discussion of likely future surface water availability, cumulative catchment water allocations are compared with the estimated un-impacted mean annual low flow (MALF) at the mouth of the river/stream (or end of the river reach)[9] in Tables 3.6 and 3.7. The un-impacted MALF is the average 1-day mean flow for the period of record, with effects of any water abstraction removed, as estimated by Keenan (2009a,b and c) and Thompson (2011a). The MALF is an appropriate statistic for assessing allocation stress due to its ecological relevance (eg, Hay 2010); it is possible that allocation limits for surface water bodies in the Wellington region will be referenced to a low flow statistic such as this in future, in line with recent national guidance (eg, Ministry for the Environment (MfE) 2008a).

Table 3.6 indicates that all of the Ruamahanga River tributaries have at least 20% of their MALF allocated for abstraction, and in some cases more than 100%.

[9] Those water bodies with only one water take consent, or a total take deemed as relatively minor, have been grouped together into ‘other stream’ categories.

Table 3.6: Current (as at December 2010) consented surface water allocation compared with MALF for Wairarapa rivers and streams. Orange shading indicates where allocation exceeds 40% of estimated mean annual low flow (MALF)

Catchment	River / stream / tributary	Existing allocation (L/s)[1]	Estimated 1-day MALF at river mouth or end of reach (L/s)[2]	% MALF allocated
Ruamahanga River	Ruamahanga River – main stem	2,296	n/a	
	Kopuaranga River	125	570	22
	Waipoua River	90	410	22
	Makoura Stream	42	150	28
	Waingawa River	1,056	1,590	66
	Tauweru River – u/s of Kourarau Stream	41	70	59
	Tauweru River – total	78[3]	n/a	
	Makahakaha Stream	41	86	48
	Parkvale Stream	135	120	113
	Booths Creek	97	70	139
	Mangatarere Stream	315	305	103
	Waiohine River – total ie, incl. Mangatarere Stream	1,042	3,190	33
	Papawai Stream	177	340	52
	Huangarua River	62	310	20
	Other small tributaries	171	n/a	
	Ruamahanga River – total u/s of Lake Onoke incl. allocation from all tributaries	**5,412**	**12,930**	**42**
Lake Wairarapa and tributaries	Abbots Creek	62	100	62
	Tauherenikau Seepage	88	400	22
	Murphys Line Drain	44	260	17
	Otukura Stream	56	85	66
	Stonestead Creek	212	500	42
	Tauherenikau River	272	270	100
	Other lake tributaries	83	n/a	
Other	Pahaoa River	50	95	53

[1]Excluding takes that may only operate during high flow conditions or above supplementary flows, and takes with flow-sharing conditions.

[2]From Keenan (2009a,b and c), Thompson (2011a). MALFs are not listed for Ruamahanga River 'main stem' as this would exclude tributary inflows, or for Tauweru River because insufficient flow data exist.

[3]Excludes non-consumptive take of 1190 L/s for the Kourarau Power Station.

Overall, water allocation from the Ruamahanga River upstream of Lake Onoke equates to around 42% of the estimated MALF. Similarly, allocation from Lake Wairarapa's tributaries ranges from about 20% to 100% of the streams' MALFs at the point of entering Lake Wairarapa.

Water allocation from rivers and streams in the Central and Kapiti Coast sub-regions is generally a lower proportion of MALF that in the Wairarapa (Table

3.7). Water allocation for whole rivers ranges from 2% of MALF (Otaki River) to 32% (Hutt River). However, allocation from the upper reaches of rivers used for water supply (Hutt, Wainuiomata, Orongorongo and Waikanae rivers) is considerably higher than for the whole rivers; allocation during mean annual low flow conditions ranges from 21% to 70% of MALF at the point of abstraction. In general the lower allocation from rivers and streams of Kapiti Coast and Central sub-regions (with the exception of public water supply river reaches) is due to the lower demand for water for agricultural activities.

Table 3.7: Current (as at December 2010) consented surface water allocation compared with MALF for Central and Kapiti Coast sub-region rivers and streams. Orange shading indicates where allocation exceeds 40% of estimated mean annual low flow (MALF).

Catchment	River / stream / tributary	Existing allocation (L/s)[1]	Estimated 1-day MALF at river mouth or end of reach (L/s)[2]	% MALF allocated
Hutt River	Hutt River – upper reach	920	1,320	70
	Hutt River – total	**1,085**	**3,400**	**32**
Wainuiomata River	Wainuiomata River – upper reach	74	174	43
	Wainuiomata River – total	**107**	**585**	**18**
Orongorongo River	Orongorongo River – upper reach	185	285	65
Otaki River	Waimanu Stream	64	215	30
	Otaki River – total	**68**	**3,560**	**2**
Waikanae River	Waikanae River – upper reach	200	950	21
	Waikanae River – total	**200**	**770**	**26**
Other	Pauatahanui Stream	13.7	100	14
	Waitohu Stream	31.5	230	14
	Mangaone Stream	24	155	15
	Waimeha Stream	19	165	12
	Other small streams	77	n/a	

[1]Excluding takes that may only operate during high flow conditions or above supplementary flows. For the upper reaches of the Hutt, Wainuiomata, Waikanae and Orongorongo rivers the restricted allocation at MALF is reported. These river reaches have large public water supply abstractions which are not subject to an allocation limit but must be restricted according to river flow conditions.

[2]From Keenan (2009a).

Translating the above information to make statements about future water availability is difficult, because we don't yet know how core allocation limits will be derived for the new Regional Plan. As previously mentioned, it is likely that proposed surface water allocation limits will be referenced to the MALF, although the proportion of MALF used to set the limits may vary across the region according to the significance of stream values (Beca 2008). Bearing this in mind, two water allocation limit scenarios are presented in Table 3.8: 30% and 50% of MALF. The current rates of water allocated are compared with the scenario limits to give an indication of remaining water availability. Both the allocation limits and the current allocation shown are cumulative; ie, represent total allocation for all upstream river reaches and tributaries. Note that the proportions selected (30% and 50%) are relatively arbitrary (as discussed in

Section 3.4.1), and lower or higher proportions of the 1-day MALF – or another flow statistic – may be used when new limits are proposed in the plan review process.

In addition to direct abstraction, river flows may be depleted due to abstraction from hydraulically-connected groundwater systems. As outlined in Section 2.6.4, Hughes and Gyopari (2011), Hughes (in prep) and Hughes et al. (in prep) have recommended that groundwater abstraction that affects flow in rivers and streams be classed as surface water allocation by Greater Wellington. Although this proposal has not yet been ratified into regional policy, the analyses of water availability under the two allocation limit scenarios in Table 3.8 include an estimate of the streamflow depletion caused by groundwater takes[10] to give the reader an indication of the likely impact of the management proposal. Note that, as shown by Table 3.8, in many waterways – particularly in the Wairarapa – the estimated streamflow depletion caused by groundwater takes is nearly as high as, or even exceeds, direct surface water allocation.

As shown by the middle column under each allocation scenario in Table 3.8, few waterways within the Ruamahanga River catchment would have significant remaining allocation if limits were set equal to 30% or 50% of MALF. If streamflow depletion is considered as part of the allocation limit then the amount of remaining available allocation is significantly less (third column under each allocation scenario). Overall, if the Ruamahanga River is considered as a whole for setting water allocation limits, then there would be no remaining surface water allocation in the catchment under scenario 1, and under scenario 2 there would only be remaining allocation if hydraulically connected groundwater takes were not incorporated into surface water management.

The only Lake Wairarapa tributaries with significant remaining allocation under both scenarios are the South Featherston Drains (Murphys Line Drain and Tauherenikau Seepage Drain). However, if streamflow depletion was incorporated as part of surface water allocation then there would be no remaining allocation from these waterways under either scenario.

In the western part of the region there is generally more surface water available under the two scenarios, although the incorporation of streamflow depletion into surface water management would make a significant difference to water availability in many rivers. Assuming streamflow depletion takes are to be managed as surface water allocation, under scenario 1 there would only be significant water remaining available from the Wainuiomata River (except for in its upper reach), Otaki River and some of the smaller streams of the Kapiti Coast. With the higher allocation limit in scenario 2 there would also be some remaining water available in the Hutt River (except for in its upper reach).

---

10 Includes both Category A and Category B groundwater depletion for the Wairarapa rivers (using area definitions and associated depletion factors of Hughes and Gyopari (2011)) but just the Category A abstractions elsewhere; while Hughes et al. (in prep) provide area definitions for Category A and B in other sub-regions, depletion factors for Category B takes are not available due to a lack of modelling data. Therefore it should be assumed that the streamflow depletion estimates for the Hutt Valley and Kapiti Coast in Table 3.8 are underestimates.

Table 3.8: Remaining water availability under two surface water allocation limit scenarios (30% and 50% of MALF). The remaining allocation with and without allowance for estimated streamflow depletion (due to groundwater takes, following Hughes and Gyopari (2011), Hughes (in prep) and Hughes et al. (in prep) is shown – see footnote 10 in the main text for more detail on streamflow depletion calculation.

Catchment	River / stream / tributary	Existing allocation (L/s)[1]	Additional groundwater take proposed as surface water allocation due to streamflow depletion (SFD) (L/s)	1-day MALF (L/s)	Scenario 1: Allocation limit 30% of MALF			Scenario 2: Allocation limit 50% of MALF		
					Allocation limit (L/s)	Remaining allocation (L/s)	Remaining allocation with SFD (L/s) accounted for	Allocation limit (L/s)	Remaining allocation (L/s)	Remaining allocation with SFD (L/s) accounted for
Ruamahanga	Ruamahanga River – main stem only	2,296	2493	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Kopuaranga River	125		570	171	46	46	285	160	160
	Waipoua River	90	66	410	123	33	0	205	115	49
	Makoura Stream	42		150*	45	3	3	75	33	33
	Waingawa River	1,056	570	1,590	477	0	0	795	0	0
	Tauweru River - u/s of Kourarau Stream	41		70	21	0	0	35	0	0
	Tauweru River - total	78		n/a*						
	Makahakaha Stream	41		86*	25.8	0	0	43	2	2
	Parkvale Stream	135	45.5	120*	36	0	0	60	0	0
	Booths Creek	97	45.5	70*	21	0	0	35	0	0
	Mangatarere Stream	315	307	305	91.5	0	0	0	0	0
	Waiohine River (incl. Mangatarere S)	1,042	852	3,190	957	0	0	1,595	553	0
	Papawai Stream	177	170	340	102	0	0	170	0	0
	Huangarua River	62	30	310*	93	31	1	155	93	63
	Tauanui, Dry and Turanganui rivers[2]	14	74	n/a						
	Other tributaries	157		n/a						
	Ruamahanga River u/s of Lake Onoke	**5,412**	**4346**	**12,930**	**3,879**	**0**	**0**	**6,465**	**1,053**	**0**
Lake Wairarapa	Abbots Creek	62		100*	30	0	0	50	0	0
	Tauherenikau Seepage Drain	88	107	400*	120	32	0	200	112	5
	Murphys Line Drain	44	107	260*	78	34	0	130	86	0
	Otukura Stream	56		85	25.5	0	0	42.5	0	0
	Stonestead Creek	212	101	500*	150	0	0	250	38	0
	Tauherenikau River	272	74	270	78	0	0	130	0	0
Hutt	Hutt River – upper reach	920		1,320	396	0	0	660	0	0
	Hutt River – total	1,085	165	3,400	1,020	0	0	1,700	615	450
Wainuiomata	Wainuiomata River – upper reach	74		174	53	0	0	87	13	0
	Wainuiomata River – total	107	29	585	176	69	40	293	186	157
Otaki	Waimanu Stream	64		215*	65	1	1	108	44	44
	Otaki River – total incl. tributaries	68	310	3,560	1,068	1,000	690	1,780	1,712	1,402
Waikanae	Waikanae River – upper reach	200		950	285	85	85	475	275	275
	Waikanae River – total	200	30	770	231	31	1	385	185	155
Other	Orongorongo River – upper reach only[3]	185		285	86	0	0	143	0	0
	Pauatahanui Stream	14		100	30	16	16	50	36	36
	Waitohu Stream	32	40	230	69	37	0	115	83	43
	Mangaone Stream	24		155*	47	23	23	78	54	54
	Waimeha Stream	19		165*	50	31	31	83	64	64
	Pahaoa River	50		95	28.5	0	0	48	0	0

[1] Excludes non-consumptive, high-flow and flow-sharing allocation. For the upper reaches of Hutt, Wainuiomata, Orongorongo and Waikanae rivers the amount reported is the restricted allocation at MALF.
[2] Grouped together following streamflow depletion advice in Hughes and Gyopari (2011). Direct surface takes from these waterways is minor.
*Further work is required to confirm MALF estimate.
[3] Lower reach is in Department of Conservation Estate and allocation in this zone is unlikely.

While some of the surface water core allocation levels across the region are relatively high, it is not possible to say yet whether any catchments will be considered ‘over-allocated’ under the new Regional Plan. This will depend on a number of catchment-specific factors including the level of instream flow protection that is desired and the impact of additional depletion from groundwater abstraction (see section 3.4.5).

Note that the assessment of water availability in Table 3.8 assumes that allocation for ‘emergency’ water supply takes from rivers and streams is counted as part of the core allocation. This equates to 40 L/s from Huangarua River, 60 L/s from Abbots Creek, 60 L/s from Tauherenikau River, and 31.5 L/s from Waitohu Stream.

3.4.3 Rivers and streams during higher flows

The analysis of surface water availability in Section 3.4.2 was based on rivers and streams during typical irrigation season flows (moderate to low flows). Under existing Policy 6.2.1, the core allocations for rivers and streams do not apply at flows above ‘supplementary flows’ (ie, flow limits above which high-flow harvesting, in addition to core allocation abstraction, may occur). This implies there may be water available from rivers and streams during higher flow conditions, subject to an assessment of the environmental effects of taking the water during high flows.

At the current time, there is limited harvesting of higher river flows in the Wellington region: approximately 97% of the water allocated is counted against the relevant core allocation (or, for rivers and streams not covered by Policies 6.2.1 or 6.2.1A of the RFP, is consented to occur during low flows subject to restriction conditions). There appears to be two main types of supplementary takes (ie, takes that may only occur when the rivers are above the supplementary flows specified in Policy 6.2.1, or above a moderate flow threshold defined in the resource consent): frost protection takes and additional takes for public water supplies and water races. The Ruamahanga River and its tributaries have the highest supplementary take allocation in the Wellington region, equating to 821 L/s from the main stem of the river and around 670 L/s from its tributaries. The Hutt, Wainuiomata, Orongorongo and Waikanae rivers – which are all used for public water supply – also have supplementary allocations; ie, the public water supplies are consented to take more water when flows in the river are above a specified threshold.

The supplementary flows specified in Policy 6.2.1 of the RFP are not considered ‘high’ flows – in general they are around the annual median flows. It is likely that these supplementary flows will be reviewed and the policies around promoting additional takes during non-low flow conditions may change significantly as part of the regional plan review process. Work has only recently commenced to assess potential options for new policies, and therefore it is not possible to make an assessment of the amount of water potentially available for use at higher river flows.

3.4.4 Lake Wairarapa

There is no core allocation limit for Lake Wairarapa in the existing RFP; water abstractions from channels connected to the lake are managed according to lake water level conditions. It is likely that, in future, an allocation limit will be proposed for the lake but it has yet to be determined how this limit should be derived; for example, whether it is based on total available lake storage or relates to a proportion of the inflow to the lake during low flow conditions. Initial investigations into lake inflows found that around 2,000 L/s of surface water enters the lake during stable base flow summer conditions (Thompson 2010) while groundwater discharge to the lake is currently estimated to range between only 350 and 500 L/s (Gyopari & McAlister 2010c). Assuming the mean annual low flow into the lake is therefore around 2,350 L/s, the current lake allocation of 523 L/s equates to around 22% of the inflow.

The preliminary nature of the numbers just presented should be noted. Further investigations to help refine the water balance of Lake Wairarapa, and identify suitable management criteria, are currently underway. Until an allocation limit is adopted it is not possible to fully assess remaining water availability from the lake.

3.4.5 Groundwater

For this report, current groundwater availability is assessed by comparing existing allocation with the ‘safe yields’ specified in Policy 6.2.3 of the RFP. Future groundwater availability in the Wairarapa Valley is also assessed by comparing existing allocation with the range of allocation limits specified in the proposed groundwater management framework (Hughes & Gyopari 2011). While this proposed framework is subject to change, it is included in this report as a possible future scenario of groundwater availability in the Wairarapa.

Under the current management framework, which comprises annual safe yields in the RFP, water remains available from many of the Wellington region’s groundwater zones (Tables 3.9 and 3.10).

However, the management zones that are associated with the major rivers such as the Ruamahanga River (Rathkeale, Middle Ruamahanga, Riverside and Tawaha zones) and Hutt River (Lower Hutt zone) – ie, which comprise groundwater systems that are directly recharged from the river and tend to be associated with high bore yields – are highly or fully allocated. In addition, groundwater zones with productive deep aquifers (such as Te Ore Ore, Parkvale, Lower Valley and Waikanae), or zones with ‘limited’ aquifers located under high-demand areas (such as Martinborough and Huangarua Terraces) also have little remaining water available for allocation.

Table 3.9: Current (as at December 2010) status of consented groundwater allocation in the Wairarapa Valley. Management zones with more than 80% of safe yield allocated are highlighted orange; this is an arbitrary threshold and used to provide an indication of where groundwater is approaching full allocation.

	Zone	Aquifer(s)	Current allocation (million m³/yr)	Safe yield in Policy 6.2.3 (million m³/yr)	% of safe yield allocated	Remaining allocation (million m³/yr)
Upper Wairarapa valley	Masterton	Shallow aquifers	0.306	5.50	5.6%	5.19
	Opaki	All aquifers	0.079	2.30	3.4%	2.22
	Rathkeale	All aquifers	2.403	3.00	80.1%	0.60
	Te Ore Ore	Shallow aquifers	1.279	4.60[1]	27.8%	3.32
		Deep aquifers	2.613	3.00[1]	87.1%	0.39
	Upper Opaki	All aquifers	0.238	4.50	5.3%	4.26
	Upper Plain	All aquifers	3.494	17.00	20.6%	13.51
Middle Wairarapa valley	Ahikouka	All aquifers	2.920	3.30	88.5%	0.38
	Carterton	All aquifers	2.854	3.90	73.2%	1.05
	East Taratahi	All aquifers	0.210	6.80[2]	3.1%	6.59
	Fern Hill	All aquifers	0.753	4.70	16.0%	3.95
	Greytown	All aquifers	5.030	20.00	25.1%	14.97
	Hodders	All aquifers	1.669	4.00	41.7%	2.33
	Mangaterere	All aquifers	1.293	7.60	17.0%	6.31
	Matarawa	All aquifers	0.439	10.00	4.4%	9.56
	Middle Ruamahanga	Shallow aquifers	7.307	7.30	100.1%	0
		Deep aquifers	1.885	2.20	85.7%	0.32
	Parkvale	Shallow aquifers	1.004	3.50[3]	28.7%	2.50
		Deep aquifers	2.531	2.62	96.6%	0.09
	West Taratahi	All aquifers	0.534	5.30	10.1%	4.77
Lower Wairarapa valley	Battersea	All aquifers	1.852	2.40	77.1%	0.55
	Huangarua	Upper Terraces	0.084	0.50	16.9%	0.42
		Lower Terraces aq. 1	0.374	0.90	41.6%	0.53
		Lower Terraces aq. 2	1.180	1.20	98.4%	0.02
	Lower Valley	Turanganui aq. 1	0.822	1.10	74.7%	0.28
		Tauanui aq. 1	0.011	0.80	1.3%	0.79
		Whangaehu aq. 1	0.181	0.50	36.3%	0.32
		Aquifer 2	12.221	13.50[4]	90.5%	1.28
		Aquifer 3	3.679	7.70[4]	47.8%	4.02
	Martinborough Terraces	Eastern terraces	0.419	0.31[5]	135.0%	0
	Martinborough Terraces	Western terraces	1.266	1.50[5]	84.4%	0.23
	Moroa	All aquifers	0.240	0.80	29.9%	0.56
	Pirinoa	All aquifers	0.040	18.10	0.2%	18.06
	Riverside	All aquifers	3.900	3.90	100.0%	0
	South Featherston	All aquifers	1.574	5.30	29.7%	3.73
	Tauherenikau	All aquifers	5.053	20.00	25.3%	14.95

	Zone	Aquifer(s)	Current allocation (million m³/yr)	Safe yield in Policy 6.2.3 (million m³/yr)	% of safe yield allocated	Remaining allocation (million m³/yr)
	Tawaha	All aquifers	11.035	11.00	100.3%	0
	Woodside	All aquifers	0.592	16.00	3.7%	15.41

[1]RFP groups all Te Ore Ore aquifers together with a safe yield of 10.6 million m³/year, which is an error. The two limits of 4.6 and 3.0 million m³/year were identified by a specific report on Te Ore Ore management zone.

[2]RFP states safe yield of 15.7 million m³/yr, which is an error.

[3]RFP states a safe yield of 4.5 million m³/yr. A 2004 study recommended the limit be reduced to 3.5 million m³/year and this lower limit is used in practise.

[4]Aquifers 2 and 3 were erroneously omitted during Plan Change 3 to the RFP. These safe yields are from the RFP prior to Plan Change 3 The RFP also states a capped limit for the Kahutara area of Aquifer 2 that essentially means there is no more allocation available from this area.

[5]In the RFP these are combined to give a safe yield of 1.8 million m³/yr for the Martinborough Terraces as a whole.

Table 3.10: Current (as at December 2010) status of consented groundwater allocation in the Central and Kapiti subregions. Management zones with more than 80% of existing safe yield allocated are highlighted orange; this is an arbitrary threshold and is used to provide an indication of where groundwater is approaching full allocation.

Area	Groundwater zone	Current allocation (million m³/yr)	Safe yield in Policy 6.2.3 (million m³/yr)	% of safe yield allocated	Remaining allocation (million m³/yr)
Hutt Valley	Mangaroa	0.01	18.40	0.1%	18.39
	Pakuratahi	0.01	5.90	0.2%	5.89
	Akatarawa	0.01	3.60	0.4%	3.59
	Upper Hutt	2.26	26.90	8.4%	24.64
	Lower Hutt	33.75	33.00	102.3%	0
Wainuiomata valley	Wainuiomata	0.14	3.00	4.8%	2.86
Kapiti Coast	Waitohu	0.54	6.40	8.4%	5.86
	Otaki	5.70	11.30	50.4%	5.60
	Hautere	0.78	6.70	11.7%	5.92
	Coastal	0.61	6.80	9.0%	6.19
	Waikanae	9.20	10.70	86.0%	1.50
	Raumati/Paekakariki	0.38	4.80	8.0%	4.42

It should be noted that the safe yields listed in Tables 3.9 and 3.10 are generally based on estimated rainfall recharge to the groundwater zone and the water may not actually be ‘available’. Upper Opaki, East Taratahi and Fernhill are all examples of management zones that have significant volumes of safe yield still available for allocation on paper, but for which groundwater investigations have shown low hydraulic conductivities and bore yields. Likewise, the safe yields overstate the amount of water available in shallow gravel aquifers in some river corridors, such as those surrounding the upper Ruamahanga River in the Opaki, Masterton and Te Ore Ore zones, as the river flow depletion effects of takes in these aquifers has not been accounted for. As previously mentioned, a new groundwater management framework is proposed for the Wairarapa Valley, and to present a complete picture of water availability in this report it is appropriate to compare existing groundwater allocations to the new proposed range of allocation limits for each proposed management zone. However, in order to accurately apply the proposed framework of Hughes and Gyopari (2011) and assign surface water – groundwater interaction categories[11] a thorough analysis of groundwater takes, including location, bore depth and rate of pumping, is required. A preliminary analysis was conducted as part of this report but it is acknowledged that the categorisation of individual takes is subject to change based on the framework that is ultimately adopted as part of the regional plan review.

Bearing the above in mind, Table 3.11 shows the existing allocation from each of the 18 proposed new Wairarapa groundwater management zones along with the range of proposed allocation limits. In four of the management zones, it is suggested that all groundwater taken is to be managed as surface water allocation; these takes were incorporated into the streamflow depletion estimates and surface water allocation assessment in Table 3.8.

It is obvious from the final column of Table 3.11 that the groundwater allocation limit adopted from within the range proposed by Hughes and Gyopari (2011) will have a large impact on remaining groundwater availability in the Wairarapa Valley. In five of the 18 proposed management zones, there may or may not be further water available depending on the limit selected. In two of the zones (Dry River and Martinborough) there is no further groundwater available under any of the proposed limits. In the remaining seven groundwater zones there is likely to be some groundwater available in the future but the amount will depend on which limit is adopted for each zone. However, in most groundwater zones, any new groundwater takes would probably have to be located away from Category A areas (where there is a strong hydraulic connectivity between groundwater and surface water systems); ie, the bores would have to be a sufficient distance from surface waterways or be sufficiently deep so as not to result in any stream flow depletion as a result of groundwater pumping. This is because, as discussed in Section 3.3.1, there is likely to be very little surface water available (for 'new' allocation) during low flows in the Wairarapa under potential future surface water allocation policies.

It is possible that some of the proposed groundwater zones will be considered 'over-allocated' under the future allocation framework (ie, indicating that the combined effect of existing surface and groundwater abstractions is unacceptable). In such cases, an approach to reduce abstraction levels may be required. From the preliminary analysis summarised in Table 3.11, the proposed zones that are most at risk of over-allocation are Te Ore Ore, Mangatarere, Huangarua, Lake and Tauherenikau zones, as well as the additional zones where all allocation is to be managed as surface water.

[11] Hughes and Gyopari (2011) recommend three categories which are related to hydraulic connectivity between groundwater and surface water. For a full explanation see Section 2.6.4.

Table 3.11: Summary of consented allocation from proposed Wairarapa Valley groundwater management zones: existing allocation (as at December 2010), proposed allocation limits (Hughes & Gyopari 2011) and remaining allocation under proposed limits. Refer to Figure 2.9 for a map of the proposed zones and categories

	Proposed management zone	Existing allocation (million m³/year) under proposed Category:			Existing allocation to be classed as groundwater allocation (million m³/year)	Range of proposed groundwater allocation limits (million m³/year)	Current remaining allocation under proposed management framework (million m³/year)
		A	B	C			
Upper Valley	Upper Ruamahanga	2.403	–	0.079	0.079	2.66 to 3.55	Up to 3.47
Upper Valley	Te Ore Ore	0.653	2.735	–	0.820	0.48 to 1.44	Zero to 0.62
Upper Valley	Waingawa	3.333	1.049	0.160	0.580	1.3 to 3.12	Up to 2.54
Middle Valley	Taratahi	–	0.554	0.190	0.580	2.12 to 3.53	Up to 2.8
Middle Valley	Fernhill-Tiffin	–	-	0.753	0.753	1.3 to 1.62	Up to 0.87
Middle Valley	Parkvale confined	–	–	2.357	1.839	2.33 to 3.9	Up to 2.10
Middle Valley	Parkvale unconfined	–	1.178	–	0.825	1.14 to 2.28	Up to 1.46
Middle Valley	Mangatarere	2.686	2.254	0.615	1.435	1.15 to 2.9	Zero to 1.47
Middle Valley	Waiohine	8.649	–	–	0	All allocation to be managed as surface water	
Middle Valley	Middle Ruamahanga	9.192	–	–	0	All allocation to be managed as surface water	
Lower Valley	Dry River	–	1.026	–	1.026	0.8 to 0.96	0
Lower Valley	Martinborough	–	–	1.406	1.406	0.65 to 1.075	0
Lower Valley	Huangarua	0.374	1.265	–	1.265	0.97 to 1.29	Zero to 0.03
Lower Valley	Onoke	1.333	–	1.107	1.107	1.44 to 1.73	Up to 0.62
Lower Valley	Moiki	3.900	–	–	0	All allocation to be managed as surface water	
Lower Valley	Lake	–	–	5.939	5.939	1.85 to 7.4	Zero to 1.46
Lower Valley	Tauherenikau	5.379	8.301	–	8.301	6.37 to 13.93	Zero to 5.63
Lower Valley	Lower Ruamahanga	14.121	–	–	0	All allocation to be managed as surface water	

As previously mentioned, work is also underway to establish a groundwater – surface water interaction framework for the western part of the Wellington region. The surface water availability analysis for Kapiti Coast rivers and streams, Hutt River and Wainuiomata River (Section 3.3.1) included an estimate of streamflow depletion caused by groundwater takes in those areas. Although not quite as critical as in the Wairarapa, it is likely that in some parts of the western region – particularly on the Kapiti Coast – future groundwater availability will be limited in places where pumping is likely to result in stream flow or wetland water level depletion.

3.5 Summary

- Consented water allocation in the Wellington region equates to approximately 414 million m^3/year, of which around two-thirds is from surface water and one-third from groundwater sources.

- Most (65%) of the region's consented water allocation is in the Wairarapa; a further 28% is within the 'central' sub-region and a relatively small proportion (7%) is in the Kapiti Coast sub-region.

- The most significant uses for which surface water is allocated are public or community water supply (41% of the annual allocation), irrigation (24%), Wairarapa water races (19%) and hydroelectricity generation (14%). The main uses of groundwater allocation are irrigation (60%) and public or community water supply (36%). Overall (from all groundwater and surface water sources), water supply and irrigation are allocated similar amounts of water on an annual basis.

- Water supply is the most dominant use of allocated water in the western part of the region. However, in the Wairarapa, irrigation accounts for 52% of water allocated. A high proportion (70%) of water allocated for irrigation in the Wellington region is for dairy pasture.

- Annual water allocation in the Wellington region increased about 54% between 1990 and 2010, with the most rapid increase between the late 1990s and 2005. Allocation from groundwater sources increased at a greater rate than allocation from surface water, reflecting the greater availability of groundwater for allocation under the RFP.

- Most (77%) of the increase in water allocation between 1990 and 2010 was for irrigation; a further 20% was for public water supply. Most (83%) of the region's increase in water allocation occurred in the Wairarapa.

- Of the increase in water allocation for irrigation between 1990 and 2010, around three-quarters (73%) was for dairy pasture, and a further 16% was for non-dairy pasture.

- Under the current allocation policies of the RFP the only rivers with significant (>30 L/s) remaining allocation available during normal to low flows are Tauherenikau, Hutt (lower reach), Wainuiomata (lower reach) and Otaki rivers. However, the existing surface water allocation limits may not be appropriate for the new Regional Plan (see next bullet point and Section 5).

- Under two future surface water allocation limit scenarios (30% and 50% of mean annual low flow) few waterways in the Wairarapa would have remaining water available for allocation, particularly if groundwater takes that result in streamflow depletion were to be managed under surface water allocation policies. In the western part of the region there would generally be more water available under the two scenarios, although the incorporation of groundwater takes that result in streamflow depletion would make a significant difference to future surface water availability.

- Under the existing RFP policies there is significant remaining groundwater available in many of the groundwater zones throughout the region. However, under the Wairarapa Valley groundwater management framework proposed by Hughes and Gyopari (2011), future groundwater availability depends strongly on the final allocation limit adopted; in some groundwater zones (Te Ore Ore, Mangatarere, Dry River, Martinborough, Huangarua, Lake and Tauherenikau) there may be no further groundwater available.

- The proposed groundwater management frameworks (Hughes & Gyopari 2011, Hughes in prep & Hughes et al. in prep) recommend that groundwater allocation in areas hydraulically-connected to surface waterbodies be managed as surface water allocation. Where rivers and streams are already highly allocated, shallow groundwater availability would be very limited in the future.

- Some rivers and groundwater management zones may be considered ‘over-allocated’ at the conclusion of the Regional Plan review process.

4. Trends in hydrological factors that affect water availability

The availability of water for abstraction is determined by allocation policies (including allocation limits) in Greater Wellington's existing Regional Freshwater Plan (RFP) but is also affected by the environment. In particular, hydrological factors affect water availability in several ways – for example:

- Allocation limits are often determined by low flow magnitude or estimated annual aquifer recharge volumes;
- The frequency of low flows determines how frequently water takes from rivers and streams are restricted;
- The frequency of high river flows affects how often high-flow or supplementary allocation takes can occur.

In this section, trends in rainfall, river low flows, and groundwater levels in the Wellington region are examined with the intention of making comment on whether these background factors affecting water availability have changed over time. A list of sites analysed and summary results can be found in Appendices 3–5 and full details of the methodology, trend analyses and complete results can be found in the background technical reports on rainfall (Thompson 2012), low river flows (Keenan 2012) and groundwater levels (Mzila 2012).

Possible reasons for any observed trends and implications for water availability are discussed in Section 5. However, this report is not intended as a thorough analysis of hydrological trends in the Wellington region and it is likely that more detailed investigation into the presence or absence of certain hydrological trends will be required on a catchment-by-catchment basis.

Note that the analysis of rainfall in this section is mainly focused on summer rainfall patterns, rainfall minima and length of dry spells and the analysis of river flows is similarly restricted to low flow magnitude and frequency. While it is acknowledged that the frequency and magnitude of medium to high river flows, annual rainfall and heavy rainfall events also affect water availability, there is strong reliance on water abstraction from rivers and streams during dry periods in the Wellington region, when flows are likely to be low. Furthermore, many of the groundwater allocation limits recommended in the proposed new conjunctive management framework for the Wairarapa Valley (Hughes & Gyopari 2011) are related to minimising the effects of groundwater abstraction on low flows in hydraulically-connected rivers.

The time period chosen for trend analyses has been dictated to a large extent by the availability of suitable monitoring data. Many river stage/flow sites in the Wellington region were established in the late 1970s so the period 1980/81 to 2010/11[12] has been chosen for the analysis of low flows to include as many of these sites as possible. A corresponding period was chosen for the rainfall

[12] Unless otherwise stated, years of data record have been split according to the hydrological year 1 July–30 June (rather than the calendar year).

analysis to allow patterns in rainfall and flow to be interpreted together. Groundwater level records in the Wellington region are generally much shorter with many sites only having suitable quality data available from the early to mid-1990s. The longest common span of time that could be achieved for groundwater level trend analysis was 1994/95 to 2010/11.

4.1 Trends in rainfall

Rainfall affects both water availability and demand, particularly for irrigation. To assess how trends in rainfall may be affecting water availability and demand, patterns in annual and summertime rainfall in the last six years as well as longer-term trends in indices of rainfall were investigated for representative rainfall sites in the Wellington region. Additional rainfall analyses were conducted as part of the assessment of groundwater level trends and these are described in Section 4.3.

4.1.1 Approach to analysis

Data from a total of 18 Greater Wellington, NIWA and MetService rainfall monitoring sites were analysed, with the sites chosen to broadly represent the variety of climatic zones in the region as well as areas of particular water resource interest. Sites are shown on Figure 4.1 and listed in Table A3.1, Appendix 3.

The cumulative deviation from the long-term mean was plotted to characterise general patterns of change in rainfall totals over time. This type of analysis highlights periods in the record when rainfall has been increasing or decreasing and has been undertaken on monthly data for the period 1980/81–2010/11 for all selected sites. To provide a longer-term context, cumulative deviation from annual means for four sites with records extending back to the early 1900s was also plotted.

In addition, two indicators of whether the nature of dry periods has changed significantly in the longer term have been assessed:

- The annual 3-month minimum rainfall total (ie, the lowest rainfall total for each year accumulated over any 3-month period); and
- The maximum number of consecutive dry days in a year (henceforth referred to as ‘annual dry spell length’).

Initially, a 5-year running mean was plotted through the data for each indicator for each site to smooth the inter-annual variability and indicate the underlying temporal pattern of change (consistent with an approach taken by Watts (2005)). Mann-Kendall trend tests were then applied to each site/indicator for two time periods: the last 30 years (1980/81–2010/11) and the entire available record for each site. Trends were assessed as statistically significant if $p<0.05$, equivalent to a confidence level of 95%.

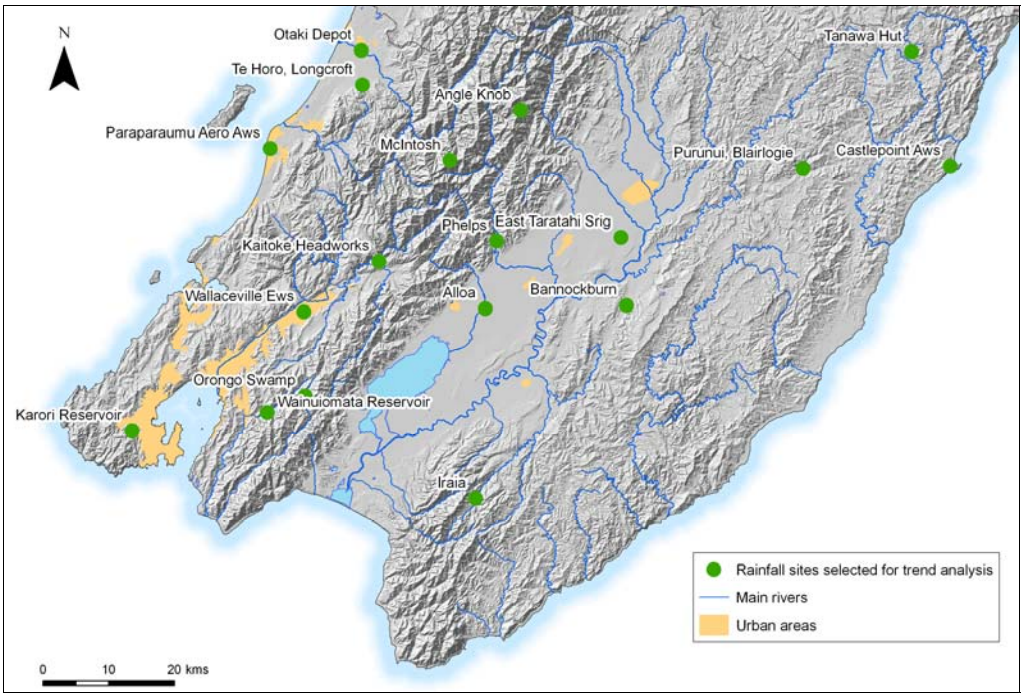


Figure 4.1: Location of rainfall monitoring sites used in trend analyses

4.1.2 Results

(a) Annual rainfall over the last six years

Analysis of recent annual rainfall patterns (for the six years to 30 June 2011) found that while there were few record high or record low annual rainfall totals in the six-year period, there was a tendency for below 'normal' (25^{th} percentile) annual rainfall in the Wellington region. The 2005/06 year was significantly dry, with nearly all rainfall sites analysed showing annual rainfall in the lowest 25% of years on record. Similarly, rainfall in the summer months (November to April inclusive) – when water stress is usually at its peak – was typically normal to below normal during the last six years (Table 4.1). In the 2007/08 summer there were lengthy dry spells, including a record low rainfall total in the eastern Tararua foothills (as indicated by the 'Phelps' site) and severe soil moisture deficits occurred across the Wairarapa.

(b) Deviation from mean rainfall

Figure 4.2 shows plots of cumulative deviation from mean monthly rainfall for the period July 1980–June 2011 (with rainfall sites grouped by sub-region). While there is clearly inter-site variability, some general region-wide patterns emerge from the compiled plots:

- From 1980 to the mid-early 1990s, a large majority of sites across the region showed a 'drying' phase with a net decline in cumulative rainfall. Outliers to this pattern were two sites in the Upper Hutt area (Wallaceville and Kaitoke Headworks) and one site in the northeastern Wairarapa hill country (Tanawa Hut).

Table 4.1: Total summer (November to April inclusive) rainfall between 2005/06 and 2010/11 for selected monitoring sites in the Wellington region. Orange shaded cells are lower than the 25th percentile for the whole record and blue shaded cells are higher than the 75th percentile for the whole record. Bolded values are either the highest or lowest annual summer total on record.

Sub-region	Site	Mean summer rainfall (mm) [start of record]	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Wairarapa	Angle Knob	2,953 [1974]	3,170	3,443	1,878	3,021	3,159	2,791
	Phelps[1]	848 [1974]	814	752	**460**	708	688	733
	Alloa	461 [1963]	467	379	329	426	411	456
	Tanawa Hut	505 [1956]	517	275	292	349	515	501
	Iraia	656 [1969]	546	539	399	426	464	569
Central	Karori	521 [1879]	427	477	563	606	373	533
	Wallaceville	539 [1940]	403	508	387	516	349	492
	Wainuiomata	742 [1890]	732	589	491	569	497	682
	Orongorongo	404 [1980]	224	550	202	280	264	287
Kapiti	Otaki	456 [1893]	375	410	438	508	529	442
	Paraparaumu	451 [1951]	379	416	439	420	383	416
	McIntosh	2,271 [1991]	2,135	2,331	1,735	2,097	2,443	1,938

[1] Phelps was closed in January 2010 and data since then were estimated from a correlation with the Waiohine at Gorge rainfall site.

- Throughout the 1990s most sites displayed a 'wetting' phase, followed by a reversal to another drying phase towards the end of the decade. This drying phase was most obvious and consistent in site records from the Wairarapa and the Upper Hutt area. Kapiti Coast sites showed a much less obvious pattern of change and have essentially been stable since about 2000.

- A very distinct phase reversal occurred in the Wairarapa across all sites in about 2004, triggered by a very wet year. However, since about 2006 most Wairarapa sites have been reasonably stable.

To put the wet and dry phases of the last 30 years into a wider context cumulative deviation from annual rainfall for four of the sites with the longest records available was examined (Figure 4.3). Using the same sites Watts (2005) provides a more in-depth interpretation of historical wet and dry phases, but in very general terms Figure 4.3 shows two patterns:

- Sites representing the Kapiti Coast (Otaki) and south central (Karori) sub-regions showed a long period of gradual drying from the beginning of their records until about 1970 and a tendency towards above average rainfall (wetting phase) since then; and

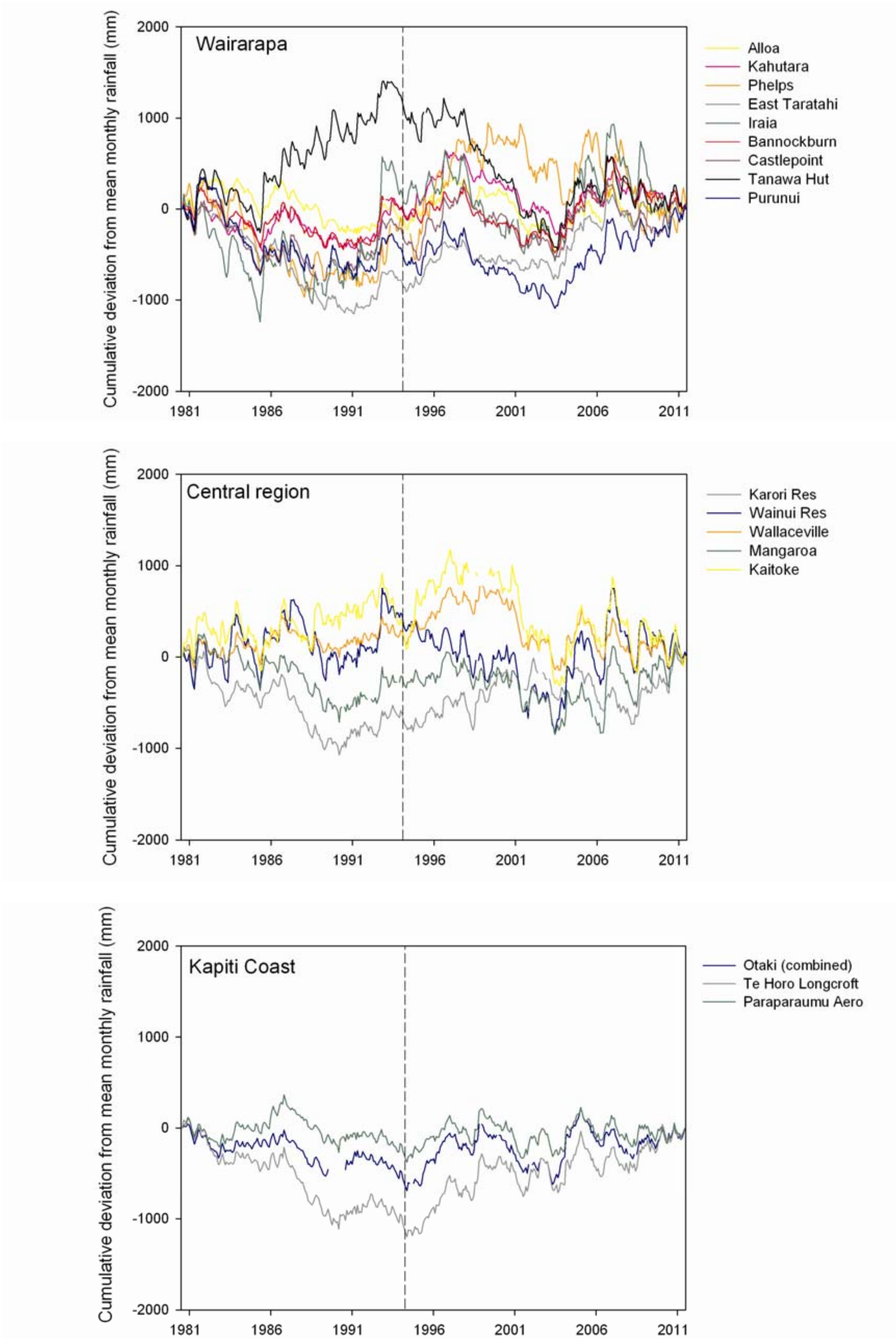


Figure 4.2: Cumulative sum of monthly deviation from average rainfall for the period 1 July 1980–30 June 2011, grouped by sub-region. For later reference (see Section 4.3), the beginning of the time period analysed for groundwater trends (1994–2011) is shown by the vertical dashed line.

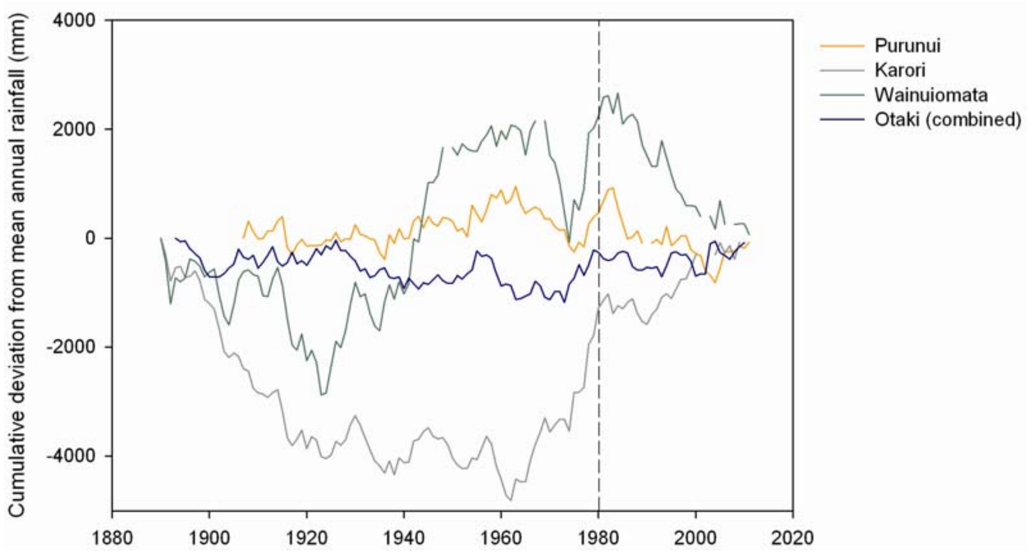


Figure 4.3: Cumulative sum of annual deviation from average rainfall for the longest rainfall records in the Wellington region. For later reference (see next sections), the beginning of the period of time analysed for summer rainfall and low flow trends (1980–2011) is shown by the vertical dashed line.

- Sites representing the eastern central (Wainuiomata) and northeastern Wairarapa (Purunui) sub-regions showed an opposite pattern, with a long period of slightly more than average rainfall until about 1970 and a tendency towards a drying phase since then.

(c) Changes in summer rainfall

This section summarises changes in summer rainfall in two ways: initially by describing general observations and patterns from rainfall time series plots (ie, in a qualitative sense) and then by describing the results of statistical tests.

(i) Observations from the data

As outlined in Section 4.1.1, the 5-year running means for annual 3-month minimum rainfall and annual dry spell length show general patterns in these rainfall indicators over time, by smoothing out inter-annual variability; Figures 4.4 and 4.5 show examples of plots for both indicators that typify the pattern of variability observed across monitoring sites.

Generally no systematic or significant changes over the long-term in the magnitude or pattern of variability of either rainfall indicator were observed, and since 1980, the 5-year running means were largely within the ranges experienced in previous periods.

However, at many of the sites there appears to have been a common period of generally declining annual 3-month minimum rainfall (as indicated by the 5-year running mean) from about the mid-1990s to present. This period of decline is apparent for the Bannockburn rainfall site in Figure 4.4 and also in Figure 4.6 which is a compilation (average) of plots for all 18 individual sites into three sub-regional plots for the common period July 1980–June 2011.

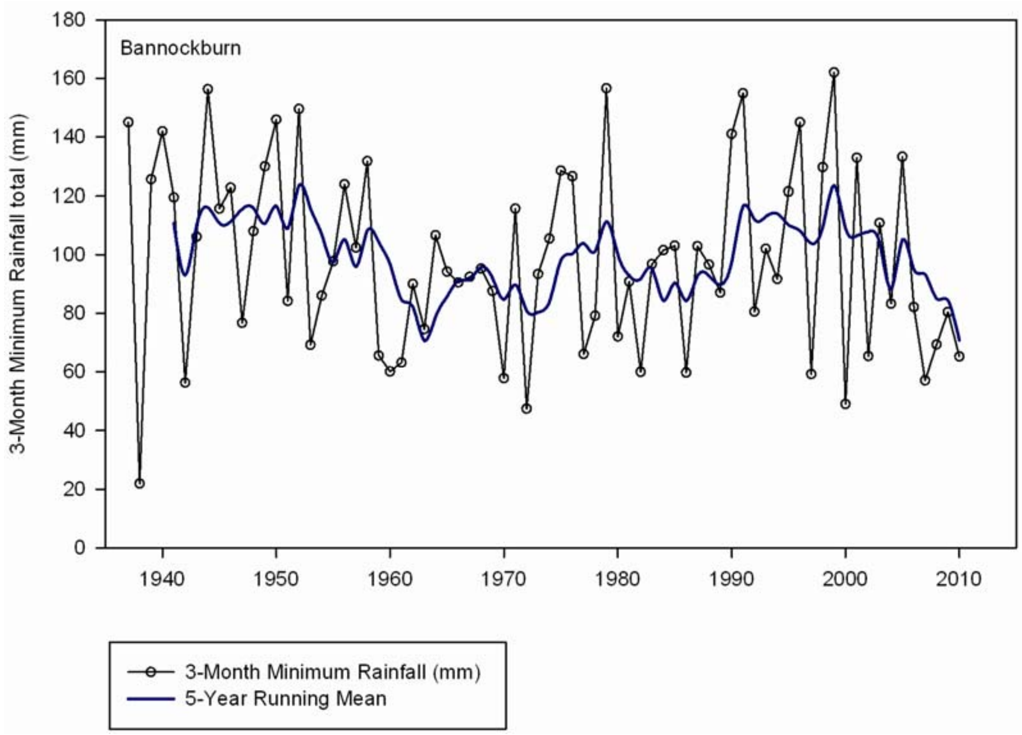


Figure 4.4: 5-year running mean of annual 3-month minimum rainfall for the monitoring site 'Bannockburn', based on the full monitoring record (July 1935–June 2011)

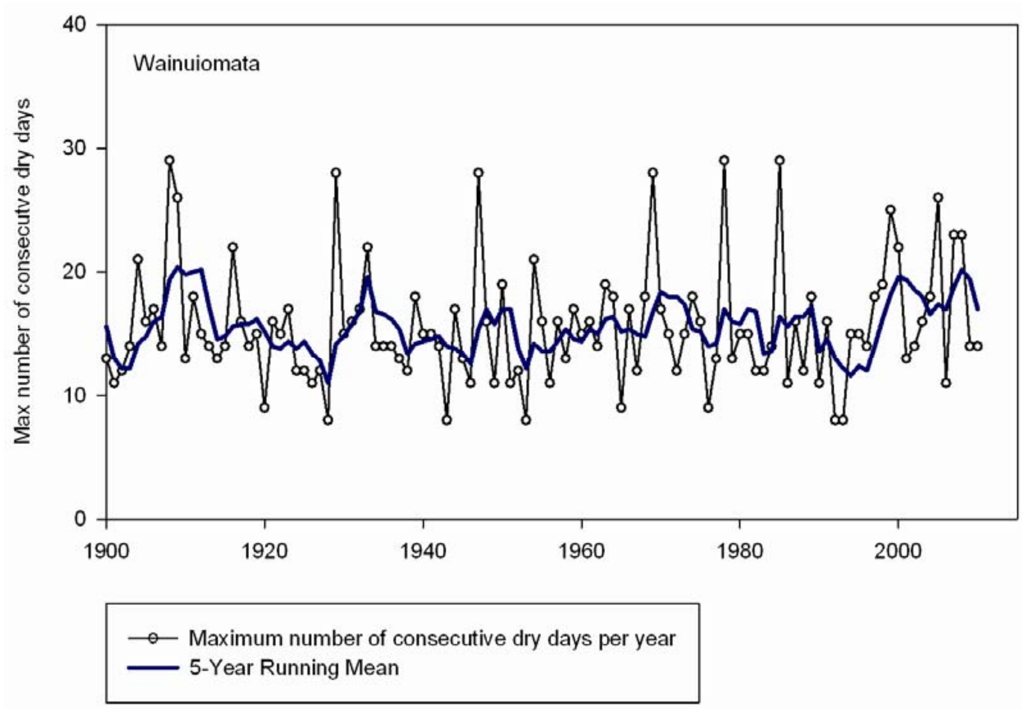


Figure 4.5: 5-year running mean of the maximum number of consecutive dry days for the rainfall monitoring site 'Wainuiomata', based on the full monitoring record (July 1900–June 2011)

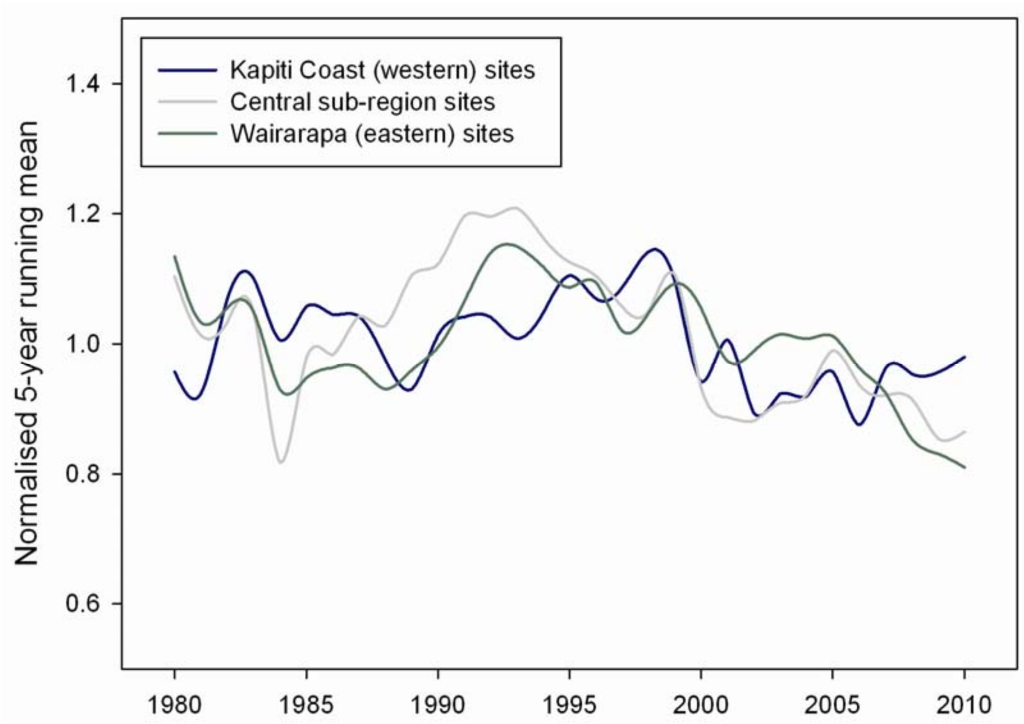


Figure 4.6: 5-year running mean of annual 3-month minimum rainfall for the period July 1980–June 2011. Plots represent averages of all sites mapped on Figure 4.1 and listed in Table A3.1, grouped by sub-region. The running means are unit-less; they are based on individual site records that have been divided by their long-term mean 3-month minimum rainfall.

Most recently (post-2000) the range of the 5-year mean annual dry spell length has been relatively subdued across the region with no record dry spells being recorded at any of the sites[13], and there has been no obvious region-wide increase or decrease. This is illustrated more clearly in Figure 4.7 where running mean results for groups of sites have again been averaged to present a regionalised pattern of change over the period July 1980–June 2011. Broadly speaking, the length of dry spells in western (Kapiti Coast) and central areas was slightly greater in the decade since 2000 than in the decade prior to that, while no real change to the length of dry spells occurred in the Wairarapa.

[13] Excluding two sites with relatively short records (beginning in the 1990s).

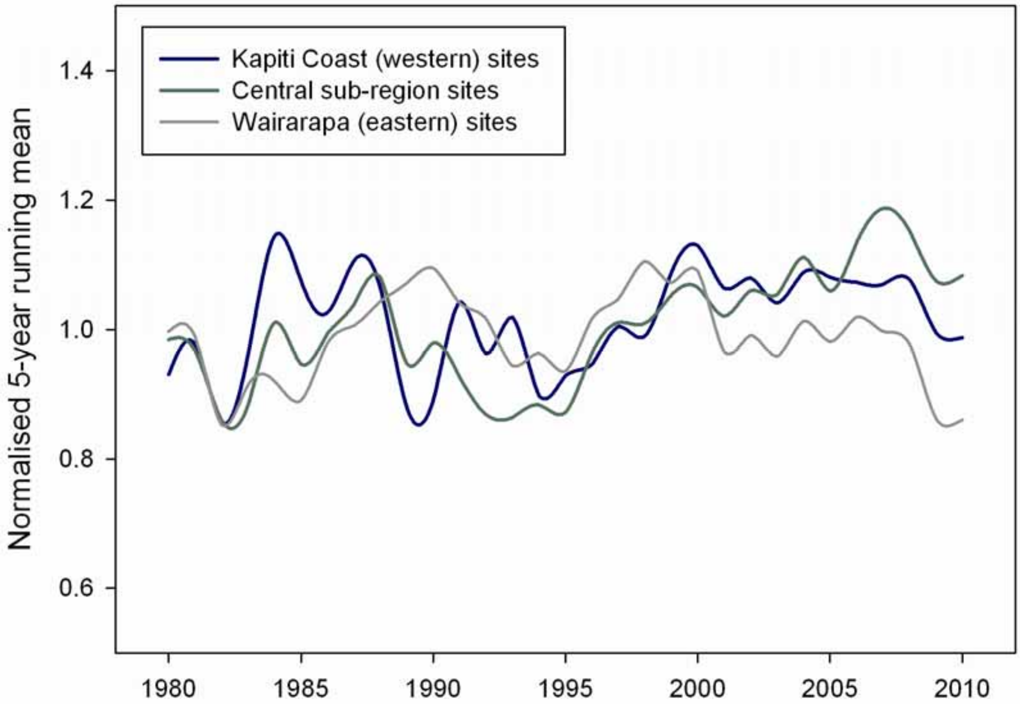


Figure 4.7: 5-year running mean of annual dry spell length for the period July 1980–June 2011. Plots represent averages of all sites mapped on Figure 4.1 and listed in Table A3.1, grouped by sub-region. The running means are unit-less; they are based on individual site records that have been divided by their long-term mean annual dry spell length.

(ii) Statistical trend tests

The linear trend analysis results for both indicators are summarised in Tables A3.2–A3.5, Appendix 3. Generally the results corroborate the running mean observations described in the previous section and show that there were no statistically significant trends in annual 3-month minimum rainfall at any of the selected sites for the common period July 1980–June 2011.

Of the 12 rainfall monitoring sites that have records extending back well before 1980, the longer term trends in 3-month minimum rainfall are largely consistent with the July 1980–June 2011 trend results: ten of the 12 sites in the analysis showed no statistically significant trend. One site, 'Tanawa Hut' in eastern Wairarapa, showed a statistically significant decreasing trend with a magnitude of change equating to a reduction in the annual 3-month minimum rainfall of about 8 mm per decade (which is about 6% of the long term median). Another site, 'Karori' in Wellington city, showed a statistically significant increase in the annual 3-month minimum rainfall, but this result requires further investigation as it appears to be inconsistent with what was observed at a nearby rainfall monitoring site (Kelburn).

Similarly, there were virtually no statistically significant linear trends observed in annual dry spell length. For the period 1980–2010, only one site ('Purunui', in northeastern Wairarapa) showed a statistically significant decreasing trend (-0.03 mm/yr, $p<0.05$) and one site ('Orongorongo', in the central sub-region) had a weakly significant increasing trend (0.14 mm/yr, $p<0.1$). Relative to the site medians, the magnitudes of change over time indicated by the significant or weakly significant trend results for Purunui and Orongorongo were small (-0.2% and 1.2% per year, respectively) and equate to absolute changes in the maximum number of consecutive dry days in the range -0.5 to 1.5 days per decade. Of the nine rainfall monitoring sites that have records extending back well before 1980, the longer-term trends in annual dry spell length are largely consistent with the July 1980–June 2011 trend results in that there were few statistically significant trends observed. One site (‘Castlepoint’, in eastern Wairarapa) had a statistically significant decreasing trend and one site (‘Otaki’, in northern Kapiti Coast) had a weakly significant ($p<0.1$) increasing trend. The remaining seven sites essentially showed no linear trend in annual dry spell length since records began (ie, trend slope values indicated average rates of change close to zero with non-significant *p*-values).

4.1.3 Summary

Summer rainfall over the past six years was not particularly unusual in the Wellington region. It was a slightly drier period than normal but almost no record minima occurred. Very few statistically significant trends in the selected indicators (annual 3-month minimum rainfall and the annual maximum number of consecutive dry days) were observed over either the common time period July 1980–June 2011 or the full site records. The conclusion from this is that there has not been any regional-scale, systematic or ‘meaningful’ change in the amount of summer rainfall or duration of dry spells over the medium to long term.

Notwithstanding the lack of statistically significant trend results for the period July 1980–June 2011, a general pattern of declining annual 3-month rainfall minima was observed for many sites during the latter half of this period (ie, indicating a tendency towards a slight drying phase since the mid 1990s). This pattern appears to be most spatially uniform in the central parts of the region: the Hutt, Wainuiomata and Wairarapa valleys. In addition, the length of dry spells in western and central areas was slightly greater in the decade since 2000 than in the decade prior to that but no real change in this indicator occurred in the Wairarapa.

The observed summer drying phase from the mid-1990s was also generally reflected in the year-round rainfall results with decreasing cumulative totals observed from the late 1990s. A very wet year in 2004 brought an end to this drying phase and, since 2006, no distinct cumulative deviation of rainfall from long term averages was apparent.

These observations and potential reasons for the patterns are discussed further in Section 5.

4.2 Trends in low river flows

The magnitude and frequency of low river flows affect water availability, because they determine the frequency and duration of water take restrictions and because (in many instances) allocation limits in the RFP are set according to low flow magnitude.

4.2.1 Approach to analysis

The sites selected for low flow analysis are shown in Figure 4.8 and listed in Table A4.1 (Appendix 4). They were chosen because they have relatively long-term flow records and are mostly located upstream of significant water takes ('unimpacted'). All of the sites, with the exception of Pahaoa River at Hinakura, have headwaters associated with the Tararua or Rimutaka ranges. Most (around 90%) of the surface water allocation for the region is from rivers or streams associated with these ranges; the exceptions are takes from small (generally spring-fed) streams mostly on the Wairarapa plains, and from Ruamahanga River tributaries fed from the eastern side of the catchment.

Two indicators of low flow patterns were assessed:

- The annual 7-day low flow. This is an indicator of low flow magnitude; and
- The number of days per year with flow less than the 90^{th} percentile low flow (Q_{90} – henceforth referred to as 'annual number of low flow days'). This is an indicator of low flow frequency.

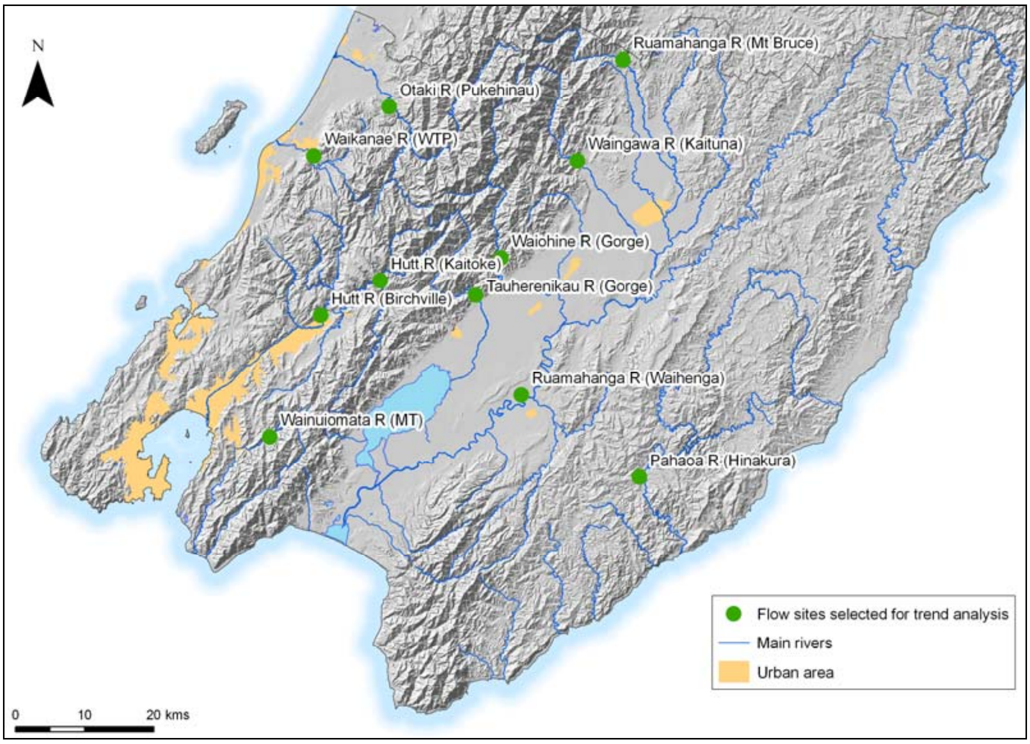


Figure 4.8: Location of river level/flow sites selected for trend analyses

As for the rainfall analysis, visual assessment of plots of the 5-year running means were followed by Mann-Kendall trend tests for the selected flow monitoring sites[15]. This was done for two time periods: the last 30 years (1980/81–2010/11) and the entire available record for each site. In addition, low flows during the last six years were assessed to determine whether recent low flow conditions (since the last round of SoE reporting (Watts 2005; Jones & Baker 2005) have been typical. Trends were assessed as statistically significant if $p<0.05$, equivalent to a confidence level of 95%.

4.2.2 Results

(a) Low flows in the last six years

Analysis of recent low flows (for the six years to June 2011 – see Table 4.2) found that there was a tendency for lower flows and more low flow days per year compared with the long-term average. The year 2007/08 was particularly significant, with low flows below the 25th percentile (ie, well below 'normal') occurring at all sites in the analysis, and a record low flow for the Ruamahanga River at Waihenga. This river and two others – the Otaki and Hutt rivers – also had a record annual number of low flow days in 2007/08.

Table 4.2: Annual 7-day low flows between 2005/06 and 2010/11 at representative flow monitoring sites in the Wellington region, grouped by sub-region. Orange shaded cells are lower than the 25th percentile for the whole record and blue shaded cells are higher than the 75th percentile for the whole record. Bolded values are either the highest or lowest annual low flow on record.

Sub-region	Site	*Mean annual 7-day low flow (L/s) for entire record*	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Wairarapa	Ruamahanga River at Mt Bruce	*1,283*	1,189	1,182	931	988	1,398	1,044
	Ruamahanga River at Waihenga*	*10,355*	10,805	7,478	**5,539**	5,553	13,091	7,530
	Waingawa River at Kaituna	*1,411*	1,227	1,390	1,100	1,068	1,655	1,122
	Waiohine River at Gorge	*3,535*	3,072	3,171	3,012	3,103	4,512	3,239
	Tauherenikau River at Gorge	*1,304*	1,434	1,135	1,064	1,285	1,833	1,335
	Pahaoa River at Hinakura	*111*	62	88	17	43	148	55
Central	Hutt River at Kaitoke	*1,422*	1,475	1,191	874	1,026	1,378	1,165
	Hutt River at Birchville*	*2,652*	2,250	2,522	1,864	2,990	2,943	2,572
	Wainuiomata R at Manuka Track	*183*	142	154	131	161	150	157
Kapiti	Otaki R at Pukehinau	*5,248*	5,899	4,859	3,576	3,742	5,362	4,843
	Waikanae R at WTP	*1,043*	829	1,005	679	856	1,109	842

*Impacted by upstream water abstraction.

15 Although not all sites on Figure 25 could be used in all parts of the analysis.

(b) Changes in low flow

This section summarises changes in low flow in two ways: initially by describing general observations and patterns from low flow time series plots (ie, in a qualitative sense) and then by describing the results of statistical tests.

(i) Observations from the data

Examination of the 5-year running means for the two low flow indicators shows several phases of low flow magnitude and frequency have tended to occur since most flow monitoring records began in the mid to late-1970s (Figures 4.9 and 4.10). The last six years seem to fit into a phase of low flows becoming lower and more frequent. In fact, in general it appears there has been an overall downward trend in the annual 7-day low flow and an upward trend in the annual number of low flow days in the Wellington region since about the mid-1990s. However, the current phase does not appear abnormal in terms of the range of the 5-year running means that have occurred for both low flow indicators during the last few decades.

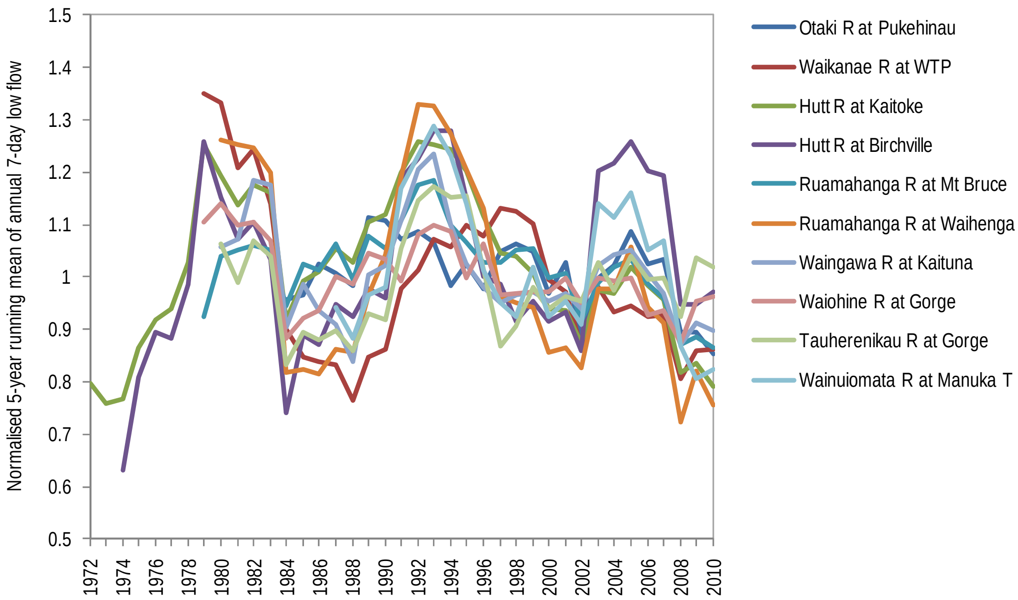


Figure 4.9: 5-year running mean of annual 7-day low flows for selected river flow sites in the Wellington region with headwaters in the Tararua Range (ie, all sites in Table A4.1, Appendix 4 are included in the analysis except for Pahaoa River at Hinakura). Flows are unit-less and have been normalised by dividing by the long-term mean annual low flow (listed in Table A4.1). Note the years indicate low flow years, ie, 1972 indicates the year beginning 1 September 1972.

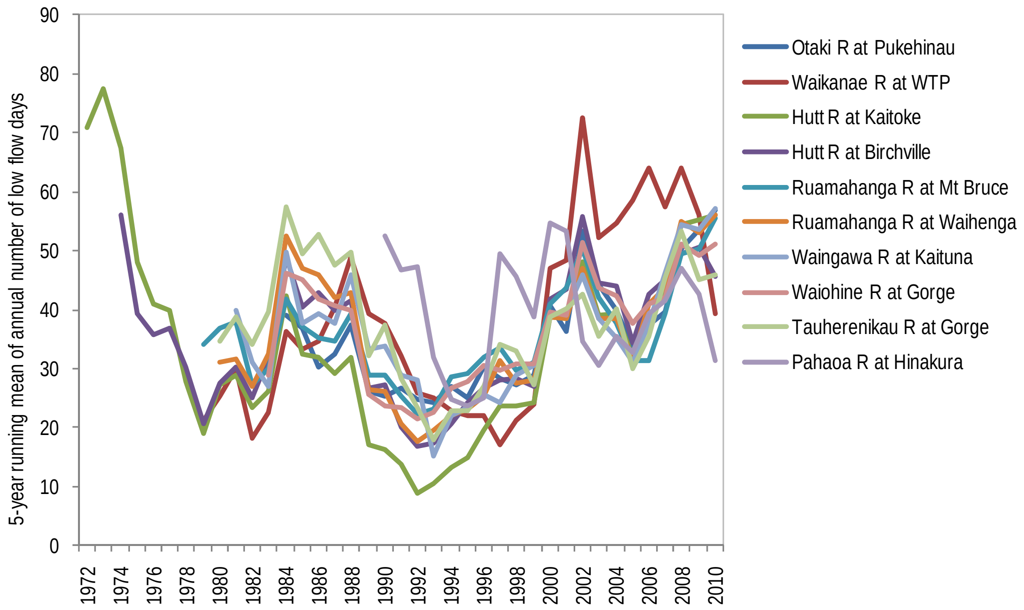


Figure 4.10: 5-year running mean of annual number of low flow days for selected river flow sites in the Wellington region (all sites in Table A4.1, Appendix 3 are included except for Wainuiomata at Manuka Track). Flows are unit-less and have been normalised by dividing by the long-term mean annual annual number of low flow days (listed in Table A4.1). Note the years indicate low flow years, ie, 1972 indicates the year beginning 1 September 1972.

(ii) Statistical trend tests

The results of the Mann-Kendall trend test, show very few significant trends in low flow magnitude (indicated by the annual 7-day low flow) and frequency (indicated by annual number of low flow days) over the last 30 years. The only site which showed a statistically significant ($p<0.05$) change was Hutt River at Kaitoke with both a decrease in the annual 7-day low flow (-13 L/s/yr equating to -1% per year) and an increase in the number of low flow days per year since 1980/81 (1 day/yr equating to 4% per year). However, no trends were apparent when the full site record for Kaitoke (which begins in the late 1960s) was analysed. This indicates – and is confirmed by the 5-year running mean graphs (eg, Figure 4.9) – that short term phases in low flow magnitude and frequency, on the scale of decades or less, tend to exist and may influence the results of trend analysis.

Several sites in the analysis (other than Hutt River at Kaitoke) showed a weak tendency for a decrease in low flow magnitude and an increase in the annual number of low flow days since flow records began, which was mostly in the mid- to late-1970s. However, none of these trends were statistically significant. Moreover, given that Hutt River at Kaitoke has the longest flow record – beginning in 1968 – and shows no trend since that time, it could be assumed that there would be no obvious change in low flows at other sites if those sites (or at least those with headwaters in the Tararua Range) had similarly long records. The data from Hutt River at Kaitoke show that extreme low flows and more frequent than normal low flow days occurred from about 1970 through until 1976; these precede the low flow records for most other sites. In addition, most sites show a period of higher than normal low flows, and less frequent than normal low flows, in the late 1970s and early 1980s, which is likely to have affected the trend analysis results for the sites with records that begin during this phase.

4.2.3 Summary

Linear trend analysis of the low flow records for the Wellington region found very few statistically significant trends in the selected low flow indicators for the last 30 years (July 1980–June 2011) and no significant trends when the full low flow records were used (with most site records beginning in the mid-1970s). As with the rainfall trend results (Section 4.1.2), the conclusion from this is that there has not been any regional-scale, systematic or ‘meaningful’ change in low flow magnitude or frequency since monitoring began in the 1970s.

Notwithstanding the lack of significant trend results, a general pattern was observed of a tendency towards lower flows and more frequent low flows typically since about the mid-1990s. In general, the six years since the last SoE hydrological technical report (Watts 2005) saw lower annual 7-day low flows and more low flow days per year compared to average.

These observations and potential reasons for the patterns are discussed further in Section 5.

4.3 Trends in groundwater levels

Groundwater levels influence water availability for both groundwater users and dependent surface water ecosystems. Groundwater levels fluctuate naturally in response to patterns in seasonal rainfall recharge and long-term climate trends but are also affected by abstraction. Declining groundwater levels may indicate over use of the resource and a need for more stringent management of water abstractions. While rainfall, natural discharges and abstraction are the primary drivers of groundwater level changes, determining the relative influence of each factor for a given aquifer is difficult. The analyses in this section represent a first attempt to summarise overall groundwater level trends in the Wellington region and possible reasons for observed patterns.

4.3.1 Approach to analysis

Trends in groundwater levels were assessed at 44 SoE groundwater level monitoring sites in the Wairarapa Valley, Hutt Valley and Kapiti Coast (Figure 4.11). These sites were selected to broadly represent the main groundwater management zones of the region. Effort was made to select a minimum of two wells in each management zone, one each representing shallow (water table) and deep (confined) groundwater aquifers. However, data constraints meant that this could not be achieved for every zone. It was assumed that the selected monitoring wells are representative of aquifer-scale storage dynamics however more localised influences on the well records can not be ruled out.

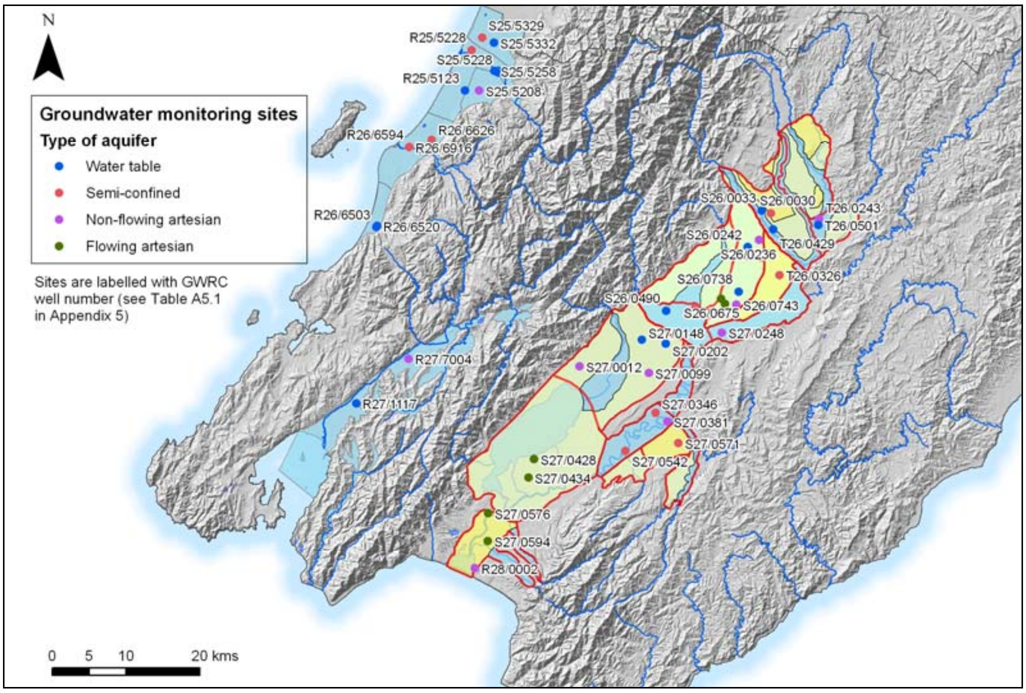


Figure 4.11: Location of groundwater monitoring sites selected for trend analyses. Water table sites are in the shallowest (unconfined) aquifers and artesian sites are in the deepest (confined) aquifers. Site labels correspond to the 'well' numbers in Table A5.1, Appendix 5. Existing groundwater management zone boundaries are shown for the Kapiti Coast and Hutt sub-regions while the proposed new zone boundaries (see Figure 2.9 for more detail) are shown for the Wairarapa Valley.

Trend analysis was conducted on three groundwater level indicators for each well record:

- The annual median level (from mean monthly measurements) – this provides an overall indication of whether 'average' groundwater levels have increased or decreased over time.
- The annual 3-month minimum level – trends in the 3-month minimum level provide an indication of the sustainability of summer groundwater takes during periods of highest water demand.
- The annual 3-month maximum level – trends in the 3-month maximum level indicate whether there is long-term sustained recovery in groundwater levels between seasonal lows.

Linear regression trend analysis and the Kendall Tau rank correlation tests were applied to test for the presence, direction and magnitude of groundwater level trends. A LOESS function was applied to test whether the trends were monotonic (systematically moving in one direction) or piecewise (changing direction within the time period of analysis). Trend assessments were carried out for the time period 1994/95–2010/11. This corresponds to the maximum common span of data that was available across all selected sites. The significance of change in groundwater level trends is described as highly significant ($p \leq 0.01$), significant ($p \leq 0.05$) or non-significant ($p > 0.05$).

(a) Interpreting environmental significance and risk

One way of reporting trend magnitude and its environmental significance is to convert the rate of change in groundwater level (from the trend slope) to an estimated rate of change in aquifer storage and then express this storage change as a percentage of safe aquifer yield. This has been done for all 44 wells with most emphasis placed on those with statistically significant trend slope results. Safe yield values for the groundwater management zones in the existing RFP (and listed in Tables 3.9 and 3.10 of Section 3 of this report) have been used. As described in Section 3, new allocation volumes for management zones in the Wairarapa Valley have been proposed (and are listed in Table 3.11 in Section 3). However, we have opted not to report storage depletion against these new values in order to preserve a consistent and robust approach across the region[16]; further detail on the methods used to derive storage and safe yield values is provided in Mzila (2012).

A rate of storage depletion that equates to greater than 5% of annual safe yield is used in this report to indicate an 'environmentally significant' result. If safe yield is depleted on average at a rate of 5% per year, non-recovering decline in groundwater level would be expected to occur after 20 years. Note that the definition here of environmental significance is largely arbitrary and used for the purposes of comparing the relative rate of change between sites; there are no guidelines or thresholds that define an 'acceptable' rate of decline in absolute terms.

To help interpret the overall meaning, in a management sense, of the groundwater trend results, analysed wells (and the aquifers they represent) are categorised according to perceived level of risk of unsustainable depletion. Four broad categories have been defined and are described in Table 4.3. The highest risk aquifers are considered to be those that have shown a statistically significant decline in median groundwater level combined with an environmentally significant decline in storage and a decline in winter recovery.

(b) Drivers of groundwater trends (rainfall and abstraction)

In addition to the analysis of groundwater level trends, an assessment of the likely causes of any observed changes was undertaken. This involved relating groundwater trends to trends in rainfall and water abstraction; these are the primary causes of groundwater replenishment and depletion, respectively.

Rainfall analysis trend results presented in Section 4.1 of this report were representative of a much longer period (1980/81 to 2010/11) than the groundwater trend analysis and were focussed primarily on summer conditions. It is therefore not appropriate to directly relate the two sets of results. Instead, rainfall was characterised further by looking at trends in median, 3-month moving average minima and 3-month moving average maxima for the period 1994/95–2010/11 (equivalent to the groundwater level indicators). This was done for a selection of seven rainfall sites considered representative of the recharge areas of the main groundwater management zones; these sites are listed in Table A5.2 in Appendix 5.

[16] The proposed allocation volume limits do not equate directly to safe yield and further work is needed to meaningfully relate storage depletion to these proposed limits.

Table 4.3: Risk categories based on results of groundwater trend analysis

Category	Risk level	Criteria[1]
1	Very high	• Decline in groundwater level[2] and • Decline in storage[3] and • Decline in winter recovery.[4]
2	High	• Decline in groundwater level and • Decline in storage but • No trend in winter recovery OR • Decline in groundwater level and • **No** decline in storage but • **Decline** in winter recovery.
3	Moderate	• Decline in groundwater level but • No decline in storage and • No trend in winter recovery OR • **No** statistically significant decline in groundwater level but results potentially indicative of storage depletion and decline in winter recovery.
4	Low	• No statistically significant decline in groundwater level or indication of decline in winter recovery.

[1] Descriptions based on results of analysis for the period 1994/95–2010/11.
[2] 'Decline in groundwater level' refers to statistically significant declines in all cases.
[3] 'Decline in storage' refers to environmentally significant declines in all cases (as defined in the preceding text).
[4] 'Decline in winter recovery' refers to statistically significant declines in all cases.

Abstraction effects were interpreted from the outputs from a previously calibrated FEFLOW numerical groundwater model developed by Gyopari and McAlister (2010a, b and c) for the Wairarapa Valley[17]. Essentially, observed groundwater level trends were compared with FEFLOW modelled groundwater levels under conditions of no abstraction (ie, the amount of water abstracted – as defined from actual metering records – was added back into the model to simulate conditions of no abstraction). The difference between modelled (with no abstraction) and observed groundwater levels indicated the influence of groundwater abstraction on measured groundwater level trends.

4.3.2 Results

In this section an overview of results is provided first, in the form of aquifer risk categorisation, followed by a more detailed summary of the trend analysis results.

(a) Overview – aquifer risk

Figures 4.12 and 4.13 synthesise results from components of the groundwater trend analyses to present a summary of aquifer risk. Twelve out of 44 wells are in high risk categories; four wells are 'Category 1 – very high risk' and eight wells are 'Category 2 – high risk'. The four very high risk wells are located in

[17] While similar numerical outputs are not available for other parts of the region, it is assumed that causes of groundwater level trends in other zones would be similar to those in the Wairarapa Valley.

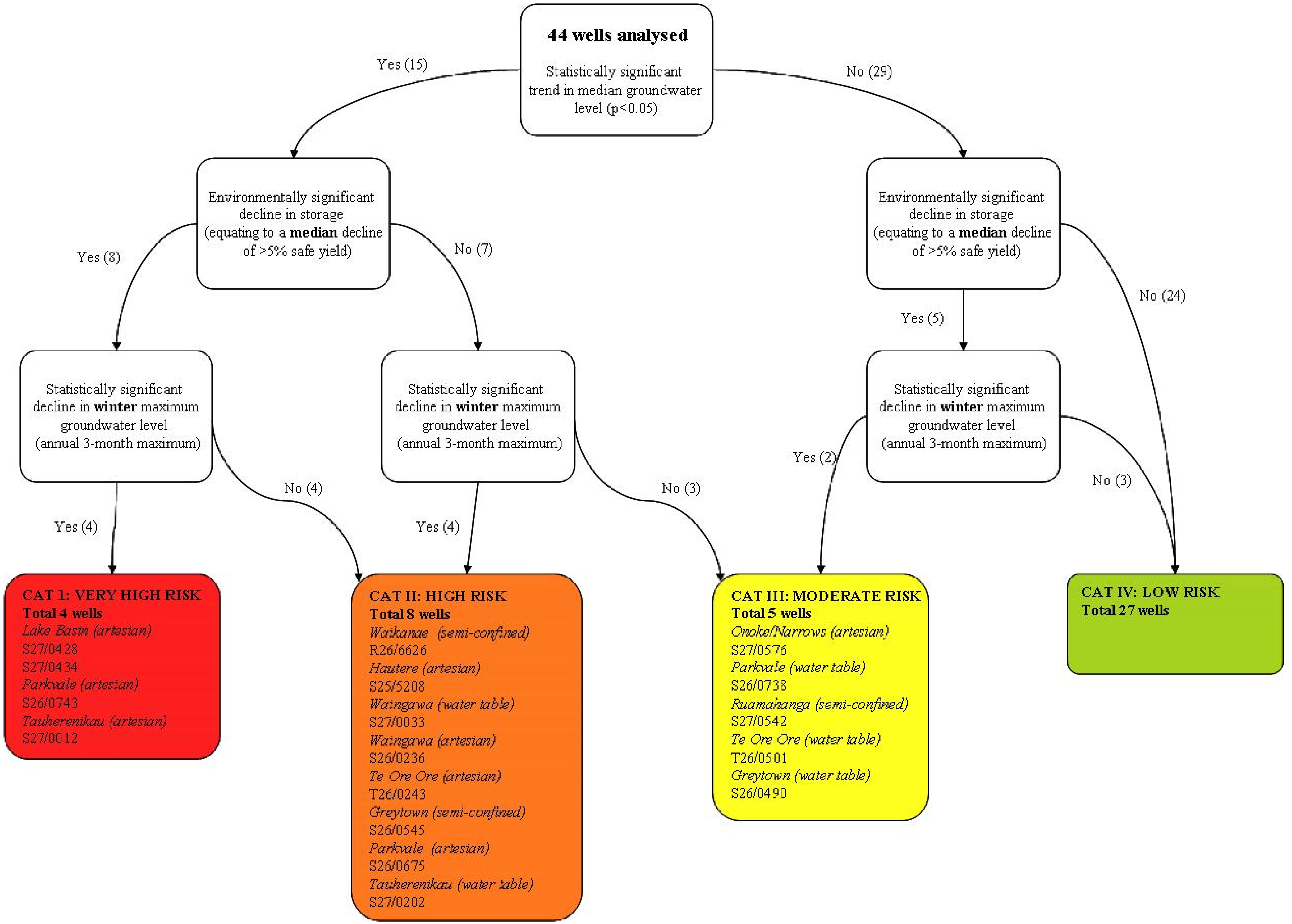


Figure 4.12: Summary of groundwater trend analysis results and interpretation of indicative risk of unsustainable depletion

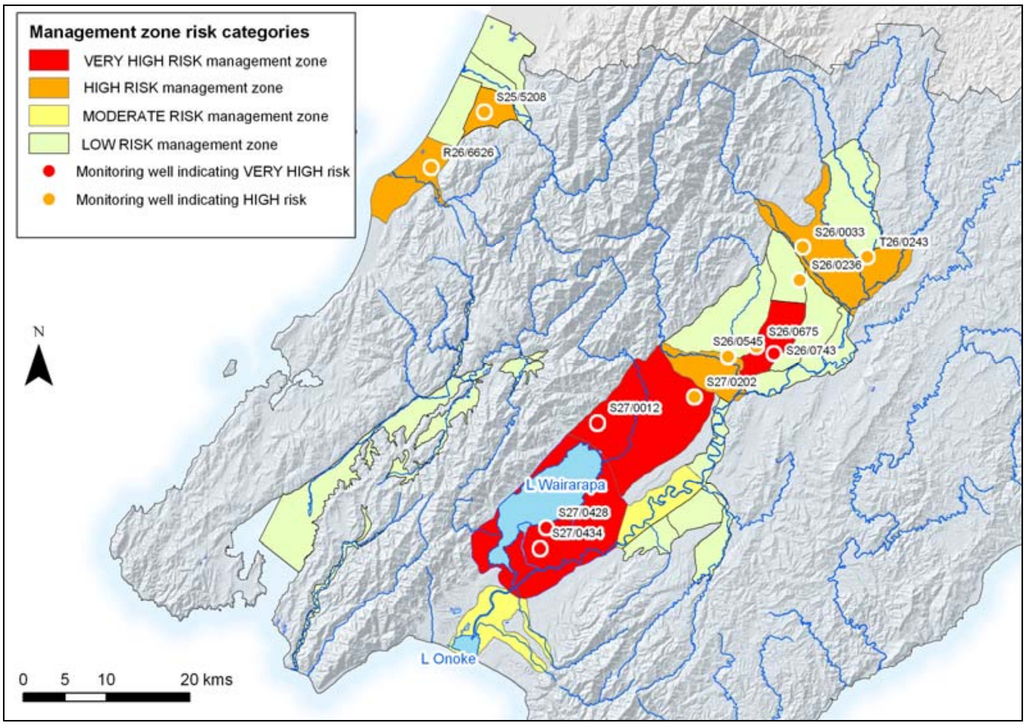


Figure 4.13: Groundwater management zones categorised according to perceived level of risk of unsustainable depletion. The categorisation is indicative only as there are usually multiple aquifer units (eg, deep confined and water table), not all of which have been analysed and not all of which are displaying the same trends. Therefore the highest risk classification has been mapped for each zone. Note also that the map does not explicitly convey the risk of groundwater depletion on rivers and streams.

the deep confined (artesian) aquifers of the middle and lower Wairarapa Valley while the high risk wells are spread between the Kapiti Coast (one wells in each of the Waikanae and Hautere groundwater management zones) and the Wairarapa Valley (six wells in the upper, middle and lower valleys) and comprise a mix of water table, semi-confined and deep confined (artesian) aquifers. The 12 wells in the 'very high' and 'high' risk categories represent eight aquifer systems.

Just over 60% of the 44 wells are categorised as 'low risk', largely because no significant trends in indicators of groundwater level were detected.

(b) Groundwater levels

Results of the trend analyses on annual median groundwater levels for the 44 selected monitoring wells are summarised in Figure 4.14 and Table 4.4. The full set of trend results is provided in Table A5.1, Appendix 5.

Across the region a total of 15 out of 44 wells showed statistically significant declines in groundwater level over the period 1994–2010; no significant trends were observed in the remaining 29 wells. In the Wairarapa, 13 out of 29 wells (45%) showed declining trends while on the Kapiti Coast only 2 out of 13 (15%) had declining groundwater levels. Only two wells were analysed in the Hutt Valley, with no statistically significant trends observed in either. Eleven

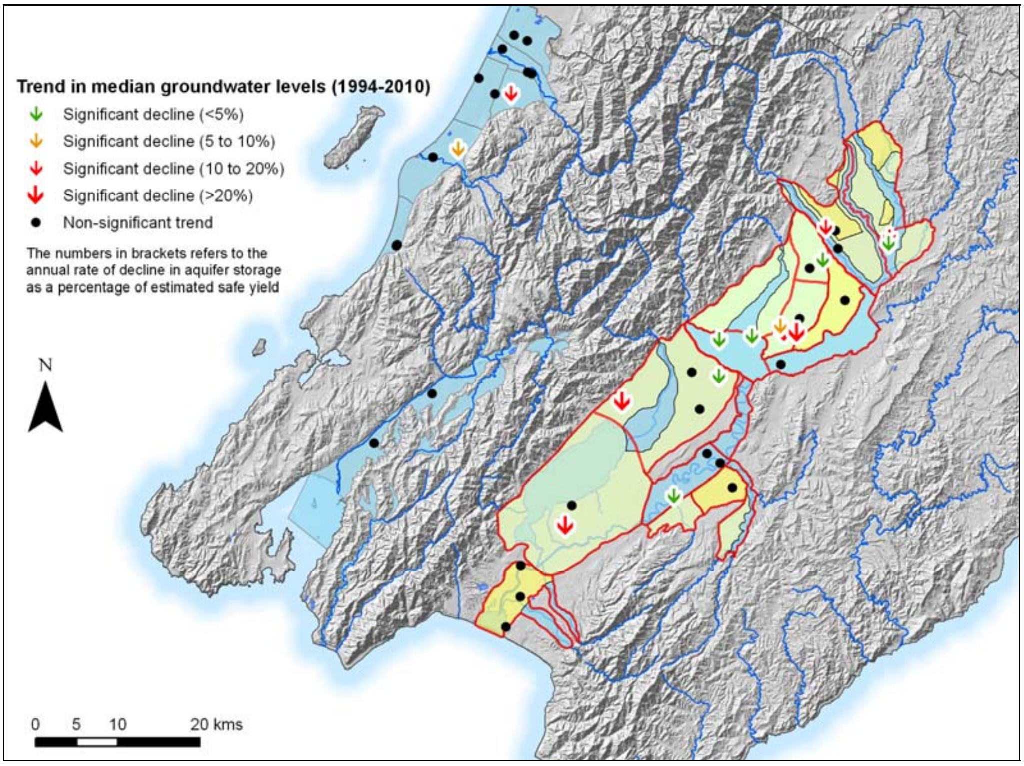


Figure 4.14: Trends in annual median groundwater level for selected wells in the Wellington region for the period 1994/95–2010/11. The magnitude of statistically significant declines has been represented as the annual rate of change of storage as a proportion of the estimated safe yield (this is explained further in the text). Existing groundwater management zone boundaries are shown for the Kapiti Coast and Hutt sub-regions and proposed new groundwater management boundaries (see Figure 2.9 for more explanation) are shown for the Wairarapa Valley.

Table 4.4: Summary of trends in annual median groundwater level for selected wells in the Wellington region for the period 1994–2010. See Table A5.1 (Appendix 5) for rates of change.

Sub-region	Type of aquifer	Number of wells	Trends in annual median groundwater level[1] [number of sites]		
			Statistically significant decline	Non-significant trends	Statistically significant increase
Wairarapa Valley	Artesian	14	7	7	0
	Semi-confined	7	2	5	0
	Water table	8	4	4	0
Central (Hutt Valley)	Artesian	1	0	1	0
	Water table	1	0	1	0
Kapiti Coast	Artesian	3	1	2	0
	Semi-confined	4	1	3	0
	Water table	6	0	6	0
Total		44	15	29	0

[1] Annual median calculated from mean monthly data.

of the 29 artesian or semi-confined aquifer wells (38%) had statistically significant declining trends, and these wells were in the Wairarapa and on the Kapiti Coast. Four out of 15 water table wells (27%) had statistically significant declining trends and these were exclusively in the Wairarapa.

None of the 44 wells had statistically significant increasing trends in groundwater level over the period of analysis.

Figure 4.14 also expresses the groundwater level trends as an annual rate of change in storage as a percentage of safe aquifer yield (conveyed using the size and colour of the trend arrows). Of the 15 wells that showed statistically significant declines in groundwater level, six had a rate of change that represented less than a 5% depletion of estimated aquifer safe yield per year. Five wells had a rate of change that represented between 5% and 20% depletion, including one in the Hautere groundwater management zone on the Kapiti Coast, and four wells had a rate of decline that represented more than a 20% depletion; these four wells are all in confined or semi-confined aquifers in the mid- to lower Wairarapa Valley (in the Lake Basin, Tauherenikau Fan and Parkvale management zones).

While trends in annual median groundwater levels provide an indication of 'average' groundwater conditions, it is also useful to examine trends in annual minima and maxima. It is the trends in these extreme values that determine the long-term average trend but also reveal how the pattern of summer draw-downs and winter recoveries are changing over time. Figure 4.15 shows an example of a well in the lower Wairarapa Valley in which summer minimum groundwater levels progressively declined during most of the period 1994/95–2010/11 but recovered fully in the winters with aquifer replenishment. The annual median groundwater level for this well did not show a statistically significant decline over the same period. A total of seven wells displayed similar characteristics to that shown in Figure 4.15 (see Table A5.2, Appendix 5); ie, significant declines in annual minima but sufficient winter recovery to retain a stable average groundwater level.

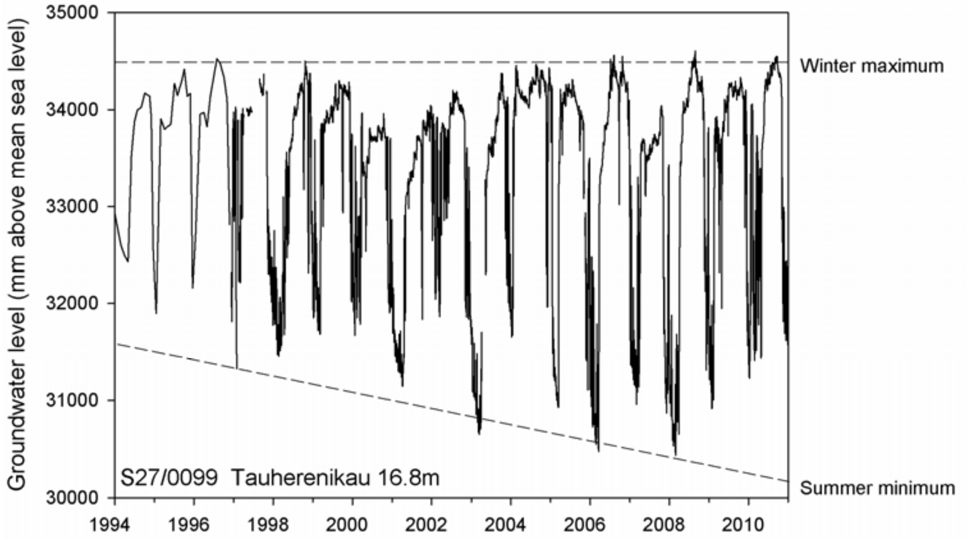


Figure 4.15: Example of a groundwater well (S27/0099 in the lower Wairarapa Valley) in which summer minimum drawdowns declined between 1994 and 2008 but full recovery occurred in winter (plotted from daily average groundwater level data)

Figure 4.16 shows an example of a well in the Parkvale area of the middle Wairarapa Valley in which both summer minimum and winter maximum groundwater levels progressively declined during most of the period 1994/95–2010/11. This decline and lack of recovery is reflected in the annual median which declined significantly in the same period, indicating that aquifer storage is being depleted beyond sustainable limits.

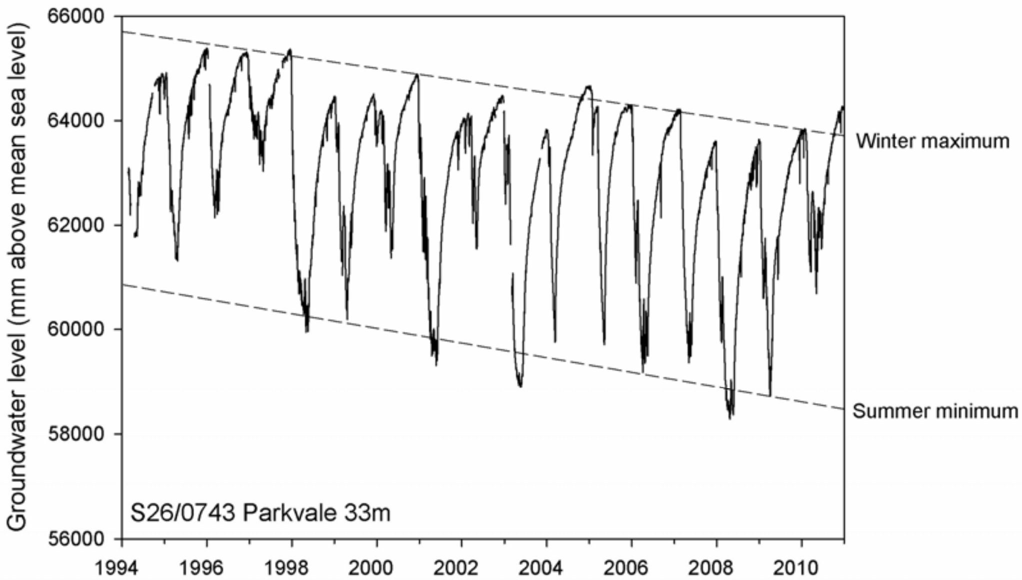


Figure 4.16: Example of a groundwater well (S26/0743 in the middle Wairarapa Valley) in which both summer minimum and winter maximum groundwater levels declined between 1994 and 2011 (plotted from daily average groundwater level data)

Overall, seven of the 44 wells analysed displayed similar characteristics to Figure 4.16 and had statistically significant declining trends for all three indicators of groundwater level (Table A5.2, Appendix 5). All these wells were in the middle and lower parts of the Wairarapa Valley.

(c) Rainfall recharge

Results of trend analysis (1994/95–2010/11) on median and 3-month moving average minima and maxima rainfall are provided in Table A5.2, Appendix 5. No results for any of the indicators for the seven rainfall sites were statistically significant. This is consistent with the results of rainfall analysis from a wider network of sites reported earlier in Section 4.1.

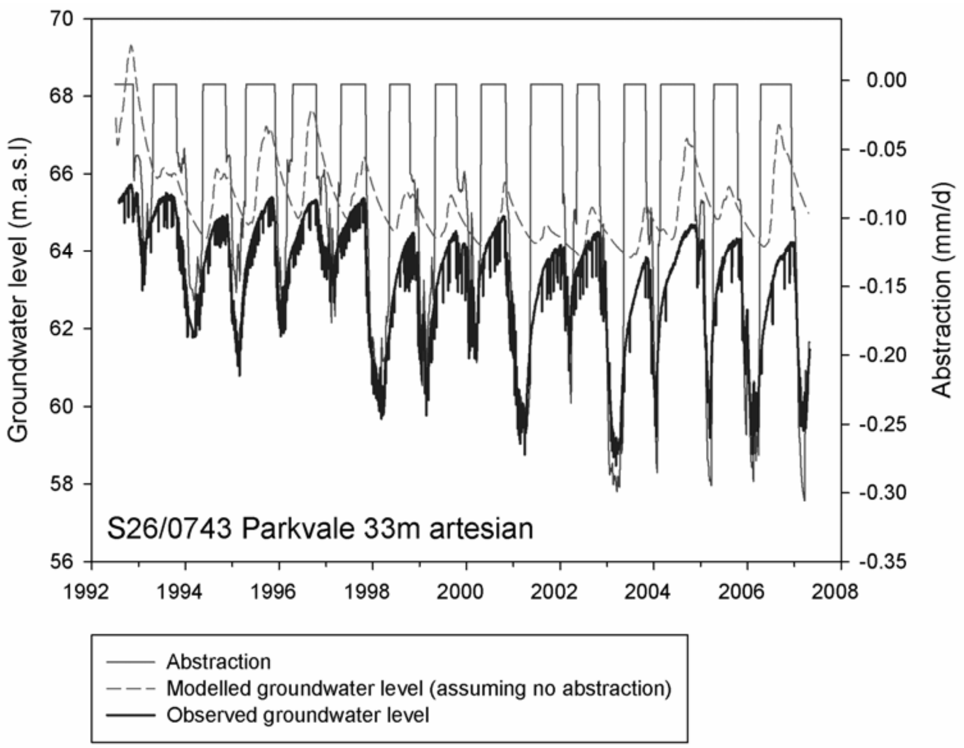
The cumulative departure from mean monthly rainfall plots in Figure 4.2 of Section 4.1.2 show that, within the groundwater analysis period, the dominant pattern across the region was one of 'drying' (ie, a phase of lower than average rainfall resulting in a deficit) from the mid 1990s to about 2005 and 'wetting' from 2005 onwards. Groundwater levels in many of the analysed wells, particularly the water table wells, responded to this rainfall pattern with declining and increasing levels corresponding to broadly the same time periods.

(d) Effects of groundwater abstraction

While demonstrating the link between water abstraction and groundwater level response is difficult in most areas, recent numerical modelling of groundwater aquifers in the Wairarapa Valley by Gyopari and McAlister (2010a, b and c) has improved the understanding of cause and effect in this highly used aquifer system.

Figures 4.17 and 4.18 demonstrate the contrasting influence of abstraction in two different aquifers in the middle Wairarapa Valley. Figure 4.17 shows an example of an aquifer (the Parkvale artesian aquifer represented by well S26/0743) in which abstraction exerts a dominant influence on water level trends. Observed groundwater levels (thick black line) declined over the period 1992–2006[18] in synchrony with increasing groundwater abstraction (grey line) while modelled groundwater levels (dashed grey line – assuming no abstraction) remained stable, and even increased slightly in the final years of the model simulation.

In contrast, Figure 4.18 shows an example of another aquifer (Greytown semi-confined aquifer represented by well S26/0545) in which natural factors (ie, mainly rainfall recharge) exert a more dominant influence on water level trends than abstraction. This is indicated by the close agreement between observed and modelled groundwater levels even with increased abstraction towards the end of the modelling period.

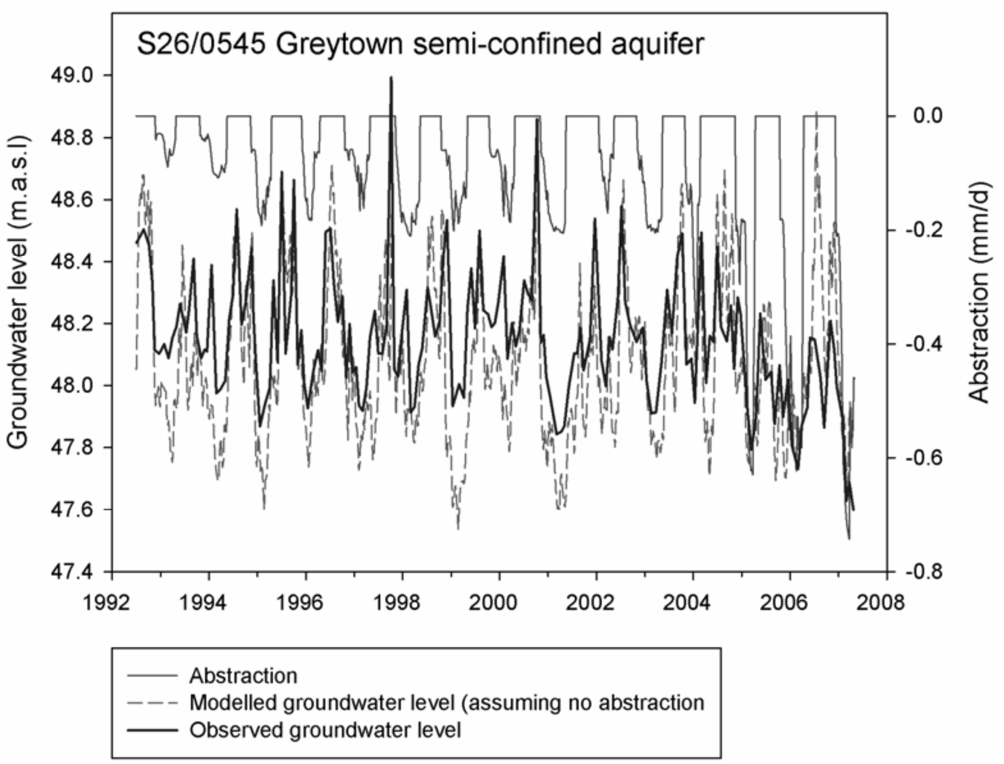


(Source: Adapted from Gyopari & McAlister (2010b))

Figure 4.17: Comparison of observed groundwater levels, modelled groundwater levels (assuming no abstraction) and aquifer abstraction (extrapolated from actual metering data) for a confined artesian well in the Parkvale groundwater management zone

---

18 This was the FEFLOW modelling period reported by Gyopari and McAlister (2010b).



(Source: Adapted from Gyopari & McAlister (2010b))

Figure 4.18: Comparison of observed groundwater levels, modelled groundwater levels (assuming no abstraction) and aquifer abstraction (extrapolated from actual metering data) for a semi-confined well (S26/0545, 18 m deep) in the Greytown groundwater management zone

Similar plots to those in Figures 4.17 and 4.18 have been presented for other groundwater management zones in the Wairarapa Valley by Gyopari and McAlister (2010a, 2010b & 2010c), along with further interpretation of the influence of abstraction on groundwater levels.

4.3.3 Summary

Across the Wellington region a total of 15 out of 44 wells assessed recorded statistically significant declines in median annual groundwater level over the period 1994/95–2010/11; the remaining 29 wells displayed no significant trends. Of the 15 wells with significant trends, 12 had environmentally significant declines in storage and/or trends of non-recovery that are indicative of ‘very high’ risk (four wells) and ‘high’ risk (eight wells) conditions and, therefore, a need for particularly careful management. The four very high risk wells are located in the deep confined (artesian) aquifers of the middle and lower Wairarapa Valley while the high risk wells are spread between the Kapiti Coast (two wells) and the Wairarapa Valley (six wells) and comprise a mix of water table, semi-confined and deep confined (artesian) aquifers. Three of the 15 wells with statistically significant declines in median groundwater level have levels of storage depletion equating to less than 5% of annual safe yield and reasonable seasonal recovery and are therefore considered indicative of ‘moderate’ risk levels.

The 29 (of 44) wells that did not display statistically significant trends in groundwater level are, subsequently, all considered to be at the lower end of the risk spectrum. However, those wells that had storage declines exceeding 5% of annual safe yield and showed signs of non-recovery in winter are considered indicative of 'moderate' risk conditions and worthy of continued close attention; initially this should involve annual processing of monitoring data to check for persistence in, or change to, indicative trends.

The 12 wells in the 'very high' and 'high' risk categories represent eight aquifer systems. Table 4.5 presents a summary list of these aquifers and Table A5.4 in Appendix 5 describes in more detail the results and recommendations for the management of these aquifers.

Table 4.5: Aquifers in the region with 'Very high' or 'High' risk of unsustainable depletion

Sub-region	Aquifer system	Aquifer type
Wairarapa Valley	Waingawa	Artesian confined
	Te Ore Ore	Both the artesian and water table aquifers
	Parkvale	Artesian confined
	Greytown	Semi-confined
	Tauherenikau	Both the artesian and water table aquifers
	Lake Basin	Artesian confined
Kapiti Coast	Hautere	Artesian confined
	Waikanae	Semi-confined

5. Discussion

This section brings together key findings from the previous two sections and discusses what these findings mean in the context of present and future resource management in the region. The discussion covers some of the likely reasons for observed trends in water allocation and availability, as well how findings from our region compare with related studies and how the region's water resources might be affected in the future under projected scenarios of climate change. The discussion also highlights some areas where management policies should be reviewed and strengthened and identifies primary knowledge gaps.

5.1 Water allocation: State and trends

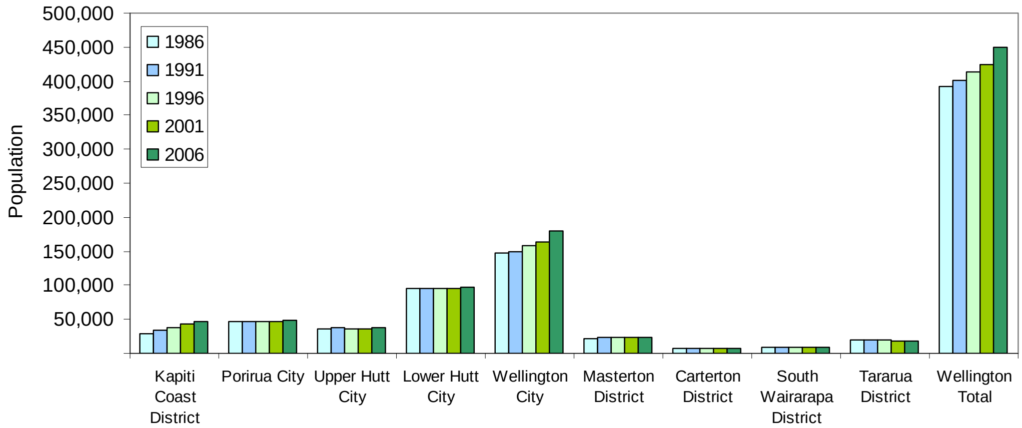
5.1.1 Regional overview

The water allocation statistics presented in Section 3 show annual consented water allocation increased by around 144.5 million m^3/year during the period 1990-2010, with the most rapid increase during the late 1990s through to around 2005. Most of the increase in water allocation was for irrigation (77%), although the increase for public water supply was also significant (20%).

Dairy pasture irrigation accounted for most (73%) of the increase in water allocation for irrigation, and for more than half (56%) of the region's overall increase in annual water allocation between 1990 and 2010. Recent analysis of land use in the Wellington region shows that, while the land area under dairy farming has not changed significantly or may have even decreased since 2002, the average dairy herd size and stocking rate increased by around 33% and 10%, respectively, over the period 2002 to 2010 (Sorensen 2012). The increase in stocking rate is likely to have resulted in an increase in the need for irrigation to boost pasture production.

Over the period 2003–2009 vineyard area in the Wellington region increased by 44% and the area under 'green-feed' (which was classed as either non-dairy pasture or horticulture irrigation in Section 3) more than doubled (Sorensen 2012). The increase in area under both of these crop types added to the increase in water allocation; vineyard, non-dairy pasture and horticulture irrigation combined account for about 25% of the overall increase in water allocation for irrigation.

The increase in consented water allocation during the period 1990–2010 is also likely to reflect climate conditions during that time. Although the analysis of rainfall and low flows in Sections 4.1 and 4.2 found very few significant trends for the period 1980/81–2010/11, there has been a tendency towards lower summer rainfall totals and 7-day mean low flows, and more frequent low flows, in the region since the mid-1990s compared to during the previous decade. Total cumulative rainfall also appeared to enter a 'drying phase' in the mid to late 1990s, especially in the Wairarapa. The particularly rapid increase in water allocation during the late 1990s and early to mid 2000s is likely to be at least partly related to demand following the severe droughts that affected the region in 1998 and 2003, both of which were caused by El Nino weather conditions (refer to Section 5.2.2). The drought of 1998 was particularly severe in the Wairarapa, where the majority of the region's farming activities occur. In addition to increasing the demand for irrigation, the droughts are likely to have led to an increase in public water supply demand. The larger volumes allocated to public water supplies that were re-consented after 1998 (the water takes for Greytown, Featherston, Martinborough, Wellington metropolitan area and Waikanae / Paraparaumu) are likely to be to some extent related to increased demand during the then-recent droughts. Population increases since the original permits were issued is also likely to have contributed to higher water demand in some areas. Figure 5.1 shows that while most Wairarapa districts have had fairly static populations over the period 1986–2006, steady increases on the Kapiti Coast and in Wellington city led to an overall population growth in the region of 14% over this period.



(Source: Statistics NZ)

Figure 5.1: Population changes in districts of the Wellington region over five census surveys (1986–2006)

Groundwater sources provided for nearly 60% of the increase in water allocation over the 20 years from 1990 to 2010. A high proportion (80%) of the increase in groundwater allocation occurred in the Wairarapa, and was mostly (78%) for irrigation. The bias towards additional utilisation of groundwater compared to surface water over the 20 years is probably due to the fact that many rivers and streams – particularly in the Wairarapa – became fully or nearly fully allocated during the same period, therefore 'forcing' new users to investigate groundwater sources. In addition, the analysis in Section 4.2 found that low river flows have tended to increase in frequency since the mid-1990s, even though no significant trends were detected for the period 1980/81–2010/11. For example, in the Ruamahanga River (at Mt Bruce) the average number of days per year with flow below the 90th percentile increased from 30.8 during 1975/76–1992/93 to 42.3 during 1993/94–2010/11. This implies that restrictions on surface water abstractions may also have increased in frequency, and during times of restriction groundwater is generally viewed as a more reliable water source.

5.1.2 National context

Recent statistics show that current consented water allocation in the Wellington region (414 million m^3/year as at December 2010) is significantly less than in the Southland, Otago and Canterbury regions but is in the same order of magnitude as the allocation from the regions of Waikato, Hawke's Bay and Bay of Plenty (Aqualinc Research 2010). The two dominant uses of allocated water in the Wellington region are water supply and irrigation, accounting for around 40% and 36% of the annual water allocation, respectively. Nationally, a higher proportion of water is allocated for irrigation (50% of national annual total), with a lesser proportion for public water supply (24%) (Aqualinc Research 2010). This reflects that Wellington has a larger population than many of the other regions, representing 11.1% of New Zealand's population and ranking third of 16 regions in terms of population (Statistics New Zealand 2011) but seventh of 16 regions in terms of irrigated land area (Aqualinc Research 2010). Of the amount of water allocated for irrigation in the Wellington region, a high proportion (70%) is for dairy pasture; this appears to be in line with the national average (Aqualinc Research 2010) (although the available data are not directly comparable).

The particularly rapid increase in water allocation in the Wellington region from the late 1990s to mid-2000s appears to be consistent with national trends in water allocation. Nationally, weekly water allocations increased around 50% from 1999 to 2006 and a further 6% from 2006 to 2010, indicating that the earlier part of the decade saw the most rapid increase in water demand on a national basis (Aqualinc Research 2006, 2010). In the Wellington region, the rate of increase in water allocation[19] was slightly less than that which occurred nationally, with an increase of around 25% between 1999 and 2006 and 4% between 2006 and 2010.

5.2 Trends in rainfall, river low flows and groundwater levels

5.2.1 Regional overview

The general conclusion from the analysis of both summer rainfall and river low flow data is that there has not been any regional-scale, systematic or 'meaningful' change in the magnitude, frequency or duration of key indicators over the past 30 years. However, there were, as expected, some very wet and dry years and multi-year phases of increasing and reducing rainfall within the last 30 years that influenced the availability of water during times of peak demand. A notable general pattern is that both the summer rainfall and river low flow data illustrated a tendency towards a slight drying trend in the last 10–15 years (ie, since the mid 1990s). Total rainfall, as indicated by cumulative departure from monthly means, also showed a cyclical pattern of change over the past 30 years. Perhaps of most note with respect to recent patterns was a distinct phase of decreasing rainfall from the mid to late 1990s to around 2004 in the Wairarapa and central sub-regions, followed by generally stable conditions since about 2006.

In contrast to the rainfall and river flow results, many statistically significant trends in groundwater level were found; overall, half of the 44 well records analysed can be considered to have shown trends of decline in either annual median groundwater levels or summer minima groundwater level (ie, drawdown) that are indicative of a need for careful resource management (and

[19] Assessed on an annual rather than weekly basis, therefore the statistics are not directly comparable but give a general indication of changes over the same period.

it is noteworthy that none of the 44 wells analysed showed significant increases in groundwater level). Many declines were small in magnitude when compared with estimated aquifer storage but are, nevertheless, indicative of long-term trends of non-recovery or only partial recovery of water levels. The largest declines relative to available storage were exclusively in deep confined (artesian) or semi-confined aquifers in the middle and lower Wairarapa Valley, mainly around Lake Wairarapa and the Carterton / Greytown / Parkvale area.

5.2.2 Factors affecting hydrological trends and patterns

Natural variations in climate occur from year to year, and also over scales of decades, centuries and thousands of years. Cyclic climate variations affect water availability because the amount of rainfall directly affects the flow in rivers, the level of lakes, and the amount of recharge to groundwater systems.

The El Nino Southern Oscillation (ENSO) is the primary mode of natural climate variability that affects New Zealand’s rainfall in the two to seven year timescale (Salinger et al. 2004). The ENSO is a result of cyclic warming and cooling of the surface of the central and eastern Pacific Ocean, and may lead to El Nino or La Nina events. A description of the effects of El Nino and La Nina events on rainfall in the Wellington region is given by Watts (2005). While the range of possible scenarios is broad, in summary:

- Both El Nino and La Nina events have been found to increase the likelihood of dry periods and low flows in different parts of the Wellington region, compared to during ‘neutral’ ENSO conditions (Harkness 1998, 1999, 2000). However, droughts may occur that are not linked with either El Nino or La Nina.
- Overall, on a regional scale La Nina more consistently brings low rainfall during the ‘summer’ period that is associated with the highest demands for water (November–April); ie, the general pattern under La Nina is reduced rainfall through all seasons on the Kapiti Coast, during spring and summer in central areas and during autumn in the Wairarapa.

The most significant region-wide droughts during the last 15 years in the Wellington region occurred in summer and autumn 1998, summer and autumn 2003 and November 2007 to March 2008. The drought events of 1998 and 2003 occurred during and following El Nino conditions and particularly low rainfall was experienced on the Kapiti Coast (in 2003) and the Wairarapa plains (in 1998 and 2003). The drought of 2007/08 occurred during La Nina conditions and led to prolonged low flows in the Hutt and Ruamahanga rivers and particularly high soil moisture deficits in the Hutt Valley, Wairarapa plains and eastern Wairarapa hills (Watts 2008).

The frequency of El Nino and La Nina tends to be modulated by the Interdecadal Pacific Oscillation (IPO). Phases of the IPO, and how it has affected New Zealand’s climate, are briefly described by Watts (2005). Following a period of strongly dominant El Nino conditions from the late-1970s to the late-1990s, which corresponds with a positive phase of the IPO, there has been a more recent tendency towards increasingly frequent and stronger La Nina episodes (Figure 5.2).

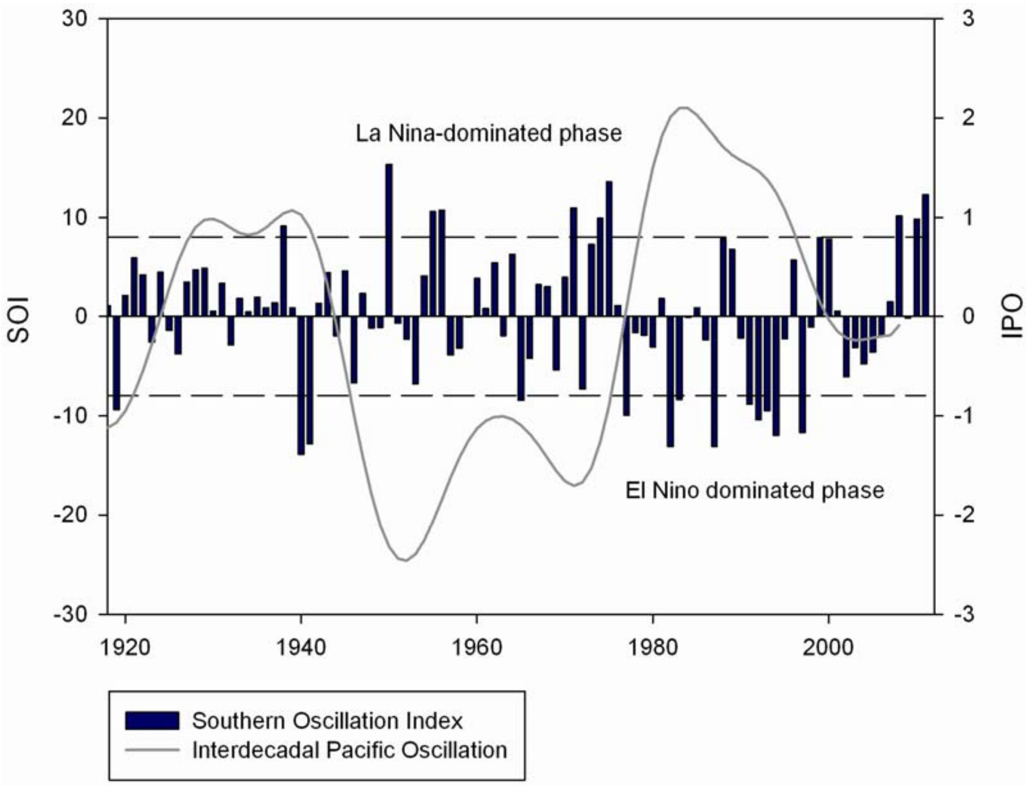


Figure 5.2: One-year average Southern Oscillation Index (SOI) and smoothed IPO since 1920. SOI values of greater than 8 (upper dashed line) indicate La Nina and less than -8 (lower dashed line) indicate El Nino (SOI values between -8 and +8 indicate generally neutral conditions). SOI time series sourced from the Australian Bureau of Meteorology and IPO values sourced from Folland (2008).

The recent tendency for a region-wide decline in the annual 3-month rainfall minima, reduced low river flows and more frequent low flows – particularly since the late 1990s – is generally consistent with our understanding of the influence of a shift away from strongly dominant El Nino conditions. For the Wairarapa, this might seem at odds with the observation that El Nino is more likely to bring low rainfall during mid-summer months (December–February) to this part of the region. However, the observed decrease in the 3-month rainfall minima indicator in the Wairarapa may well reflect the tendency towards drier periods in late summer/autumn that comes with La Nina.

A recent study of river flow data from 35 sites across New Zealand found that during the decade 2000–10, since the IPO switched to a negative (or near-neutral) phase and climate conditions became more dominated by La Nina, mean river flows and mean annual low flows were around 10% lower than during the period 1978–1999 (when the IPO was in a positive phase (Woods 2011). The observed tendency for lower 3-month rainfall minima, reduced low flows and more frequent low flows in the Wellington region since the late 1990s is consistent with Woods' (2011) findings.

A similar tendency for reduced annual 3-month rainfall minima and low flows is seen to have occurred at a number of the monitoring sites in the Wellington region prior to the mid-1970s, in general correspondence with a climate phase dominated by La Nina conditions and increased easterly airflows (which coincides with a negative phase of the IPO that occurred from about 1945–1977). The river flow site with the longest reliable low flow record – Hutt River at Kaitoke (from 1968) – shows severe and frequent low flows occurred in the late 1960s and early 1970s. In fact, the low flows in the Hutt River at Kaitoke during recent droughts (in 2003 and 2007/08) were not quite as severe or prolonged as those that occurred in the early 1970s.

The natural climate cycles and rainfall patterns just described are generally expected to exert a control (through rainfall recharge) on groundwater levels. However, the lack of statistically significant trends in any indicators of rainfall suggests that reduced rainfall recharge can be discounted as the dominant explanatory variable over the period of groundwater analysis reported. Trends in groundwater use could not be tested in a statistical sense due to a lack of suitable data so it has not been possible to unequivocally demonstrate the abstractive influence on groundwater levels either. However, modelled data for the Wairarapa Valley implicates groundwater abstraction as a dominant causal factor of declines in groundwater levels in the confined wells in this area.

Given the challenges in precisely quantifying the factors that affect groundwater levels and storage in the region, a conservative approach is to assume that identified significant declines are largely related to abstraction beyond sustainable limits (until further data can be collected and analysed).

5.2.3 Projected hydrological impacts of human-induced climate change

The timing, magnitude and intensity of seasonal rainfall in all regions of New Zealand is predicted to depart from historical ranges over the coming century as a result of increasing global air temperatures (MfE 2008b). Current projections of changes to seasonal rainfall for New Zealand, down-scaled from 12 global climate models, have been reported by MfE (2008b) and are summarised here for the Wellington region. These projections are for a ‘middle-of-the-range’ emission scenario (A1B), and are the average over the 12 models. More information about the full range of possible changes in rainfall is available in the MfE (2008b) publication.

By 2040 mean annual rainfall is expected to increase (relative to 1990) by up to 5% in the west and decrease by the same margin in the east. By 2090, Figure 5.3 shows that the reduction in mean annual rainfall (again, relative to 1990) is expected to be up to 7.5% for parts of the east coast of the Wairarapa.

Figure 5.4 breaks the 2090 mean annual rainfall changes into seasonal projections. The largest projected seasonal changes are expected to occur in winter and spring when rainfall may be up to 15% higher (relative to 1990) in the west and 10% lower in the east. Mean summer rainfall is projected to be up to 7.5% lower in the west and higher in the east by the same margin, while autumn rainfall is expected to be up to 5% higher across the region (and up to 7.5% higher on the east coast of the Wairarapa). The seasonal patterns are similar for the earlier 2040 projections but with reduced magnitudes of change.

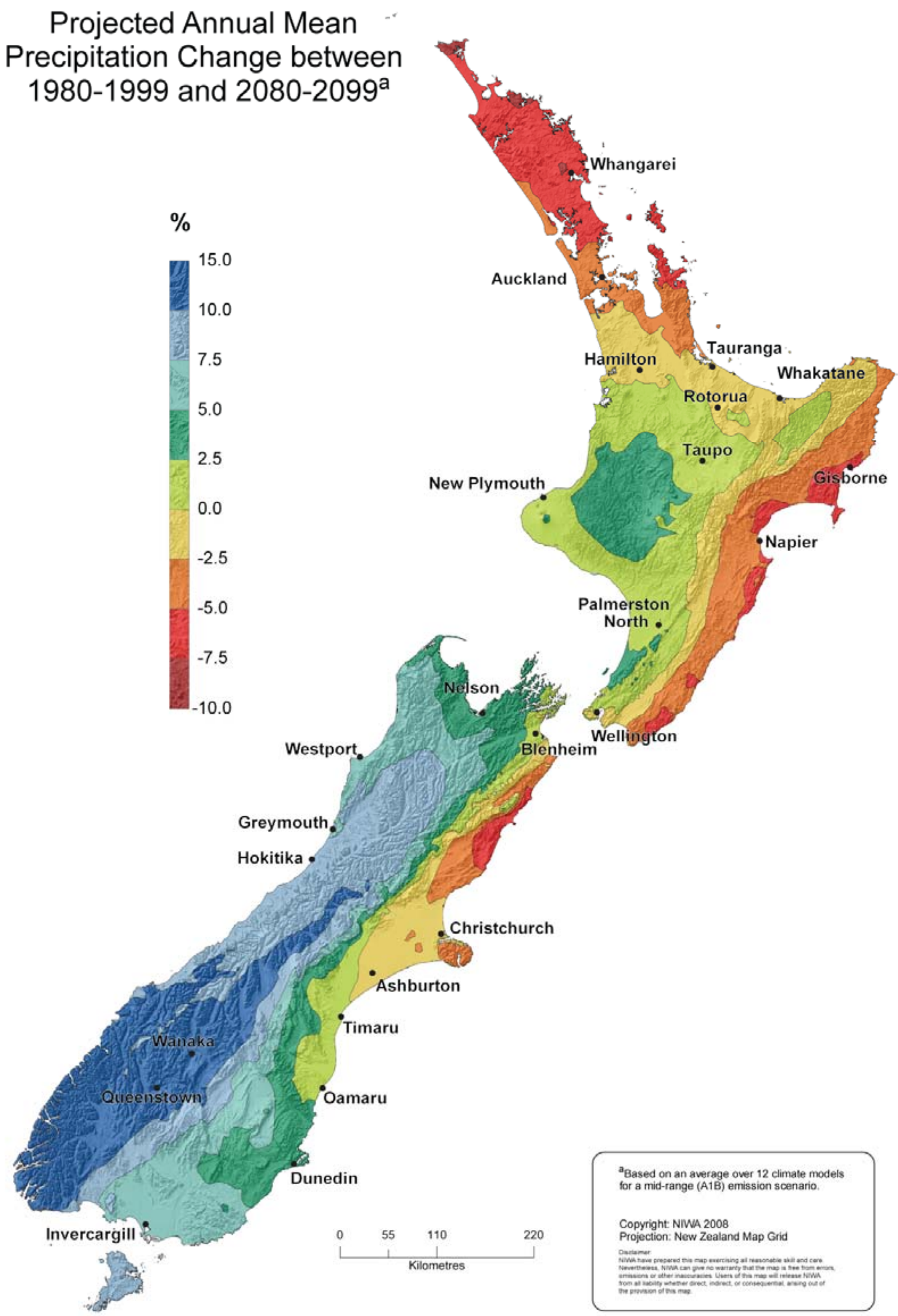


Figure 5.3: Projected change to mean annual rainfall by 2090 relative to 1990; average over 12 climate models for A1B emission scenario. Figure reproduced from MfE (2008b).

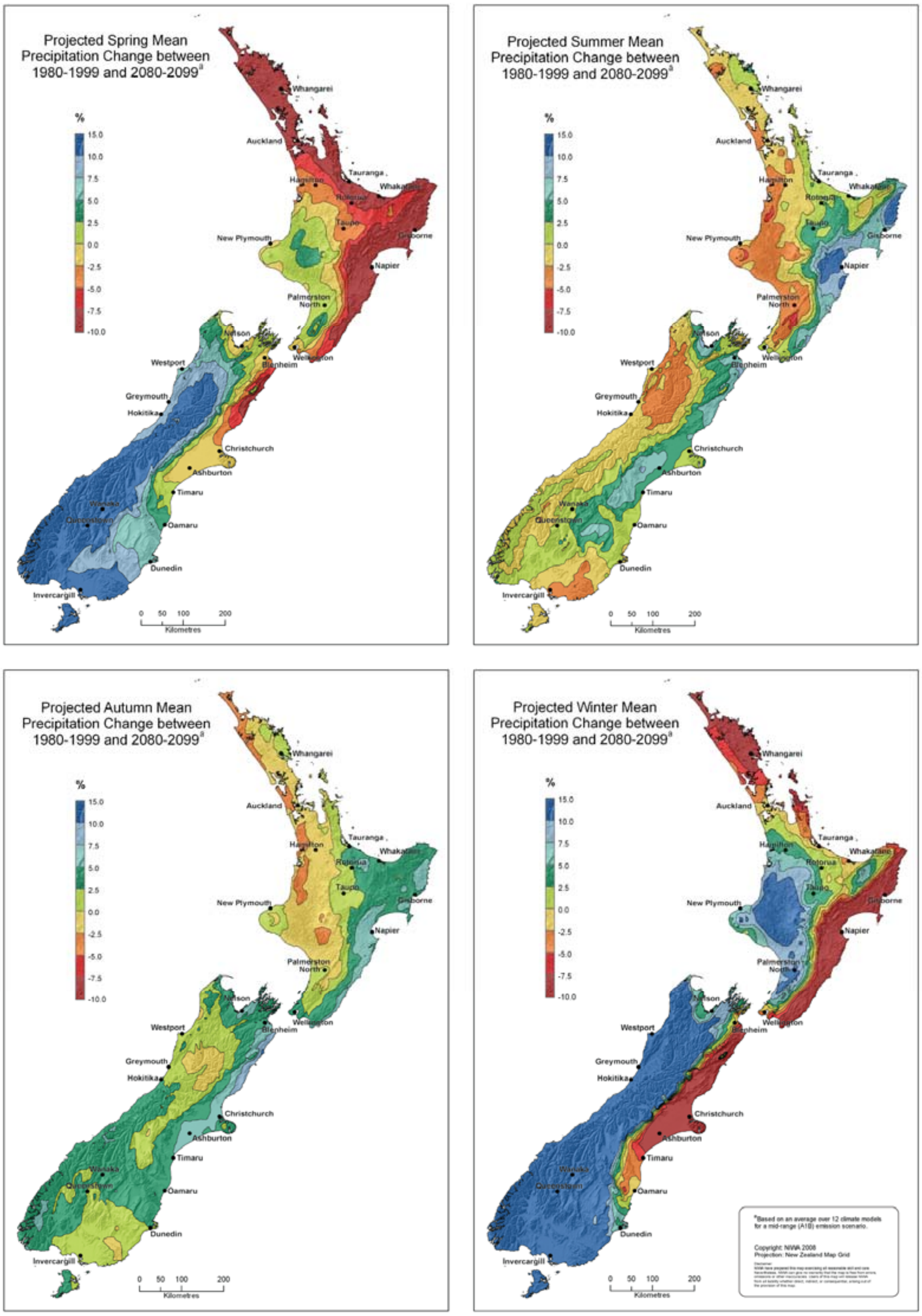


Figure 5.4: Projected changes in seasonal mean rainfall by 2090 relative to 1990; average over 12 climate models for A1B emission scenario. Figure reproduced from MfE (2008b).

The general picture for the Wellington region under predicted climate change scenarios is therefore one of more rainfall in the west and less in the east. While summer rainfall in the Wairarapa is expected to increase, the overall drought risk is also projected to increase principally due to increased summer air temperatures resulting in more evapotranspiration. Mullan et al. (2005) predicted that by the 2080s, severe droughts (ie, one in 20-year events) may occur at least twice as often in parts of the Wairarapa.

There has not been any in-depth quantitative research into the effects of projected changes to seasonal rainfall on river flows and groundwater levels in the Wellington region, at least not on a region-wide basis, and this report does not attempt to make in-depth predictions. Any effects will be determined not just by seasonal rainfall totals but also changes in the intensity, timing and distribution of rainfall. However, some general points can be made:

- The projected decrease in winter and spring rainfall totals in the Wairarapa is likely to affect recharge to groundwater systems and may result in lower groundwater levels throughout the year. A reduction in groundwater levels may impact flow in groundwater-fed rivers and streams during the low flow season. The reverse is true for the Kapiti Coast groundwater systems.

- The effect on low flows occurring in late spring in the Wairarapa may be particularly significant with projected decreases in rainfall of up to 10% in this season.

As well as the changes to seasonal rainfall totals, it is projected that the frequency and intensity of heavy rainfall events will increase throughout the Wellington region as a result of human-induced climate change (MfE 2008b). Therefore there are likely to be more frequent and severe floods in the region's rivers and streams.

Warmer average temperatures and higher average rainfall in the west may bring some benefits relating to pasture productivity and crop yields, although the extent to which any such benefits are offset by increased flooding and erosion are unknown (Ministry of Agriculture and Forestry 2010a). In the Wairarapa, higher air temperatures may provide opportunities for growing a greater diversity of crops, however, the projected decrease in average rainfall is likely to reduce water availability for irrigation across the pastoral and horticultural sectors (Ministry of Agriculture and Forestry 2010b).

5.2.4 Synthesis

The observed decline in annual rainfall minima and low flow magnitude and frequency since the mid-1990s is important, in the sense that it highlights the variability in the hydrological system but also that it implies there has been a recent reduction in water availability during times of highest demand, and possibly additional stress on river systems. However, there is no evidence to suggest the trend will continue beyond historical ranges in the medium-term future or that it is being forced by anything other than known climate cycles. Longer-term, projected seasonal changes in rainfall resulting from human-induced climate change indicate water stress may become more of a problem in the Wairarapa and less of a problem in the west over the coming century.

Generally, water levels in shallow groundwater aquifers have reflected temporal rainfall patterns while many of the deeper semi-confined and confined aquifer systems have displayed groundwater level trends with, as expected, a less apparent relationship to coincident (or recent) rainfall. Numerical groundwater modelling and trend analysis has clearly implicated the influence of abstraction and indicated long term declines that are largely independent of natural climate cycles are occurring in some parts of the region – primarily in the Wairarapa Valley. While the subtleties of the response patterns of groundwater levels to the decadal and shorter-term climate cycles is difficult to interpret from the monitoring record available, the long-term outlook under likely climate change scenarios is one of reduced recharge to those aquifer systems already under the highest stress.

5.3 Water availability: present and future

5.3.1 Surface water availability and the regional plan review

Following the assessment in Section 3.3, under the existing policies of the Regional Freshwater Plan (RFP) the only rivers with significant (>30 L/s) remaining allocation available during normal to low flows are the Tauherenikau, Hutt (lower reach), Wainuiomata (lower reach) and Otaki rivers. There is also a small rate of allocation (5 to 30 L/s) available from the Tauweru and Waiohine rivers and Parkvale, Papawai and Waitohu streams. However, some of these streams have capped allocation limits under Policy 6.2.1A, the intention of which was to prevent further allocation until a sustainable allocation limit was adopted.

In Section 3.3 it was noted that, for several reasons, the current core allocations for rivers and streams in the RFP may not be appropriate for the next Regional Plan, and that many waterways (including Lake Wairarapa) utilised for abstraction are not covered by Policies 6.2.1 and 6.2.1A. Given that nearly all (about 97%) of surface water allocation in the Wellington region is ‘run-of-river’ it is clear that the setting (or review) of allocation limits is critical to determining future surface water availability in the Wellington region. Some issues relating to the setting of allocation limits and other surface water allocation policies are discussed below. The outcomes of policy decisions relating to these issues may have a large impact on future surface water availability in the Wellington region.

(a) Determining allocation limits

There are currently no national standards for setting allocation limits for rivers, streams and lakes. However, many regional councils base allocation limits for rivers and streams on a proportion of mean annual low flow (MALF) and the proposed National Environmental Standard (pNES) for Ecological Flows and Water Levels (MfE 2008a) suggests the following interim allocation limits based on river size[20]:

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

[20] Based on the premise that larger rivers with relatively high summer base flows are generally less sensitive to flow alteration during low flows than smaller rivers and streams.

Technical guidance accompanying the pNES states that an allocation of more than 40% of MALF is considered a ‘high level’ of hydrological alteration (Beca 2008) irrespective of hydrological characteristics. Analysis in Section 3.3 of this report found that under the allocation limit scenario of 30% of MALF very few waterways in the Ruamahanga, Lake Wairarapa and Hutt catchments would have any remaining water available for allocation.

If Greater Wellington is to set future allocation limits relating to MALF then the approach to determining what proportion of MALF is appropriate will need to be decided; it is important to remember that the interim limits suggested above are only intended to be applied by default if there is no better information or method available to apply a river-specific limit. It is likely that the proportion of flow allocated will vary within the region, for example, according to river values and risk of impact. In other words, it may be acceptable to allocate a higher proportion of flow from ‘low value’, ‘low risk’ rivers than higher value/risk rivers. Decisions will also need to be made regarding the derivation of MALF. Key considerations are:

- At what point in the catchment should MALF be measured / estimated? (see Section (b) following).
- For river reaches downstream of abstraction, to what extent should MALF be naturalised? (ie, ‘corrected’ to a pre-abstraction value by adding back in estimated abstraction). It is relatively straightforward to just naturalise for direct surface water takes but attempting to also naturalise for groundwater abstraction that is depleting the river reach (see Section (c) below) is much more difficult and uncertain.
- What period of flow record should be used to calculate MALF given that climate phases have been found to affect low flow magnitude? (see Section 5.3.3).

Some regional councils have used flow statistics other than the MALF to determine an allocation limit, such as the one-in-five-year low flow. Whatever flow statistic is used, a water availability assessment should occur, along with a hydrological assessment of the effects of the allocation limit on the river flow regime. Another consideration when setting allocation limits is the security of supply for water users; generally, the larger the volume of water allocated, the more frequent restrictions on users will be during times of low flow.

There is currently no allocation limit for Lake Wairarapa; it was noted in Section 3.3.4 that current allocation from the lake equates to about 22% of the estimated inflow during mean annual low flow conditions. To ensure abstraction from the lake is kept at a sustainable level, an allocation limit should be developed, to have in addition to the current policies around water level targets (preliminary work is already underway to consider methods for establishing an ecologically sustainable lake allocation limit).

(b) Catchment vs reach-based allocation policies

The current core allocations in the RFP generally are reach-based; ie, the core allocations specified for the lower reaches of major rivers do not incorporate upstream allocations. In order to ensure instream values are protected, it is important that overall catchment allocation limits are set; for example by setting an overall limit according to a selected proportion of MALF at the catchment outlet. Reach or tributary allocations within the catchment will also be needed to protect tributary flows and critical reaches (for example, reaches where there is considerable flow loss to groundwater).

Incorporation of catchment-based allocation limits into Greater Wellington's new Regional Plan may significantly affect water availability, depending on how they are applied. For example, under the scenario of 30% of MALF as a catchment-wide allocation limit (assessed in Section 3.3.1) there would be no further allocation of water from the Ruamahanga catchment upstream of Lake Onoke during normal flow conditions (in addition to the amount currently allocated), despite some of the individual Ruamahanga River tributaries having current allocations of less than 30% of MALF.

(c) Streamflow depletion caused by groundwater takes

It was noted in Section 3.3.1 (and shown in Table 3.8 that, in many waterways – particularly in the Wairarapa – the estimated streamflow depletion caused by groundwater takes is nearly as high as, or even exceeds, direct surface water allocation. The proposed frameworks for the management of groundwater – surface water interaction in the Wellington region (Hughes & Gyopari 2011, Hughes in prep & Hughes et al. in prep) recognise this situation and recommend that groundwater takes that directly result in streamflow depletion be managed essentially as surface water takes. Analysis in Section 3.3.1 showed that, if such groundwater takes[21] were counted in allocation limit scenarios of 30% or 50% of MALF then surface water availability would be severely impacted; in fact, this would essentially mean many of the Wairarapa waterways would become 'over-allocated'.

Regardless of the effects on allocation status of rivers and future surface water availability, decisions will need to be made on how groundwater takes that potentially will result in streamflow depletion will be managed. For example, if there will be a separate 'block' of allocation for groundwater takes in addition to direct surface water allocation limits, and whether or not low flow restrictions will apply to these groundwater takes.

(d) Supplementary water allocation

As previously noted in Section 3.3.3, most (around 97%) of the surface water allocation in the Wellington region is run-of-river 'core' allocation, and consented to be taken during normal to low flows (subject to low flow restriction conditions). This implies that there is very little utilisation of high river flows for water harvesting (referred to as 'supplementary' abstraction in the RFP) in the region, and is likely to be due to several factors including:

---

[21] Those estimated to be from the proposed Category A and B areas of Hughes and Gyopari (2011a; Hughes et al. in prep) – see Figure 2.9 in Section 2.6.4.

- Lack of land area for water storage;
- Poor water quality during flood conditions; and
- Lack of incentive to harvest high flows when, at least in the past, other water sources were available.

Given that there is likely to be very little water remaining available from rivers and streams during normal flow conditions in the future, particularly in the Wairarapa, the harvesting of high river flows needs to be promoted. In fact, preliminary feasibility studies are already underway by the Wairarapa Water Use Project, which is seeking to identify suitable locations and mechanisms to secure high flow water for additional irrigation (Wairarapa Water Use Project 2011).

Promoting and managing high flow water use will require the development of policies or rules that ensure abstraction occurs in a sustainable manner. As noted in Section 3.3.3, the current supplementary flow levels (above which the core allocation no longer applies) are relatively low, being around the median flow in most cases. This has the potential to lead to adverse effects, because it means there is essentially no ‘cap’ on allocation during median flow conditions. While analysis of suitable supplementary flow levels and possibly high-flow allocation limits is currently underway (as part of the regional plan review), this process is somewhat constrained because limited quantitative data are available on the effects on rivers of mid to high range flow alteration. Nevertheless, some key principles to guide supplementary flow policy development include:

- The magnitude and frequency of ‘flushing’ flows (eg, flows of ‘three times the median flow’ is a common standard, Biggs (2000)) should be maintained. These flows remove nuisance periphyton growth as well as turn over river bed gravels and boulders. Some rivers in the Wellington region suffer from prolific periphyton growth, including toxic cyanobacteria proliferations, during warm, stable flow conditions (eg, the Waipoua, Waikanae and Hutt rivers – see Greenfield et al. 2012). Ensuring supplementary takes do not exacerbate periphyton growth in these rivers by affecting flushing flow characteristics will be especially important.
- The overall flow removal when supplementary allocation is being fully exercised (in addition to core allocations) should not alter the natural flow regime by more than a specified margin. The allowable margin may depend on river values and flow characteristics.
- In the absence of site-specific and robust data on environmental consequences, supplementary flow limits and policies should be conservative in favour of protecting instream values.

5.3.2 Groundwater availability and the regional plan review

Under the current policies of the existing RFP there is a significant amount of groundwater remaining available in many of the groundwater zones throughout the region; 32 of the 50 identified groundwater zones and aquifers in the RFP have less than half of their 'safe yield' allocated for use. However, as noted in Section 3.4.5, in some areas the actual availability of the groundwater may be limited due to low bore yields (eg, the Upper Opaki, East Taratahi and Fernhill groundwater management zones) or surface water depletion effects that have not been accounted (ie, in some of the river corridor shallow gravel aquifers).

Future groundwater availability in the Wairarapa depends strongly on the final allocation limit adopted from the range suggested by Hughes and Gyopari (2011) in the recently proposed Wairarapa Valley groundwater management framework. In some of the highly-used groundwater zones (Te Ore Ore, Mangatarere, Dry River, Martinborough, Huangarua, Lake and Tauherenikau) – many of which correspond to those identified as 'high risk' in this report due to observed declines in groundwater level – there may be no further groundwater available. In other areas future groundwater availability is likely to be significantly less than that currently available under the safe yields in the existing RFP, although because the zone boundaries vary between the RFP and the proposed new management framework it is difficult to calculate the change in availability for particular areas. Overall, remaining groundwater availability in the Wairarapa will reduce significantly if the recommendations of Hughes and Gyopari (2011) are adopted; under the least conservative allocation limits proposed at this stage there would be approximately 17.7 million m^3/year of groundwater remaining available[22], compared to about 143.4 million m^3/year currently available (ie, not currently allocated) under the safe yields in the existing RFP.

As discussed in Section 5.3.1, under the draft groundwater management frameworks (Hughes & Gyopari 2011, Hughes in prep and Hughes et al. in prep) – both for the Wairarapa Valley and the western parts of the region – it is proposed that groundwater allocation in areas hydraulically connected to surface waterbodies be managed as surface water allocation. Depending on how this recommendation is implemented into policy, the additional availability of groundwater in zones where there is a strong hydraulic connection to surface water may be very limited. For example, there may be no further allocation of groundwater from shallow aquifers alongside the Ruamahanga and Waingawa rivers in future, because surface water allocation from these rivers already constitutes a relatively high proportion of low flows.

Further consideration of some important questions is needed to guide the approach taken to allocating water under the proposed management framework. For example:

- Will 'blocks' of water be set aside for allocation within certain abstraction categories (eg, one block of allocable water for Category A and B takes and a separate block for Category C)?

[22] Excludes groundwater that may be available from Category A areas that is proposed to be managed under surface water allocation policies.

- What hydrological baseline or period of data is most appropriate to use for determining existing allocation status (for surface and groundwater) and future availability? For example, in the Wairarapa it may be appropriate to select the period 1992–2008 for deriving allocation limit criteria since this period corresponds to the Wairarapa Valley groundwater model calibration period and was found to be non-biased towards any particular rainfall phase.

A further consideration is that non-consented (eg, permitted activity) water takes were not considered in this report. However, water management policies need to ensure that permitted takes are acknowledged when setting allocation limits and do not adversely impact on environment. Work within Greater Wellington is currently underway to estimate the scale of permitted takes from surface and groundwaters in the region.

5.3.3 Climate phases, climate change and water availability

While there has not been any region-wide significant trends in summer rainfall and low flows in the last 30 years there has been a tendency for a decline in rainfall minima, reduced low flows and more frequent low flows in the Wellington region since the late 1990s. This is consistent with nationwide results (Woods 2011) and is as expected under La Nina-dominated climate conditions and a shift in the IPO to a negative phase.

The continuation of the current negative IPO phase may mean that catchment inputs remain at the current overall reduced level in the short- to medium-term. Previous IPO phases have lasted 20–30 years, so the current negative phase *may* last another 10–20 years (Woods 2011). This is therefore an issue to bear in mind, particularly for the setting of allocation limits in the new Regional Plan. For example, if surface water allocation limits are to be set according to a proportion of MALF, a conservative approach would be to use data from the late 1990s onwards to calculate MALF. However, this approach will see a reduction in surface water allocation availability compared to if longer flow records are used. With respect to suggested new allocation volumes in the proposed conjunctive management framework for the Wairarapa Valley, the calibration period (1992–2008) for the groundwater modelling underlying the framework was found to have high rainfall variability and not be biased toward any particular climatic phase (Gyopari & McAlister 2011c). It may therefore be appropriate to align allocation limit criteria relating to surface waters with the groundwater modelling period.

The observed linkage between decadal-scale climate phases and catchment inputs (rainfall minima and low flows) suggests that regular (ie, decadal) review of allocation limits is warranted, to ensure environmental values are protected while not unfairly restricting water availability. However, given that under the Resource Management Act (1991) provisions, regional plans are to be reviewed every 10 years, by default the allocation limits are essentially reviewed on a similar timescale to the observed climate phases.

In the future, human-induced climate change is expected to influence catchment hydrology in addition to the background natural climate phases observed to date. In Section 5.2.3 it was suggested that, the general future picture for the region under the most likely climate change scenarios is one of higher overall rainfall in the west and drier, more drought-prone conditions in the east. These projections are an important consideration in the long-term, particularly when setting allocation limits based on current groundwater recharge rates and low flow magnitudes. However, in the context of the current regional plan review and allocation scenarios for the next decade, it is difficult to say how much consideration climate change should be given. In any case, it was noted above that proposed groundwater allocation limits for the Wairarapa were formulated based on 'reduced' catchment inputs in the last decade or so and are therefore relatively conservative. Ongoing monitoring to check for trends in groundwater levels, particularly in highly allocated and 'high risk' (see Section 4.3.3) groundwater zones and aquifers, is vital to ensure that any reduction in recharge and increase in abstraction is not causing adverse effects.

As noted in Section 5.2.3, it is anticipated that there will be more frequent high-intensity rainfall events, and subsequent high river flows, as a result of human-induced climate change. Given the lack of surface water likely to be additionally available during normal flow conditions, the increased frequency of floods will potentially provide an opportunity for more high-flow water harvesting in the future (ie, supplementary allocation).

5.3.4 Maximising water availability

There are two main ways in which water availability could be maximised under the likely future regime of reduced groundwater allocation limits and limited surface water availability during normal flow conditions. The first is high flow harvesting, which has already been discussed in Sections 3.3.3 and 5.3.1(d). The second is by increasing the efficiency of allocation policies and the actual abstractions themselves.

It was noted in Section 2.6.2 that actual water use is likely to be significantly less than consented allocation, particularly in the case of seasonal and annual allocations (which usually apply to groundwater takes); during times of highest demand most users will abstract a high proportion of their daily and instantaneous limits. If groundwater allocation limits in the future remain as seasonal and/or annual volumes[23], then aligning consented allocations with actual use (or predicted actual water needs) is likely to 'free-up' groundwater for other potential users.

In terms of surface water availability, aligning consented and actual use will not necessarily mean more water becomes available, because surface water allocation limits are set on an instantaneous or daily basis (and during times of highest demand this will be fully utilised). However, there is potential for greater flow-sharing between users if individual consented water takes do not need to operate continuously during periods of highest demand.

One way to help better align consented allocation and actual water use is widespread water metering, along with recording and analysis of water use (particularly during high-demand periods). Greater Wellington is currently

[23] The existing RFP includes annual safe yields only. The proposed new groundwater management framework for the Wairarapa Valley (Hughes & Gyopari 2011) recommends daily as well as annual allocation limits.

taking steps to expand water metering in line with a national regulation that came into force in 2010[24]. Improved storage of, and access to, metering data will be an important part of meeting the requirements of this regulation. Another way to help better align consented allocation and actual water use is the assessment of site-specific irrigation requirements based on soil, crop and climate conditions; to this end, a Soil Plant Atmosphere System Model – Irrigation (SPASMO-IR) tool has been developed for use in the Wellington region by Green (2010).

The points above generally apply to water takes for irrigation; by their nature, water takes for public water supply need to build in conservatism so that the public's reasonable water needs can be met during times of drought. However, it was noted in Section 3.3.1 that there are consented water takes from four rivers and streams (Tauherenikau River, Huangarua River, Abbots Creek and Waitohu Stream) that are 'emergency' public water supply abstractions; ie, as a back-up to the primary water supply system for use during times of contamination or drought. In addition, there are several consents for groundwater abstraction to supplement or replace surface water supplies during times of low flow. In reality, many of these abstractions are seldom utilised. Allowing flow-sharing between these emergency (or back-up) takes and other users is another way of maximising water availability while not exceeding sustainable allocation limits.

5.4 Limitations and knowledge gaps

There are some limitations and knowledge gaps that challenge our ability to interpret results presented in this report and deserve particular emphasis. Some of these limitations relate to the existing hydrometric monitoring network.

The primary limitation with respect to understanding how much water remains available for allocation is a lack of agreed criteria for determining 'safe' limits. This is because at the time of writing this report Greater Wellington is in a transitory phase between using criteria specified in the existing RFP (WRC 1999) and completing the technical work to revise these criteria for the next regional plan. Therefore results have been presented in some cases – particularly for groundwater management zones and Lake Wairarapa – in the form of possible scenarios. The revised limits, incorporating judgements about what level of abstractive effect is 'acceptable', are needed before a clearer understanding of water availability in the Wellington region emerges.

There are also some data and methodological constraints to the analysis and interpretation of hydrological trends:

- The indicators chosen in this report to describe hydrological trends will not reveal all important patterns and trends and the results therefore should be considered indicative rather than comprehensive. Hydrological patterns exhibit a large amount of spatial and temporal variability. While attempts have been made to select sites that are considered generally representative of major hydrological sub-regions (while also meeting data quality criteria) there may be local scale variations in rainfall, river flow and

[24] The 'Resource Management (Measurement and Reporting of Water Takes) Regulations 2010' under Section 360 of the Resource Management Act.

groundwater level patterns and trends that have not been captured by the analyses presented in this report.

- The major gap in our understanding of low flows is whether temporal trends in flows at the bottom of catchments differ significantly from the trends representing natural flows in the upper catchment. Because of a scarcity of lower catchment flow monitoring, a region-wide analysis could not be done in any meaningful way. The increase in surface and groundwater abstraction in the last two decades was substantial (see Table 3.4, Section 3.3.2) and is expected to have had some additional depletion effect on rivers. While the magnitude of the effect, especially in terms of annual flow minima, will to some extent have been mitigated by low flow restrictions, the duration of low flows at the bottom of some catchments may well have increased. Effort is needed to improve 'bottom-of-catchment' monitoring in the future.

Understanding the reasons for, and 'environmental consequences' of, observed groundwater level declines remains particularly challenging for several reasons:

- The period of groundwater trend analysis is relatively short compared with that used to analyse rainfall and river flow trends. This is a legacy of monitoring sites and networks being established at different times. The shorter period of available data means we are less confident (than for rainfall and river flow) in concluding whether observed trends lie within the envelope of a 'normal' long term range. The ability to conduct a long-span, truly integrated analysis of groundwater trends in the context of other water resources will improve over time, as will the interpretive power.

- The recharge characteristics of major aquifer systems (ie, the land area of recharge and the time lag between rainfall and storage replenishment) are not fully understood – although recent numerical modelling has substantially improved the state of knowledge about the Wairarapa Valley groundwater system.

- For most groundwater management zones we do not know at what point water level reductions become problematic for water users (eg, wells run dry or production volumes drop) or dependent surface water bodies (eg, reduced discharge to springs and wetlands). Further analysis is needed to determine safe drawdown limits. Management zones should be prioritised for this work according to the level of risk and aquifer condition highlighted by the trend analysis.

- Increased irrigation abstraction to offset soil moisture deficit normally coincides with reduced rainfall recharge. The interaction between these two factors means that separating the relative degree of influence each factor has on groundwater levels is difficult and requires case-by-case assessment.

6. Conclusions

Consented water allocation has increased markedly in the past two decades in the Wellington region, primarily due to expanding and intensifying irrigation. Most rivers and streams are fully allocated and there is little remaining 'run of river' water available during times of low flow, especially in the areas where further irrigation growth is likely (ie, the Wairarapa Valley). While under existing RFP policies there is still significant remaining groundwater available, it is likely that these policies overstate the actual availability of groundwater in many areas, especially in shallow gravel aquifers in river corridors. This is largely because the depletion effect of groundwater abstraction on hydraulically-connected surface water bodies is not explicitly accounted for in existing aquifer safe yield estimates; allocation assessments in this report have shown that the estimated streamflow depletion caused by groundwater takes is nearly as high as, or even exceeds, direct surface water allocation.

While there has been a tendency in the last 10–15 years towards slightly drier than normal conditions in the Wellington region, and lower rainfall and river flow minima, there is no evidence that patterns in the natural 'supply' of water have departed from historical ranges. Few statistically significant trends in several indicators of rainfall or river flow were found when assessed over the common period 1980–2011 or full length site records. Despite this, several groundwater aquifer systems – primarily the deeper aquifers in the Wairarapa Valley – showed declining trends in water levels and signs of storage depletion between 1994 and 2011. In common with most measures of environmental wellbeing, there remains considerable uncertainty about the exact causes of observed depletion trends or whether it they will continue into the future. This uncertainty relates in part to constraints on the spatial and temporal coverage of available monitoring data (recommendations to address some of the uncertainty are outlined in Section 6.1). However, analysis in this report suggests that abstraction beyond sustainable limits is an issue for some aquifers.

A new groundwater – surface water management framework for the Wairarapa Valley has been proposed and work is underway to develop conceptually similar frameworks for the Hutt Valley and Kapiti Coast. A key issue highlighted by this report is the potential impact these proposed frameworks will have on future water availability, if groundwater takes that result in streamflow depletion are to be managed under surface water allocation policies. Providing for competing values in the process of revising allocation limits should recognise the uncertainty in our understanding of how water resources and dependent ecosystems respond to human pressures; policies ought to be conservative in favour of environmental protection.

It is clear that more efficient use and accurate accounting of water is needed to maximise the utility of available resources. Mechanisms discussed in this report include 'free-ing up' unused (but currently allocated) water and flow-sharing between users. Higher flow harvesting also has the potential to alleviate pressure on catchments during times of water stress.

Climate change is likely to alter the seasonal and annual average availability of water in the region. Most significantly, drought risk is likely to increase in the

Wairarapa. While the net change by 2090 may be significant relative to a 1990 baseline, it can probably be dealt with incrementally through regional plan policy reviews, making use of the most current projections as they become available.

6.1 Recommendations

Given the technical focus of this report, recommendations relate primarily to improving our understanding of the region's water resources through monitoring and analyses. However, there are clearly findings that lead to freshwater management recommendations so brief mention is also made of these.

1. In the next review of Greater Wellington's SoE hydrological monitoring programme:

   - Implement a low flow gauging programme focused on routine repeat visits to critical river and stream reaches. Priority should be given to 'bottom-of-catchment' sites on all major rivers and streams that have significant abstraction pressure (eg, Waiohine, Waingawa, Waipoua, Tauherenikau, Huangarua and Waikanae rivers).
   - Consider additional groundwater level monitoring in the Parkvale artesian aquifer (to ensure representative results are being obtained) and along the Taratahi faultline (to better quantify the relationships between shallow groundwater and spring flow).
   - Undertake an integrated assessment of climate, flow and groundwater data relating to Lake Wairarapa to assist in development of a dynamic lake water balance[25] and identification of sustainable allocation options.

2. Further improve our understanding of the state, and trends in, the region's water resources through undertaking further analyses to:

   - Assess whether the timing or seasonality of rainfall, river flow and groundwater level patterns are changing significantly over time (focussing primarily on high-demand and/or water-stressed catchments). For example, are dry spells tending to occur more frequently later in the summer?
   - Review groundwater level monitoring data on an annual basis for all monitoring wells in the 'very high' and 'high' risk aquifers identified in this report. This should include checking for persistence in, or change to, trends that have been identified.
   - Further investigate and quantify the cause of the most significant groundwater level declines and storage depletions. This should

[25] As of March 2012 two new meteorological stations have been installed on the western and eastern shores of Lake Wairarapa (with a further station planned for the centre of the lake) to help refine evaporation estimates. An Acoustic Doppler Current Profiler (ADCP) is being installed at the lake outlet to continuously measure flow and a field programme to concurrently measure tributary inflows has been established.

include determination of the implication of observed trends for allocation management.

3. Improve the alignment of consented water allocation volumes with actual water use by continuing to use water use efficiency tools such as SPASMO-IR and implementing data management strategies to capture records in accordance with Resource Management (Measurement and Reporting of Water Takes) Regulations 2010.

4. Ensure that periods of time when restrictions on abstraction are in force are accurately recorded (by catchment and management zone) and permanently archived.

5. Take into account the findings of this report in the review of Greater Wellington's existing Regional Freshwater Plan, giving priority to the following tasks:

   - Calculating allocation limits in a consistent way for rivers and streams based primarily on 'bottom-of-catchment' and/or critical reach assessments of water availability.
   - Reviewing catchment-specific 'supplementary flow' limits.
   - Considering the adoption of maximum groundwater level drawdown thresholds for some 'at-risk' aquifers (in addition to sustainable allocation volumes / limits being revised for groundwater management zones).

References

Aqualinc Research Ltd 2006. *Snapshot of water allocation in New Zealand.* Report ME 782 prepared for Ministry for the Environment, Wellington.

Aqualinc Research Ltd 2010. *Update of water allocation data and estimate of actual water use of consented takes 2009–10.* Report No. H10002/3 prepared for Ministry for the Environment, Wellington.

Baker T and King B. 2007. *Water meter reading report: Summary of meter reading/logging undertaken December 06–April 07.* Unpublished internal report, Greater Wellington Regional Council.

Beca 2008. *Draft guidelines for the selection of methods to determine ecological flows and water levels.* Report prepared for Ministry for the Environment, Wellington.

Biggs B. 2000. *New Zealand periphyton guideline: Detecting, monitoring and managing enrichment of streams.* Report prepared for the Ministry for the Environment, Wellington.

Folland C. 2008. *Interdecadal Pacific Oscillation time series (updated July 2008).* Downloaded from the website www.iges.org/c20c/IPO_v2.doc on 25 October 2011.

Greater Wellington Regional Council. 2005. *Measuring up: The state of the environment report for the Wellington region 2005*. Greater Wellington Regional Council, Publication No. GW/ENV-G-05/278, Wellington.

Greater Wellington Regional Council. 2010. *Proposed Regional Policy Statement for the Wellington region*. Greater Wellington Regional Council, Publication No. GW/EP-G-08/200, Wellington.

Green S. 2010. *The SPASMO-IR tool to determine reasonable water use for the Greater Wellington region.* Prepared for Greater Wellington Regional Council by Plant and Food Research, Palmerston North.

Greenfield S, Ryan A and Milne JR. 2012. *Recreational water quality in the Wellington region: State and trends.* Greater Wellington Regional Council, Publication No. GW/EMI-T-12/142, Wellington.

Gyopari M and McAlister D. 2010a. *Wairarapa Valley groundwater resource investigation: Upper Valley catchment hydrogeology and modelling.* Greater Wellington Regional Council, Publication No. GW/EMI-T-10/74, Wellington.

Gyopari M and McAlister D. 2010b. *Wairarapa Valley groundwater resource investigation: Middle Valley catchment hydrogeology and modelling.* Greater Wellington Regional Council, Publication No. GW/EMI-T-10/73, Wellington.

Gyopari M and McAlister D. 2010c. *Wairarapa Valley groundwater resource investigation: Lower Valley catchment hydrogeology and modelling.* Greater Wellington Regional Council, Publication No. GW/EMI-T-10/75, Wellington.

Hay J. 2010. *Instream flow assessment options for Greater Wellington Regional Council.* Cawthron Institute, Publication No. 1770, prepared for Greater Wellington Regional Council, Wellington.

Harkness M. 1998. *Predicting droughts in Kapiti Coast catchments using the Southern Oscillation Index.* Wellington Regional Council, Publication No. WRC/RINV-T-98/24, Wellington.

Harkness M. 1999. *Predicting rainfall droughts in Kapiti Coast catchments using the Southern Oscillation Index.* Wellington Regional Council, Publication No. WRC/RINV-T-99/18, Wellington.

Harkness M. 2000. *Predicting rainfall droughts in the Wairarapa using the Southern Oscillation Index.* Wellington Regional Council, Publication No. WRC/RINV-T-00/15, Wellington.

Hughes B and Gyopari M. 2011. *Wairarapa Valley groundwater resource investigation: Proposed framework for conjunctive water management.* Greater Wellington Regional Council, Publication No. GW/EMI-T-11/53, Wellington.

Hughes B. In prep. *Proposed framework for conjunctive water management in the Hutt Valley.* Greater Wellington Regional Council.

Hughes B, Gyopari M and Mzila D. In prep. *Kapiti Coast groundwater resource investigation: Proposed framework for conjunctive water management.* Greater Wellington Regional Council.

Jones A and Baker T. 2005. *Groundwater monitoring technical report.* Greater Wellington Regional Council, Publication No. GWRC/RINV-T-05/86, Wellington.

Keenan L. 2009a. *Mean annual low flow statistics for rivers and streams in the Wellington region.* Unpublished internal report, Document #715651, Greater Wellington Regional Council, Wellington.

Keenan L. 2009b. *Waiohine River instream values and minimum flow assessment.* Greater Wellington Regional Council, Publication No. GW/EMI-G-09/276, Wellington.

Keenan L. 2009c. *Instream flow assessment for Papawai Stream.* Greater Wellington Regional Council, Publication No. GW/EMI-G-09/332, Wellington.

Keenan L. 2012. *River low flow trend analysis for the Wellington region: Internal technical paper prepared in support of state of the environment reporting.* Unpublished internal report, Document #1056498, Greater Wellington Regional Council, Wellington.

Ministry of Agriculture and Forestry 2010a. Effects and impacts: Taranaki to Wellington. Fact sheet in the *Introduction to climate change 8* series. Ministry of Agriculture and Forestry, Wellington.

Ministry of Agriculture and Forestry 2010b. Effects and impacts: Gisborne to Wairarapa. Fact sheet in the *Introduction to climate change 8* series. Ministry of Agriculture and Forestry, Wellington.

Ministry for the Environment 2008a. *Proposed National Environmental Standard on ecological flows and water levels.* Discussion Document. Ministry for the Environment Publication No. ME 868, Wellington.

Ministry for the Environment 2008b. *Climate change effects and impacts assessment: A guidance manual for local government in New Zealand.* 2nd Ed. Prepared by Mullan B, Wratt D, Dean S, Hollis M, Allan S, Williams T, Kenny G and MfE. Ministry for the Environment, Wellington.

Mullan B, Porteous A, Wratt D and Hollis M. 2005. *Changes in drought risk with climate change.* NIWA Client Report: WLG2005-23 prepared for the Ministry for the Environment and the Ministry of Agriculture and Forestry.

Mzila D. 2012. *Groundwater level trend analysis for the Wellington region: Internal technical paper prepared in support of state of the environment reporting.* Unpublished internal report, Greater Wellington, WGN_DOCS#1056632.

Sorensen P. 2012. *Soil quality and stability in the Wellington region: State and trends.* Greater Wellington Regional Council, Publication No. GW/EMI-T-12/138, Wellington.

Salinger MJ, Gray W, Mullan B and Wratt D. 2004. Atmospheric circulation and precipitation. In Harding J, Mosley P, Pearson C and Sorrell B. (eds) *Freshwaters of New Zealand.* New Zealand Hydrological Society and New Zealand Limnological Society. Caxton Press, Christchurch.

Thompson M. 2010. *Improving our understanding of Lake Wairarapa's hydrology.* Unpublished internal memorandum, Document #842486, Greater Wellington Regional Council, Wellington.

Thompson M. 2011a. *Naturalising the flow record for the Ruamahanga River at Waihenga.* Unpublished internal memorandum, Document #933189, Greater Wellington Regional Council, Wellington.

Thompson M. 2011b. *Otaki River instream values and minimum flow assessment.* Greater Wellington Regional Council, Publication No. GW/EMI-T-11/133, Wellington.

Thompson M. 2012. *Rainfall trend analysis for the Wellington region: Internal technical paper prepared in support of state of the environment reporting.* Unpublished internal report, Document #1056267, Greater Wellington Regional Council, Wellington.

Thompson M. In prep. *Tauherenikau River instream values and minimum flow assessment.* Greater Wellington Regional Council.

Thompson M and Gordon M. 2010. *Annual hydrology monitoring report for the Wellington region, 2009/10.* Greater Wellington Regional Council, Publication No. GW/EMI-G-10/161, Wellington.

Tidswell S, Annear L and Lee E. 2010. *Annual groundwater monitoring report for the Wellington region, 2009/10.* Greater Wellington Regional Council, Publication No. GW/EMI-G-10/162, Wellington.

Wairarapa Water Use Project. 2011. *Wairarapa water project enters new phase.* Press release from Wairarapa Water Use Project retrieved from http://www.wairarapawater.org.nz/news (15 April 2012).

Watts L. 2005. *Hydrological monitoring technical report.* Greater Wellington Regional Council, Publication No. GWRC/RINV-T-05/88, Wellington.

Wellington Regional Council. 1995. *Regional Policy Statement for the Wellington region.* Wellington Regional Council, Publication No. WRC/RP-G-95/28, Wellington.

Wellington Regional Council 1999. *Regional Freshwater Plan for the Wellington region.* Wellington Regional Council, Publication No. WRC/RP-G-99/31, Wellington.

Woods R. 2011. *Long-term fluctuations in river flow conditions linked to the Interdecadal Pacific Oscillation.* Retrieved from http://sciblogs.co.nz/waiology/2011/11/17/ (1 December 2011).

Acknowledgements

Rainfall and flow data for several of the sites included in the analyses in this report come from NIWA and MetService (specific NIWA and MetService sites are identified in site tables and maps in the report).

The following Greater Wellington staff reviewed draft versions of the report:

- Stephen Thawley
- Miranda Robinson
- Murray McLea
- Juliet Milne
- Lindsay Annear
- Mike Gordon
- Alastair McCarthy

The following external reviewers are thanked for providing helpful comments on aspects of the report:

- Dr Ross Woods (NIWA)
- Dr Andrew Tait (NIWA)
- Dr Chris Daughney (GNS)

Appendix 1: Hydrological monitoring site details

Sites listed in the following tables are those that are part of Greater Wellington's long-term SoE hydrological monitoring network. Monitoring sites established as part of short-term investigations are not listed.

Note: Easting and northing map references for all sites in the following tables are in the 'New Zealand Trans Mercator' (NZTM) format.

Table A1.1: Rainfall monitoring sites

Sub-region	Site name	Catchment/location	Altitude (m)	Start date	Easting (NZTM)	Northing (NZTM)
Wairarapa	Bannister	Ruamahanga (Tararua Range)	1,000	30/09/1974	1808833	5487428
	Angle Knob	Waingawa (Tararua Range)	1,200	27/12/1974	1805258	5475462
	Carkeek	Waiohine (Tararua Range)	1,158	30/09/1974	1802166	5481870
	Bull Mound	Tauherenikau (Tararua Range)	1,000	23/03/1976	1795128	5460805
	Mt Bruce	Ruamahanga	300	30/07/1984	1819278	5485284
	Mauriceville	Kopuaranga	230	07/05/2008	1826879	5483853
	Westons	Waipoua	470	08/11/2007	1816567	5480958
	Wairarapa College	Ruamahanga (Masterton)	115	29/05/2002	1822753	5463166
	Kaituna	Waingawa	240	09/05/1994	1812545	5470730
	Valley Hill	Mangatarere	483	21/04/1997	1806484	5464882
	Waiohine Gorge	Waiohine	140	02/02/2006	1801682	5456581
	Parkvale	Parkvale (Carterton)	100	08/01/2008	1813496	5449490
	Alloa	Tauherenikau (Featherston)	40	01/03/1963	1799870	5445286
	Racecourse	Tauherenikau (Featherston)	40	04/07/2007	1799488	5445146
	Matthews	Waiorongomai	25	18/05/2009	1780017	5430263
	Waihi	Whangaehu	175	10/01/2001	1834110	5476076
	Castlehill	Tauweru	240	10/04/1991	1852366	5483971
	Te Weraiti	Tauweru	80	09/09/1997	1832112	5458262
	Longbush	Southern Whangaehu	255	01/11/2006	1819836	5436843
	Iraia	Ruakokoputuna	260	09/04/1969	1798384	5416435
	Tanawa Hut	Whareama	280	01/01/1956	1864716	5484384
Central	Kaitoke Headworks	Hutt	223	02/01/1991	1783680	5452483
	Te Marua	Hutt	150	22/07/1993	1780080	5450684
	Savage Park	Hutt	70	12/07/2010	1773805	5445685
	Pinehaven	Pinehaven Stream	150	03/08/2010	1768529	5441785
	Centre Ridge	Pakuratahi	510	06/04/1984	1784579	5444183
	Maymorn Pumping Stn	Mangaroa	130	20/01/2005	1778980	5447039
	Tasman Vaccine Ltd	Mangaroa	229	03/05/1968	1768979	5437885
	Warwicks	Akatarawa	345	16/06/1980	1774781	5463885
	Cemetery	Akatarawa	100	29/03/1988	1776280	5449484
	Blue Gum Spur	Whakatikei	335	13/10/1981	1769680	5453885
	Birch Lane	Hutt (Lower Hutt)	10	25/04/2001	1760979	5435886

Sub-region	Site name	Catchment/location	Altitude (m)	Start date	Easting (NZTM)	Northing (NZTM)
	Shandon Golf Club	Hutt (Petone)	4	03/04/2000	1758998	5434456
	Orongo Swamp	Orongorongo	420	03/10/1980	1772477	5431985
	Wainuiomata Reservoir	Wainuiomata	125	01/01/1890	1766677	5429485
	Lake Kohangatera	Gollans / Pencarrow Lakes	8	22/08/2007	1755922	5418015
	Whenua Tapu	Taupo	45	17/04/1991	1757581	5453386
	Battle Hill	Horokiri	60	30/03/2010	1762880	5452885
	Seton Nossiter Park	Porirua	100	06/07/1992	1752279	5436387
Central (cont)	Quartz Hill	Makara	270	03/09/2007	1741915	5432265
	Mill Creek Windfarm	Makara	210	10/02/2011	1745584	5436545
	Karori Reservoir	Kaiwharawhara	141	02/01/1879	1746078	5426688
	Regional Council Centre	n/a (Wellington city)	30	26/07/1996	1748878	5427488
	Tawa Pool*	Porirua Stream (Tawa)	40	29/08/1996	1753480	5441387
	Duthie Street*	Wellington city (Karori)	200	08/10/1990	1746178	5428088
	Berhampore*	Wellington city	20	29/07/1996	1748278	5423888
	Hataitai Old Post Office*	Wellington city	15	25/02/1997	1750178	5425988
	Khandallah at Library*	Wellington city	160	29/08/1996	1750079	5432287
	Miramar North Rd*	Wellington city	25	04/10/2004	1752678	5426088
	Newtown Mansfield*	Wellington city	25	11/09/1996	1749078	5424488
Kapiti Coast	Kapakapanui	Otaki (Tararua Range)	1,090	06/09/1991	1782082	5467184
	McIntosh	Otaki (Tararua Range)	1,020	26/09/1991	1794483	5467883
	Oriwa	Otaki (Tararua Range)	1,050	08/09/1991	1798285	5486386
	Taungata	Otaki (Tararua Range)	980	06/09/1991	1790183	5479685
	Otaki Depot	Otaki	17	18/07/1984	1780983	5484586
	Transmission Lines	Mangaone	140	13/10/1992	1782983	5477185
	Shoveller Lagoon	n/a (Te Hapua wetlands)	3	30/03/2009	1775282	5479885
	Water Treatment Plant	Waikanae	40	02/08/1969	1774582	5471585
	QE Park	Whareroa (Paekakariki)	15	12/09/2001	1766239	5462294

* These sites are maintained by Greater Wellington but owned by Wellington City Council.

Table A1.2: River level/flow monitoring sites

Sub-region	Site name	Start date	Catchment area (km²)	Easting (TM)	Northing (TM)	Comments
Wairarapa	Ruamahanga R at Mt Bruce	01/01/1975	76.5	1819288	5485284	
	Ruamahanga R at Wardells	10/11/1954	637	1824685	5457478	
	Ruamahanga R at Gladstone Br	06/06/1992	1315	1820883	5449878	Rated for high flows only
	Ruamahanga R at Waihenga Br	31/12/1956	2340	1804579	5436679	
	Ruamahanga R at Barrage South	01/01/1974	3341	1783641	5423998	River level only (tidal)
	Waipoua R at Mikimiki Bridge	05/02/1979	80.5	1820587	5475182	
	Te Mara S at Kiriwhakapapa	28/11/2008	13.4	1819413	5479407	
	Waingawa R at Kaituna	14/05/1976	79	1812685	5470682	
	Mangatarere S at Gorge	09/02/1999	33.3	1811469	5465421	
	Mangatarere S at Belvedere Br	26/01/2004	55.9	1811046	5456798	Rated for low flows only
	Mangatarere S at SH2	01/09/2009	119	1809682	5451980	
	Waiohine R at Gorge	27/12/1954	180	1801682	5456581	
	Tauherenikau R at Gorge	30/03/1976	112	1797981	5451181	
	Kopuaranga R at Palmers	15/03/1985	100	1825288	5477882	
	Kopuaranga R at Stuarts	28/08/2010	166	1826601	5469872	
	Tauweru R at Te Weraiti	10/12/1969	373	1832087	5458377	Rated for high flows
	Tauweru R at Te Whiti Rd Br	06/09/2009	496	1824084	5450777	
	Huangarua R at Hautotara	01/01/1968	140	1807277	5425378	Rated for flows stage only
	Otukura S at Weir	17/12/1997	36.2	1798579	5437780	
	Papawai S at U/S Oxidation Pond	06/12/2005	–	1809149	5446809	Catchment area not defined (spring)
	Tilsons Ck at Scott Culvert	03/11/2005	–	1809331	5447839	Catchment area not defined (spring)
	Booths Ck at Golf Club Pond	20/12/2010	0.9	1813632	5457701	
	Parkvale S at Renalls Weir	15/01/2002	–	1813496	5449490	Catchment area not defined
	Parkvale Tributary at Lowes Res.	17/03/2011		1818094	5458352	Catchment area not defined (spring)
	Whangaehu R at Waihi	10/05/1967	36.3	1834120	5476086	
	Pahaoa R at Hinakura	04/09/1986	563	1821678	5424774	NIWA site partly funded by GWRC
	Kaiwhata R at Stansborough	28/07/1988	84	1844584	5436070	NIWA site
	Whareama R at Waiteko	09/04/1970	398	1856073	5461248	NIWA site
Central	Hutt R at Kaitoke Weir	03/02/2004	86.8	1784181	5453283	River level only
	Hutt R at Te Marua	05/03/1984	191	1780080	5450684	
	Hutt R at Taita Gorge	16/03/1979	556	1766410	5441797	
	Hutt R at Estuary Bridge	28/09/1976	623	1759278	5433586	River level only (tidal site)

Sub-region	Site name	Start date	Catchment area (km²)	Easting (TM)	Northing (TM)	Comments
	Hutt R at Kaitoke	21/12/1967	89	1784181	5453283	NIWA site partly funded by GWRC
	Hutt R at Birchville	07/09/1970	427	1775580	5448184	NIWA site partly funded by GWRC
	Pakuratahi R at Truss Br	22/05/1978	37.2	1783679	5445183	
	Mangaroa R at Te Marua	20/05/1977	102	1778753	5448583	
	Akatarawa R at Cemetery	19/02/1979	114	1776288	5449499	
	Whakatikei R at Dude Ranch	08/09/1976	46	1770580	5450185	
	Waiwhetu S at Whites Line East	31/05/1978	11.6	1760996	5434500	
	Wainuiomata R at Manuka Track	10/06/1982	27.1	1768226	5430632	
	Wainuiomata R at Leonard Wood Park	14/04/1977	77.5	1763092	5427825	
	Orongorongo R at Upper Dam Site	09/10/1980	7.1	1772477	5430985	
	Orongorongo R at Truss Br	12/03/1998	31.7	1770159	5426164	
	Pauatahanui S at Gorge	30/05/1975	-	1761480	5446486	NIWA site
	Mill Ck at Papanui	24/04/1969	-	1748880	5439987	NIWA site
	Taupo S at Flax Swamp	17/08/1979	8.2	1757073	5451057	Funded by PCC
	Horokiri S at Snodgrass	15/02/2002	28.8	1761780	5450686	
	Porirua S at Town Centre	08/09/1965	44.8	1754677	5443970	
Kapiti Coast	Waitohu S at Water Supply Intake	17/10/1994	19.2	1786886	5484786	
	Mangaone S at Ratanui	13/01/1993	9.2	1781874	5478174	
	Waikanae R at Water Trt Plant	03/03/1975	125	1774571	5471385	
	Mazengarb S at Scaife Drive	03/05/1995	4.5	1769081	5470867	Owned and funded by KCDC
	Wharemauku S at Coastlands	16/12/1980	7.8	1768842	5468427	Owned and funded by KCDC
	Otaki R at Pukehinau	17/07/1980	306	1785483	5478485	NIWA site partly funded by GWRC

Table A1.3: Lake/wetland level and soil moisture monitoring sites

Sub-region	Site name	Type	Start date	Easting (TM)	Northing (TM)
Wairarapa	Lake Wairarapa at Burlings	Lake level	18/09/1953	1781777	5433083
	Lake Onoke at Lake Ferry	Lake level	27/04/1953	1779174	5415284
	Lake Wairarapa at Barrage North	Lake level	01/01/1974	1783376	5424083
	Ruamahanga R at Barrage South	Lake level	01/01/1974	1783376	5424083
	Taumata Lagoon	Wetland level	19/04/2010	1811660	5447952
	Wairarapa College	Soil moisture	04/06/2002	1822686	5463080
	Alloa	Soil moisture	21/09/1999	1799880	5445281
	Longbush	Soil moisture	23/07/2007	1819836	5436843
	Tanawa Hut	Soil moisture	15/10/2002	1864701	5484379
Central	Lake Kohangapiripiri	Lake level	20/08/2007	1755213	5419272
	Lake Kohangatera	Lake level	17/08/2007	1755922	5418015

Sub-region	Site name	Type	Start date	Easting (TM)	Northing (TM)
Kapiti Coast	Te Hapua Wetland at Pateke	Wetland level	07/04/2009	1775764	5479452
	Te Hapua Wetland at Shoveller Lagoon	Wetland level	30/03/2009	1775288	5479884
	Te Hapua Wetland at Trotter	Wetland level	04/06/2009	1774724	5479152
	Te Hapua Wetland at Jill and Joy	Wetland level	03/04/2009	1774344	5479298

Table A1.4: Greater Wellington's automatic groundwater level monitoring network

Site name	Site No.	Groundwater zone	Start date	Easting (TM)	Northing (TM)
Wairarapa					
Bicknell	S27/0883	Ahikouka	07/08/2008	1810184	5447188
Simmonds	S27/0099	Battersea	10/12/1996	1803170	5442510
Hilton Road Deep	S26/1034	Carterton	14/11/2008	1811188	5453628
Hilton Road Shallow	S26/1035	Carterton	14/11/2008	1811188	5453628
Perry	S26/0490	Greytown	13/08/1990	1805492	5450976
Hammond	S27/0225	Greytown	06/09/1994	1807071	5447719
Simmonds	S27/0309	Kahutara	11/01/2002	1797877	5436461
Simmonds	S27/0317	Kahutara	21/12/2001	1797799	5437083
Green	S27/0467	Kahutara	13/11/2001	1792820	5433065
M/B Golf Club	S27/0571	Martinborough Eastern Terraces	05/10/1988	1807158	5433014
Duggan	S27/0522	Martinborough Western Terraces	01/12/2000	1803032	5431324
Taumata Lagoon – Inner	S27/0881	Middle Ruamahanga	01/09/2005	1811485	5447885
Taumata Lagoon – Outer	S27/0878	Middle Ruamahanga	01/09/2005	1811485	5447885
Blundell	S26/0749	Middle Ruamahanga	17/12/1997	1815842	5449088
Didsbury	S27/0885	Riverside	14/08/2008	1808967	5445646
Croad	S27/0202	Moroa	26/04/1988	1805461	5446520
Luttrell Shallow	S27/0587	Onoke	07/02/1990	1781042	5423379
Towgood	S26/0738	Parkvale	03/08/1983	1815311	5453577
Baring	S26/0743	Parkvale	06/11/1986	1815028	5451785
Renall Deep	S26/1032	Parkvale	29/09/2008	1813337	5449868
Renall Shallow	S26/1033	Parkvale	29/09/2008	1813337	5449868
Mcnamara Shallow	S26/1053	Parkvale	21/08/2008	1814051	5452481
Dry River Beef	S27/0481	Pukeo	19/09/1989	1799718	5431317
Zyzalo	T26/0239	Rathkeale	26/08/1997	1825441	5469001
Tucker	S27/0884	Riverside	14/08/2008	1808478	5441241
Burt	S27/0330	Tauherenikau	30/11/2001	1797767	5440421
Herrick	S27/0381	Tawaha East	09/03/1984	1805651	5435941
Smith	S27/0346	Tawaha West	02/12/1983	1804059	5437102
Wairoria	S27/0434	Te Hopai	02/02/1994	1786852	5428337
Himona	T26/0246	Te Ore Ore	10/03/2009	1827679	5464157
Oliver Deep	T26/0494	Te Ore Ore	27/11/1981	1828039	5462681
Oliver Shallow	T26/0501	Te Ore Ore	15/07/1983	1826098	5462612

Site name	Site No.	Groundwater zone	Start date	Easting (TM)	Northing (TM)
Lucas	T26/0814	Te Ore Ore	05/08/2008	1826428	5460584
Robinson Transport	S27/0442	Tuhitarata	30/08/2005	1789891	5426884
Downing Recorder	S26/0033	Upper Plain	30/09/1983	1818493	5464562
Wairio	S27/0428	Wairio	11/02/1983	1787618	5430809
Hutt Valley					
H.V.M.T.C	R27/0120	Lower Hutt	24/09/1968	1758778	5434956
McEwan Park	R27/0122	Lower Hutt	03/03/1971	1758748	5433546
McEwan Park Deep	R27/7153	Lower Hutt	14/03/2008	1758681	5433523
IBM No 1	R27/0320	Lower Hutt	22/09/1992	1756996	5434508
IBM No 2	R27/1265	Lower Hutt	02/06/1991	1756998	5434516
UWA 3	R27/1086	Lower Hutt	24/12/1997	1759813	5433246
Hutt Rec	R27/1115	Lower Hutt	15/12/1967	1759588	5435716
Mitchell Park	R27/1116	Lower Hutt	24/09/1968	1761599	5436816
Taita Int. School	R27/1117	Lower Hutt	24/09/1968	1763574	5438391
Randwick Reserve	R27/1122	Lower Hutt	24/06/1975	1759757	5434602
Somes Island	R27/1171	Lower Hutt	28/01/1969	1756493	5431227
Marsden Street	R27/6386	Lower Hutt	01/05/2000	1759039	5435971
TS Tamatoa Shallow	R27/7154	Lower Hutt	05/02/2008	1757020	5434294
TS Tamatoa Deep	R27/7215	Lower Hutt	05/02/2008	1757022	5434298
South Pacific Tyres	R27/1137	Upper Hutt	09/06/2006	1773406	5444956
Coca Cola/Unibag	R27/6978	Upper Hutt	01/08/2006	1772082	5444732
Trentham Memorial Park	R27/7004	Upper Hutt	25/05/1973	1770649	5444445
Kapiti Coast					
Sims Road South	R25/0003	Coastal	28/03/1985	1776328	5482692
Jensens Deep	R25/5262	Coastal	26/03/2009	1775470	5479412
Jensens Shallow	R25/7086	Coastal	30/03/2009	1775295	5479894
Jill and Joys	R25/7087	Coastal	30/03/2009	1774698	5479298
Housiaux 2	R26/6879	Coastal	25/11/2004	1775707	5479424
Centrepoint	S25/5208	Hautere	19/12/1991	1780182	5480785
Bettys	S25/5258	Otaki	04/03/1993	1782227	5483430
Waikanae Park	R26/6284	Waikanae	14/07/2003	1772736	5473167
Rangihiroa St	R26/6287	Waikanae	16/12/2002	1770587	5474307
KCDC Rutherford Dr	R26/6378	Waikanae	13/09/2006	1771995	5475389
Larch Grove	R26/6831	Waikanae	13/10/2000	1768770	5469188
Maclean Park	R26/6833	Waikanae	13/10/2000	1766872	5471508
KCDC K6 Observation	R26/6992	Waikanae	18/11/2005	1773140	5475374
Te Harakeke Bore 3	R26/6886	Waikanae	14/05/2002	1771939	5474425
Waikanae CHP Shall	R26/6916	Waikanae	10/08/1994	1770722	5473136
Waikanae CHP Deep	R26/6594	Waikanae	30/05/1994	1770722	5473136
Taiata St Shallow	R26/6673	Waikanae	18/02/2005	1770439	5474422
Taiata St Deep	R26/6955	Waikanae	18/02/2005	1770439	5474422

Site name	Site No.	Groundwater zone	Start date	Easting (TM)	Northing (TM)
Estuary Shallow	R26/6566	Waikanae	18/02/2005	1769407	5473310
Estuary Deep	R26/6956	Waikanae	18/02/2005	1769407	5473310
GWRC Nga Manu	R26/6991	Waikanae	18/11/2005	1773517	5474443
KCDC W1	R26/7025	Waikanae	18/11/2005	1772141	5473628
Taylors	S25/5332	Waitohu	14/08/1995	1782183	5487286

Table A1.5: Greater Wellington's manual groundwater level monitoring network

Site name	Site No.	Groundwater zone	Start date	Easting (TM)	Northing (TM)
Wairarapa					
Craig Deep	S26/0545	Ahikouka	03/08/1983	1809483	5451390
Craig Shallow	S26/0547	Ahikouka	03/08/1983	1809453	5450175
Nicholson	S26/0223	East Taratahi	18/03/1998	1816203	5459285
East Coast Fert Shallow	S26/0242	East Taratahi	03/08/1983	1816553	5459603
East Coast Fert Deep	S26/0229	East Taratahi	14/05/1984	1816546	5459589
Oldfield	S26/0236	East Taratahi	03/08/1983	1818120	5460574
Mckay	T26/0326	Fern Hill	02/08/1991	1820860	5455804
List	S27/0572	Huangarua Lower Terraces	30/11/2000	1809440	5432047
Simmonds	S27/0271	Kahutara	21/04/1982	1797796	5437060
Awaroa Deep	S27/0446	Kahutara	11/11/1982	1794482	5432237
Awaroa Shallow	S27/0465	Kahutara	20/04/1982	1794056	5431529
Wither	S26/0658	Mangatarere	03/08/1983	1810633	5454760
Wall	S27/0403	Martinborough Eastern Terraces	13/11/2001	1807960	5433462
MacCullum	S27/0560	Martinborough Eastern Terraces	03/11/2000	1807965	5432882
Te Kairanga Deep	S27/0640	Martinborough Eastern Terraces	01/05/2002	1808122	5433651
Annear Nursery Rd	T26/0366	Masterton	08/04/2002	1823982	5461416
Trans.Wai.	T26/0429	Masterton	10/02/1986	1820022	5461986
Stevenson (Ex Wenden)	S26/0756	Middle Ruamahanga	29/05/1998	1815919	5448296
Morrison	S27/0248	Middle Ruamahanga	03/08/1983	1813058	5448004
Warren	S27/0594	Narrows	18/08/1981	1781351	5419721
Luttrell Deep	S27/0576	Onoke	29/11/1982	1781419	5423507
Tocher	T26/0208	Opaki	12/01/1984	1823048	5467347
Tulloch Shallow	S26/0155	Parkvale	03/08/1983	1813828	5456110
Tulloch Invest	S26/0656	Parkvale	12/05/1982	1813362	5455652
Denbee	S26/0568	Parkvale	17/08/1983	1813487	5451921
McNamara	S26/0675	Parkvale	30/10/1996	1812924	5452588
Wairarapa A & P Clareville	S26/0837	Parkvale	04/08/2009	1814435	5457638
Ness Deep	S27/0484	Pukio	07/12/1990	1798305	5431172
Ness Shallow	S27/0485	Pukio	28/11/1995	1798305	5431172
Stuart	S27/0517	Pukio	22/09/1989	1800865	5430454

Site name	Site No.	Groundwater zone	Start date	Easting (TM)	Northing (TM)
Windy Farm House	S27/0009	South Featherston	01/05/2002	1793895	5443482
Windy Farm Pig Unit	S27/0012	South Featherston	03/08/1983	1793778	5443400
Windy Farm Deep New Irrigation	S27/0839	South Featherston	03/11/2009	1794106	5443659
Sth Featherston School	S27/0035	Tauherenikau	03/08/1983	1797506	5443107
Butcher	S27/0542	Tawaha	21/12/1988	1799989	5431940
Waicon	T26/0232	Te Ore Ore	19/09/1983	1825940	5463448
Mast.Boro	T26/0243	Te Ore Ore	26/09/1988	1826226	5463379
Annear Lake Ferry	R28/0002	Turanganui	11/06/1994	1779603	5416045
Lenton	T26/0003	Upper Opaki	02/04/1997	1822559	5473236
Dick Invest	S26/0030	Upper Plain	17/01/1983	1819666	5464185
Kells Stream	T26/0709	Upper Plain	15/11/1993	1820021	5460426
Atkinson	S27/0618	Whangaehu / Tuhitarata	16/04/1982	1785168	5422471
Carlisle	S27/0148	Woodside	03/08/1983	1802221	5447044
Lower Hutt					
Nevis Street	R27/1223	Lower Hutt	03/03/1971	1756414	5434542
Kapiti Coast					
Faith	R25/5123	Coastal	26/02/1993	1778282	5480785
Quinn	R26/6747	Coastal	30/06/1982	1775247	5477235
Housiaux 1	R26/6861	Coastal	25/11/2004	1775689	5479431
Housiaux 5	R26/6882	Coastal	25/11/2004	1775630	5479498
Housiaux 6	R26/6883	Coastal	25/11/2004	1775695	5479458
Housiaux 2b	R26/6936	Coastal	23/02/2005	1775707	5479422
Jamieson	R25/5111	Hautere	26/02/1993	1778182	5479085
Windsor Park	R25/5135	Hautere	30/06/1982	1779152	5481483
Common Property	S25/5200	Hautere	12/03/1993	1781182	5479785
Penray	S25/5256	Hautere	26/02/1993	1780491	5483154
KCDC Rangiuru	R25/5228	Otaki	08/04/1993	1779182	5486286
Lutz	S25/5212	Otaki	26/03/1993	1784454	5482334
Andrews	S25/5228	Otaki	26/02/1993	1782737	5483246
Horowhenua Racing Club	S25/5287	Otaki	12/03/1993	1782583	5484686
QE Park No3	R26/5102	Raumati/Paekak	12/09/2001	1766541	5462545
QE Park No1	R26/6503	Raumati/Paekak	26/02/1993	1766253	5462295
QE Park No2	R26/6520	Raumati/Paekak	12/12/1994	1766365	5462470
QE Park No4	R26/6919	Raumati/Paekak	12/09/2001	1766543	5462545
QE Park No5	R26/6920	Raumati/Paekak	12/09/2001	1766226	5462840
KCDC Weka Park	R26/6521	Waikanae	26/02/1993	1767208	5468481
KCDC Mazengarb	R26/6557	Waikanae	26/03/1993	1768981	5471083
NZ Staff College	R26/6569	Waikanae	26/02/1993	1770929	5470578
McLauchlan	R26/6626	Waikanae	26/02/1993	1773782	5474085
McCardle	R26/6738	Waikanae	26/02/1993	1775682	5476685
Te Harakeke Bore 1	R26/6884	Waikanae	14/05/2002	1772093	5475388
Te Harakeke Bore 2	R26/6885	Waikanae	14/05/2002	1772488	5475034
Edhouse	S25/5322	Waitohu	26/03/1993	1782983	5487486
Laurensen Estate	S25/5329	Waitohu	26/03/1993	1780583	5487986

Appendix 2: Mean annual low flow statistics

Table A2.1: 1-day and 7-day Mean Annual Low Flow (MALF) estimates for main rivers and streams in the Wellington region

Catchment or sub-region	River / stream / tributary	Start of continuous flow record	1-day MALF at flow recorder	7-day MALF at flow recorder^	Estimated 1-day MALF at river mouth or end of reach (L/s)[1]	Estimated 7-day MALF at river mouth or end of reach (L/s)[1]
Ruamahanga River	Kopuaranga R	1985	280	310	570	605
	Waipoua R	2007[2]	310	375	410	490
	Makoura S	No recorder	–	–	150	–
	Waingawa R	1976	1,230	1,440	1,590	1,720
	Tauweru R – u/s of Kourarau S	No recorder	–	–	70	80
	Tauweru R – total	2009	–	–	–	500[3]
	Makahakaha S	No recorder	–	–	–	85
	Parkvale S[4]	2002	120	140	120	140
	Booths Crk	No recorder	–	–	70	–
	Mangatarere S	1999	135	165	305	370
	Waiohine R	1975	3,050	3,570	3,190	3,550
	Papawai S[4]	2005	340	350	340	350
	Huangarua R	No recorder	–	–	310	360
	Ruamahanga R[5]	1976	11,100	12,870	12,930	14,785
Lake Wairarapa and tributaries	Abbots Crk	No recorder	–	–	100[6]	–
	Tauherenikau Seepage Drain	No recorder	–	–	400[6]	–
	Murphys Line Drain	No recorder	–	–	260[6]	–
	Otukura S[3]	1997	85	100	85	100
	Stonestead (Dock) Crk				500[6]	
	Tauherenikau R[7]	1976	1,135	1,320	270	320
Eastern Wairarapa	Pahaoa R[8]	1986	95	115	_	_
	Whareama R[8]	1970	25	30	_	_
	Kaiwhata R[8]	1988	10	10	_	_
Central Wellington	Pautahanui S	1975	90	100	100	110
	Wainuiomata R[9]	1982	175	185	585	600
	Orongorongo R – upper reach[10]	–	285	320	–	–
Hutt River	Hutt R – upper reach[11]	1967	1,320	1,435	–	–
	Hutt R – lower reach[12]	1970	3,400	3,845	3,400	3,845
	Pakuratahi R	1978	220	240	–	–
	Mangaroa R	1977	340	390	–	–
	Akatarawa R	1979	975	1050	–	–
Kapiti Coast	Waitohu S	1994	140	150	230	250
	Otaki R	1980	4,770	5,220	3,870	4,230
	Mangaone S	1993	65	70	155	165
	Waikanae R	1975	950	1,050	770	845

^ In some cases the estimates here differ slightly from those presented in the low flow trend analysis (eg, Table A4.1, Appendix 4). This is because slightly different methods may have been applied to the analysis and/or data exclusions in arriving at the estimates.

[1] Unless otherwise stated, MALF estimates are from Keenan (2009a) and are 'naturalised' (ie, the loss of flow from direct surface water abstractions in the catchment has been accounted for either by adding an estimate of abstraction back in to the flow record or by using concurrent flow gauging data collected when there was a cease-take order in place).

[2] A flow correlation between flow gaugings at the Waipoua at Mikimiki and a continuous flow record for the Atiwhakatu River was used to extend the record back for MALF estimation.

[3] This is a rough estimate. A continuous flow monitoring site was established in 2009 but there is still insufficient data to derive a good estimate

[4] The recorder site is near the catchment mouth, hence MALF estimates are the same.

[5] Estimates from Thompson (2011a) based on naturalisation of flow record at 'Waihenga' monitoring site and extrapolation to catchment mouth. Note these estimates are naturalised for both surface water and category.

[6] These are preliminary estimates that should be considered broadly indicative only. They are based on a small number of gaugings.

[7] Estimates from Thompson (in prep) – *Tauherenikau River instream values and minimum flow assessment.*

[8] While estimates of MALF have not been assessed for the bottom of the catchment, MALF is so low in these catchments that the at-site value is likely to be reasonably representative of the lowest reaches.

[9] Monitoring site 'Manuka Track'.

[10] Upper reach defined as upstream of monitoring site 'Truss Bridge'.

[11] Upper reach defined as upstream of monitoring site 'Kaitoke Weir'.

[12] Upper reach defined as upstream of monitoring site 'Melling'.

Appendix 3: Rainfall trend analysis – sites and results

Table A3.1: Greater Wellington (GWRC) and NIWA sites used in the trend analysis

Area represented	Rainfall site name	Site ID	Altitude (m)	Start of record
Wairarapa – Tararua Range	Angle Knob	GWRC	1,200	1974
Wairarapa – Tararua Range	Phelps[2]	GWRC	124	1974
Wairarapa – central/western valley	Alloa	GWRC & NIWA	40	1963
Wairarapa – northeastern valley	East Taratahi (closed 2009)	METSERVICE	91	1981
Wairarapa – eastern valley	Bannockburn [D15161]	NIWA	102	1937
Wairarapa – northeastern hills	Purunui [D05911]	NIWA	119	1906
Wairarapa – northeastern hills	Tanawa Hut	GWRC	280	1956
Wairarapa – southeastern hills	Iraia	GWRC	260	1969
Wairarapa – east coast	Castlepoint[3]	METSERVICE	9	1931
Central – Wellington city/south coast	Karori	GWRC	140	1879
Central – Hutt Valley	Wallaceville EWS [E1510G]	NIWA	56	1940
Central – Wainuiomata Valley	Wainuiomata	GWRC	125	1890
Central – Tararua foothills	Kaitoke Headworks	GWRC	190	1951
Central – Orongorongo Valley	Orongorongo	GWRC	420	1980
Western – Kapiti Coast	Otaki[1]	GWRC & NIWA	30	1893
Western – Kapiti Coast, inland	Te Horo Longcroft [E05811]	NIWA	61	1969
Western – Kapiti Coast,coastal	Paraparaumu Aero AWS [E04491]	METSERVICE	5	1951
Western – Tararua Range	McIntosh	GWRC	1,286	1991

[1] Combined record (Otaki1, Temuka Street [E05713] and Otaki Depot).

[2] Site closed in 2009 and subsequent record from adjusted Waiohine at Gorge site.

[3] Combined record (Castlepoint Light [D06921] and Castlepoint Station [D06821]).

Table A3.2: Results of Mann-Kendall trend test on Min3Month for the period 1980–2010. Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Results that are significant, or approaching significant ($p<0.1$) are bolded.

Sub-region	Site	Period of analysis[1]	Median for period (mm)	Median annual change (mm)	*p*	Significance
Wairarapa	Angle knob	1980–2011	937	-0.24	0.97	NS
	Alloa	1980–2011	139	-0.22	0.26	NS
	Bannockburn	1980–2011	92	-0.23	0.66	NS
	Purunui	1980–2011	108	1.02	0.22	NS
	Phelps	1980–2011	235	-0.44	0.71	NS
	East Taratahi	1980–2011	100	0.18	0.86	NS
	Iraia	1980–2011	179	-1.52	0.31	NS
	Tanawa Hut	1980–2011	116	-1.22	0.17	NS
	Castlepoint	1980–2011	91	-0.23	0.76	NS
Central	Karori	1980–2011	178	1.00	0.23	NS
	Wallaceville	1980–2011	164	-0.89	0.25	NS
	Kaitoke Headworks	1980–2011	302	-0.65	0.74	NS
	Wainuiomata	1980–2011	203	-1.07	0.54	NS
	Orongorongo	1980–2011	337	-1.07	0.43	NS
Kapiti Coast	Otaki	1980–2011	130	0.36	0.33	NS
	Te Horo Longcroft	1980–2011	161	0.28	0.73	NS
	Paraparaumu	1980–2011	122	-0.72	0.17	NS
	McIntosh	1993-2011	739	0.28	0.94	NS

[1]Rainfall years, eg, for Otaki this is 1 July 1980–30 June 2011.

Table A3.3: Results of Mann-Kendall trend test on Min3Month over the full available record for each long standing site (ie, that opened well before 1980). Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Results that are significant, or approaching significant ($p<0.1$) are bolded.

Sub-region	Site	Period of analysis[1]	Median for period (mm)	Median annual change (mm)	*p*	Significance
Wairarapa	Alloa	1963–2011	128	-0.01	0.99	NS
	Bannockburn	1937–2011	96	-0.25	0.20	NS
	Purunui	1906–2011	107	-0.01	0.95	NS
	Iraia	1970–2011	180	-0.7	0.43	NS
	Tanawa Hut	**1951–2011**	**131**	**-0.81**	**0.05**	**S (decreasing)**
	Castlepoint	1940–2011	96	-0.32	0.14	NS
Central	**Karori**	**1879–2011**	**145**	**0.39**	**<0.01**	**HS (increasing)**
	Wallaceville	1940–2011	163	-0.26	0.27	NS
	Wainuiomata	1890–2011	215	-0.32	0.13	NS
Kapiti Coast	Otaki	1893–2011	128	-0.02	0.79	NS
	Te Horo Longcroft	1969–2011	160	0.44	0.35	NS
	Paraparaumu	1951–2011	127	-0.28	0.37	NS

[1]Rainfall years, eg, for Otaki this is 1 July 1893–30 June 2011.

Table A3.4: Results of Mann-Kendall linear trend test on DryDay for the period 1980–2010. Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Results that are significant, or approaching significant ($p<0.1$) are bolded.

Sub-region	Site	Period of analysis[1]	Median for period (day/yr)	Median annual change (day/yr)	*p*	Significance
Wairarapa	Alloa	1980–2011	16	0.05	0.51	NS
	Bannockburn	1980–2011	18.5	0.08	0.41	NS
	Purunui	**1980–2011**	**16**	**-0.03**	**0.03**	**S (decreasing)**
	Phelps	1980–2011	13	-0.09	0.17	NS
	East Taratahi	1980–2011	18	0.11	0.22	NS
	Iraia	1980–2011	17	-0.05	0.43	NS
	Tanawa Hut	1980–2011				N/A[2]
	Castlepoint	1980–2011	19	0	0.72	NS
Central	Karori	1980–2011	18	0.04	0.55	NS
	Wallaceville	1980–2011	17	0.06	0.46	NS
	Kaitoke Headworks	1980–2011	14	0.07	0.24	NS
	Wainuiomata	1980–2011	15	0.1	0.35	NS
	Orongorongo	**1980–2011**	**13**	**0.14**	**0.06**	**NS**
Kapiti Coast	Otaki	1980–2011	19	0.02	0.72	NS
	Paraparaumu	1980–2011	21	0.07	0.33	NS
	McIntosh	1993-2011	8	0	0.44	NS
	Angle knob	1980–2011	8	0	0.80	NS

[1] Rainfall years, eg, for Otaki this is 1 July 1980–30 June 2011.

[2] Data not suitable for analysis.

Table A3.5: Results of Mann-Kendall trend test on DryDay for the whole period of record for long standing sites (ie, that opened well before 1980). Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Results that are significant, or approaching significant ($p<0.1$) are bolded.

Sub-region	Site	Period of analysis[1]	Median for period (day/yr)	Median annual change (day/yr)	*p*	Significance category
Wairarapa	Alloa	1963–2011	17	0	0.58	NS
	Bannockburn	1936–2011	19.5	-0.02	0.41	NS
	Purunui	1906–2011	18	0.01	0.14	NS
	Iraia	1970–2011	17	0	0.76	NS
	Tanawa Hut	1951–2011				N/A[2]
	Castlepoint	**1940–2011**	**20**	**-0.05**	**0.01**	**S (decreasing)**
Central	Karori	1879–2011	18	0	0.91	NS
	Wallaceville	1940–2011	17	0	0.81	NS
	Kaitoke Headworks	1980–2011	14	0.02	0.30	NS
	Wainuiomata	1890–2011	15	0	0.62	NS
Kapiti Coast	Otaki	1893–2011	18	0.02	0.06	NS
	Paraparaumu	1951–2011	20	0.02	0.46	NS

[1] Rainfall years, eg, for Otaki this is 1 July 1893–30 June 2011.

[2] Data not suitable for analysis.

Appendix 4: Low flow trend analysis – sites and results

Table A4.1: Greater Wellington (GWRC) and NIWA sites used in the trend analysis

Area represented	Site name	Operating authority	Catchment	Start of record[1]	Mean annual 7-day low flow (L/s)
Wairarapa – central valley	Ruamahanga R at Mt Bruce	GWRC	Ruamahanga	1974	1,285
Wairarapa – central valley	Ruamahanga R at Waihenga	GWRC	Ruamahanga	1976	10,355
Wairarapa – central valley	Waingawa R at Kaituna	GWRC	Ruamahanga	1976	1,410
Wairarapa – central valley	Waiohine R at Gorge	GWRC	Ruamahanga	1979	3,535
Wairarapa – central valley	Tauherenikau R at Gorge	GWRC	Ruamahanga / L. Wairarapa	1976	1,305
Wairarapa – eastern hills	Pahaoa R at Hinakura	NIWA	Pahaoa	1986	110
Central – Hutt Valley	Hutt R at Kaitoke	NIWA	Hutt	1968	1,420
Central – Hutt Valley	Hutt R at Birchville	NIWA	Hutt	1970	2,650
Central – Wainuiomata Valley	Wainuiomata R at Manuka Track	GWRC	Wainuiomata	1983	180
Kapiti Coast	Otaki R at Pukehinau	NIWA	Otaki	1980	5,250
Kapiti Coast	Waikanae R at WTP	GWRC	Waikanae	1975	1,045

[1] Start of reliable low flow records – may be different to the date the site was originally installed.

Table A4.2: Results of Mann-Kendall trend analyses for annual 7-day low flows, for last 30 years (1981-2011). Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Results that are significant, or approaching significant ($p<0.1$) are bolded.

Sub-region	Site	Period of analysis*	Median for period (L/s)	Median annual change (L/s)	*p*	Significance
Wairarapa	Ruamahanga R at Mt Bruce	1981–2011	1,281	-7.6	0.31	NS
	Ruamahanga R at Waihenga	1981–2011	8,868	-56.0	0.24	NS
	Waingawa R at Kaituna	1981–2011	1,352	-5.7	0.65	NS
	Waiohine R at Gorge	1981–2011	3,257	-2.3	0.91	NS
	Tauherenikau R at Gorge	1981–2011	1,229	4.6	0.38	NS
	Pahaoa R at Hinakura	1986–2011	55	1.7	0.17	NS
Central	**Hutt R at Kaitoke**	**1981–2011**	**1,429**	**-13.1**	**0.02**	**S (decreasing)**
	Hutt R at Birchville	1981–2011	2,572	14.6	0.37	NS
	Wainuiomata at Manuka Track	1983–2011	158	-0.5	0.51	NS
Kapiti Coast	Otaki R at Pukehinau	1981–2011	5,161	-22.8	0.27	NS
	Waikanae R at WTP	1981–2011	915	-0.6	0.87	NS

*Low flow years, ie, 1981 denotes the year starting 1 September 1981.

Table A4.3: Results of Mann-Kendall trend analyses for annual 7-day low flows (entire record of low flows). Trend description: HS=Highly significant (*p* ≤ 0.01), S=Significant (*p* ≤ 0.05), NS=Not significant (*p*>0.05). Results that are significant, or approaching significant (*p*<0.1) are bolded.

Sub-region	Site	Period of analysis*	Median for period (L/s)	Median annual change (L/s)	*p*	Significance
Wairarapa	Ruamahanga R at Mt Bruce	1974–2011	1,281	-2.7	0.69	NS
	Ruamahanga R at Waihenga	1976–2011	9,036	-69.9	0.11	NS
	Waingawa River at Kaituna	1976–2011	1,360	-3.8	0.62	NS
	Waiohine R at Gorge	1979–2011	3,292	-10.4	0.39	NS
	Tauherenikau R at Gorge	1976–2011	1,248	2.6	0.77	NS
Central	Hutt R at Kaitoke	1968–2011	1,378	-1.8	0.79	NS
	Hutt R at Birchville	1970–2011	2,251	18.2	0.11	NS
Kapiti Coast	Otaki R at Pukehinau	1980–2011	5,229	-25.5	0.21	NS
	Waikanae R at WTP	1975–2011	943	-7.3	0.19	NS

*Low flow years, i.e,1980 denotes the year starting 1 September 1980.

Table A4.4: Results of Mann-Kendall trend analyses for annual number of days with flow <Q90, last 30 years only. Trend description: HS=Highly significant (*p* ≤ 0.01), S=Significant (*p* ≤ 0.05), NS=Not significant (*p*>0.05). Results that are significant, or approaching significant (*p*<0.1) are bolded.

Sub-region	Site	Period of analysis*	Median for period (no of days per year)	Median annual change (no of days/year)	*p*	Significance
Wairarapa	Ruamahanga R at Mt Bruce	1981–2011	36	0.62	0.23	NS
	Ruamahanga R at Waihenga	1981–2011	32	0.54	0.36	NS
	Waingawa R at Kaituna	1981–2011	33	0.9	0.13	NS
	Waiohine R at Gorge	1981–2011	32.5	0.6	0.24	NS
	Tauherenikau R at Gorge	1981–2011	37.5	0.04	0.91	NS
	Pahaoa R at Hinakura	1986–2011	28	-0.34	0.61	NS
Central	**Hutt R at Kaitoke**	**1981–2011**	**24.5**	**1.0**	**0.03**	**S (increasing)**
	Hutt R at Birchville	1981–2011	25	0.29	0.71	NS
Kapiti Coast	Otaki R at Pukehinau	1981–2011	31.5	0.59	0.24	NS
	Waikanae R at WTP	1981–2011	31	0.26	0.60	NS

*Low flow years, ie, 1981 denotes the year starting 1 September 1981.

Table A4.5: Results of Mann-Kendall trend analyses for annual number of days with flow <Q90. Trend description: HS=Highly Significant (*p*≤ 0.01), S=Significant (*p*≤ 0.05), NS=Not significant (*p*>0.05). Results that are significant, or approaching significant (*p*<0.1) are bolded.

Sub-region	Site	Period of analysis*	Median for period (no. of days/year)	Median annual change (no. of days/year)	*p*	Significance
Wairarapa	Ruamahanga R at Mt Bruce	1974–2011	35	0.54	0.26	p>0.1 (NS)
	Ruamahanga R at Waihenga	1976–2011	32	0.4	0.41	p>0.1 (NS)
	Waingawa R at Kaituna	1976–2011	34	0.5	0.34	p>0.1 (NS)
	Waiohine R at Gorge	1979–2011	32.5	0.72	0.12	p>0.1 (NS)
	Tauherenikau R at Gorge	1976–2011	36	0.1	0.79	p>0.1 (NS)
Central	Hutt R at Kaitoke	1968–2011	29	0	0.85	p>0.1 (NS)
	Hutt R at Birchville	1970–2011	30	-0.08	0.90	p>0.1 (NS)
Kapiti Coast	Otaki R at Pukehinau	1980–2011	32	0.57	0.28	p>0.1 (NS)
	Waikanae R at WTP	1975–2011	30	0.5	0.17	p>0.1 (NS)

*Low flow years, ie, 1980 denotes the year starting 1 September 1980.

Appendix 5: Groundwater level trend analysis – sites and results

Table A5.1: Summary of groundwater level trend information for representative wells in the Wellington region (1 July 1994–30 June 2011). Trend description: HS=Highly significant ($p \leq 0.01$), S=Significant ($p \leq 0.05$), NS=Not significant ($p>0.05$). Bolded rows indicate where declining trends in median were statistically significant and annual rate of storage depletion >5% safe yield (ie, environmentally significant).

Well	Sub-region	Management zone	Aquifer type	Well depth	Groundwater level trend (mm/yr)			*p*-value			Trend description			Trend persistence	Recovery	Annual rate of change in storage as % of safe yield[#]
					Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum			
S27/0428	Wairarapa Valley	Lake Basin	Flowing Artesian	43.56	-24.6	-43	-23	0.15	0.02	0.02	NS	S	S	Monotonic	No Recovery	-29.2
S27/0434	**Wairarapa Valley**	**Lake Basin**	**Flowing Artesian**	**45.2**	**-57**	**-65**	**-47**	**<0.01**	**<0.01**	**<0.01**	**HS**	**HS**	**HS**	**Monotonic**	**No Recovery**	**-67.6**
T26/0326	Wairarapa Valley	Fernhill	Semi-Confined	10	-18	-17	-14.8	0.32	0.35	0.4	NS	NS	NS	Piecewise	Partial Recovery	-2.9
S26/0545	Wairarapa Valley	Greytown	Semi-Confined	18	-26	-19	-22	<0.01	<0.01	<0.01	HS	HS	HS	Piecewise	No Recovery	-0.5
S26/0490	Wairarapa Valley	Greytown	Water Table	5	-25	-20	-18	<0.01	0.03	0.5	HS	NS	NS	Piecewise	Full Recovery	-0.5
S27/0571	Wairarapa Valley	Martinborough	Semi-Confined	32	19.41	-52	76	0.51	0.16	0.14	NS	S	NS	Piecewise	Full Recovery	4.8
S27/0248	Wairarapa Valley	Mid Ruamahanga	Non-Flowing Artesian	7.9	-15.6	-18.74	-13.9	0.17	0.34	0.16	NS	NS	NS	Monotonic	Partial Recovery	-5.7
R28/0002	Wairarapa Valley	Onoke/Narrows	Non-Flowing Artesian	17	4.4	-5	12.58	0.48	0.62	0.05	NS	NS	S	Piecewise	No Recovery	
S27/0576	Wairarapa Valley	Onoke/Narrows	Flowing Artesian	55.53	-33	-81.6	-1.9	0.22	0.15	0.9	NS	NS	NS	Piecewise	Full Recovery	-15.4
S27/0594	Wairarapa Valley	Onoke/Narrows	Flowing Artesian	44	3.58	-61	11.73	0.7	0.09	0.073	NS	NS	NS	Monotonic	Full Recovery	1.7
S26/0568	**Wairarapa Valley**	**Parkvale**	**Flowing Artesian**	**45**	**-139**	**-84**	**-134**	**<0.01**	**0.07**	**<0.01**	**HS**	**NS**	**HS**	**Monotonic**	**No Recovery**	**-31.5**
S26/0743	**Wairarapa Valley**	**Parkvale**	**Non-Flowing Artesian**	**33**	**-138**	**-154**	**-120**	**<0.01**	**<0.01**	**<0.01**	**HS**	**HS**	**HS**	**Monotonic**	**No Recovery**	**-31.3**
S26/0738	Wairarapa Valley	Parkvale	Water Table	5.4	-30	-17	-31	0.1	0.24	0.03	NS	NS	S	Monotonic	No Recovery	-6.4
S26/0675	**Wairarapa Valley**	**Parkvale-Carterton**	**Flowing Artesian**	**31.5**	**-95**	**-136**	**-70**	**0.02**	**0.13**	**0.09**	**S**	**NS**	**NS**	**Monotonic**	**No Recovery**	**-7.3**
S27/0381	Wairarapa Valley	Ruamahanga Valley	Non-Flowing Artesian	20.95	-1.56	-2	2.36	0.85	0.82	0.84	NS	NS	NS	Piecewise	Full Recovery	-0.3
S27/0542	Wairarapa Valley	Ruamahanga Valley	Semi-Confined	19	-50	-57	-19	<0.01	<0.01	0.14	HS	HS	NS	Monotonic	Partial Recovery	-2.9
S27/0346	Wairarapa Valley	Ruamahanga Valley	Semi-Confined	9.5	-13	-35	-2.6	0.21	0.04	0.83	NS	S	NS	Monotonic	Partial Recovery	-2.6
S27/0012	**Wairarapa Valley**	**Tauherenikau Fan**	**Non-Flowing Artesian**	**66.5**	**-154**	**-120**	**-70**	**<0.01**	**0.03**	**0.027**	**HS**	**S**	**S**	**Monotonic**	**No Recovery**	**-23.4**
S27/0099	Wairarapa Valley	Tauherenikau Fan	Non-Flowing Artesian	16.76	-27	-26	-4	0.31	0.02	0.9	NS	S	NS	Monotonic	Partial Recovery	-4.1
S27/0148	Wairarapa Valley	Tauherenikau Fan	Water Table	8.77	-38.5	-26	-27	0.16	0.46	0.54	NS	NS	NS	-	Full Recovery	-5.9
S27/0202	Wairarapa Valley	Tauherenikau Fan	Water Table	4.8	-20.72	-23.5	-13.5	<0.01	<0.01	<0.01	HS	HS	HS	Monotonic	No Recovery	-3.1
T26/0243	**Wairarapa Valley**	**Te Ore Ore**	**Non-Flowing Artesian**	**47.5**	**-76**	**-87**	**-26**	**<0.01**	**<0.01**	**0.42**	**HS**	**HS**	**NS**	**Monotonic**	**Partial Recovery**	**-13.7**
T26/0501	Wairarapa Valley	Te Ore Ore	Water Table	5.1	-23.5	-24	-17	0.03	<0.01	0.54	S	HS	NS	Monotonic	Partial Recovery	-2.8
S26/0236	Wairarapa Valley	Upper Waingawa	Non-Flowing Artesian	41.4	-118	-178	-118	<0.01	<0.01	<0.01	HS	HS	HS	Piecewise	No Recovery	-4.9
S26/0229	Wairarapa Valley	Upper Waingawa	Semi-Confined	23.8	-4.9	-15.8	18.94	0.89	0.55	0.146	NS	NS	NS	Monotonic	No Recovery	-0.2
S26/0242	Wairarapa Valley	Upper Waingawa	Water Table	7.5	-50.5	-82	9.5	0.14	0.07	0.6	NS	NS	NS	Piecewise	Full Recovery	-2.1
S26/0030	Wairarapa Valley	Waingawa Fan (N.	Semi-Confined	38	-20.65	-22.2	-4.1	0.1	0.028	0.82	NS	S	NS	Monotonic	Partial Recovery	
S26/0033	Wairarapa Valley	Waingawa Fan (N.	Water Table	12	-47.2	-47.2	-40	<0.01	<0.01	<0.01	HS	HS	HS	Monotonic	No Recovery	
T26/0429	Wairarapa Valley	Waingawa Fan (S.	Water Table	9.92	15	4.42	26.5	0.34	0.75	0.05	NS	NS	S	Monotonic	Full Recovery	
R27/1117	Hutt Valley	Lower Hutt (S)	Water Table	14.4	-1.54	-15	12.82	0.9	0.25	0.26	NS	NS	NS	Monotonic	No Recovery	0
R27/7004	Hutt Valley	Upper Hutt (D)	Non-Flowing Artesian	32.4	-11.8	-18	-2.5	0.06	<0.01	0.69	NS	HS	NS	Piecewise	No Recovery	-0.8
R25/0003	Kapiti Coast	Coastal GW Zone	Non-Flowing Artesian	60.5	-2.2	-6	1.5	0.52	0.22	0.67	NS	NS	S	Piecewise	No Recovery	-0.7
S25/5208	**Kapiti Coast**	**Hautere (D)**	**Non-Flowing Artesian**	**192.02**	**-64**	**-79**	**-28**	**<0.01**	**<0.01**	**0.08**	**HS**	**HS**	**NS**	**Monotonic**	**No Recovery**	**-13.6**
R25/5123	Kapiti Coast	Hautere (S)	Water Table	13	14.5	20	19	0.23	0.57	0.32	NS	NS	NS	Monotonic	Full Recovery	2.3
R25/5228	Kapiti Coast	Otaki	Semi-Confined	31.71	-9	-7	-8	0.06	0.1	0.25	NS	NS	NS	Monotonic	Partial Recovery	-1.1
S25/5228	Kapiti Coast	Otaki (S)	Water Table	0	-4	1.9	-1	0.67	0.82	0.9	NS	NS	NS	Piecewise	Full Recovery	-0.5
S25/5258	Kapiti Coast	Otaki (S)	Water Table	6	-3.8	-0.6	6.9	0.91	0.59	0.39	NS	NS	NS	Piecewise	Full Recovery	-0.3
R26/6503	Kapiti Coast	Paekakariki (D)	Water Table	14.8	0.5	-11	-0.93	0.94	0.21	0.85	NS	NS	NS	Piecewise	Partial Recovery	0.1
R26/6520	Kapiti Coast	Paekakariki (S)	Water Table	6	-19	-22	-3.7	0.15	0.2	0.73	NS	NS	NS	Piecewise	Partial Recovery	-2.8
R26/6594	Kapiti Coast	Waikanae (D)	Non-Flowing Artesian	74	-7.6	-24	-2.7	0.09	0.18	0.45	NS	NS	NS	Piecewise	Partial Recovery	-2.6
R26/6626	**Kapiti Coast**	**Waikanae (S)**	**Semi-Confined**	**15.8**	**-12**	**-14**	**-8.8**	**0.03**	**0.12**	**0.1**	**S**	**NS**	**NS**	**Piecewise**	**Partial Recovery**	**-5.8**
R26/6916	Kapiti Coast	Waikanae (S)	Semi-Confined	21	-4.8	-9.5	-1.9	0.18	<0.01	0.56	NS	HS	NS	Piecewise	Partial Recovery	-0.7
S25/5329	Kapiti Coast	Waitohu (D)	Semi-Confined	25.3	3.4	5.42	3.1	0.34	0.18	0.5	NS	NS	NS	Monotonic	Full Recovery	0.6
S25/5332	Kapiti Coast	Waitohu (S)	Water Table	9.09	22	25	26	0.12	0.57	0.07	NS	NS	NS	Piecewise	Full Recovery	2.3

Adopting an assumed storage coefficient (sy) of 0.2 – see Mzila (2012) for further details

Table A5.2: Rainfall trend results for sites selected as representative of main groundwater recharge areas in the Wellington region (1 July 1994–30 June 2011). Trend description: HS=Highly significant (*p*≤ 0.01), S=Significant (*p*≤ 0.05), NS=Not significant (*p*>0.05)

Groundwater zone	Rainfall site	Sen's slope (mm/yr)			Trend description (based on p-value)		
		Median[1]	Max[2]	Min[3]	Median[1]	Max[2]	Min[3]
Wairarapa – Upper Valley	Te Ore Ore rainfall station	1.44	0.47	6.52	NS	NS	NS
Wairarapa – Middle Valley	Bannockburn rainfall station	-1.34	-0.37	-0.32	NS	NS	NS
Wairarapa – Lower Valley	Kahutara rainfall station	-5.07	-1.14	-1.64	NS	NS	NS
Hutt Valley	Mangaroa rainfall station	0.20	-1.71	5.22	NS	NS	NS
Kapiti Coast	Te Horo Longcroft	-2.19	-1.28	2.18	NS	NS	NS
	Otaki at depot	-1.13	-0.88	1.00	NS	NS	NS
	Waikanae rainfall station	-3.03	-4.04	4.82	NS	NS	NS

[1] Annual median rainfall (based on monthly means)

[2] Annual 3-month moving average maximum rainfall

[3] Annual 3-month moving average maximum rainfall

Table A5.3: Growth in groundwater abstraction during the period 1992–2006 for identified 'very high' and 'high' risk aquifers in the region

Sub-region	Management zone[1]	Aquifer type	Growth in groundwater abstraction[2] (Mm^3/yr)	Safe yield[3] (Mm^3/yr)	Growth in groundwater abstraction as a % of safe yield
Wairarapa Valley	Waingawa	Artesian confined	0.028	17.0	0.16
	Te Ore Ore	Both the artesian and water table aquifers	0.071	1.3	5.46
	Parkvale	Artesian confined	0.060	2.6	2.29
	Waiohine (Greytown[4])	Semi-confined	0.100	20.0	0.50
	Tauherenikau	Both the artesian and water table aquifers	0.170	20.0	0.85
	Lake Basin	Artesian confined	0.035	3.7	0.94
Kapiti Coast	Hautere	Artesian confined	0.004	2.0	0.20
	Waikanae	Semi-confined	0.008	5.3	0.15

[1] Unless otherwise stated, zones for the Wairarapa are from the new proposed conjunctive management framework (Hughes and Gyopari 2011) and are the existing RFP zones for the Kapiti Coast.

[2] Derived from abstraction modelling data presented in Hughes and McAlister (2011a, b, c). Modelled abstraction was based on several seasons of actual groundwater use survey data collected by Greater Wellington.

[3] As set out in the RFP (1999) and listed in Tables 3.9 and 3.10 in this report.

[4] Growth in allocation numbers provided in this table relate to the existing 'Greytown' groundwater management zone rather than the new proposed 'Waiohine' management zone (that incorporates the existing Greytown zone) to reflect conditions closest to the analysed bore.

Table A5.4: Summary interpretation of groundwater trend findings for the 'very high' and 'high' risk aquifers in the region

Sub-region	Aquifer system	Summary
Wairarapa Valley	Waingawa	The Waingawa artesian aquifer is categorised as high risk mainly because of highly statistically significant declines in median groundwater levels during the period 1994/05–2010/11. Winter recovery and summer drawdown trends also declined significantly. However, declines did not represent high levels of storage depletion relative to safe yield (<5%), and are not considered to be driven by abstraction as this only increased at a rate equating to an estimated <1% of safe yield during the period 1992–2006. Further analysis of rainfall influence is needed and if observed trends are confirmed to be primarily climate-driven then it may be appropriate to re-classify this aquifer to a lower risk level.
	Te Ore Ore	Both the artesian and water table aquifers in this zone had significant and monotonic declining trends in median groundwater level (1994/95–2010/11). Summer drawdown minima in both aquifers also declined significantly although winter recovery was reasonable (non-significant trends). The estimated rate of storage depletion in the artesian aquifer equated to around 14% of annual safe yield and is considered environmentally significant. Groundwater take from the artesian aquifer increased at a rate of 0.071 million m^3 per year during the period 1992–2006, a volume equivalent to 5.5% of annual aquifer safe yield for the artesian well. The results indicate that the rate of increase in water use is likely to have had a significant effect on the artesian aquifer water balance.
	Parkvale	Two wells in the Parkvale artesian aquifer system gave similar results; both showed significant and monotonic declining trends in median groundwater level (1994/95–2010/11) and trends of non-recovery. The rate of storage depletion equated to an estimated 31% of annual safe yield. Groundwater take from the artesian aquifer increased at a rate of 0.06 million m^3 per year during the period 1992–2006, a volume equivalent to 2.3% of annual safe yield for this aquifer. This aquifer has previously been identified as having a potential issue with long term sustainability (eg, Hughes and Gyopari, 2010b) and there is an existing moratorium on further groundwater abstractions from this aquifer. Results from this study indicate the risk of non-recovery in groundwater levels and aquifer storage is high in this aquifer system and support the continuation of the moratorium.
	Greytown	The Greytown zone semi-confined aquifer had significant or highly significant declines in median, summer and winter groundwater levels. Although the declines did not represent significant storage depletion (<5% of annual safe yield) they are potentially indicative of a long term undesirable trend – particularly the observed lack of winter recovery. Groundwater take from the artesian aquifer increased at a rate of 0.1 million m^3 per year during the period 1992–2006, a volume equivalent to 0.5% of annual safe yield for this aquifer.
	Tauherenikau	Three of four wells analysed in the Tauaherenikau zone showed significant and monotonic declines in at least one fo the three indicators of groundwater level. In particular one well in each of the water table and one deep artesian aquifers of the Tauherenikau zone showed highly significant declines in median groundwater levels and limited recovery. While the water table aquifer did not show an environmentally significant decline in aquifer storage (<5% of annual safe yield) the artesian aquifer had a decline in storage equating to 23% of aquifer annual safe yield; this is considered environmentally significant. Rainfall recharge declined for this zone during the period of analysis (although the trend was non-statistically significant). Groundwater take from the artesian aquifer increased at a rate of 0.17 million m^3 per year during the period 1992–2006, a volume equivalent to about 1% of annual safe yield for this aquifer. Furthermore, the overall

Sub-region	Aquifer system	Summary
		increase in groundwater allocation in the Tauherenikau zone during the period 1990–2010 was the highest in any part of the Wairarapa Valley (see Figure 3.10). The Tauherenikau zone has been identified (Gyopari & McAlister 2010c) as the recharge zone for the confined aquifers of the middle and lower valley in the Wairarapa. Therefore, trends in the water balance of the Tauherenikau artesian aquifer will affect artesian aquifers in adjoining zones and vice versa. Further analysis of impacts of continued groundwater level declines (especially in the water table wells) on connected rivers and springs should be undertaken to establish drawdown management criteria
	Lake Basin	Both wells in the Lake Basin zone artesian aquifer showed significant and monotonic declines in at least two of the three indicators of groundwater level and had limited recovery. One well had a highly statistically significant decline in median groundwater level that equated to an annual rate of decline in aquifer storage of almost 70% of safe yield. Groundwater use for this aquifer increased by 0.035 million m^3 per year during the period 1992–2006, an annual volume equivalent to about 1% of aquifer safe yield. Overall, a conservative approach is to characterise this aquifer as high risk, particularly in recognition of the likelihood that any continued decline in groundwater levels in this zone will rapidly propagate to other connected confined aquifer zones.
Kapiti Coast	Hautere	A well in the artesian aquifer of the Hautere zone showed a highly significant decline in median groundwater levels representing a decline in aquifer storage equating to around 14% of annual aquifer safe yield. Rainfall recharge for this zone declined slightly during the period of analysis but not at a rate that was either statistically significant or that could explain the groundwater storage depletion. Allocation growth in the Hautere zone between 1994 and 2010 was fairly modest compared with other groundwater zones but is still considered likely to be a contributing to the observed declines in groundwater level and storage. Aquifer responses on the Kapiti Coast are generally not as well understood as in the Wairarapa Valley and further numerical modelling is required. In the meantime, the Hautere deep aquifer merits close attention to monitoring data and a high risk classification.
	Waikanae	The Waikanae semi-confined aquifer showed statistically significant declines in median groundwater levels that were indicative of environmentally significant depletion of storage (>5% of annual safe yield). The increase in groundwater use from the Waikanae groundwater management zone during the period 1992–2006 was relatively large (equating to 17% of aquifer safe yield) and is likely to have had a significant effect on the semi-confined aquifer water balance. However, another well in the same semi-confined aquifer showed environmentally non-significant declines in aquifer storage with a relative change in storage of less than 1% of aquifer safe yield. This highlights the difficulty in separating localised drawdown from aquifer-scale effects in monitoring well data, and the need for high risk aquifers to have multiple monitoring sites.

Water, air, earth and energy – elements in Greater Wellington's logo that combine to create and sustain life. Greater Wellington promotes **Quality for Life** by ensuring our environment is protected while meeting the economic, cultural and social needs of the community

For more information, contact Greater Wellington:

Wellington office
PO Box 11646
Manners Street
Wellington 6142
T 04 384 5708
F 04 385 6960

Masterton office
PO Box 41
Masterton 5840
T 06 378 2484
F 06 378 2146

www.gw.govt.nz

May 2012
GW/EMI-T-12/141

Please recycle
Produced sustainably