Climate Change adaptation options for Greater Wellington Regional Council's wholesale water supply

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Abstract

Greater Wellington Regional Council currently supplies water to 380 000 consumers. This number is expected to rise to about 480 000 by the year 2050. Water is currently drawn from three rivers in the region and the Lower Hutt aquifer. Only a small amount of off-river storage is available, so the system is heavily reliant upon frequent and adequate rainfall. Under projected climate change scenarios, rainfall is likely to become less frequent and falls will be of higher intensity. In addition, projected increases in temperature will cause the per capita demand to rise, and a rise in sea level will increase the potential for saline intrusion into the aquifer.

For long term planning purposes the water supply system is modelled using the Sustainable Yield Model (SYM) based on the Wathnet network linear programming software. Inputs to the system consist of daily river flows, and rainfalls on the aquifer recharge zone. Outputs from the system are the daily demands of the four cities of the Greater Wellington region and evaporative demands on the aquifer recharge zone. Operation of the system is constrained primarily by environmental considerations: the aquifer must not be over-pumped to avoid salt water intrusion, and all the river sources have both minimum flow and sharing rules applied to abstractions

Examination of the likely effects of climate change began with downscaling to the Wellington Region the results of the IPCC third climate change scenario data. Both rainfall and temperature changes were considered for low, mid and high scenarios. The modified rainfall and temperature data were used as input to rainfall-to-runoff models for each of the three river systems. The resultant flows were then used as input to the planning model. Temperature and rainfall data were also used in a regression style model of per capita demand to estimate the likely impacts on demand. The revised river flows and demands were fed into the SYM for each climate change scenario and the likely population that could be supplied under a number of different scenarios has been investigated. By examining different demand management scenarios, options for what might be sustainable under different supply restrictions can be investigated. Although demand management is unlikely to be a politically palatable option, it may be a more economically acceptable one.

1. Introduction

Greater Wellington Regional Council (GWRC) operates a water supply system that is heavily reliant on run of the river supplies. The system is very dynamic in its

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response to changes in the weather. Hence to get the best out of the system requires up-to-date information on system components, and modelling tools able to estimate what will happen under various scenarios, so that choice of the most robust options can be taken.

To assess the reliability of their wholesale water supply, GWRC uses a network linear programming model. The model, called the Sustainable Yield Model (SYM), is also used as a planning tool to determine the benefits of future supply options and distribution upgrades. In all cases, the target reliability is an Annual Shortfall Probability (ASP) of 2 percent, or a 50-year shortfall return period.

The SYM input data have recently been modified to provide an assessment of the potential effects of climate change on GWRC's wholesale water supply. The modifications include changes in river flows, per capita demand, and sea level rises expected during the period 2021 to 2050.

Under current population projections, a regional urban population of 480 000 is expected to be reached around 2050. Recent strategic planning studies have shown that such a population could be supplied if both the proposed Upper Hutt aquifer source and the Whakatikei storage dam were in place (Williams, 2008).

The objective of the work reported in this paper is to assess the likely impact of climate change on the reliability of the wholesale water supply, including the Upper Hutt aquifer and the Whakatikei dam. The results will be fed back into the planning process to aid decision-making on the most appropriate adaptation measures that need to be made to allow for the effects of climate change.

2. The Greater Wellington water supply system

Figure 1 shows the main features of the Wellington water supply system. Surface water is taken from the Hutt, Wainuiomata, and Orongorongo catchments. Abstractions from the Wainuiomata and Orongorongo catchments are minority supplies that are treated and feed directly into the distribution system. Abstractions from the Hutt catchment are a major source for the region and can be either treated and fed into the distribution system or stored in the Te Marua lakes. The lakes are constructed reservoirs with a storage capacity of approximately 3000 ML (ML=mega-litre or 1000 m^3). The other major feature is the Lower Hutt aquifer. Water is pumped directly from the aquifer, through a treatment plant and into the supply. The Upper Hutt aquifer is included in the model of the water supply system (Figure 2) for potential future use. Apart from the Te Marua lakes, remaining constructed storage is restricted to service reservoirs primarily concerned with evening out the day-to-day supply to the various communities that obtain their water from the system.

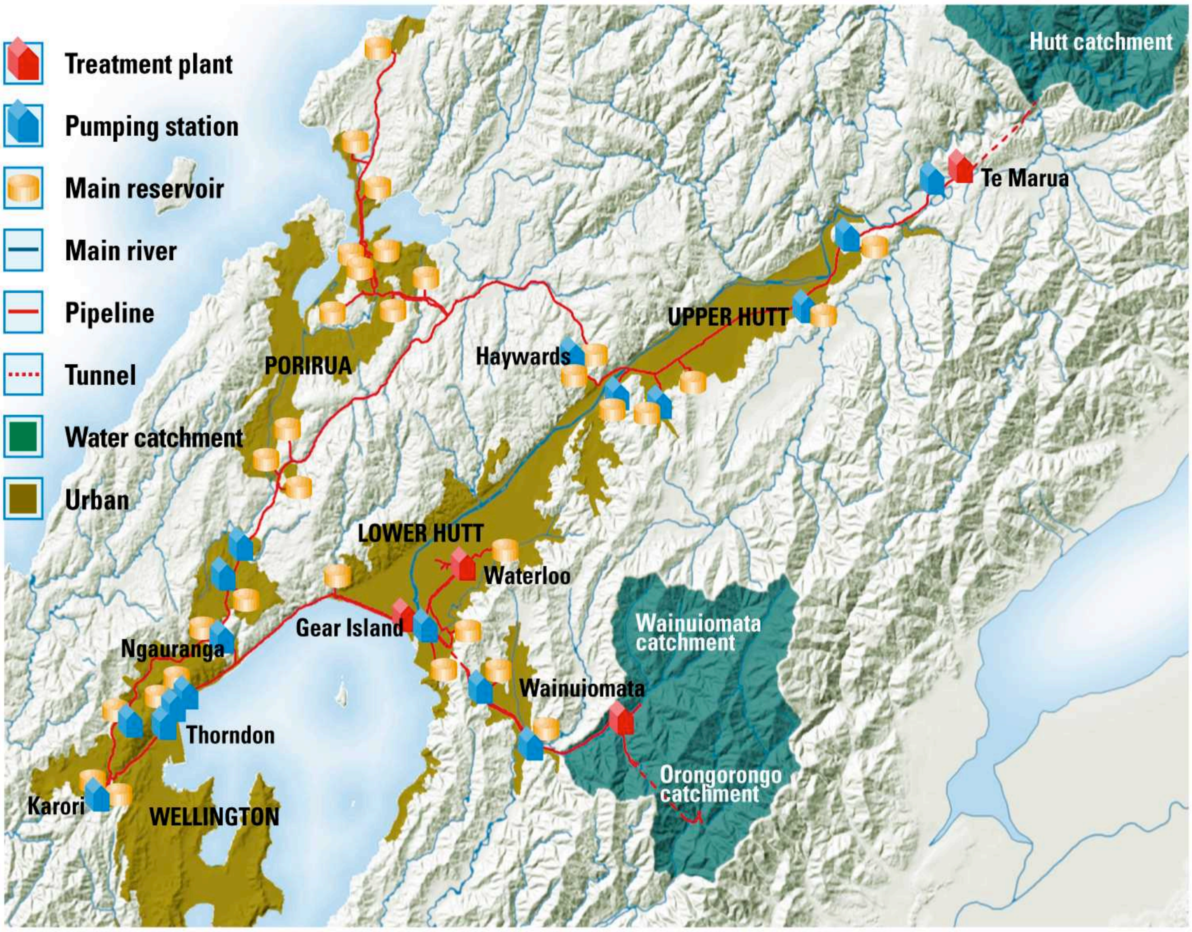

Figure 1 - The main features of the Wellington wholesale water supply system.

As part of the future development a number of options have been considered for augmenting the supply. The two most significant options are the development of the Upper Hutt aquifer, and a dam on the Whakatikei River, a tributary to the Hutt River. These schemes have the potential to increase the water resources available for supply by up to 6% and 16% respectively, of the current maximum.

As there is currently only a small amount of controllable off-river storage available, the system is heavily reliant upon frequent and adequate rainfall. It is thus a system that benefits from the climate of the region and so is potentially susceptible to small changes in the climatic regime. Climate change is therefore a major concern, and investigations aimed at mitigating the potential effects of climate change through adaptation measures have been taking place for several years.

What is not always apparent in systems such as Wellington's, is that not only is the supply climate dependent, but so is the demand. Unfortunately most of the likely effects of any climate change are likely to cumulatively increase demand – hotter temperatures and less frequent but more intense rainfalls will lead to increased demand for longer periods. It is against this background that GWRC have been using their planning model of the water supply system to study possible future demand and supply scenarios.

3. The Sustainable Yield Model

To help with planning, GWRC uses an objective-orientated network linear programming model based on the work of Kuczera (1992, 1993). Figure 2 shows a schematic of the model, called the Sustainable Yield Model (SYM). The SYM is made up of nodes connected together by arcs. Nodes represent network components such as reservoirs, pipe junctions and demand centres. The arcs represent flows in pipes and stream channels. One of the innovative aspects of the SYM is the use of a series of reservoir nodes and streamflow channels to simulate the behaviour of the aquifer system that is subject to pumped abstraction.

The SYM has been set up to simulate the operational and environmental controls that affect running of the actual supply network, e.g., minimum flows in rivers. Owing to the nature of New Zealand's environmental legislation many of the environmental rules are complex and the system is able to handle these satisfactorily.

The SYM uses daily demand, rainfall and river flow data to model water supply under specific operating procedures. The network can be altered easily to add new components, such as reservoirs, or to change the properties of existing components, such as pipe size. This allows assessment of the response of the water supply system to changes in infrastructure and/or changes in operating practices, such as changes in environmental constraints. The rainfall and river flow data can be altered to assess the sensitivity of the system to changes in climate, and the demand data can be altered to assess changes in water use under different climate scenarios, new stresses imposed by population growth, or the potential effects of demand restriction scenarios.

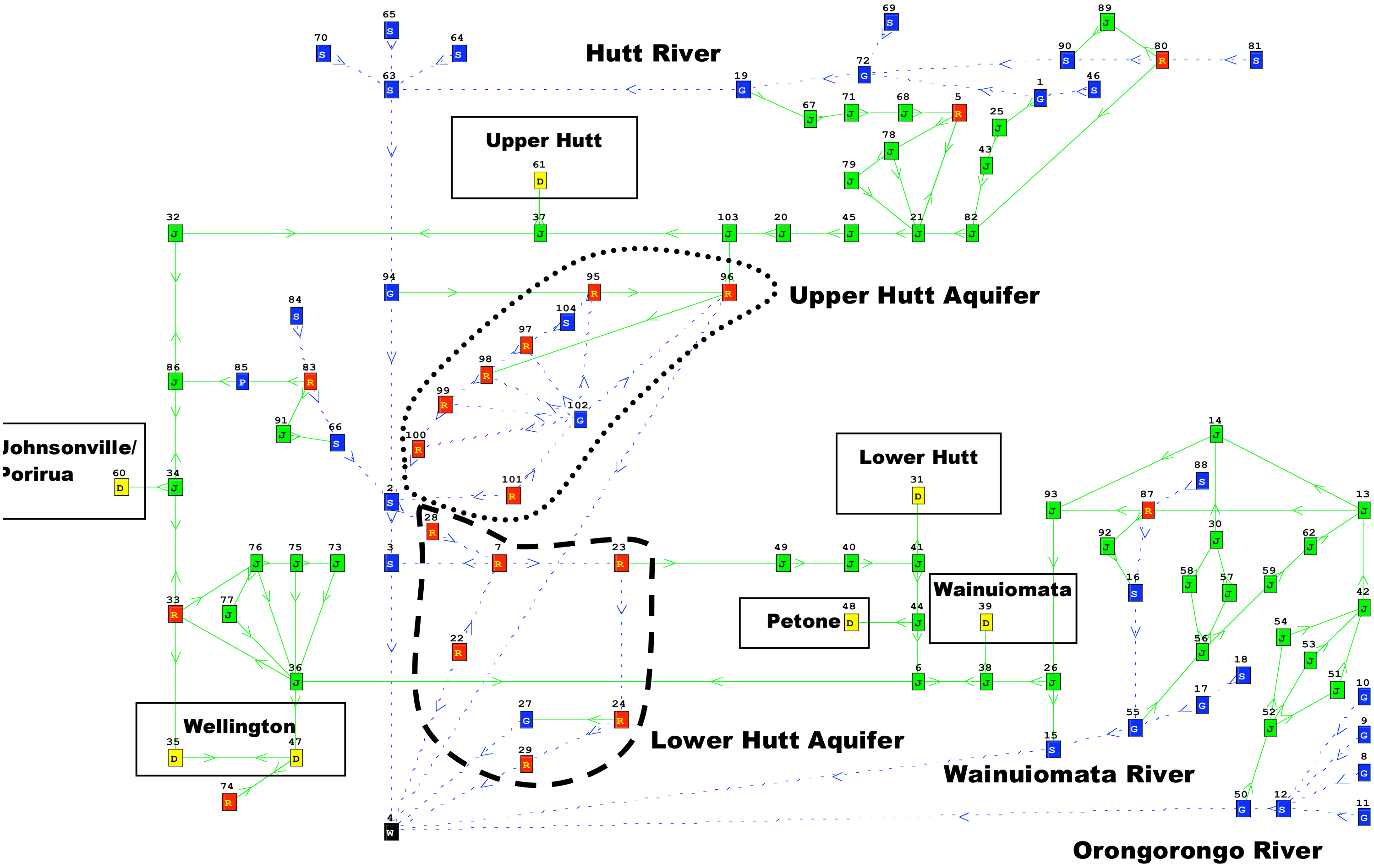

Figure 2 - The schematic layout of the network model called the SYM. The "D" nodes surrounded by rectangular boxes are the main demand centres in the region. The "J" nodes act as junctions between arcs. The "S" and "G" nodes are river confluences and abstraction points, while "R" nodes are reservoirs. Solid arcs are pipes while dotted arcs are open channels. The six reservoir nodes enclosed in the heavy dashed line represent the Lower Hutt aquifer while the nodes enclosed in the dotted line represent the Upper Hutt aquifer. The "W" node at the bottom of the schematic is where water goes that is not used to meet demand, e.g., to the sea.

4. Modification of the SYM input data

To investigate the possible consequences of climate change and the ability of the proposed new sources to meet the changes in demand and supply, GWRC commissioned NIWA to produce new input data likely to be representative of conditions in 2021-2050 (Ibbitt and Mullan, 2007). To produce scenario data for this period the historical temperature, rainfall and river flows needed to be modified. The modifications were constrained to be consistent with results from the Third Assessment released by the Intergovernmental Panel on Climate Change, (IPCC, 2001), in which they projected global temperature increases of between 1.4°C and 5.8°C by 2100.

The following steps were taken to modify the SYM's input data:

- Three representative climate change scenarios relevant to New Zealand were selected:
    - The Mid6 scenario, which averages the monthly rainfall and temperature increases from six global climate models. The changes were rescaled to represent the mid-point of the full IPCC range in global temperature increase. The Mid6 scenario is thought to be the "most likely" scenario.
    - The Lohad and Hihad scenarios, which are based on results from the United Kingdom Meteorological Office HadCM2 model. The scenarios give results for the 25th and 75th percentile of the full IPCC range in global temperature increase respectively. The Lohad and Hihad scenarios provide a means for assessing uncertainty without drawing criticism for being either overly conservative or alarmist.

- A "detrended" temperature series was produced by removing a linear trend of -0.005° C/y from the 44 years of measured temperature data. This correction, although small, was tested and found to be significant, Ibbitt and Mullan (2007). Its effect on the climate-changed temperature series was more than offset by the temperature adjustments made for the three different climate change scenarios. The "detrended" data provided a baseline for the current climate (taken as the period 1971 to 2000). No trend was detectable in the rainfall data over this period.

- Monthly rainfall and temperature changes were produced for Wellington by "downscaling" global climate model results using the methodology of Mullan et al. (2001). The changes were applied to the observed data in a way that altered the mean but not the interannual standard deviation of monthly totals.

- A distributional adjustment (Ministry for the Environment guidance manual on "Tools for estimating the effects of climate change on flood flow", in prep.) was made to the daily rainfall record for the Hihad and Mid6 scenarios. The adjustment resulted in an increase in rainfall amounts in the upper 10 percent of wettest days, and a corresponding decrease in the lower 90 percent. A distributional adjustment was not applied to the Lohad scenario because the changes were small compared with the other two scenarios.

- A revised set of daily river flows was produced for each scenario by feeding the adjusted climate data into the rainfall/run-off model developed by NIWA in 2006 (Ibbitt, 2006).

- Daily per capita demands for each scenario were produced by feeding the adjusted climate data into the demand model developed by NIWA in 2007 (Ibbitt, 2007).

- The rules governing abstraction from the Lower Hutt aquifer were adjusted to account for the expected rise in sea level by 2035 and thereby reduce the risk of future saline intrusion. The changes raised the artesian pressure at which abstraction is restricted by 0.07 m, 0.12 m and 0.16 m for the Lohad, Mid6 and Hihad scenarios respectively. Although these estimates are based on the IPCC Third Assessment as presented in Ministry for the Environment (2004), Figure A2.7, they were reviewed in the light of the IPCC Fourth Assessment, (IPCC, 2007). The main emphasis of this new report is on greater confidence in past and future changes being attributable to greenhouse gas increases. The projections of sea level rise are subtly different from the Third Assessment, but are essentially consistent with those earlier estimates.

5. Scenario assessment

The base run adopted for the climate change assessment was an option that included development of the proposed Upper Hutt aquifer and the proposed Whakatikei storage dam. Previous modelling has shown that these upgrades could support a regional urban population of 480 000. This scenario uses demand and hydrological data that is affected by climate change that occurred during the 20th Century. The base run is therefore best described as “not allowing for future climate change”.

The three climate change scenarios were assessed by determining the maximum population supported at 2 percent annual shortfall probability. Monte Carlo simulations using 10 000 two-year replicates of daily demand and hydrological data were used for the assessment. In each case, network optimisation was completed to ensure the rules governing bulk water transfers between different parts of the system were best matched to source availability.

6. Population and demand

The latest Statistics New Zealand population projections include three alternative series (low, medium and high) representing different assumptions for fertility, mortality and migration. GWRC has adopted the mean of the medium and high series for planning purposes, because it is seen as slightly conservative without being extreme.

Figure 3 shows the combined regional urban population (referred to as the “urban population”) of the four cities connected to the wholesale water supply. The graph shows the estimated population to 30 June 2007, Statistics New Zealand projections to 2031, and extrapolated projections beyond 2031. The extrapolated projections assume a continuation of the 2026-2031 growth rates. The Statistics New Zealand projections were reduced by 1 percent, to allow for the rural population in the Wellington region that is not connected to the wholesale water supply system.

The SYM uses seven demand areas to represent supply to the conurbations connected to the wholesale water supply system. An approach consistent with recent strategic planning was adopted for distributing future populations across the demand areas. The approach assumed all growth occurred in Wellington City. Wellington is at the end of the distribution system, so this approach was conservative in that any other growth combination would place less stress on the system. The same assumption was applied to all the scenarios modelled, and the relative differences from the baseline scenario were used to estimate the potential impact of climate change.

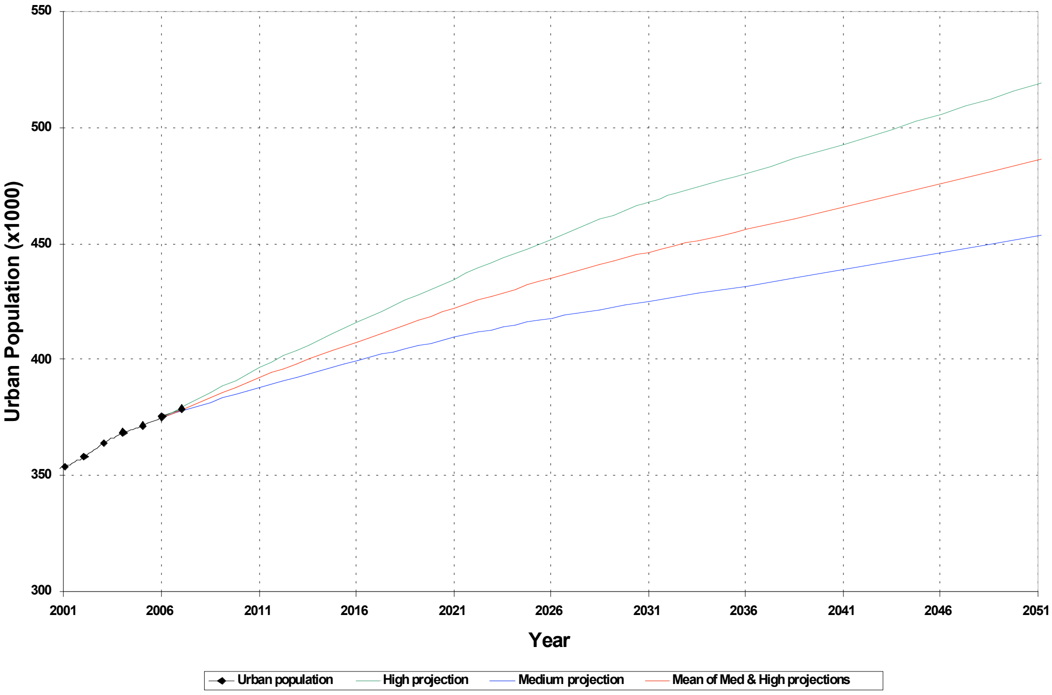

Figure 3 - Population projections. Note use of a false origin to highlight differences.

The demand on any one day is calculated by the SYM using the population on that day and the per capita demand (PCD) for that day. To estimate the effect of a change over time the standard practice is to hold the population value constant for the duration of the simulation run, but vary the PCD from day-to-day to take into account the effects of weather and time of year on demand. The average PCD for the climate change scenarios is a slight increase to 434, 435 and 435 L/p/d for Lohad, Mid6 and Hihad respectively. The increases represent changes of 1.6-1.9% above the base scenario of 427 L/p/d without adjustment for future climate change or demand management reduction.

Figure 4 shows average day demands versus urban population, grouped by city. The graph also shows the marginal effect of climate change on system demand.

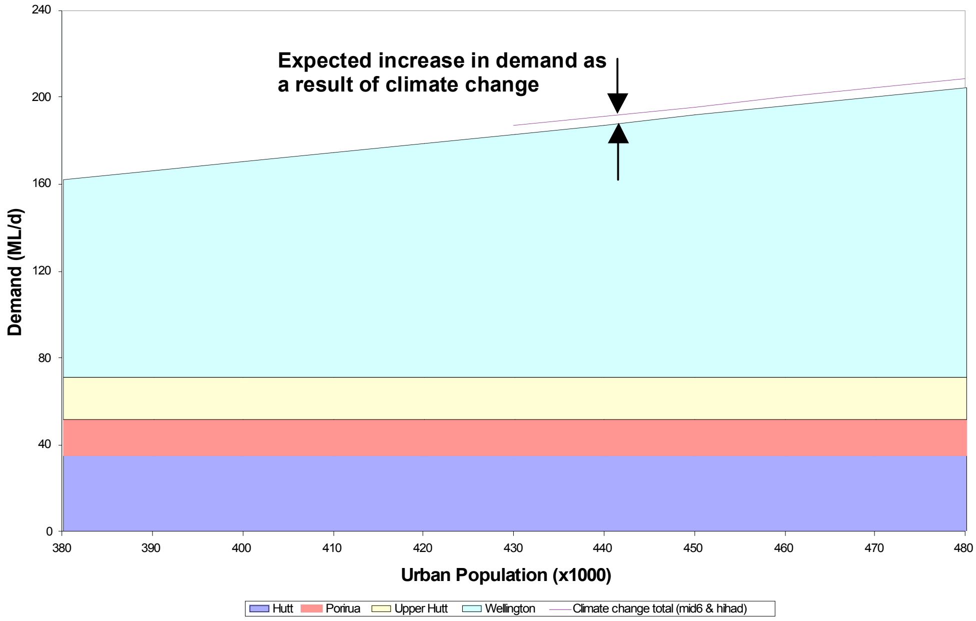

Figure 4 - Projected average day demands

The peak day per capita demand in all cases is capped at 650 L/p/d. Figure 5 shows the potential effect of climate change on the PCD frequency distribution, and shows the PCD distributions for the climate change scenarios marginally shifted to the right. This is consistent with the earlier comment on average per capita demands.

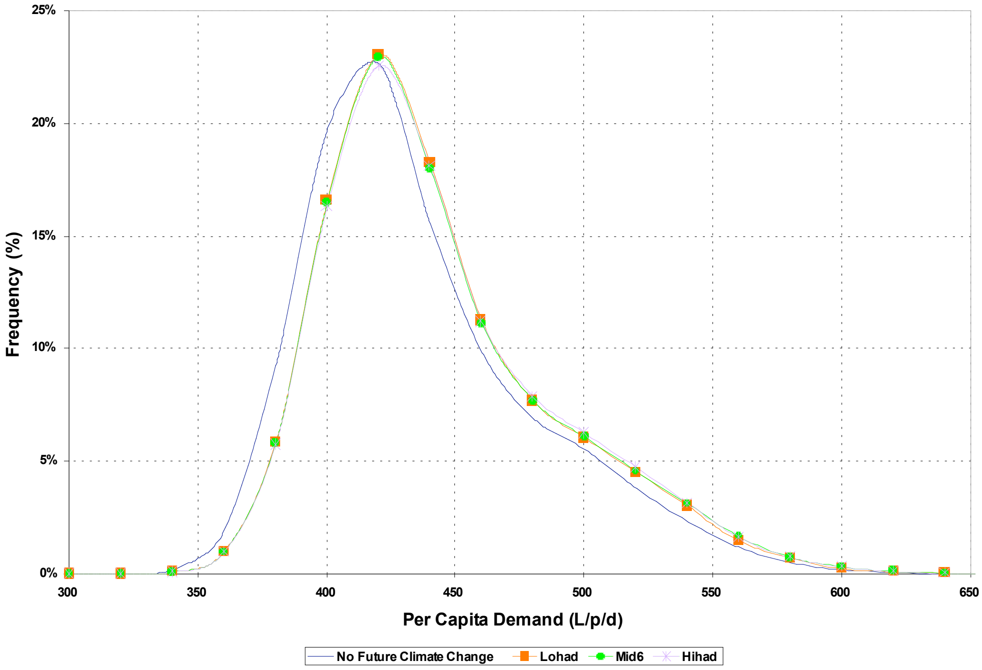

Figure 5 - Per capita demand frequency distribution

7. impact on source water availability

7.1. Hutt River at Kaitoke

Almost half the total yield for the wholesale water supply is sourced from the Hutt River at Kaitoke. Flows in the river at this point are therefore a useful indicator of the impact of climate change on the system, in particular the 7-day Mean Annual Low Flow (MALF).

The 7-day MALFs for the Hutt River at Kaitoke for the period 1890 to 2004 are 108 ML/d, 109 ML/d and 104 ML/d for the Lohad, Mid6 and Hihad scenarios, respectively, while if there were to be no future climate change the value would be 115 ML/d. The statistics are derived from the NIWA synthetic flow sequence used as input to the SYM, which are not actual flow records. By way of comparison, the current 7-day MALF based on the actual record commencing in 1967 is approximately 126 ML/d (Wilson, 2006). The lower value obtained using the SYM data is essentially due to the lower rainfalls that occurred in the early part of the 20th Century (Salinger et al. 1992).

The Lohad and Mid6 scenarios show a reduction in MALF of approximately 5%, while the Hihad scenario has a reduction of approximately 10%. The result for the Mid6 scenario appears somewhat inconsistent with the other two in that it does not fall in the middle. However, the difference is small and the assigned scenario names relate to relative changes in global temperature, not rainfall or river flows.

To further investigate the issue of reduced source availability, a flow volume analysis was completed for Kaitoke. The total flow volume was first split into two groups: summer, taken as December to April, because it is the time when demand is greatest and river and aquifer levels are generally falling; and winter, taken as May to November, and in which the converse conditions prevail. Figure 6 shows the results of this analysis.

Figure 6 shows there is a trend of slightly drier summers and slightly wetter winters across all climate change scenarios.

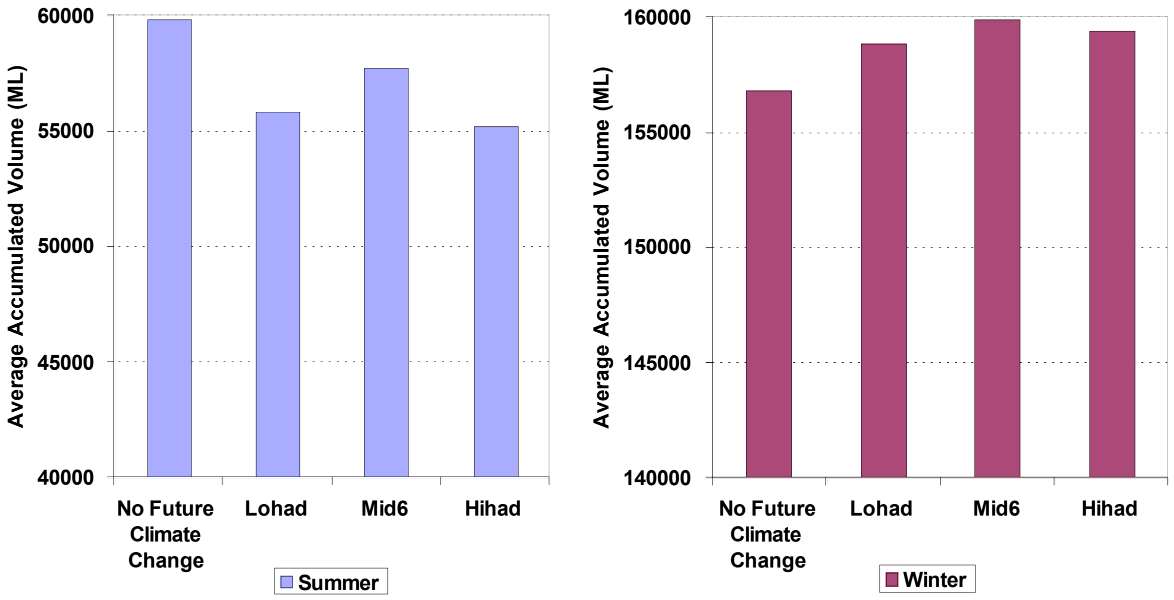

Figure 6 Hutt River at Kaitoke – annual average volume accumulated during summer and winter. Note use of a false origin to highlight differences, but the same data scales.

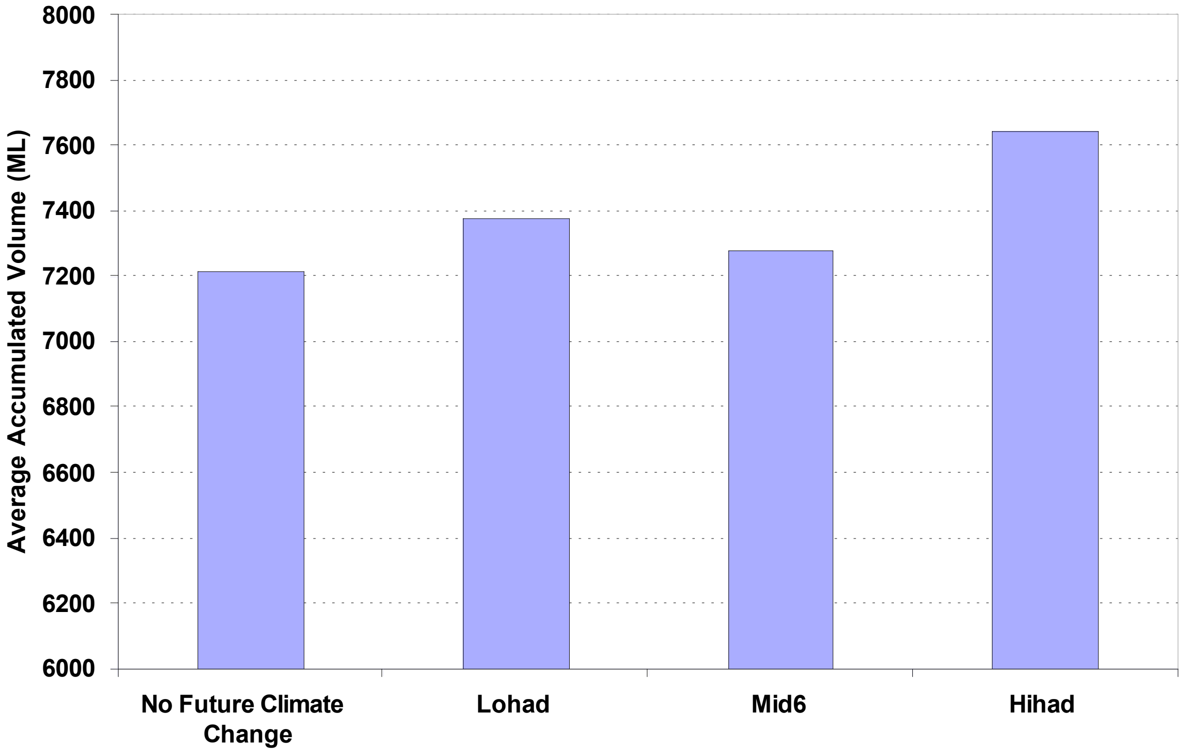

Figure 7 - Hutt River at Kaitoke – "summer low flow". The annual average of accumulated flow unavailable, or available at a restricted rate, between December and April inclusive. Note use of a false origin to highlight differences.

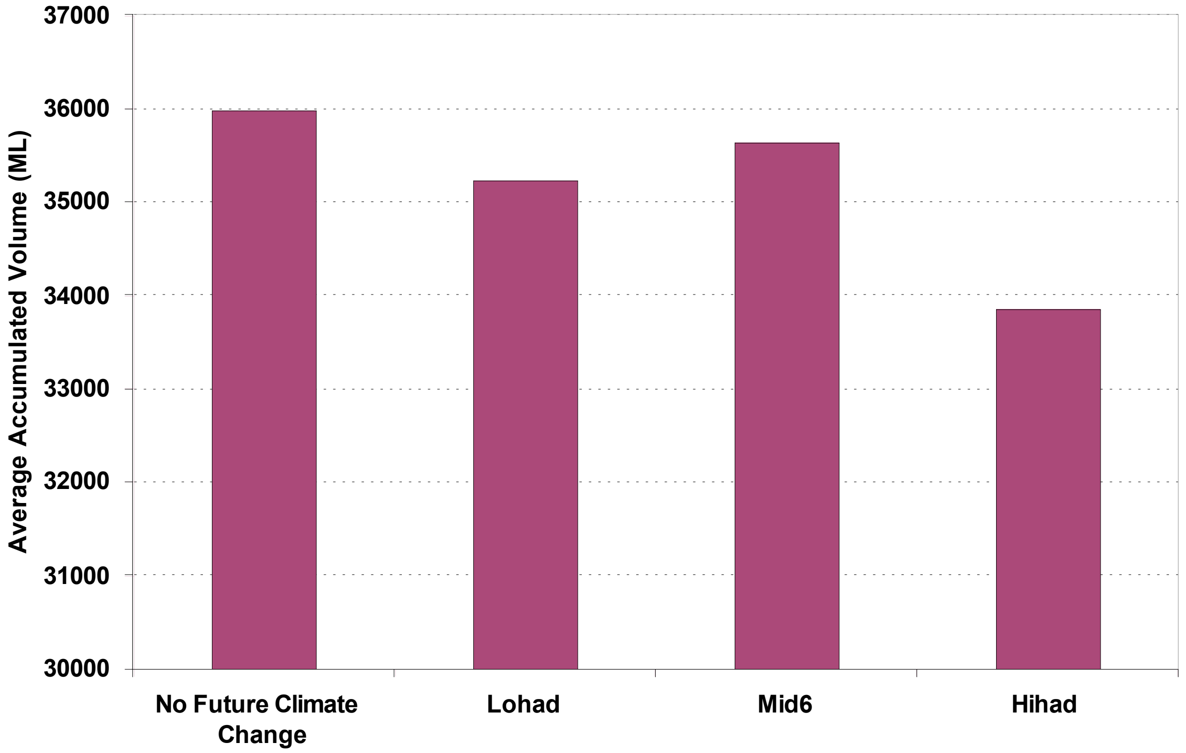

Figure 8 - Hutt River at Kaitoke – "summer mid flow". The annual average of accumulated flow where abstraction at 130 ML/d is possible given resource consent and high flow turbidity rules between December and April inclusive. Note use of a false origin to highlight differences.

The Kaitoke summer flows were then split into three categories (refer Figures 7-9):

(1) Summer low flows: these are less than 182 ML/d and represent water that is either unavailable or available at a restricted rate because of conditions of the resource consent (i.e., less than 130 ML/d is available because the residual flow must exceed 52 ML/d).

(2) Summer mid flows: the fraction that allows abstraction at the maximum daily rate of 130 ML/d if required by the SYM. This corresponds to river flows of between 182 ML/d and the cut-off point where the SYM's high flow turbidity rule prevents abstraction (currently set to 1414 ML/d).

(3) Summer high flows: these exceed the high flow turbidity cut-off mentioned above. This water is effectively not available for abstraction.

Under the three climate change scenarios, Figures 7-9 show small increases in Kaitoke summer low flows, small decreases in summer mid flows and generally more significant decreases in summer high flows.

Figure 7 shows subtle differences between the scenarios in the summer low-flow range. The variation from the base scenario, which does not account for the future effects of climate change, is an increase in low flows of 1-6%. The SYM is sensitive to Kaitoke yield in this flow range because this is where Te Marua lake depletion is most significant and where system shortfalls tend to occur.

Figure 8 shows a marginal decrease in water available in the mid flow range for all climate change scenarios. In percentage terms, the decreases are 1-6%, which match the low-flow increases. However, the volumes are 4 to 5 times greater. The mid flow range is important because it shows the unrestricted potential yield during summer months.

The increase in Kaitoke summer low flows and decrease in summer mid flows shown in Figures 7 and 8 would be expected to have a negative impact on source yield and system reliability. The Mid6 scenario shows a 1 percent increase in summer low flows and 1 percent decrease in summer mid flows.

The climate change scenarios show the greatest reduction in Kaitoke summer high flows both in volume and percentage terms, Figure 9. The reductions are 21%, 11% and 18% for the Lohad, Mid6 and Hihad scenarios respectively. Water passing Kaitoke in this flow range is not available to the SYM because of the high flow turbidity rule. This rule, which prevents abstraction at river flows greater than or equal to 1414 ML/d, is a simplistic approach to addressing the water quality issues associated with “fresh events”, however it is the best that can be done within the constraints of the model. The decrease in summer high flows would not have a negative impact on system reliability.

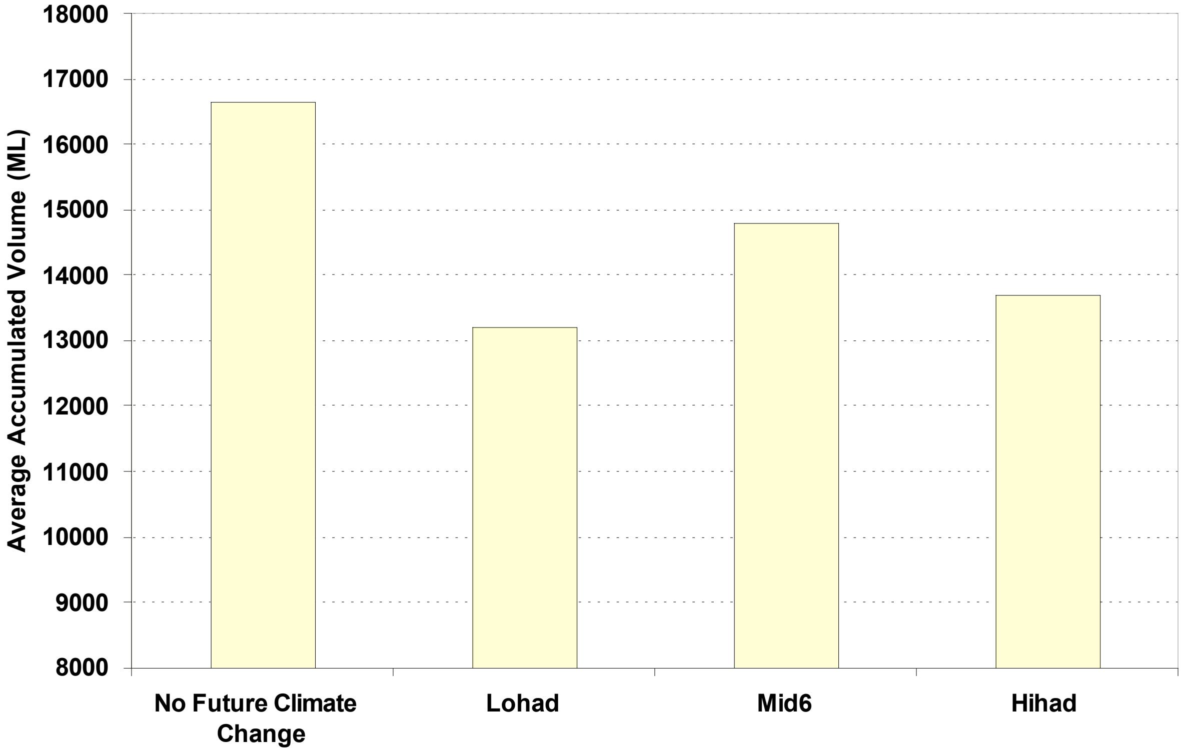

Figure 9 - Hutt River at Kaitoke – "summer high flow". The annual average of accumulated flow passing at greater than or equal to the high flow turbidity rule between December and April inclusive. Note use of a false origin to highlight differences.

7.2. Whakatikei

A comparison of flow volumes was also completed for the Whakatikei River at the proposed dam site. Low flows during summer months are not critical for this site because of the storage volume behind the proposed dam. Figure 10 shows the annual average flow volume for the base scenario and three climate change scenarios.

Figure 10 shows negligible variation in annual average accumulated flow (±1 percent). Further analysis shows there is a pattern of drier summers and wetter winters similar to Kaitoke. However, the effect is neutral when taken over a full year. The summer-winter allocation of flows would have some impact on the Whakatikei storage. However, this is not likely to be significant considering the proposed storage volume is approximately 1/7th of the annual average flow.

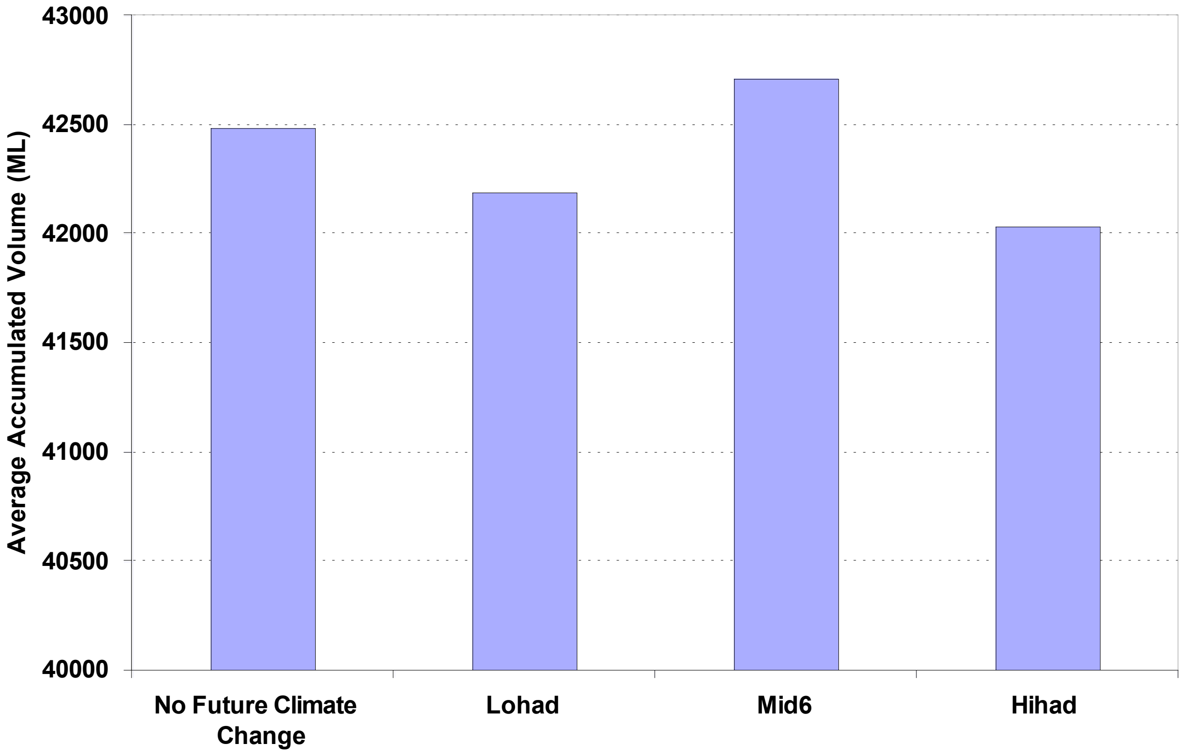

Figure 10 - Whakatikei River at proposed dam - annual average accumulated flow. Note use of a false origin to highlight differences.

8. Effect of climate change on sustainable population

Including the potential effects of future climate change, the maximum population supported at 2 percent annual shortfall probability, for the Upper Hutt aquifer plus Whakatikei dam options is:

Lohad	460 000
Mid6	453 000 ("most likely")
Hihad	444 000

When compared with the base population of 480 000, the above results are a reduction in population of 20 000 (Lohad), 27 000 (Mid6) and 36 000 (Hihad). The population reduction of just under 6% for the most likely scenario represents approximately half of the incremental benefit of the Whakatikei dam (population increase of 56 000 people).

9. Effect of increasing storage volume

An assessment of the likely benefit of increasing the size of the Whakatikei storage has also been completed. Increasing the storage volume by 50 percent to a nominal 9 000 ML available (11 500 ML total volume) on its own had no impact on system reliability. This was because the water treatment plant capacity limit of 40 ML/d was insufficient to make use of the additional storage.

If the available Whakatikei storage volume was increased to 9 000 ML and the water treatment plant capacity was increased to 60 ML/d or 80 ML/d, the population supported under the Mid6 scenario would increase to 474 000 or 477 000 respectively. A treatment capacity beyond approximately 60 ML/d showed little benefit because of the downstream capacity limitation of the Kaitoke trunk main.

Based on the population projection given in Figure 3, a regional urban population of 474 000 would be reached around 2045.

10. Discussion

There are two factors contributing to the reduction in population that can be supplied with water under the climate change scenarios. The first is the slight increase in per capita demand (PCD) discussed in section 6. The second is reduced source availability, both volume and timing, discussed in section 7.

The changes in PCD represent an average increase in demand of the order 1-2%. The demand increases, by themselves, are unlikely to have a significant effect on the results of the SYM.

In recent years, there has been a trend of slightly decreasing PCD. There is no certainty about how long this trend might last, so no account has been taken of any reduction in PCD that may occur naturally over time, or through active demand management. The current approach of reviewing the SYM's demand file on a 5-yearly basis provides a mechanism for ensuring demand assumptions are not overly conservative.

Analysis of water availability at Kaitoke showed an expected reduction in MALF, increase in summer low-flow volumes and decrease in summer mid flow volumes for all climate change scenarios. The 1% increase in summer low flows and 1% decrease in summer mid flows for the Mid6 scenario does not fully account for the overall reduction in population of nearly 6%. It does, however, show a pattern of change that would logically have a negative impact on source yield and system reliability. The 5% reduction in MALF is more consistent with the reduction in supportable population for the Mid6 scenario, which may indicate that the flow reductions during the critical periods are being disguised by the December-April volume averaging.

There are many factors that combine in the SYM to produce system shortfalls, an indicator of system reliability. These include reduced recharge to the Lower Hutt aquifer, reduced availability from the Wainuiomata and Orongorongo sources, and the marginal effect of rising sea levels on Lower Hutt aquifer abstractions, but are more difficult to separately quantify.

The likely reduction in supported population of 27 000 people for the Mid6 scenario seems significant. However, it is an overall reduction of less than 6%, consistent with the relatively minor increase in demand and decrease in source availability described above.

11. Conclusion

The most likely climate change scenario for the climatological period 2021 to 2050 will result in a reduction in population supported at 2 percent annual shortfall probability of approximately 27 000 people (just under 6% reduction). The assessment assumes that the Upper Hutt aquifer plus Whakatikei dam development option are operational.

An analysis of flows in the Hutt River at Kaitoke and the proposed Whakatikei dam site show a pattern of wetter winters and drier summers with little change in the annual totals. The decrease in Kaitoke flows during summer months would be expected to result in a reduction in system reliability. Other factors such as reduced recharge to the Lower Hutt aquifer, reduced availability from the Wainuiomata and

Orongorongo sources, increased demand, and the marginal effect of rising sea levels on Lower Hutt aquifer abstraction also contribute to this reduction.

Increasing the proposed Whakatikei dam usable storage volume from 5 900 ML to 9 000 ML (total volume 11 500 ML) and increasing the capacity of the water treatment plant from 40 ML/d to 60 ML/d would largely offset the "most likely" effects of climate change. Although increasing the height of the dam itself would be relatively inexpensive (approximately $1m if completed during initial construction), significant additional investment would be required to increase the capacity of the Whakatikei water treatment plant and pumping station, and the pipeline connection to the system. These costs have not been evaluated at this stage.

Since the likely reductions in supply are modest, an alternative to providing more water would be to accept more frequent shortfalls in supply. By examining different demand management scenarios, options for what might be sustainable under different supply restrictions can be investigated. Although demand management is unlikely to be a politically palatable option, it may be a more economically acceptable one.

Acknowledgments

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