Reducing Impacts of Climate Change on the Urban and Built Environment

Toolbox Case Study: Modelling Future Water Demand for Wellington using Multiple Climate Change Scenarios

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Modelling Future Water Demand for Wellington using Multiple Climate Change Scenarios

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1 Introduction

1.1 Study Context

This work forms part of a climate change research programme funded by the Foundation of Science, Research and Technology ("FRST"). The parent project is entitled "Reducing Impacts of Climate Change on the Urban/Built Environment". NIWA is leading the project with assistance from MWH New Zealand, GNS Science and BRANZ.

The project is intended to assist central and local government identify opportunities and reduce the impacts of climate change on urban and built environments and infrastructure, through the development and use of science-based risk assessment process and adaptation options. The project output is a Toolkit comprising a set of guidance in the form of tools that allow the user to step though an evaluative process for a variety of risk from climate change on infrastructure in the urban environment. The tools are supported by a number of case studies.

This report is concerned with the Wellington case study and specifically Project 3 - Model Future Water Supply and Demand for Wellington using Multiple Climate Change Scenarios. This study is intended to support Tool 2.5.3 dealing with bulk potable water demand trend modelling.

The objective of the demand aspect of this project is to investigate the impact of climate change on future Wellington metropolitan water demands with a focus on average summer and peak summer daily demands including:

- Likely increases below the Wellington supply cap (which affect available storage)
- Likely impacts on potential peaks above the cap
- Potential impacts of climate change on garden watering.

Project 3 is primarily intended to provide guidance for local authorities on their water supply/demand assessment processes, and covers the following aspects:

1. Bulk potable water demand trend modelling and a practical case study of its application to the Greater Wellington area'
2. An alternative approach to more detailed modelling of present-day and future potable water supply and demand as exemplified by NIWA's SYM model, as used by Greater Wellington Regional Council (GWRC).
3. Linkage to the Victoria University of Wellington project dealing with the social impact of climate change on water supply and local authority response mechanisms.

This report describes findings from the bulk potable water trend modelling cases study of the Wellington region using WaterTrac.

1.2 Wellington Water Supply

Throughout New Zealand there is a movement to improve the methodologies used to forecast the future water needs of individual communities. Historically a simple linear forecast has been used by some water service providers; however it is increasingly being acknowledged that the forecasting of future water demands is a complex task that requires the understanding, modelling and interpretation of many drivers, including:

- Changes to the demographic and non-residential profile of a region;
- The installation of water efficient fixtures and source substitution options within the community;
- The introduction of a wide variety of demand management initiatives;
- Increased discretionary use such as garden watering and car washing;
- Improvements in metering and loss management; and,

- The impacts of climate change on water demand.

Each of these drivers poses a significant challenge to a water service provider as they involve complex problems with uncertain inputs.

Greater Wellington Water (GWW), the bulk water supply operation within the Greater Wellington Regional Council (GWRC), supplies water to the four cities of Hutt, Porirua, Upper Hutt and Wellington. This is called the Wellington metropolitan bulk water supply and is the area of interest for this case study.

The “supply cap” referred to in the project objective is 650 L/capita/day and is a design peak day adopted by GWW as a planning assumption. The current bulk water supply is multi-source and has no physical cap.

1.3 Layout of Report

Section 2 outlines the methodology for this case study. The results are presented in Section 3, Predicted Change in Future Climate Conditions, and Section 4, Modelled Impacts of Climate Change on Water Demand. A summary of the key findings is given in Section 5.

Appendices provided detailed tables of the model results.

2 Approach

The evaluation utilises a methodology developed by MWH to examine the impacts of climate change on communities across Queensland in Australia, it contains five key steps:

1. Development of WaterTrac, a water production trend tracking model that utilises non-linear least square regression approach, to determine the response to a variety of climate conditions such as temperature, rainfall, evaporation and soil moisture index[1].
2. Hindcast of the modelled water demands using historical daily climate data provided by NIWA.
3. Prediction of the changes to climate based on advice provided by NIWA.
4. Adjustment of the historical daily climate records for each period, in this case 2040 and 2090, to account for the predicted impacts of climate change to determine the change in total water production per capita.
5. Distribution of total supply system water demand changes to demand end uses, to estimate the impact of climate change on the water demand of specific sectors.

The overall approach assumes that the potential climate change impacts on future water demands follow the same climate variable responses observed in the WaterTrac model calibration.

The methodology for these five steps is explained in detail in the following sub-sections.

2.1 Introduction to WaterTrac

MWH has developed an in-house software package called WaterTrac which is used to monitor trends in bulk water production. This bulk water trend tracking model package has a 15 year development history and has been successfully used in over 100 separate applications in Australia, New Zealand and North America.

WaterTrac uses the convenience and familiarity of the MS Excel spreadsheet environment for data input and output, but is hard-coded in Visual Basic and does not need to rely on MS Excel for the complex calculations required. WaterTrac uses a unique non-linear multi-variable regression analysis approach to explain the day to day climate influences on water demands.

Model outputs include:

- Regression calibration statistics.
- The long-term hindcast of calibrated model demands and flows through the full climate record.
- Climate corrected demands (including upper and lower 95% confidence intervals).
- Historical peak to climate corrected average demands.

Once the climate influence has been established the influence of other demand drivers can be estimated, such as:

- water restrictions
- demand management programs
- water pricing changes.

2.2 Input Data for WaterTrac

The following raw input data was used to run WaterTrac for the GWW bulk water supply:

1. Daily readings of maximum temperature, rainfall and potential evapotranspiration (24-hour Penman potential evapotranspiration) from the NIWA virtual climate station for Wellington city (38 years of record from 1 January 1972 to 31 December 2009).

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[1] Soil moisture index is a calculated regression variable which accounts for the impacts of the previous period's rainfall and evaporation on a sample day.

2. Daily bulk water production data from 9 February 2000 to 16 February 2010.
3. Annual population served by the bulk water supply from 1990 to 2009. This was provided by GWRC as the Wellington region urban population.

A full climate record is required therefore the virtual climate station data was used. Virtual climate station data is interpolated between defined climate measurement stations. Evaporation is typically one of the four climate variables used in the WaterTrac model but evaporation data is not available from the virtual climate station dataset. We used potential evapotranspiration data as a proxy for evaporation but have continued to refer to both evaporation and potential evapotranspiration throughout this report.

2.3 Determining the Historic Demand Response to Climate Variables

The process of climate correction in the WaterTrac model (key steps 1 and 2 in our methodology) can be summarised as follows:

1. A soil moisture index is derived from the input climate data and is included as one of four climate variables.
2. A regression model is progressively calibrated using the four climate variables and recognised statistical techniques. The calibration is undertaken over a period of relatively 'normal' water consumption (e.g. free of water restrictions) with a reasonable range of climatic conditions.
3. A 'hindcast' is created which uses the calibrated model to predict water production over a long time period given the climatic conditions. This provides long term modelled demand responses to climate drivers. It also allows verification of the long term stability of the model.
4. Statistical techniques are used to create a climate corrected trend of water production and a 365 day rolling average graph of observed versus climate corrected water production.

The model is unique in that it offers a simple soil moisture store model as a climate variable in the regression analysis. The soil moisture index is used to model the antecedent soil moisture effects on demand or flow. This particular soil moisture store model has been found to generate high correlations with water demand or flow in many separate applications.

The calibration period for the regression model sets the baseline for the comparative trend tracking. Although any time period can be selected for the baseline, there are a couple of guidelines:

- The calibration period should cover at least a full year. Two or even three years can be used for establishing the baseline.
- The calibration period should incorporate a hotter, drier than average summer period. This is to ensure that when encountering the more extreme hotter and drier summer periods, the model is not extrapolating when predicting the response.

The calibration period selected for the GWW WaterTrac model was 1 January 2007 to 31 December 2008. This time period does include the brief introduction of a sprinkler ban in February 2008, however this was very short (four days) and is not considered statistically significant within the two year calibration period. The 2007/2008 summer was hotter and drier than average and this calibration period gave good results. One benefit of calibrating over a recent short duration (such as the selected two year period) is that the time period can be selected to reflect the influence, or otherwise, of known demand drivers to the historic demand record, such as restrictions and pricing changes. Ideally the calibration period is selected to be representative of the way water is expected to be used in the future.

The calibration is good for this type of model and produced an R^2 statistic of 0.72, which is to say that 72% of the variations in daily per capita water production could be explained by the fitted model.
The modelled variable responses for the four climate variables are shown in Figure 1.

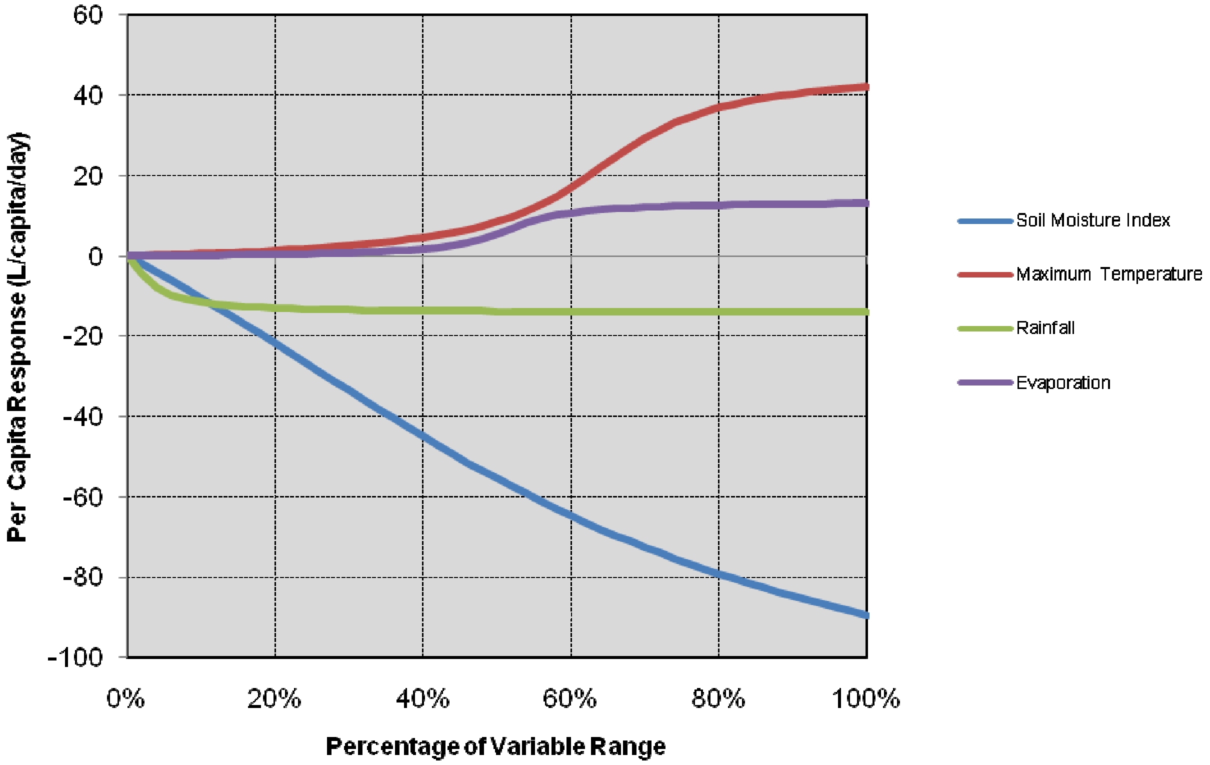

Figure 1: Modelled Variable Responses for the Four Climate Variables

The vertical axis on the plot represents the per capita response in L/capita/day from each of the four explanatory climate variables. The x-axis shows the corresponding percentage of the range for each of the four climate variables. The plot shows that the four climate variables produced the expected responses for the GWW model. Maximum temperature and evaporation show a positive response with water demands (e.g. as maximum temperature increases, water demands increase and the highest range of maximum temperature corresponds to a maximum response of approximately 40 L/capita/day). The plot also shows that maximum temperature has a greater climate response on demands than evaporation.

Rainfall and soil moisture index show a negative response with water demands (e.g. as rainfall increases, water demands decrease). The plot also shows that soil moisture index has a greater climate response on demands than rainfall and is the most significant of the four climate variables.

The test used to determine the significance of individual variables is the statistical hypothesis t-test. Variables exhibiting a t statistic higher than the critical t value (as shown in tables available in most statistical texts) are deemed to be significant. As a rule of thumb, in the regression analysis of daily water demand, a t value of absolute value greater than 1.6 suggests that the variable is significant in the regression and should be included in the regression model. For the GWW model, the t-test identified all four climate variables to be significant (in explaining the daily water production during the calibration period), as shown in Table 1.

Table 1: T-Test Statistics for the Climate Variables

Climate Variable	T-test Statistic
Soil Moisture Index	-19.6
Maximum Temperature	9.7
Rainfall	-6.1
Evaporation	5.0

The WaterTrac model includes a hindcast of predicted per capita daily water production over the full historic climate record. The hindcast can be used to estimate the long-run frequency distribution of demands. There were 38 years of climate record for the GWW model and the model hindcast is shown in Figure 2.

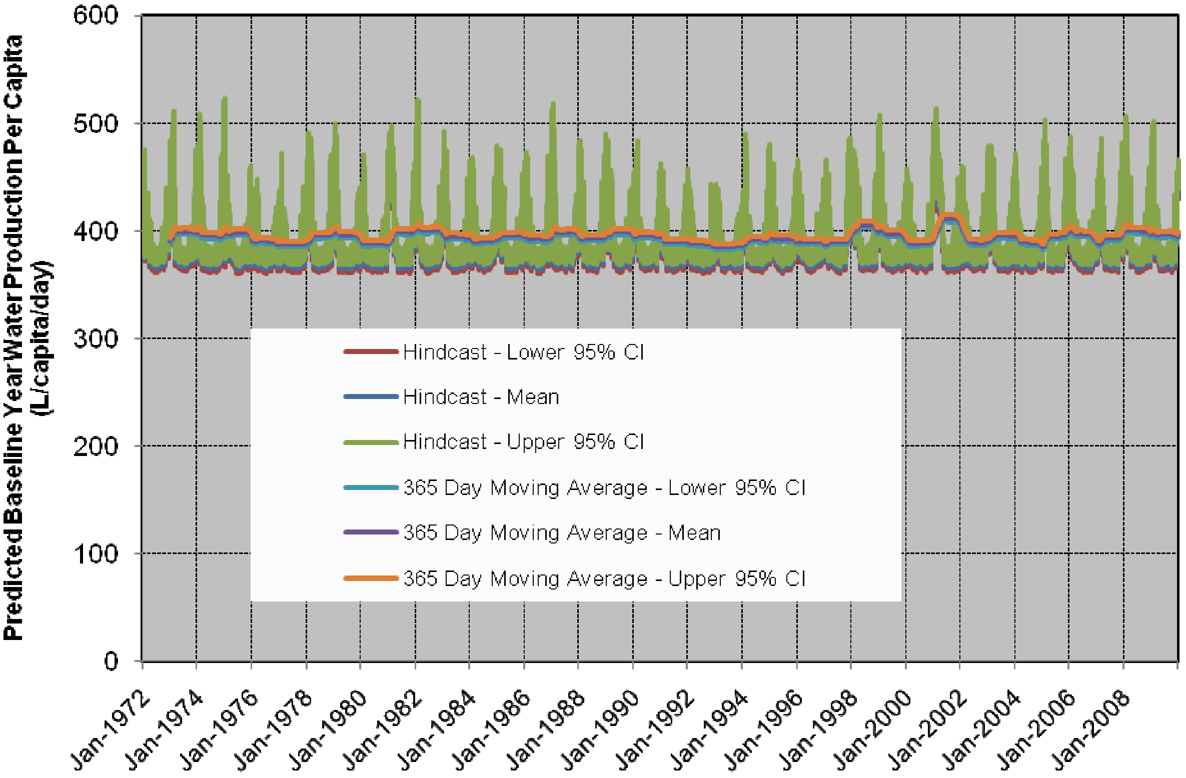

Figure 2: Hindcast of Predicted Baseline Year Water Production Per Capita

The model hindcast also provides a “sanity” check on the regression model. A stable regression model will provide sensible demand estimates through the full period of climate record, including a regular winter demand pattern. The plot above shows that the GWW model produced a stable regression model as there are no extreme high or low predicted demands.

The hindcast demonstrates that climate condition influence on GWW demands. With a long-term mean per capita demand of 394 L/capita/day, the hindcast shows that the hottest\driest 365 days in the climate record will result in a demand of 412 L/capita/day (4% above average). Alternatively, the coolest/wettest period will result in a demand of 385 L/capita/day (2% below average). The hindcast plot also shows that climate has a greater influence on daily demand variations.

The long term annual average demand of 394 L/capita/day is derived from the full hindcast period. This figure is comprised of a fixed non-seasonal demand of 364 L/capita/day (the minimum hindcast value) and a seasonal demand of 30 L/capita/day. On this basis the long term annual average seasonal demand is equivalent to 8% of the long term annual average demand. This level of seasonal demand is lower than typically observed for town water supplies in moderate climates.

2.4 Climate Change Predictions

The predictions for seasonal and annual changes in temperature and rainfall (key step 3 in our methodology) were based on Tables 2 and 3 in the Ministry for the Environment guide for local government, “Preparing for Climate Change” (2008). These tables provide 2040 and 2090 predictions for a "middle-of-the-road" scenario, along with a "low" and "high" range (i.e. the probable temperature and precipitation changes for the two future periods lie within these values). The middle-of-the-road estimates are the average of all emissions scenarios and all circulation models. The low and high ranges are the extremes from this modelling.

It should be noted that the extreme ends of the temperature and rainfall projection ranges are not from the same models. For example, the model that produced the lowest predicted change in precipitation for spring 2090 is not the same model that produced the lowest predicted change in temperature for spring 2090. Combining these end-of-range values represents "hypothetical" extreme minimum and maximum effects on demand. It is not physically realistic to combine the extreme predictions from two models as the models that yield sizeable increases in rainfall may also be projecting the most warming, as warmer air can hold more moisture.

The seasonal 2040 and 2090 predictions (medium, low and high) were then applied to each relevant month for that season.

A basic approach was taken to predict the future seasonal and annual changes in potential evapotranspiration (PET) due to climate change. This was based on the assumption that there is a linear relationship between temperature and PET as demonstrated using historic mean monthly values. A scatter plot of mean monthly temperature versus mean monthly PET (Penman formula) provided a slope which describes the change in PET as a function of the change in temperature. The slope equation is:

delta PET = 12.36 X delta T

i.e. a 1°C increase in temperature for Wellington implies a 12.36 mm increase in PET

It is recognised that there is debate about the directness of the PET response to temperature increases due to a number of other influencing factors (particularly radiation, vapour pressure and wind). An area for possible future research would be to test the sensitivity of the climate change impacts on demands to changes in PET.

2.5 Prediction of Climate Change Impacts on Average Water Demand

The climate response factors and the soil moisture index equation from the WaterTrac model are used as input parameters into a MWH model called ClimateTrac (key step 4 in our methodology). ClimateTrac is a model developed for annual and monthly forecasting of the impacts of climate change on water demands. The model adjusts the historical daily climate records for the predicted monthly climate changes and then produces demand forecasts (in L/capita/day) for the full climate record (for each of the three scenarios for 2040 and 2090). The results were then summarized on a monthly basis to determine the predicted impact of climate change on water demands. The predicted impacts on a monthly basis were then averaged to provide an annual average impact.

2.6 Prediction of Climate Change Impacts on Peak Water Demands

The GWW bulk water supply network must be capable of supplying the demand for water at all times, in order to meet the expectation that water is available upon turning a tap. The system is most heavily stressed at those times when demand reaches a peak, with the peak day being defined as that day of the year when the highest volume of water is supplied to the combined metropolitan area of the four cities. Peak supply day may not coincide with the day of peak consumption in each of the four cities due to the effects of local consumption and reservoir balancing. The true peak day consumption could be determined through investigation into the individual demand nodes within the bulk supply system (and taking into account changes in reservoir storage).

Peak demand periods almost always occur during prolonged periods of hot, dry weather, and may not necessarily occur in a hot or dry year. Garden and lawn watering are likely to have the most significant contributors to peak day demands. The Wellington region typically has a mild temperate climate with relatively frequent rainfall events through the seasons. Peak day demands for the GWW bulk water supply often occur after just a few dry warm days with temperatures in the low to mid 20's. Figure 3 shows the historic daily water demands with the key climate variables of maximum temperature and soil moisture index.

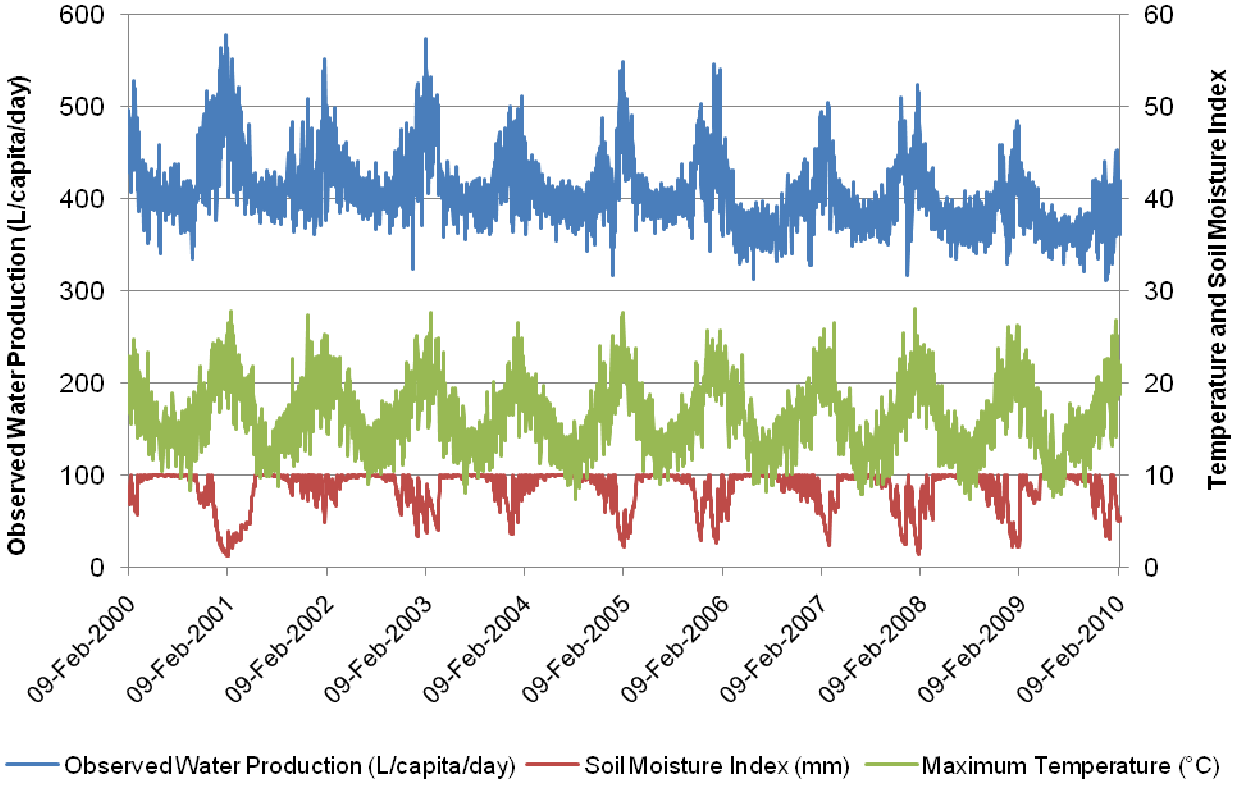

Figure 3: Observed Daily Water Production with Soil Moisture Index and Maximum Temperature

The plot above shows a clear correlation between maximum temperature and peak day demands. It also shows that the highest daily demands have typically occurred during prolonged periods of low soil moisture index (which is derived from the previous day's rainfall and evaporation).

A relatively minor peak demand period occurring in a cool, wet year will result in a high maximum day to average day ratio. Likewise, a high peak demand occurring in a hot, dry year will result in a low maximum day to average day ratio. Thus it is important to compare peak demands with the climate-corrected demand for a useful comparison.

Figure 4 shows the ratio of the observed peak day to the climate corrected rolling 365 day average. The plot shows that this peak day ratio has typically been quite consistent, between 1.2 and 1.4 for the past ten years. The long term average peak day ratio over the full hindcast of 38 years is 1.2. These low peak day ratios imply that GWW does not experience high seasonal demands. GWW's observed peak day ratio is lower than the NZ Standard 4404 design recommendation of a peak day factor of 1.5 for populations above 10,000.

Time of day and alternate day garden watering restrictions will affect the peak day ratio. Garden watering restrictions have been in place in the Wellington metropolitan water supply for a number of years without significant changes. The peak day ratio appears to be declining in the past few years which is likely to be due to cooler summers.

The long term average peak day ratio of 1.2 was adopted for this study to estimate the impact of climate change on the peak day. This assumes that the future peak day ratio is the same as the historic average but it could change with time particularly if demand management efforts are focussed on dropping average demands.

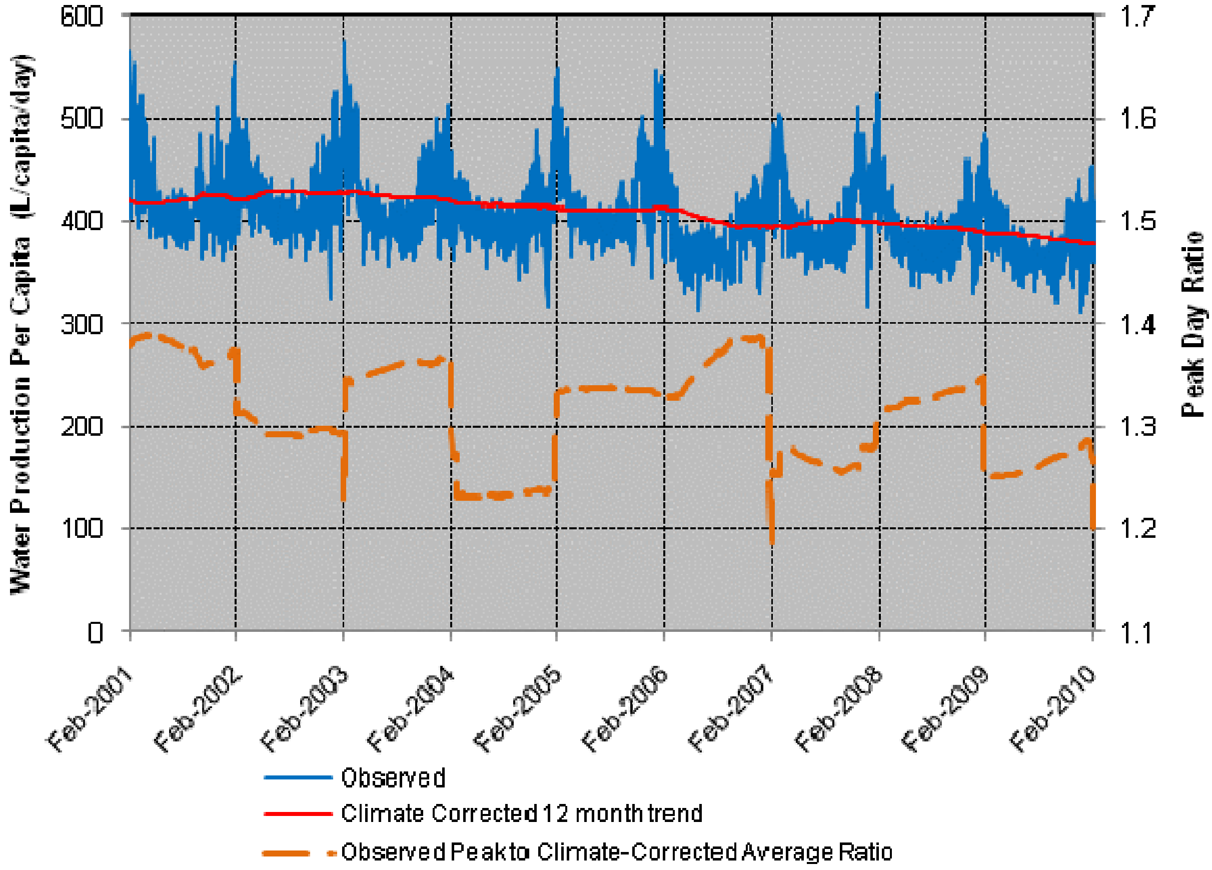

Figure 4: Historic Peak to Climate-Corrected Average Day Ratio

2.7 Assumed Breakdown of Demands by End Use

Once the effects of climate change on the total system water demand is understood, the change in demand is distributed to each sector (residential sector, the non-residential sector and non-revenue water) and then to individual enduses within the sectors to determine the impact effect on end use such as external residential use (key step 5 in our methodology).

The Wellington metropolitan water supply area does not have universal metering therefore there is little data available on water end uses. Most but not all commercial customers are metered. Under a water balance approach, unmetered commercial and residential consumption are both estimated and the remainder is assumed to be non revenue water. We used the sector estimates for the most recent year as provided by Porirua City Council and Capacity.

There was no data available to break the sector use down into internal and external, therefore we made assumptions based on typical data from other New Zealand and Australian water supplies.

Figure 5 shows a typical New Zealand residential end use breakdown based on the Building Research Association of New Zealand studies in the Kapiti Coast and Auckland.

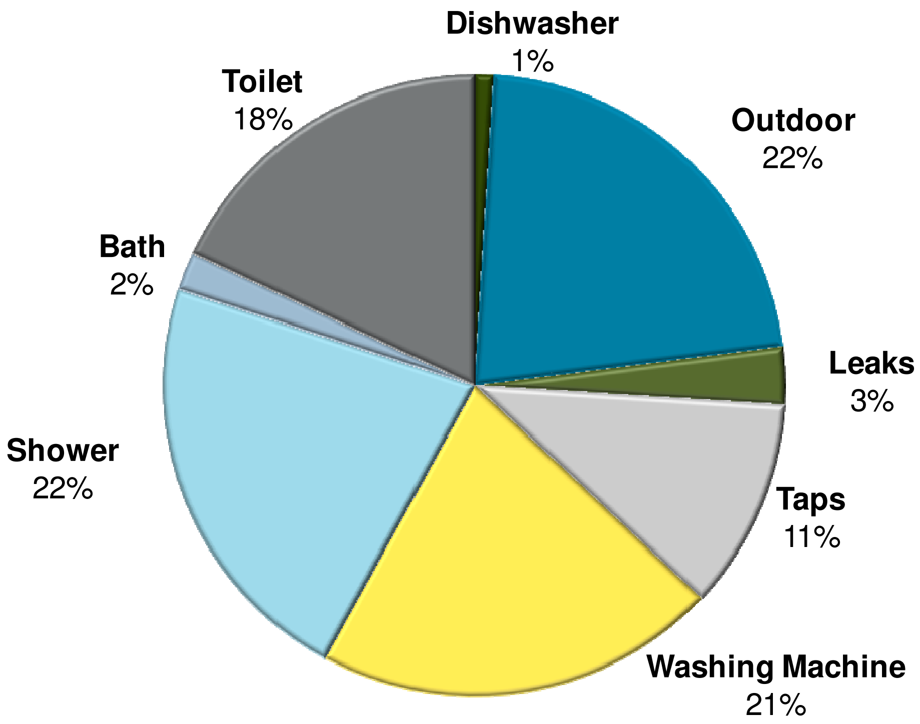

Figure 5: Residential End Use Breakdown (combined data from BRANZ studies)

The above pie graph shows a residential external use of 25% (outdoor and leaks) and this was adopted for the GWW model.

The following tables outline the assumed breakdown in water use within the Greater Wellington Region based on available customer billing and end use data.

Table 2: Assumed Breakdown of Water Use

Sector	End Use	Breakdown (%)	
Residential	**Internal**	61%	75%
	External		25%
Non Residential	**Internal**	24%	80%
	External		20%
Non Revenue Water	**Real Losses**	15%	35%
	Apparent Losses		35%
	Unbilled Authorised Consumption		30%

The estimated combined residential and non residential external water use is 20% in the above table. This is considerably higher than the long term annual average seasonal demand of 8% which reflects the potential for year to year variability. The lack of accurate end use data is a limitation to providing accurate estimates of the climate change impact on sectoral demands. We used these sectoral assumptions in preference to the seasonal demand estimates from WaterTrac to estimate the climate change impact on sectoral demands.

3 Predicted Change in Future Climate Conditions

Three climate change scenarios (a low range scenario, a mean scenario and a high range scenario) for two separate time periods (2040 and 2090) were developed for the Greater Wellington Region. As discussed in Section 2.4, the low and high range scenarios represent hypothetical extremes. A summary table of the predicted annual changes is shown in the table below. Tables showing the monthly predictions are included in Appendix A.

Table 3: Predicted Annual Effects of Climate Change

Period	2040			2090		
Scenario	*Mean (1)*	*Low Range (2)*	*High Range (3)*	*Mean (1)*	*Low Range (2)*	*High Range (3)*
Temperature (°C)	0.9	0.3	2.2	2.1	0.6	5.2
Rainfall (%)	2.0	-3.0	10.0	3.0	-7.0	14.0
Evaporation (mm)	0.3	0.1	0.7	0.7	0.2	1.6

Soil moisture index and maximum temperature were shown to be the most significant climate variables for GWW water demands in the regression model results presented in Section 2.3. The monthly variation in soil moisture index compared to baseline for the 2040 is shown in Figure 6. Additional graphs showing the monthly variation in soil moisture index and maximum temperature compared to baseline for the two time periods are included in Appendix A.

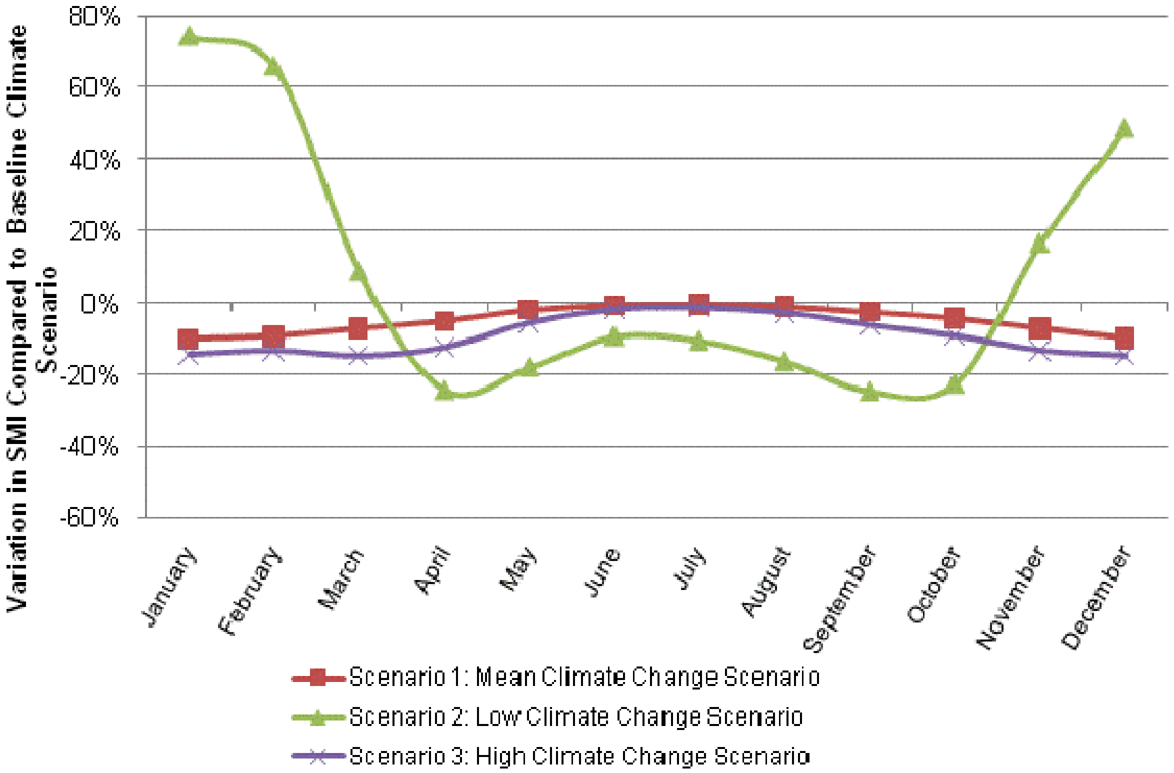

Figure 6: Monthly Variation in Soil Moisture Index Compared to Baseline for 2040

3.1 Increase in Extreme Events

The most recent advice from NIWA indicates that extreme events related to hot and dry weather will increase in the Greater Wellington Region. Hot days above a temperature threshold and consecutive hot and dry days are extreme events that have potential to affect water demands.

The following table indicates the average annual historic and the predicted mean number of hot days above two temperature thresholds (25℃ and 30℃) as predicted by the ClimateTrac model over the full 38 years. In addition, there is expected to be an increase in the occurrence of consecutive days where the temperature exceeds the temperature threshold of 25℃ which will have a greater impact on water demands than single hot days occurring in isolation.

Table 4: Predicted Increase in Hot Days from ClimateTrac model

Temperature Threshold	Average Annual Historical # of Hot Days (>Temperature Threshold)	Mean Annual (50th percentile) # of Hot Days in 2040	Mean Annual (50th percentile) # of Hot Days in 2090
25℃	5	11	23
30℃	0 (1 day in 38 years)	0 (2 days in 38 years)	0 (10 days in 38 years)

The ClimateTrac predictions can be compared with NIWA's work on the New Zealand Transport Agency project "Climate change effects on the land transport sector" that looked at the risk of rail buckling from future extreme temperatures. NIWA predicted that, given a 2℃ increase in the mean temperature by 2090, the number of days with a maximum temperature above 25℃ would increase by 5 to 15 days in the Wellington region. The ClimateTrac predictions are for an increase of 18 hot days which lines up with the NIWA predictions.

It is more difficult to predict the increased occurrence of multiple days of high temperatures. The ClimateTrac model shows an increase in the occurrence of multiple days of high temperatures however this has not been fully quantified.

4 Modelled Impacts of Climate Change on Water Demand

4.1 Impacts on Monthly Average Demands

Figure 7 and Figure 8 show the impact on the average daily demands on a monthly basis for each of the evaluated climate scenarios. For further details of the results refer to the tables in Appendix C which also show the impact on the monthly average demands for each of the evaluated climate scenarios in L/capita/day.

The impact of soil moisture index as the most significant climate variable is evident in the distinctive “M” shape of the curve for scenario 2, the hypothetical extreme low climate change scenario. This reflects the “W” shape of the scenario 2 curve for monthly variation in soil moisture index shown in Figure 6 (as soil moisture index shows a negative response with water demands i.e. as soil moisture index increases, water demands decrease).

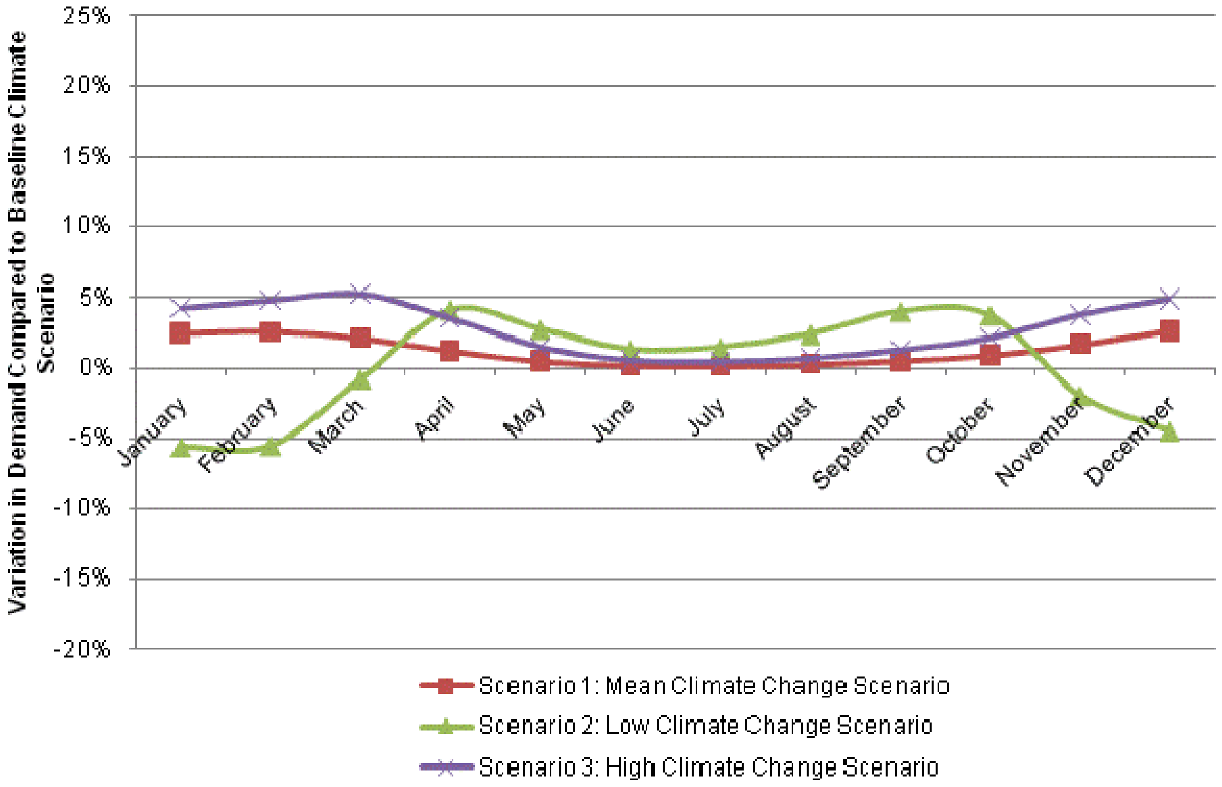

Figure 7: Forecast Impact on Monthly Average Day Demands for Greater Wellington Region (2040)

A variation of demand of between -4% to 12% is forecast to be experienced in the Greater Wellington Region in 2090 due to climate change impacts, with over 5 months of the year experiencing an increase of 10% or greater.

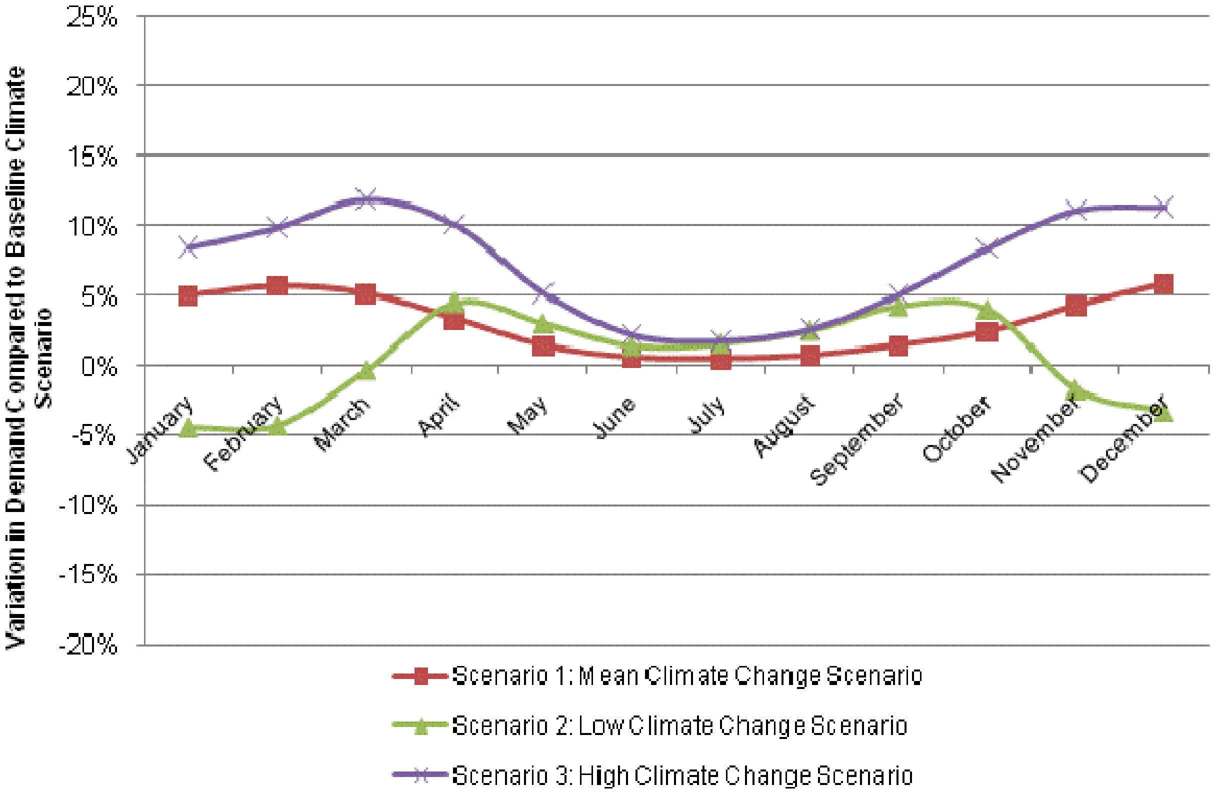

Figure 8: Forecast Impact on Monthly Average Day Demands for Greater Wellington Region (2090)

4.2 Impacts on Peak Day Demands

The climate change impact on peak day demands were estimated by applying the historic peak day ratio of 1.2 to the predicted annual average daily demand under each climate change scenario. The results are shown in Table 5.

Table 5: Forecast Impact on Peak Day Demand

Predicted Demands (L/capita/day)	Baseline	Mean	Low	High
2040 Average Day	401	406	401	412
2040 Peak Day	489	495	489	503
Variation from Baseline		+1.2%	0%	2.9%
2090 Average Day	401	414	402	431
2090 Peak Day	489	505	490	526
Variation from Baseline		+3.3%	+0.2%	+7.6%

The table shows that the peak days are forecast to remain below the current design peak day planning assumption of 650 L/capita/day for both 2040 and 2090. The predicted impact on peak day demand assumes that the future peak day ratio is the same as the historic average but it could change with time particularly if demand management efforts are focussed on dropping average demands.

The variability in peak day demands compared to baseline is expected to range from 0% to 2.9% in 2040. The variability in peak day demands compared to baseline is expected to range from 0.2% to 7.6% in 2090. This variability is slightly greater than the predicted variability in monthly average demands.

4.3 Impacts on Sectoral Demands

Changes in climate will not affect end uses equally across each sector. It is expected that changes will be predominantly in external use, however some change in internal demand is expected due to factors such as longer showers or increased clothes washing.

The four tables outline the baseline scenario (based on approximately 40 years of daily climate data and the outcomes of the regression analysis) and the forecast change in water demand by sector and provide an internal / external breakdown of demand. For a more detailed breakdown of the calculations, refer to Appendix B. The climate influence factors for each sector end use shown in Appendix B are based on assumptions from other MWH studies on climate change impacts on water demand.

Table 6: Forecast Sectoral Demands for the Greater Wellington Region for 2040

Sector		Average Day Demand (L/capita/day)				Change relative to Baseline			
		Baseline	**Mean**	**Low**	**High**	**Baseline**	**Mean**	**Low**	**High**
Residential	**Internal**	185	186	184	189	0.0%	1.0%	-0.1%	2.2%
	External	62	63	61	65	0.0%	2.3%	-0.2%	4.9%
Non Residential	**Internal**	76	76	76	77	0.0%	0.5%	0.0%	1.1%
	External	19	19	19	20	0.0%	2.0%	-0.2%	4.4%
Non Revenue Water		60	61	60	63	0.0%	2.2%	-0.2%	4.6%
	Total	**401**	**406**	**400**	**412**	**0.0%**	**1.3%**	**-0.1%**	**2.9%**

Table 7: Forecast Sectoral Demands for the Greater Wellington Region for 2090

Sector		Average Day Demand (L/capita/day)				Change relative to Baseline			
		Baseline	**Mean**	**Low**	**High**	**Baseline**	**Mean**	**Low**	**High**
Residential	**Internal**	185	189	185	195	0.0%	2.4%	0.3%	5.7%
	External	62	65	62	69	0.0%	5.4%	0.6%	12.9%
Non Residential	**Internal**	76	77	76	78	0.0%	1.2%	0.1%	2.9%
	External	19	20	19	21	0.0%	4.8%	0.6%	11.5%
Non Revenue Water		60	60	63	60	67	0.0%	5.1%	0.6%
	Total	**401**	**414**	**402**	**431**	**0.0%**	**3.1%**	**0.4%**	**7.5%**

Residential external end uses are forecast to have the greatest impact from climate change (up to 12.9% in 2090 under the hypothetical extreme high climate change scenario), as can be expected. The impact on residential external end uses is expected to be primarily on garden and lawn watering.

Compared to the baseline climate scenario the mean (50th percentile) forecast of climate change indicates that the annual GWW water demands will increase by 1.3% and 3.1%, for 2040 and 2090 respectively.

For the hypothetical extreme low and high climate scenarios, demands can be seen to have further decreases (i.e. -0.1% in 2040) and increases (7.5% in 2090) as expected.

4.4 Impact from Extreme Events

There is expected to be an increase in the occurrence of single and consecutive days where the temperature exceeds a temperature threshold of 25℃. Consecutive hot days will have a greater impact on water demands than single hot days occurring in isolation. If the future peak day ratio is expected to stay the same as the historic ratio, the model will predict minimal change to peak days due to these types of extreme events. However it is logical to assume that future peak days will increase with an increase in the occurrence of consecutive hot and dry days.

4.5 Population Growth

It is important to establish how significant the increase in demand due to climate change is compared to the other drivers identified in Section 1 of this study. One of the most significant drivers in demand growth is population growth. The Greater Wellington Region has a forecast population growth of approximately 50% between 2010 and 2090 (this is based on the figures adopted by GWRC, i.e. the mean of the medium and the high Statistics New Zealand forecasts for the region).

While these growth rates are expected to have a greater impact on future water demands than climate change, it is important to recognise that the drivers for water demand are cumulative. For example a 10% increase in water demand due to climate change would offset a 10 % reduction in water demands through the implementation of a leakage program.

Based on the modeling assumptions stated in this report and all other factors remaining constant, we have prepared a plot of the predicted variation in annual average demand projections due to population growth and climate change in Figure 9.

Figure 9 illustrates that the potential variation in demands due to population growth (simulated using the baseline demand of 401 L/capita/day combined with the medium and high Statistics NZ population projections) are greater than the potential variation in demands due to climate change (simulated using the predicted demands under the hypothetical extreme low and high climate change scenarios combined with the mean population growth projections adopted by GWRC). The baseline shown on the plot is based on the baseline demand of 401 L/capita/day and the mean population growth projections adopted by GWRC).

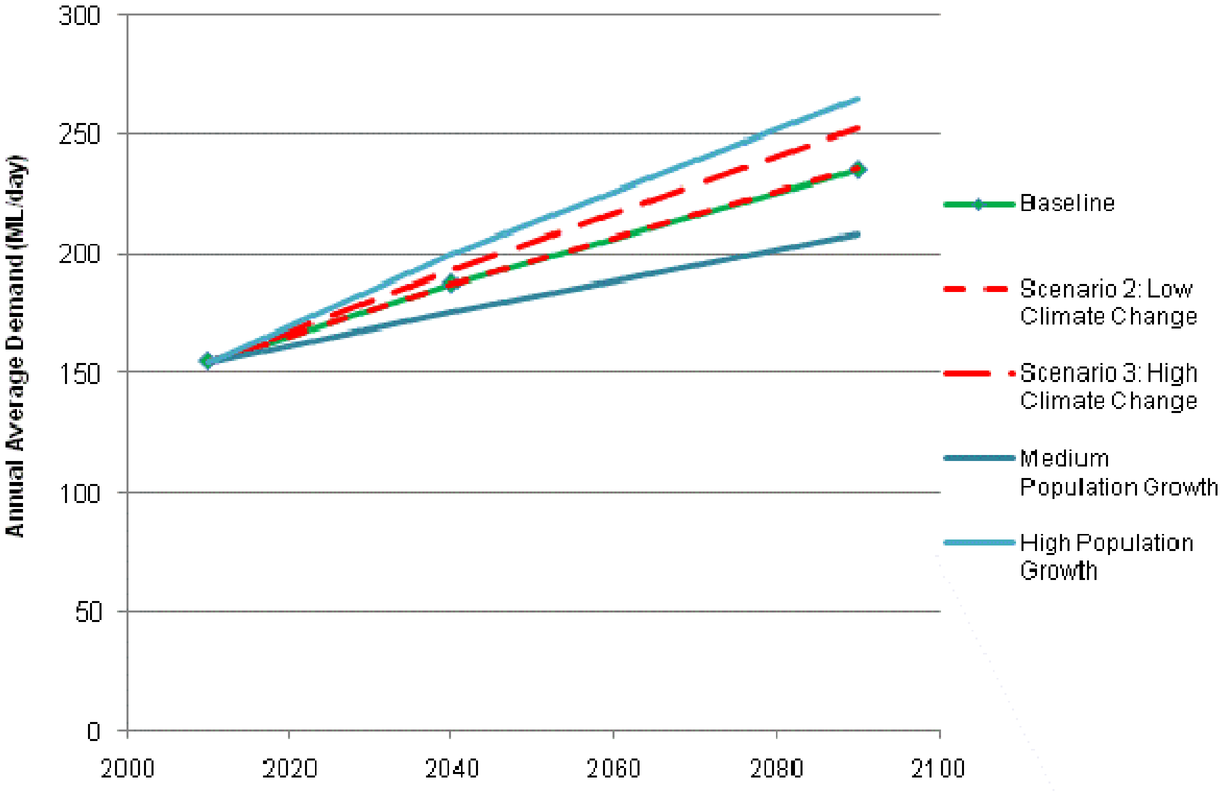

Figure 9: Variation in Annual Average Demand Projections due to Population Growth and Climate Change

5 Key Findings

Based on the assumptions and available information outlined in this study, the key findings from the evaluation of the impacts of climate change on future water demands for the Wellington metropolitan bulk water supply are:

- The Ministry for the Environment (2008) seasonal climate change projections for the Wellington region were converted into monthly climate change projections (see Tables A1 and A2 in the Appendix). These monthly temperature projections were used to estimate the projected change in evaporation. The projected monthly increase in temperature is up to 2.5℃ for 2040 and 5.7℃ for 2090. Significant variation in rainfall patterns arises from the low and high projections (the projected monthly rainfall lies between a decrease of 21% and an increase of 14% by 2040 and a decrease of 38% and an increase of 26% by 2090).
- In 2040 the overall monthly average daily demand in the GWW bulk supply can be expected to vary by -0.1% to 2.9% (hypothetical extremes), with an increase of up to 4.6% in residential sector external use. For the 2040 mid-range climate change scenario, this change could be 0.1% to 2.6%.
- In 2090 the overall monthly average demand in the GWW bulk supply can be expected to vary by 0.4% to 7.5% (hypothetical extremes), with an increase up to 12.2% in residential sector external use. For the 2090 mid-range climate change scenario, this change could be 0.4% to 5.8%.
- In 2040 the variability in peak day demands in the GWW bulk supply compared to baseline is expected to range from 0% to 2.9% (hypothetical extremes) with a mean prediction of 1.2%.
- In 2090 the variability in peak day demands in the GWW bulk supply compared to baseline is expected to range from 0.2% to 7.6% (hypothetical extremes) with a mean prediction of 3.3%.
- The number of extreme events with days >25℃ are forecast to increase by up to 400% by 2090 and the number of consecutive hot dry days are also expected to increase in the Wellington Region. These extreme events will increase the frequency of peak day demand events.
- Based on the modeling assumptions stated in this report and assuming all other factors remain constant, the impact of the potential variability in population growth is expected to be greater than the predicted variation in the GWW bulk demands due to climate change. However it is important to recognise that the drivers for water demand are cumulative and could be different from what we have assumed. For example a 10% increase in water demand due to climate change would offset a 10% reduction in water demands through the implementation of a leakage program.
- The lack of accurate end use data for the Wellington region is a key limitation to providing accurate estimates of the climate change impact on sectoral demands.
- The climate change modeling process outlined in this report has promise but it is important to note that each water supply will be unique due to local factors in climate, sectoral end use and peak day ratios.
- The Wellington modeling could be improved by investigating the true peak day consumption at individual demand nodes in the GWW bulk supply (and taking into account changes in reservoir storage).
- To improve the robustness of this study and provide recommendations for other local authorities, it is recommended that additional water supplies are investigated with higher seasonal and climate variation as Wellington is unlikely to be typical of other New Zealand water supplies due to its low peak day ratio. Christchurch city would be a logical starting point as the WaterTrac model has already been prepared by MWH under their water demand forecasting work.

Regarding the three desired project objectives:

1. The results of this case study will be used to assist preparation of a guidance tool for local authorities to apply their water supply/supply assessment processes in the next stage of work.
2. The modeling results can be provided as 38 years of daily record for use as an alternative demand input module for inclusion in the NIWA model used by GWRC.
3. Discussions have been held with the Victoria University of Wellington project dealing with the social impact of climate change on water supply and local authority response mechanisms.

Appendix A: Predicted Effects of Climate Change

The following two tables outline the predicted effect of climate change on the climate conditions for the Greater Wellington Region.

Table A1: Predicted Climate Change for the Greater Wellington Region for 2040

			Scenario 1	Scenario 2	Scenario 3
		Month	**Mean**	**Low Range**	**High Range**
Temperature (°C)	**Annual**		0.9	0.3	2.2
	Summer	Dec	1.0	0.2	2.2
		Jan	1.0	0.2	2.2
		Feb	1.0	0.2	2.2
	Autumn	Mar	1.0	0.3	2.5
		Apr	1.0	0.3	2.5
		May	1.0	0.3	2.5
	Winter	June	0.9	0.2	2.1
		July	0.9	0.2	2.1
		Aug	0.9	0.2	2.1
	Spring	Sept	0.8	0.1	1.9
		Oct	0.8	0.1	1.9
		Nov	0.8	0.1	1.9
Rainfall (%)	**Annual**		2.0	-3.0	10.0
	Summer	Dec	0.0	-21.0	13.0
		Jan	0.0	-21.0	13.0
		Feb	0.0	-21.0	13.0
	Autumn	Mar	4.0	-3.0	14.0
		Apr	4.0	-3.0	14.0
		May	4.0	-3.0	14.0
	Winter	June	4.0	-1.0	13.0
		July	4.0	-1.0	13.0
		Aug	4.0	-1.0	13.0
	Spring	Sept	2.0	-5.0	14.0
		Oct	2.0	-5.0	14.0
		Nov	2.0	-5.0	14.0
Evaporation (mm)	**Annual**		0.3	0.1	0.7
	Summer	Dec	0.3	0.1	0.7
		Jan	0.3	0.1	0.7
		Feb	0.3	0.1	0.7
	Autumn	Mar	0.3	0.1	0.8
		Apr	0.3	0.1	0.8
		May	0.3	0.1	0.8
	Winter	June	0.3	0.1	0.7
		July	0.3	0.1	0.7
		Aug	0.3	0.1	0.7
	Spring	Sept	0.3	0.0	0.6
		Oct	0.3	0.0	0.6
		Nov	0.3	0.0	0.6

Table A2: Predicted Climate Change for the Greater Wellington Region for 2090

			Scenario 1	Scenario 2	Scenario 3
		Month	Mean	Low Range	High Range
Temperature (℃)	Annual		2.1	0.6	5.2
	Summer	Dec	2.2	0.9	5.7
		Jan	2.2	0.9	5.7
		Feb	2.2	0.9	5.7
	Autumn	Mar	2.1	0.6	5.1
		Apr	2.1	0.6	5.1
		May	2.1	0.6	5.1
	Winter	June	2.1	0.6	5.0
		July	2.1	0.6	5.0
		Aug	2.1	0.6	5.0
	Spring	Sept	1.8	0.3	4.8
		Oct	1.8	0.3	4.8
		Nov	1.8	0.3	4.8
Rainfall (%)	Annual		3.0	-7.0	14.0
	Summer	Dec	-1.0	-38.0	16.0
		Jan	-1.0	-38.0	16.0
		Feb	-1.0	-38.0	16.0
	Autumn	Mar	2.0	-12.0	14.0
		Apr	2.0	-12.0	14.0
		May	2.0	-12.0	14.0
	Winter	June	9.0	0.0	26.0
		July	9.0	0.0	26.0
		Aug	9.0	0.0	26.0
	Spring	Sept	2.0	-15.0	26.0
		Oct	2.0	-15.0	26.0
		Nov	2.0	-15.0	26.0
Evaporation (mm)	Annual		0.7	0.2	1.6
	Summer	Dec	0.7	0.3	1.8
		Jan	0.7	0.3	1.8
		Feb	0.7	0.3	1.8
	Autumn	Mar	0.7	0.2	1.6
		Apr	0.7	0.2	1.6
		May	0.7	0.2	1.6
	Winter	June	0.7	0.2	1.6
		July	0.7	0.2	1.6
		Aug	0.7	0.2	1.6
	Spring	Sept	0.6	0.1	1.5
		Oct	0.6	0.1	1.5
		Nov	0.6	0.1	1.5

The monthly variation in soil moisture index compared to baseline is shown in Figures A1 and A2. The monthly variation in maximum temperature compared to baseline is shown in Figures A3 and A4.

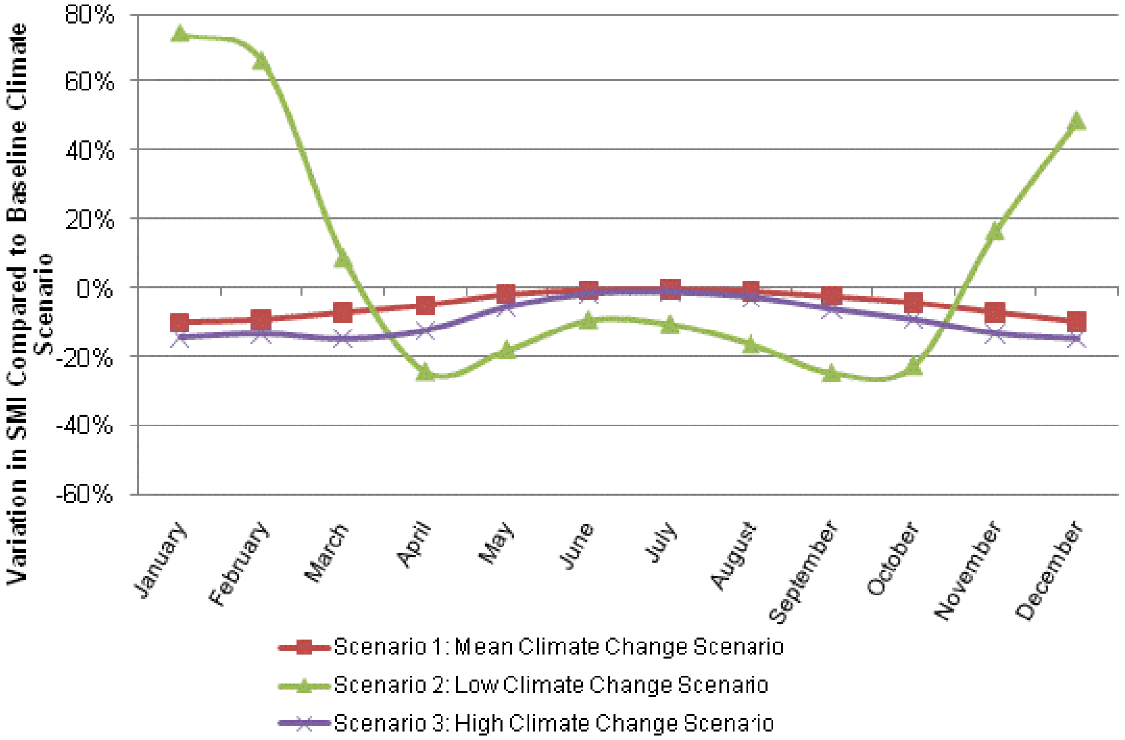

Figure A1: Monthly Variation in Soil Moisture Index Compared to Baseline for 2040

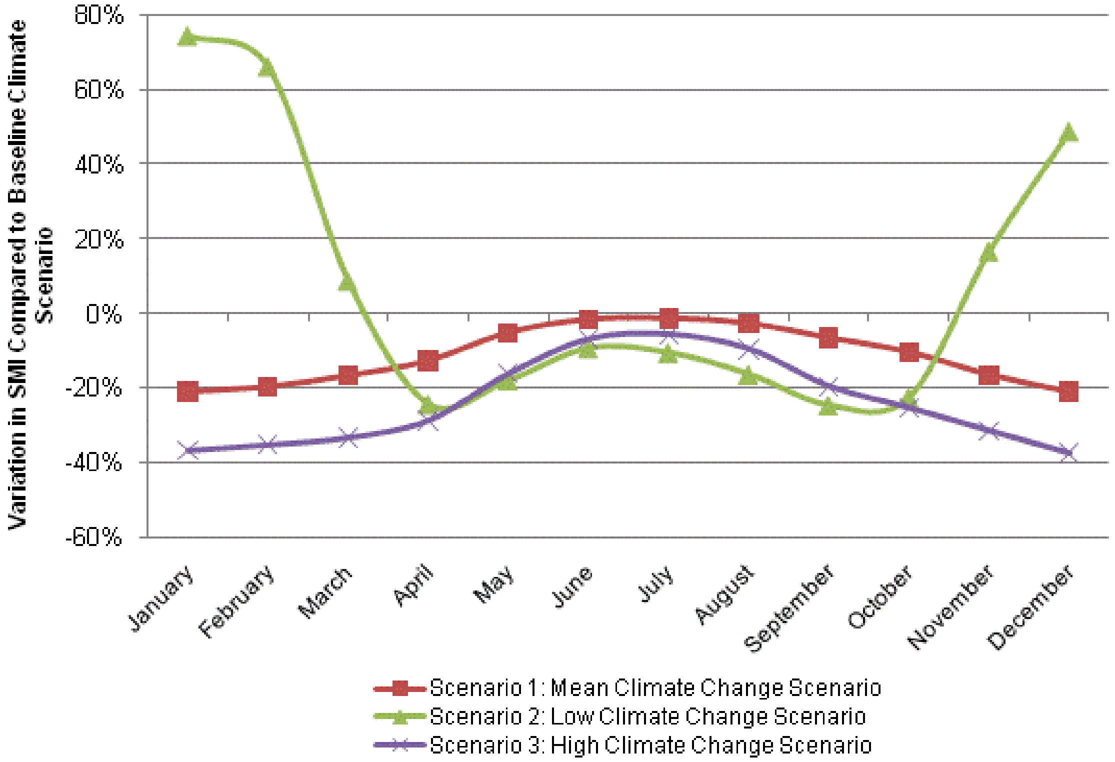

Figure A2: Monthly Variation in Soil Moisture Index Compared to Baseline for 2090

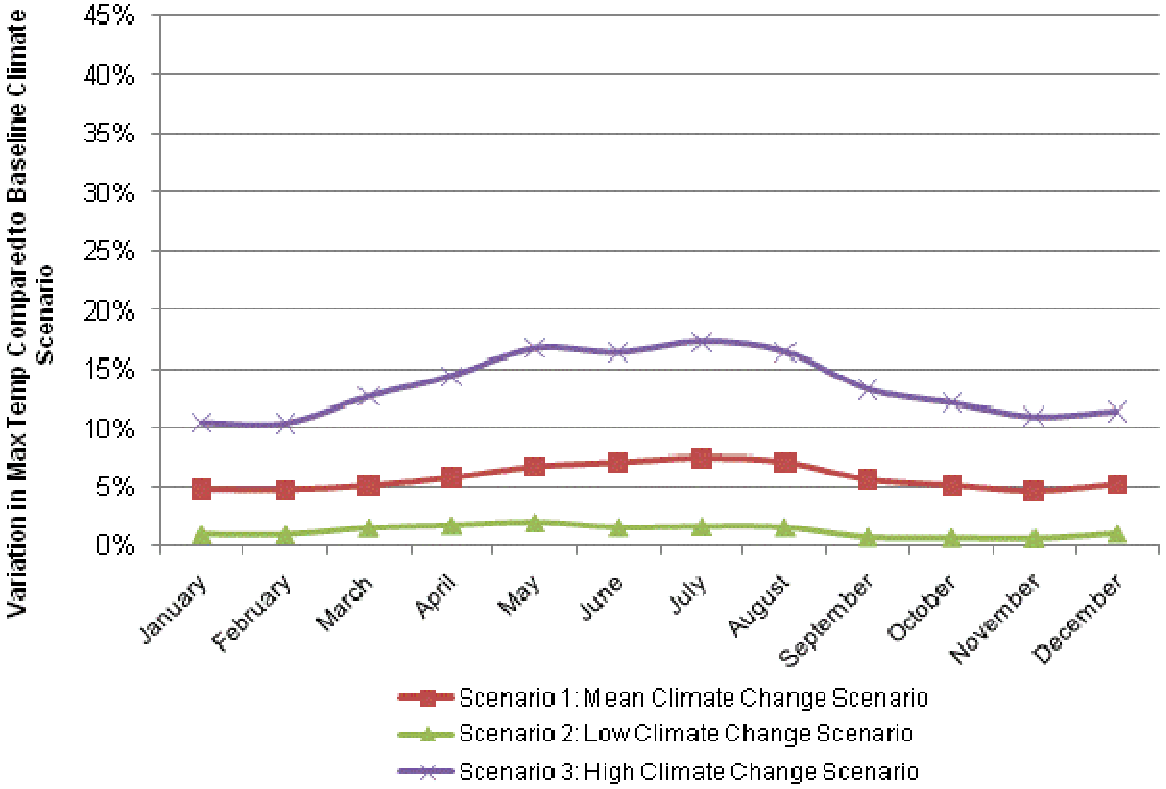

Figure A3: Monthly Variation in Maximum Temperature Compared to Baseline for 2040

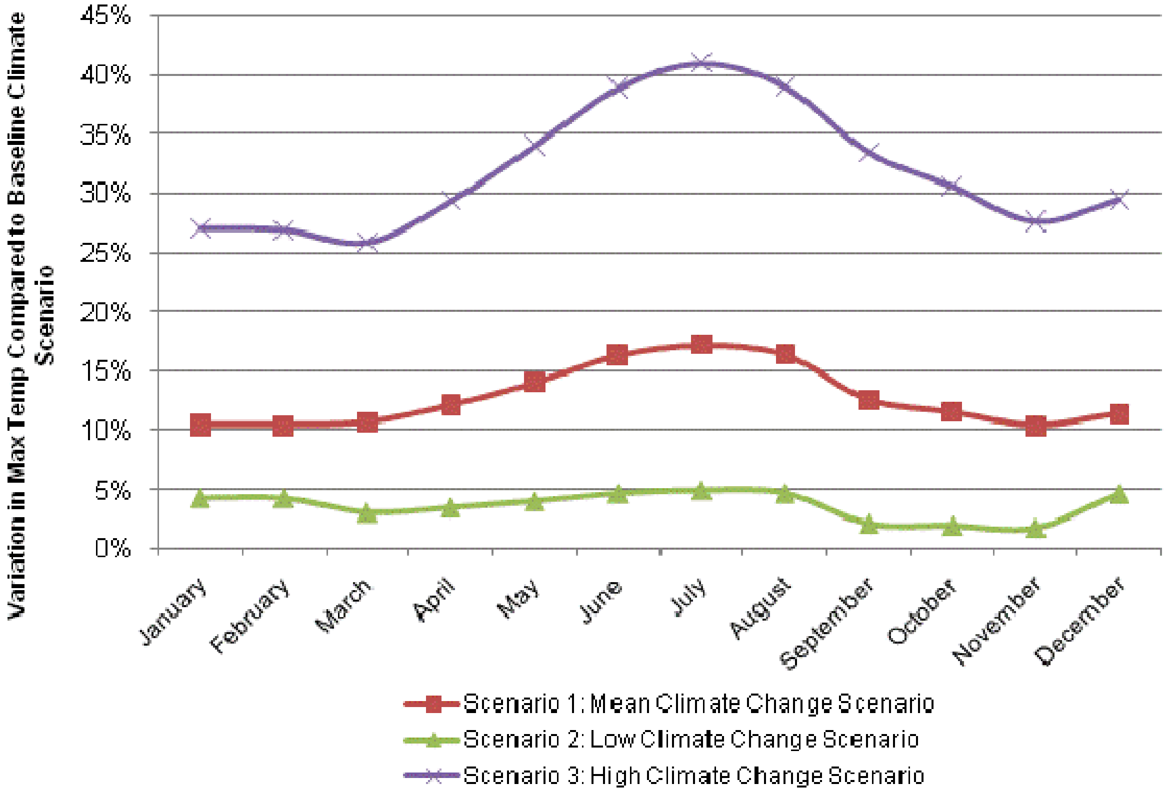

Figure A4: Monthly Variation in Maximum Temperature Compared to Baseline for 2090

Appendix B: Climate Change Impact on Average Day Demands by End Use

The following two tables outline the modelled impacts of annual water by end use for the Greater Wellington Region.

Table B1: Predicted Climate Change for the Greater Wellington Region for 2040

						Demand Predictions (L/capita/day)			
Sector		**Sectoral Breakdown**	**End Use Breakdown**	**Climate Influence Factors**		**Baseline**	**Mean Scenario 1**	**Low Range Scenario 2**	**High Range Scenario 3**
Residential	**Internal**	61%	75%	**Climate Influenced**	40%	73.8	75.7	73.7	77.9
				Non Climate Influenced	60%	110.8	110.8	110.8	110.8
	External		25%	**Climate Influenced**	90%	55.4	56.8	55.2	58.4
				Non Climate Influenced	10%	6.2	6.2	6.2	6.2
Non Residential	**Internal**	24%	80%	**Climate Influenced**	20%	15.2	15.6	15.2	16.0
				Non Climate Influenced	80%	60.8	60.8	60.8	60.8
	External		20%	**Climate Influenced**	80%	15.2	15.6	15.2	16.0
				Non Climate Influenced	20%	3.8	3.8	3.8	3.8
Non Revenue Water	**Real Losses**	15%	35%	**Climate Influenced**	75%	15.7	16.1	15.7	16.6
				Non Climate Influenced	25%	5.2	5.2	5.2	5.2
	Apparent Losses		35%	**Climate Influenced**	90%	18.9	19.3	18.8	19.9
				Non Climate Influenced	10%	2.1	2.1	2.1	2.1
	Unbilled Authorised Consumption		30%	**Climate Influenced**	90%	16.2	16.6	16.1	17.1
				Non Climate Influenced	10%	1.8	1.8	1.8	1.8
					Total	**401**	**406**	**401**	**412**

Table B2: Predicted Climate Change for the Greater Wellington Region for 2090

						Demand Predictions (L/capita/day)			
Sector		**Sectoral Breakdown**	**End Use Breakdown**	**Climate Influence Factors**		**Baseline**	**Mean Scenario 1**	**Low Range Scenario 2**	**High Range Scenario 3**
Residential	**Internal**	61%	75%	**Climate Influenced**	40%	73.8	78.3	74.4	84.4
				Non Climate Influenced	60%	110.8	110.8	110.8	110.8
	External		25%	**Climate Influenced**	90%	55.4	58.7	55.8	63.3
				Non Climate Influenced	10%	6.2	6.2	6.2	6.2
Non Residential	**Internal**	24%	80%	**Climate Influenced**	20%	15.2	16.1	15.3	17.4
				Non Climate Influenced	80%	60.8	60.8	60.8	60.8
	External		20%	**Climate Influenced**	80%	15.2	16.1	15.3	17.4
				Non Climate Influenced	20%	3.8	3.8	3.8	3.8
Non Revenue Water	**Real Losses**	15%	35%	**Climate Influenced**	75%	15.7	16.7	15.8	18.0
				Non Climate Influenced	25%	5.2	5.2	5.2	5.2
	Apparent Losses		35%	**Climate Influenced**	90%	18.9	20.0	19.0	21.6
				Non Climate Influenced	10%	2.1	2.1	2.1	2.1
	Unbilled Authorised Consumption		30%	**Climate Influenced**	90%	16.2	17.1	16.3	18.5
				Non Climate Influenced	10%	1.8	1.8	1.8	1.8
					Total	**401**	**414**	**402**	**431**

Appendix C: Climate Change Impact on Average Monthly Demands

The following tables outline the modelled impacts of climate change on the monthly average day for the Greater Wellington Region.

Table C1: Predicted Climate Change Impacts on Monthly Average Demands for the Greater Wellington Region for 2040

	Monthly Average Day Demand (L/capita/day)				Change relative to Baseline		
Month	**Baseline Climate Scenario**	**Scenario 1 (Mean)**	**Scenario 2 (Low)**	**Scenario 3 (High)**	**Scenario 1 (Mean)**	**Scenario 2 (Low)**	**Scenario 3 (High)**
January	457	469	431	477	2.5%	-5.6%	4.3%
February	446	458	421	468	2.6%	-5.6%	4.8%
March	415	423	411	436	2.1%	-0.8%	5.3%
April	388	392	404	401	1.2%	4.1%	3.5%
May	376	378	386	382	0.5%	2.8%	1.5%
June	372	373	377	374	0.2%	1.3%	0.5%
July	372	372	377	373	0.1%	1.5%	0.4%
August	374	375	383	376	0.2%	2.4%	0.6%
September	379	381	394	383	0.5%	4.0%	1.3%
October	387	390	401	395	0.9%	3.7%	2.1%
November	411	418	403	427	1.7%	-2.0%	3.8%
December	435	447	416	457	2.6%	-4.5%	4.9%
Average	**401**	**406**	**400**	**412**	**1.3%**	**-0.1%**	**2.9%**

Table C2: Predicted Climate Change Impacts on Monthly Average Demands for the Greater Wellington Region for 2090

	Monthly Average Day Demand (L/capita/day)				Change relative to Baseline		
Month	**Baseline Climate Scenario**	**Scenario 1 (Mean)**	**Scenario 2 (Low)**	**Scenario 3 (High)**	**Scenario 1 (Mean)**	**Scenario 2 (Low)**	**Scenario 3 (High)**
January	457	480	437	496	5.0%	-4.4%	8.4%
February	446	471	427	490	5.6%	-4.3%	9.9%
March	415	436	413	464	5.1%	-0.3%	11.9%
April	388	400	405	427	3.3%	4.4%	10.1%
May	376	381	387	396	1.4%	3.0%	5.2%
June	372	374	377	380	0.5%	1.4%	2.2%
July	372	374	378	379	0.4%	1.5%	1.8%
August	374	376	383	383	0.7%	2.5%	2.6%
September	379	384	394	398	1.4%	4.2%	5.1%
October	387	396	402	419	2.4%	4.0%	8.4%
November	411	429	404	457	4.3%	-1.7%	11.1%
December	435	460	421	485	5.8%	-3.3%	11.3%
Average	**401**	**414**	**402**	**431**	**3.1%**	**0.4%**	**7.5%**