Impacts of Climate Change
on Urban Infrastructure
& the Built Environment

A Toolbox

Tool 2.5.3: SYM Approach to Present-day and Future Potable Water Supply and Demand

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Contents

1. Introduction

This report outlines an approach to understanding urban water supply and demand dynamics, including the effects of climate change.

1.1 Background

A case study was undertaken into water supply management for the four cities of Wellington, Porirua, Lower Hutt and Upper Hutt, serviced by the one reticulated network. The aim of this research was to gain a detailed understanding of the factors and determinants influencing water use and management in Wellington, and how specific response options could affect future community and institutional adaptive capacity, and increase or decrease resilience to water shortages.

One of the objectives of this case study looked at interactions between water supply and demand factors, and climate change trends. This objective was addressed through the use of scenarios and projections based on water use in Wellington, using Greater Wellington Regional Council's hydrological computer model, the Sustainable Yield Model (SYM). The SYM was an essential tool for this objective, and this tool presents the methodology used.

1.2 This Tool

Under the Resource Management Act 1991, agencies such as Greater Wellington Regional Council (GW) are required to have particular regard to the effects of climate change. When considering long-term infrastructure projects this has particular salience, for example rainfall to Melbourne. water supply catchments decreased by about 19% in 1997-2008 compared to 1950-1997, reducing dam inflows by about 40% (Jones 2010, p.16). Regional scale analysis may indicate the potential for such shifts in operating conditions, which can then be taken into account when comparing adaptation options and pathways.

This tool provides an overview of the data that was generated by the SYM, how this data relates to the water supply system, and how the data was used.

1.3 Wellington's Water management Context

Greater Wellington Water (GWW) treat and distribute 'bulk' water to Upper and Lower Hutt, Porirua and Wellington cities (Figure 1.1). Water is sourced from the Waiwhetu Aquifer and the Hutt, Orongorongo and Wainuiomata Rivers. On average 40% of Wellington's water comes from the aquifer and 60% from rivers (MWH 2011). The 3000 ML Stuart Macaskill water storage lakes[1] at Te Marua provide a few weeks of summer storage (MWH 2011) and the Waiwhetu Aquifer[2] also acts as a buffer during dry periods Williams 2011, pers comm). In the year to June 2010, GWW supplied an average of 145 million litres (ML) of bulk water daily to 390,000 people (GW 2010).

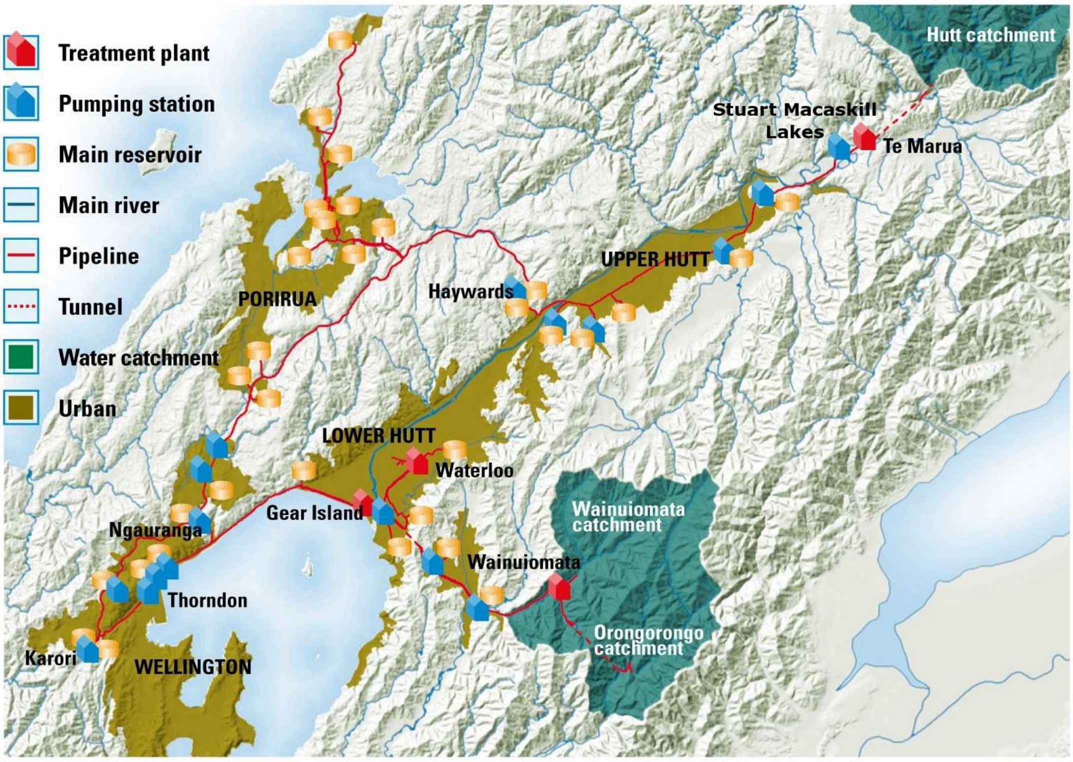

Figure 1.1: Wellington Regional Council water supply network (GW 2010).

Under the Resource Management Act 1991 (RMA), Regional Authorities such as Greater Wellington Regional Council (GW) are responsible for the management, use and allocation of freshwater resources. The purpose of the

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[1] The storage capacity of the Stuart Macaskill Lakes will be 3390 ML once current upgrades are complete (Shaw and McCarthy 2009).
[2] Abstraction occurs at Waterloo and Gear Island, ranging from 20 – 120 ML/day, and averaging 60 ML/day (GW 2008b).

RMA is *"to promote the sustainable management of natural and physical resources… to meet the reasonably foreseeable needs of future generations".* GWW's purpose statement reflects this legislative influence:

> *We aim to provide enough high-quality water each day, now and in the future, to meet the reasonable needs of the people of our region's four cities, in a cost-effective and environmentally responsible way* (GW 2010, p.2).

Capacity Infrastructure Services Limited, a Council-Controlled Trading Organisation owned by Wellington and Hutt City Councils, manages the water infrastructure (including wastewater) and retailing services for the water that GW deliver to Wellington, Hutt and Upper Hutt City Councils, while Porirua City Council manages its own water retailing and infrastructure. Capacity does not own the water, stormwater and wastewater assets, set policies, or control rates and user charges; these roles remain with the councils (Capacity 2010).

> *Capacity Infrastructure Services plans and manages the development and maintenance of the 'three waters' – drinking, storm and waste water. This includes maintaining pipes, managing and monitoring pump stations and providing advice and information on water conservation to preserve the Wellington region's water wealth now and into the future* (Capacity 2010, p.2).

GWW aims to meet a 2% 'security of supply' or Annual Shortfall Probability (ASP) standard, i.e. they aim to meet demand 49 out of 50 years. The security of supply standard represents a level of service to customers, indicating the frequency with which water restrictions could be imposed in order to manage demand (WCC 2009). As seen in Figure 1.2, overall the demand for water has not kept pace with population growth since the early 1990s. This has been due to factors such as the decline in manufacturing in Wellington since the 1980s, urban intensification, infrastructure renewal and increased public awareness of the need for water conservation (Williams and McCarthy 2010, pers comm.).

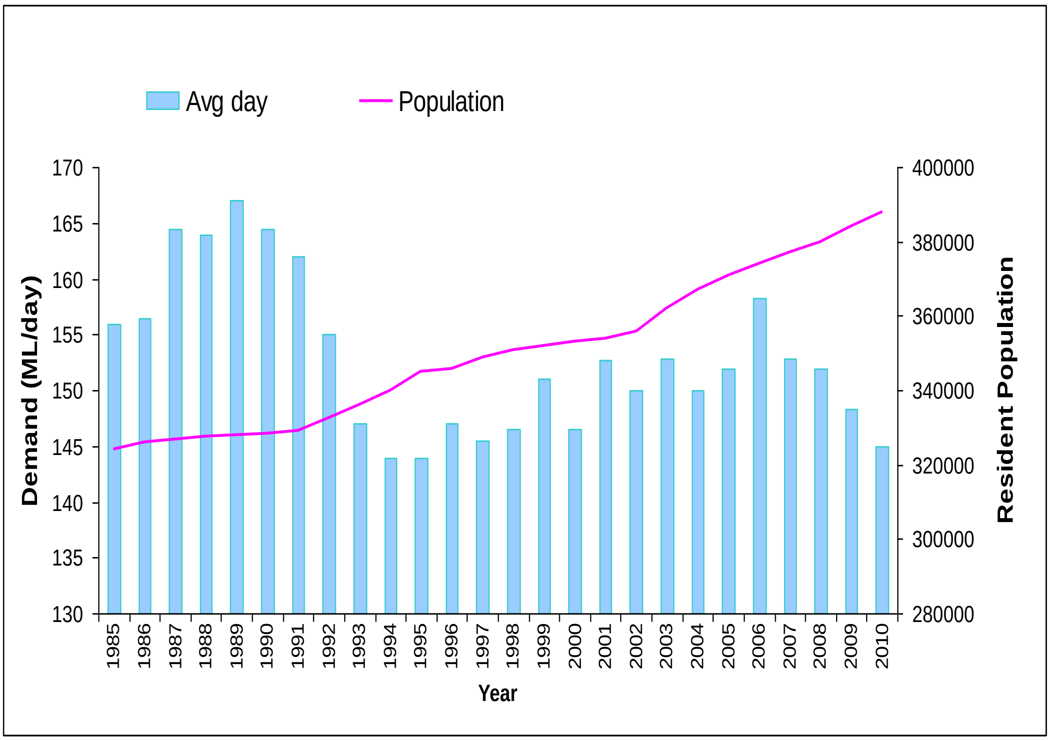

Figure 1.2: Average daily demand (Avg day) and resident population (serviced by water reticulation network) for Wellington 1985 to 2010 (Graph updated from GW 2008).

As bulk supplier, GWW charges a water levy to its city council customers based on the relative percentage of water they use. Wellington City uses the majority (54%) of the water, Lower Hutt (25.3%), Porirua (11.7%) and Upper Hutt (9.2%) (GW 2010). Most commercial and industrial consumers are metered; but only one percent of domestic water users have meters (GW 2008). In Wellington City, meters are voluntary for residential consumers unless the residence has a swimming pool greater than 10kL in capacity (WCC, undated). The vast majority of domestic water users are not charged for water on a user pays basis, but only in relation to their property value.

2. Methodology

2.1 Data Generation and Treatment

GWW uses a computer model, the Sustainable Yield Model (SYM) to enable water managers to assess the response of the water supply system to changes in infrastructure or operational practice, as well as changes in climate and demand scenarios. The National Institute of Water and

Atmospheric research (NIWA) produces supply and demand input files for the SYM using synthetic daily climatic and water demand sequences that are based directly on historic climate and water demand data for the four city councils supplied by GWW.

For this project, NIWA input files were also produced for each of three Intergovernmental Panel on Climate Change (IPCC) emissions scenarios (B1, A1B, A2) for '2040' (averaged over the 2030 to 2049 period[3]) and '2090' (averaged over the 2080 to 2099 period). The NIWA input files for the SYM are based on a number of relevant regional climate parameters. These parameters were derived from daily data sequences based on 12 different downscaled climate model projections as well as a projection based on the average of these 12 models, for each of the IPCC scenarios for 2040 and 2090. The 12 model average provides a useful general trend projection for each scenario, while the individual models themselves provide some indication of a range of possibilities and the level of 'agreement' between models, based on the present level of understanding of the climate system. A 'low-carbon', 2°C stabilisation scenario was also used to produce input files for the SYM. This scenario was used for 2090 only as the trends projected by the high and low carbon scenarios do not differ significantly in 2040 (Figure 2.1). Background on using this General Circulation Model set for New Zealand scenario analysis is available in Reisinger et al. (2010).

[3] This 20 year averaging removes *"much but not all"* of the natural variability as represented by the models (Resinger et al. 2010).

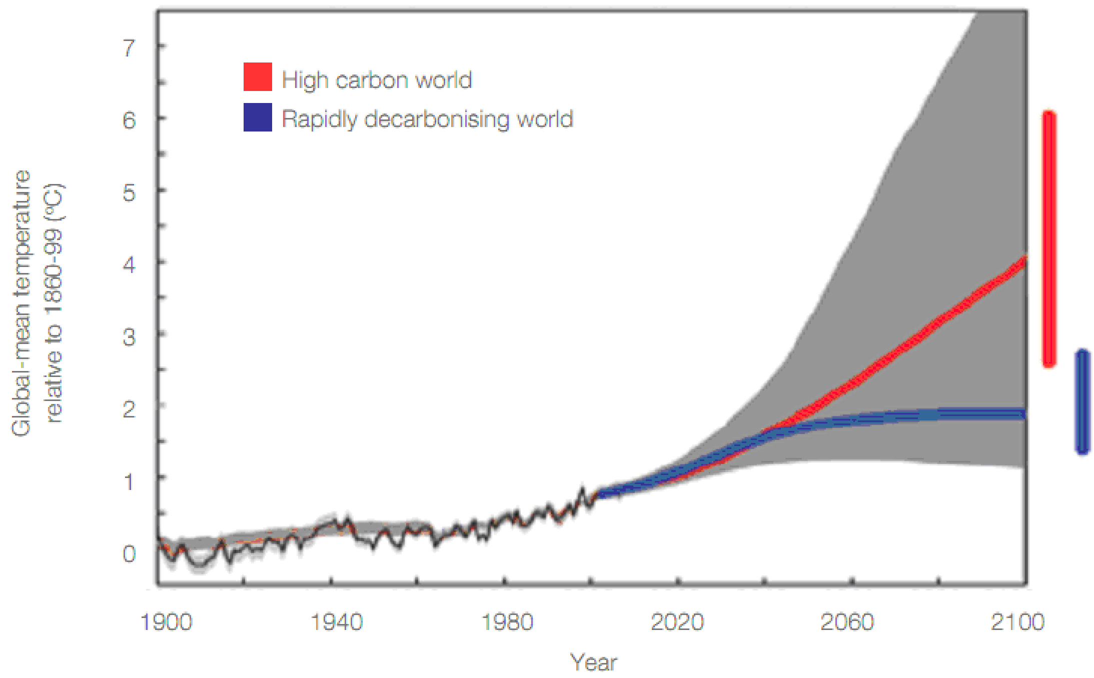

Figure 2.1: Global average temperature increase relative to pre-industrial times for the A2 "high carbon world" and the low-carbon "Rapidly decarbonising world" scenarios (relative to 1860-1899). The vertical bars to the right indicate the likely range (66% probability) for each scenario during 2090-2099 (Reisinger et al. 2010). The grey area shows the range of temperatures simulated for the 20th and 21st centuries, indicating that due to uncertainties in the climate system, the 'high carbon' scenario is not an 'upper end'.

For the Wellington case study, the SYM was used to generate daily Potentially Available Water (PAW) and Per Capita Demand (PCD) data, providing both supply and demand projections, without storage. PAW represents daily abstractable volume in ML from Te Marua, Waterloo and Wainuiomata water treatment plants combined, with existing consent limits and treatment plant capacities. Total System Demand (TSD) was calculated by the sum product of the PCD for each of the eight demand centres and the corresponding population (Williams 2010). Net-flows and running net-balances (running net-flows) were calculated in order to explore the various scenarios ('net-flow' was calculated by subtracting TSD from PAW). The effect of climate change was isolated from population increase by comparing projections with the population held constant. The relationship between PCD, PAW, net-flow and TSD is shown in Figure 2.2, with values for Wellington.

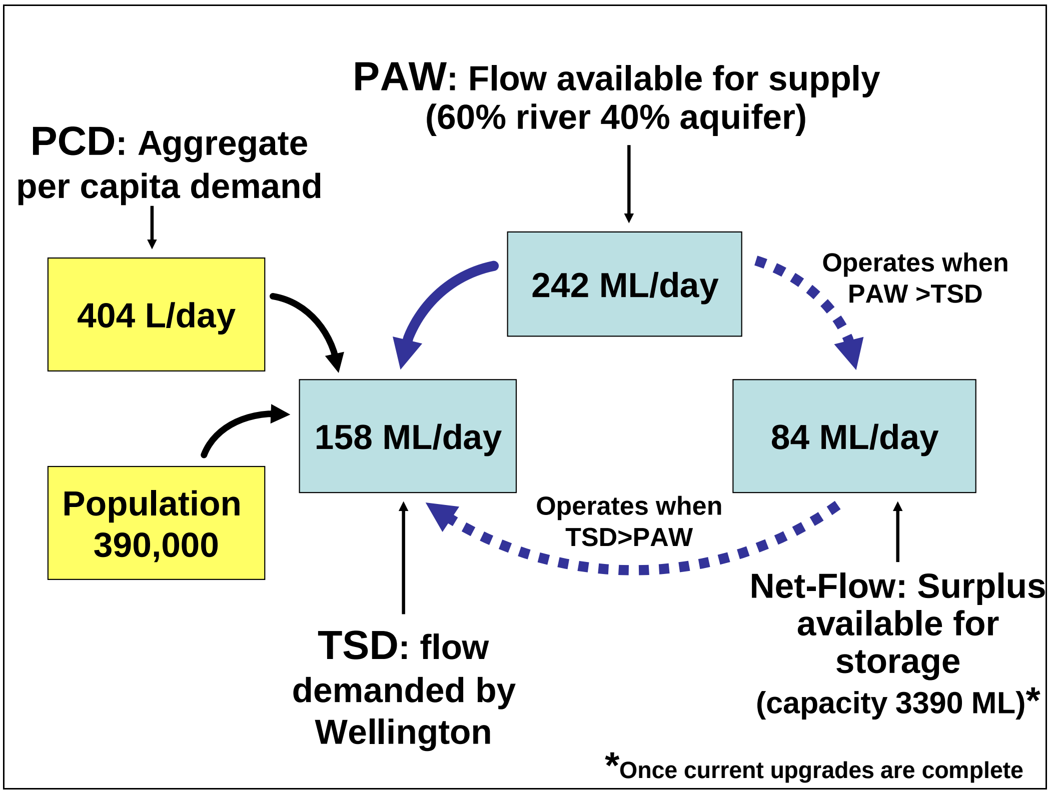

Figure 2.2: Relationships between PCD, PAW, TSD and Net-flow with their respective daily average current values for Wellington (data from 2009/2010, PCD based on 5 year average).

PCD in the SYM model is based on average water consumption of the last five years, which is 404 ML/day for Wellington. However, daily per capita water consumption for Wellington has been decreasing steadily for both peak and base demand. The average rate of decline has been 3.3% per year over the last four years, or 1.5% per year averaged over the last 10 years (see Figure 2.3). While Wellington's population has been growing at an average of 1% over the last 10 years, total demand has been falling and in total, PCD fell 25% between 1990 and 2010[4].

[4] Calculated from data for Fig. 1.2.

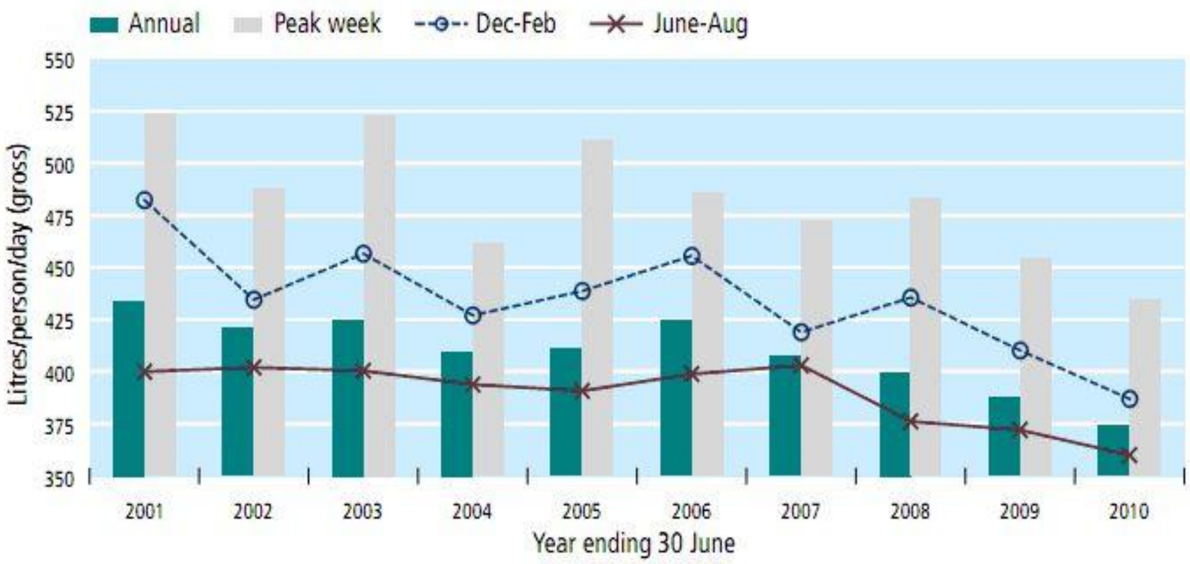

Figure 2.3: Declining per Capita Demand in Wellington 2001- 2010 (Capacity 2010).

If the 1.5% average annual reduction in per capita demand continues to 2025, along with a 1% annual population increase, Wellington's aggregate consumption of 375 L per capita/day will shrink to a similar level to Auckland's (302 L per capita/day; Kenway 2008) by 2025. In addition, Wellington's average total daily demand will decrease from 146 ML/day to 135 ML/day (Table 2.1). The calculations in Table 2.1 show that a reduction in Wellington's water-intensity to 303 L/day is theoretically feasible by 2025.

Table 2.1: Water savings and changes in consumption and population to 2025 with 1.5% annual demand reduction and 1% population growth. Projections for the '2040 scenario' are presented in section 3.2.

Year	2010	2015	2020	2025	2040 Scenario
Aggregate PCD (L/day)	**374**	347	322	***298***	303
Domestic PCD[5] (L/day)	**235**	218	203	***189***	191
Population	**390,000**	410,000	431,000	***453,000***	467,500[6]
Annual Average Consumption (ML/day)	**146**	142	139	***135***	***142***
Water saving (Per Capita, 2010 baseline)	0%	7%	14%	**20%**	20%[7]

In light of this local analysis indicating potential for a significant decline in Wellington's water intensity, a further data treatment was to explore a scenario where average aggregate daily per capita demand is reduced from 404 L to 303 L. The 303 L/day scenario was calculated by multiplying the applicable PCD data by a factor of 0.75.

2.1.1 Scenario Presentation

The output data from the SYM consisted of projections for 115 year daily data sequences from each of 12 General Circulation Models (GCMs) and the 12 model average, for three IPCC emissions scenarios for 2040 and four for 2090. Such data sets were produced for TSD, PCD and PAW. Line graphs and box plots were used in order to present the data graphically and

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[5] 63% of Aggregate PCD

[6] Projected population used for the Wellington case study scenarios, equates to an average annual population increase of 0.6% from 2010.

[7] Includes 1% projected increase in PCD due to climate change.

to compare the range of scenarios and models. Figure 2.4 shows the conventions that are used in the Wellington case study to display the data using box plots, and how the box plots relate to the probability density of the data. Figure 2.5 shows how the boxplots relate to flow variability over time. The 'box' contains 50% of the data, and 96% of the data is within the whiskers (2nd and 98th percentiles). The 2nd and 98th percentiles were used as the lower whisker relates to GWW's 2% security of supply standard (one-in-50 years 'annual shortfall probability') in the 'running net flow' graphs. The 2% security of supply standard is commonly used by water suppliers (MWH 2011).

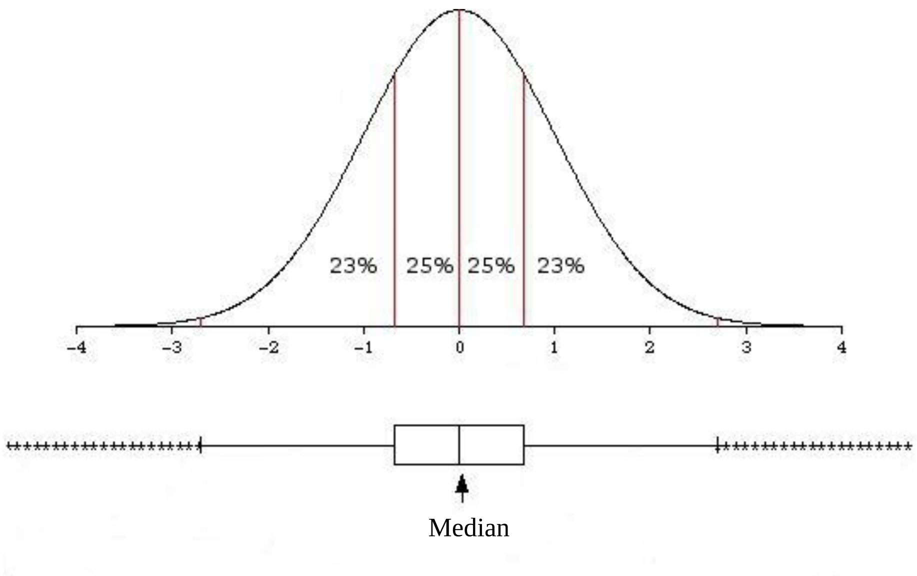


Figure 2.4: Box plot relationship to probability density for this analysis. The 'box' contains 50% of the data and 96% of the data is within the whiskers (2nd and 98th percentiles). Only the lowest and highest data points will be plotted as 'outliers'.

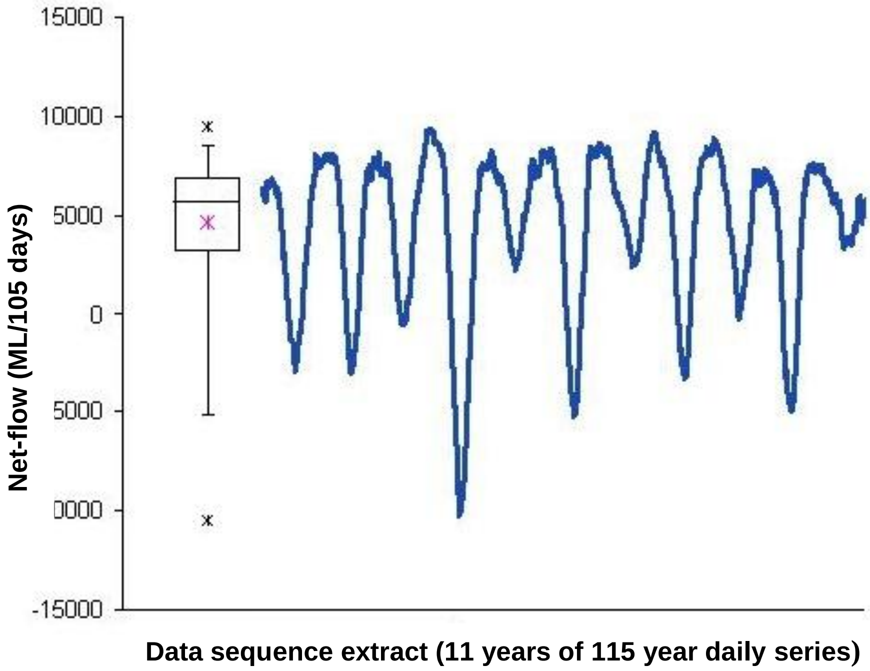


Figure 2.5: Box plot showing distribution of values for 105 day running net-flow (PAW – TSD) for the miub 2040 A2 scenario. The pink asterisk indicates the mean and the plotted blue line adjacent to the box is for an eleven-year sample of the data series.

Data Generation and Treatment Summary

- The SYM produces supply and demand output files.
- 115 years of daily supply (PAW) and demand (PCD) sequences were produced for the B1, A1B, A2 and low-carbon scenarios for 2040 and 2090, and for each of the 12 downscaled model projections and the 12 model average.
- PAW and PCD were generated for the Wellington case study. TSD and net-flow were calculated from PAW, PCD and population projections.
- Net-flow is displayed using box-plots, the 'box' shows 50% of the data, and the lower whisker indicates the 2% level.

2.2 Scenario and Model Selection

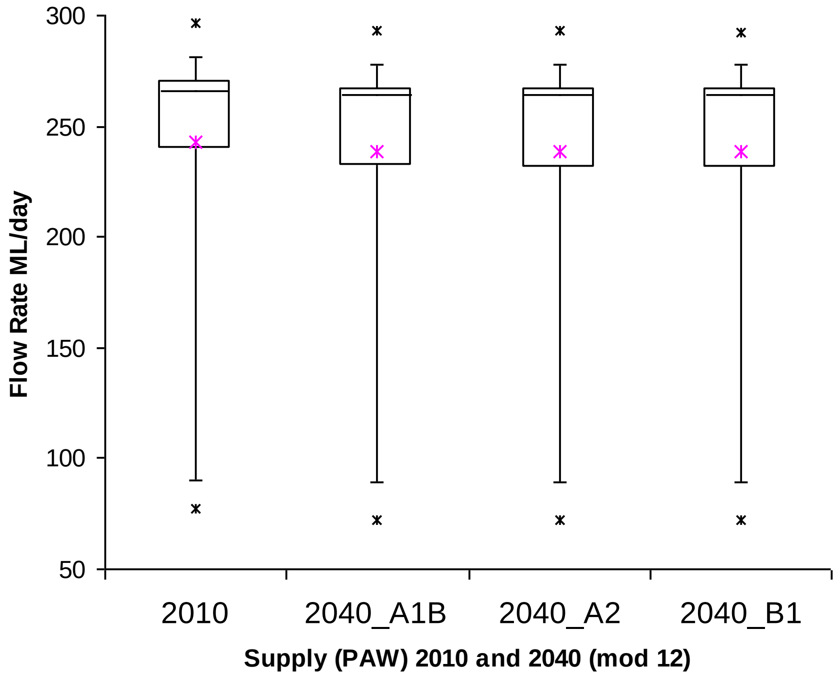
The projected climate parameters for the SYM input files are averaged over a 20 year period, this averaging is necessary in order to capture changes in long-term climate versus more short-term variation. Averaging removes much of the natural variability as represented in the models (Reisinger et al. 2010), yet this variability is a significant consideration at the local scale (Jones 2010). Not surprisingly, the most likely failing of local-level analysis is that it **under-represents climate variability** (Jones 2010). However, many of the impacts of climate change are the result of 'surprises' that come with extreme weather (Climate Commission 2011), as this is where most of the damage to communities and assets occurs.

While caution should always be taken when interpreting the results of a single model or projection, at the same time no one model can be ruled out (Kundzewicz et al. 2007). Current trends show IPCC projections to be conservative since many variables are tracking at or above the level of the 'high' IPCC projections (Jones 2010). Moreover past and present emissions represent a commitment to further warming for the **next few decades**, yet sufficient mitigation policy commitments are still lacking, and if/when they arrive will take further time to implement and have an effect (Jones 2010). Therefore in selecting specific models and scenarios for analysis for the Wellington case study, a key principle was that **prudent adaptation planning needs to take high projections into account, including 'extreme' events**.

> *"Many of the impacts of climate change are due to extreme weather events, not changes in average values of climatic parameters"*
> (Climate Commission 2011, p.38).

For the Wellington case study, the projected demand (TSD) and supply (PAW) flows for the climate scenarios were first explored using the 12 model average to check the variation between the projections for 2040 and 2090 (Figures 2.6 and 2.7). As there was very little variation between flows for the scenarios in 2040, the A2 scenario was selected in order to compare the 2040 projections with the 2090 scenarios and 2010. The differences between scenarios for 2090 were greater than for 2040, and the A2 and low-carbon scenarios were selected for comparative analysis.

Daily net-flow was then calculated for the A2 scenario in order to look at the variation between models for 2040 (Fig. 2.8). The miub model was selected as it captures the greatest range over both 2040 and 2090, particularly in terms of the extent of deficits that Wellington may need to adapt to. Figure 2.8 also shows considerable ‘agreement’ between models, particularly for 2040.



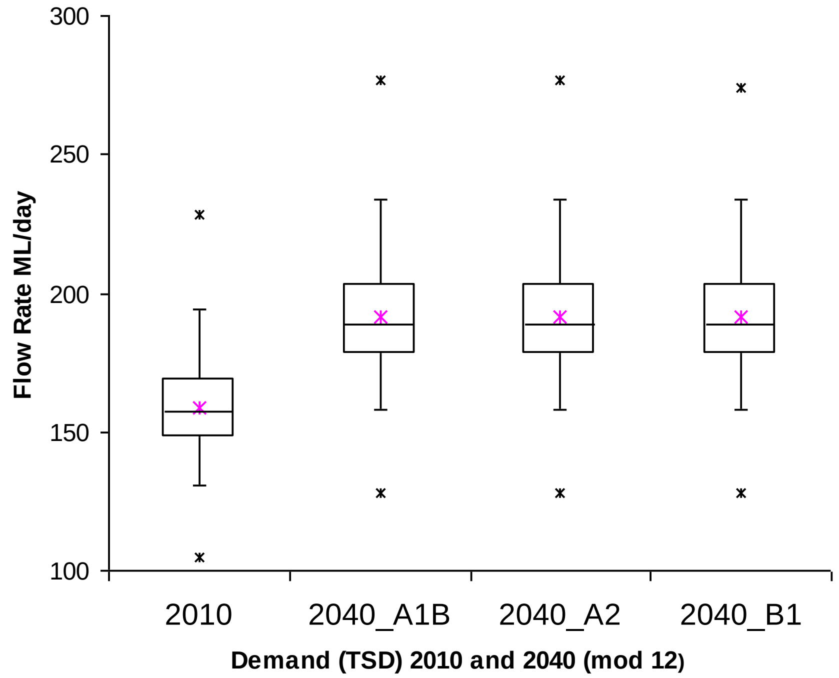
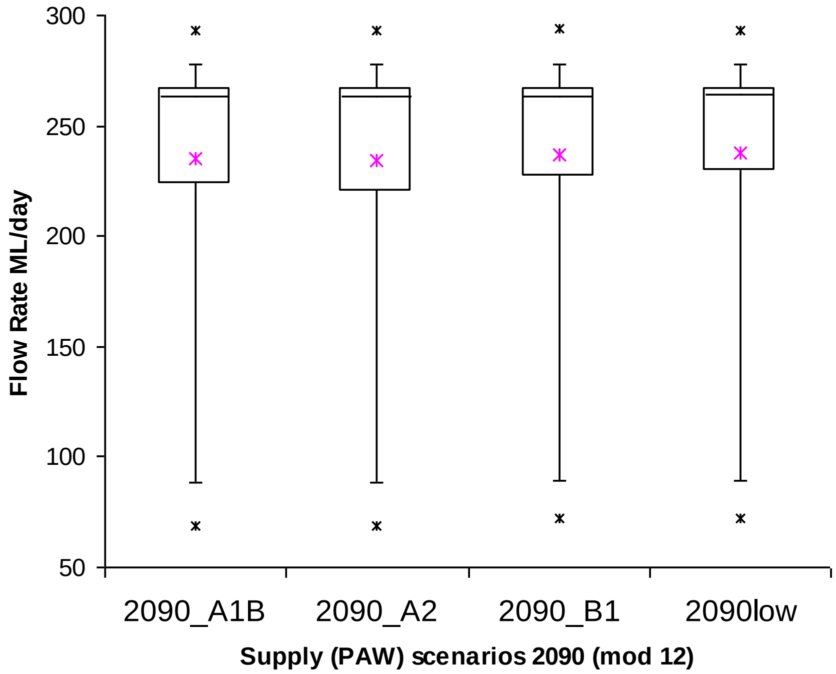


Figure 2.6: Projected daily supply (top) and demand (above) flows for Wellington for 2010 and by scenario for 2040. The boxes show the first and third quartiles and median. Whiskers go to the 2nd and 98th percentiles, and the largest and smallest data points are marked as 'outliers' with black crosses. The means are shown with pink crosses.



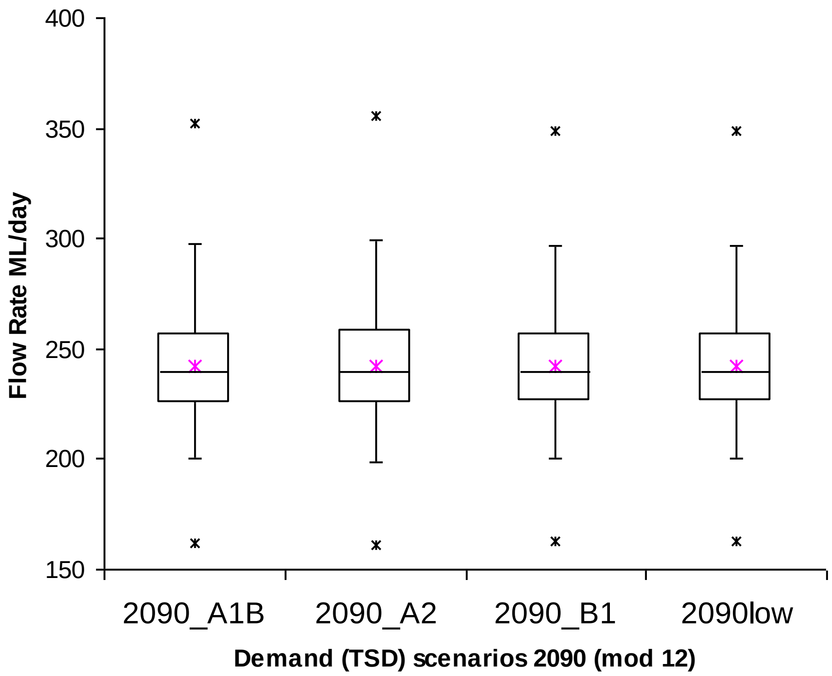


Figure 2.7: Projected daily supply (top) and demand (above) flows by scenario for Wellington for 2090.

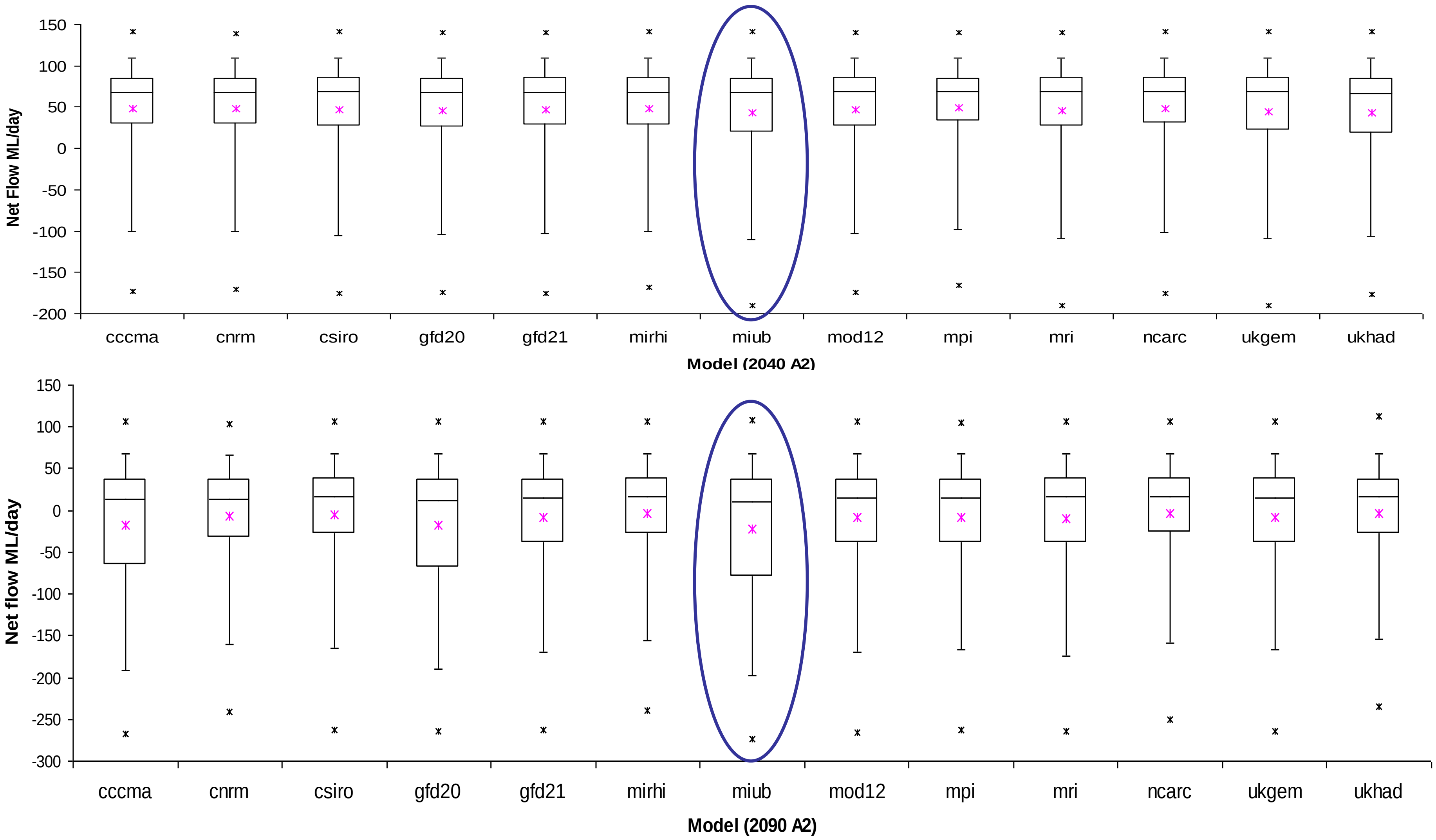


Figure 2.8: Net-flow (PAW-TSD) by model for the A2 scenario for 2040 and 2090. The miub model projections are circled.

2.3 Exploring Extremes

A water shortage event is the net effect of both supply and demand factors, which includes a range of variables such as population, intensity of water use, storage capacity and water supply dynamics (e.g. aquifer and/or river extraction). Therefore the occurrence frequency of 'water shortage' events in the context of an urban water supply system may differ considerably from drought frequency, which is primarily climate related (more or less depending on water intensity and supply and storage capacity). For example, a community with a high water intensity, dependant on a 'run of river' supply, and minimal storage, may be more vulnerable to water shortages than a community with a much lower water intensity, and with less dependence on river flows.

Trenberth (2011) suggests that **trend** plus **variability** may be useful for understanding extremes. The 2040 and 2090 projections produced as outputs by the SYM indicate the extent of the trend increase for that point in the future, while a running-net balance can be used to indicate variability. A scenario with average PCD of 300 L/ day was calculated for Wellington for 2040 (A2 mod12)[8]. The net-flow over an 80 day period (80 day running-net, as seen in the event profiled in Figure 3.10 gives the largest deficit for this scenario (a longer or shorter duration fails to capture the full extent of the largest deficit). The 12 model average projection for the A2 scenario was used to enable a more rigorous analysis of individual events within the data series, with miub and mpi model projections used to indicate the range of variability at the peak of the deficit.

2.4 Limitations and Uncertainty

The approach outlined for this tool uses a combination of emissions and demand scenarios, based on both historical data and on recent trends in order to explore the relative contribution of key variables; for example the potential for a 'greater than expected' decline in per capita demand to offset population growth. This section briefly outlines factors identified for the Wellington case study, that require caveats with regard to the scenarios and projections that were used in the analysis for this case study.

Total System Demand (TSD) data was based on aggregate per capita consumption (PCD) of 404 L/day. This level of water intensity is relatively high in comparison with

[8] i.e. using the IPCC A2 scenario projected by the 12 model average.

Auckland and major Australasian cities which average 310 L/day (Kenway et al. 2008). As seen in Figure 2.3, aggregate per capita water consumption in Wellington was 374 L/day in the 2009-2010 year and in recent years has been trending downward at an increasing rate. Changing consumption patterns was initially identified as a significant source of uncertainty for the PCD data, and this was addressed by introducing a scenario for average PCD of 303 L/day.

The potential for greater than expected population growth due to 'climate migration' creates substantial uncertainties for projected TSD. Projections of population growth are based on current trends, but New Zealand is a relatively sparsely populated country, and may escape some of the more severe impacts of climate change (Hennesy et al. 2007). Already millions of people have been displaced in recent years due to extreme weather in Malaysia, Pakistan, China, the Philippines, and Sri Lanka (ADB 2011). Therefore as the global average temperature increases there is considerable potential for climate change to increase Wellington's population particularly due to immigration from the Pacific and Australia (Reisinger et al. 2010, p.31), Asia (ADB 2011) and returning expatriates. Reducing Wellington's currently high water-intensity offers significant potential for offsetting greater than expected population growth. If such a population scenario were to occur, and Wellington's water intensity can be brought down to a similar level as Auckland's, the 404 L/day scenario can then be used as an indicator of a scenario with a population one third greater than expected; requiring an average annual growth rate of 1.7% from 2010. Reducing Wellington's water-intensity is a 'no-lose' strategy for dealing with this uncertainty.

Wellington receives 40 % of its water supply from the Waiwhetu aquifer. There will be a threshold at which abstraction from the aquifer may need to be reduced in order to counter an increased risk of saline intrusion as a result of sea-level rise (Ibbit and Mullan 2007). However, the projected Potentially Available Water (PAW) data used in the present study excludes the effects of sea-level rise on the Waiwhetu Aquifer. This was due to insufficient information regarding the impact of the more recent and higher sea-level rise projections on the aquifer (Royal Society 2010, Vermeer and Rahmstorf 2009), and since sea-level parameters within the SYM are based on the IPCC third and fourth assessment reports (Ibbit and Mullan 2007). As seen in Figure 2.9, the IPCC projections for sea-level rise are much lower than the more recent projections. The projections by Vermeer and Rahmstorf shown in Figure 2.9 are the highest, with a range of 20 to 40 centimetres by 2040, and 60 to 160 centimetres by 2090; in which case abstraction from the Waiwhetu Aquifer may be affected by 2040. The primary implications of sea level rise for uncertainty with PAW projections will be for the high emissions scenarios towards the end of the century. With 40% of Wellingtons water supply coming from the aquifer, additional research into the effects of sea-level rise on water abstraction rates from this source is needed.

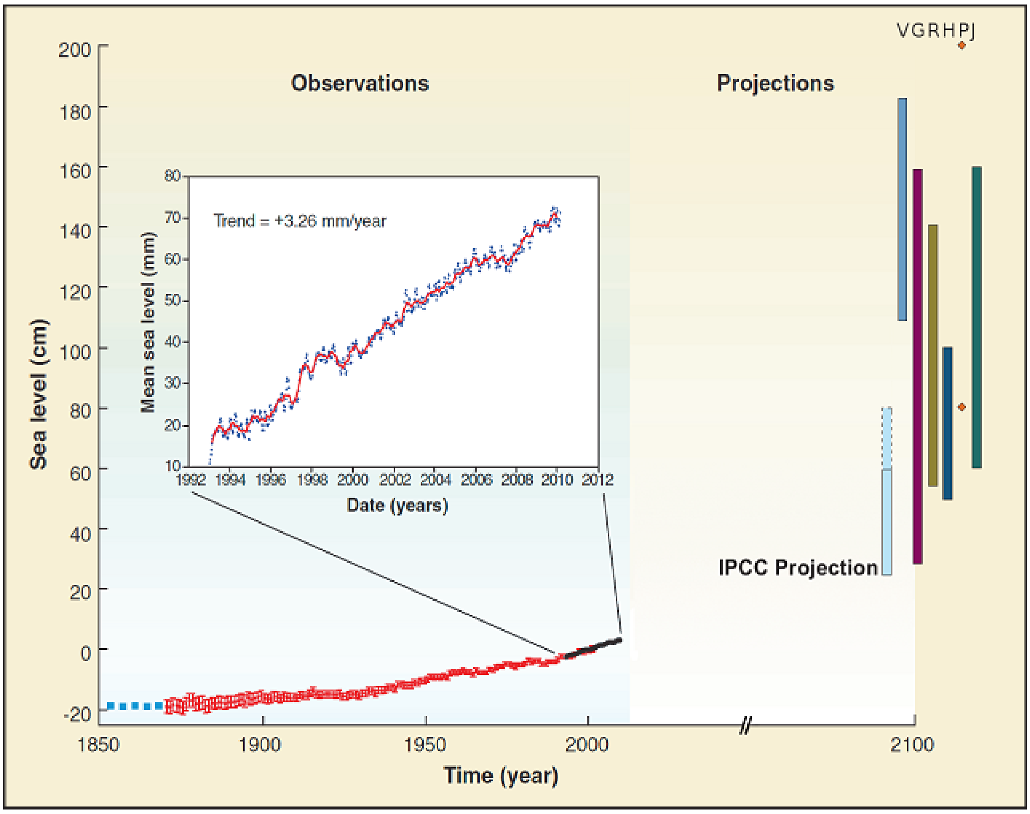


Figure 2.9: IPCC sea-level rise projections for the A1FI (greatest emissions) against more recent work[9]. The IPCC was unable to provide an upperbound for sea-level rise and the dotted area above the IPCC projection relates to dynamic ice behaviour for which inadequate information was available to include in that projection (Royal Society 2010, graph adapted from Nicholls and Cazenave 2010).

[9] VGRHPJ in the top right of the graph refer to the authors as follows:
Vermeer and Rahmstorf (2009); Grinstead, A., et al. (2009); Rahmstorf, S. et al. (2007); Horton, R. et al. (2008); Pfeffer, W.T., et al. (2008); and Jevrejeva, S., et al. (2010).

Scenario and Model Selection Summary

- Local-level analysis under-represents climate variability.

- Committed to further warming for the next few decades, i.e. 2010 to 2040 period.

- Prudent adaptation planning needs to take high climate change projections into account, including extreme events - 'trend plus variability'.

- Scenario selection: The 12 model average projections was used to show variation between scenarios for 2040 and 2090. Very little variation in 2040 for Wellington, A2 selected for 2040, and A2 and low-carbon scenarios selected to indicate a range for 2090.

- Model selection: A2 daily net-flow used to show variation between models, considerable agreement between models for Wellington projections. Miub model selected as captures greatest range for deficits for 2040 and 2090.

- Extremes: 2040 and 2090 SYM outputs indicate the extent of the trend increase, running-net balance used to indicate variability.

- Uncertainty: Areas of significant uncertainty identified, reduced consumption scenario added, projections based on current water-intensity also indicates significantly greater population growth with lower water intensity.

- Local Context: Consideration of local factors is essential.

3. Results from the Wellington Case Study

3.1 Potential Impacts – scenario analysis

The seasonal variation of supply and demand can clearly be seen in Figures 3.1, 3.2 and 3.3; demand is greatest in summer when supply is most restricted. Whilst there is sufficient water to meet projected demand under average summer conditions, substantial overlap occurs during January, February and March at just one standard deviation (Figure 3.1).

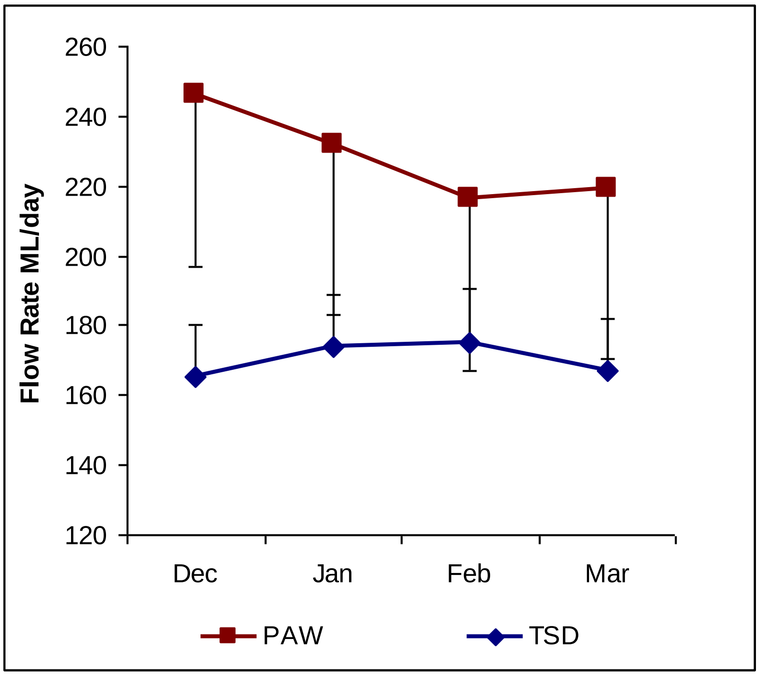


Figure 3.1: Average daily supply (PAW) -1 standard deviation, and average daily demand (TSD) + 1 standard deviation in ML/day, from December to March under present climate variability.

By 2040 climate change could decrease PAW by 5% or 12 ML per day on average for January and February (Fig. 3.2), with a corresponding 4.5 litre or 1% increase in average per capita demand (PCD) (Fig. 3.3). The 12 ML difference in PAW is the gap between ‘current’ and the 2040 scenarios for ‘Jan/Feb’. The projected decrease in PAW between 2040 and 2090 is 5.5%, and the projected increase in PCD from 2010 to 2090 due to climate change is 3%. The combined effect of climate change and population growth on demand would be an average increase of 2.1 ML/day for January and February 2040. With average PCD modelled at 404 L/day, and the projected population increase, climate change accounts for 14.1 ML of water for January and February 2040 (i.e. in relation to a reduction in net-flow), or a average daily shortfall of an equivalent volume of water sufficient to supply 35,000 people.

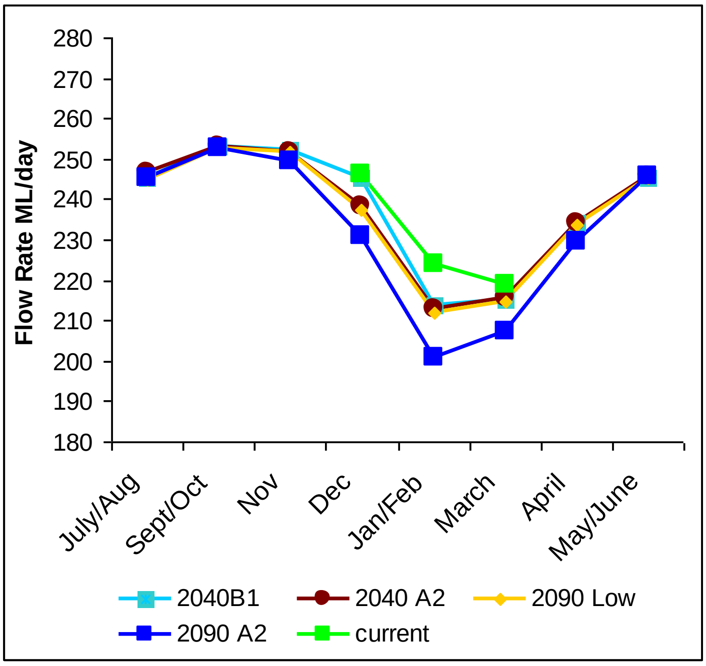


Figure 3.2: Average daily supply (PAW) 2040 and 2090 by month and IPCC A2, B1 and low carbon scenarios (Mod 12).

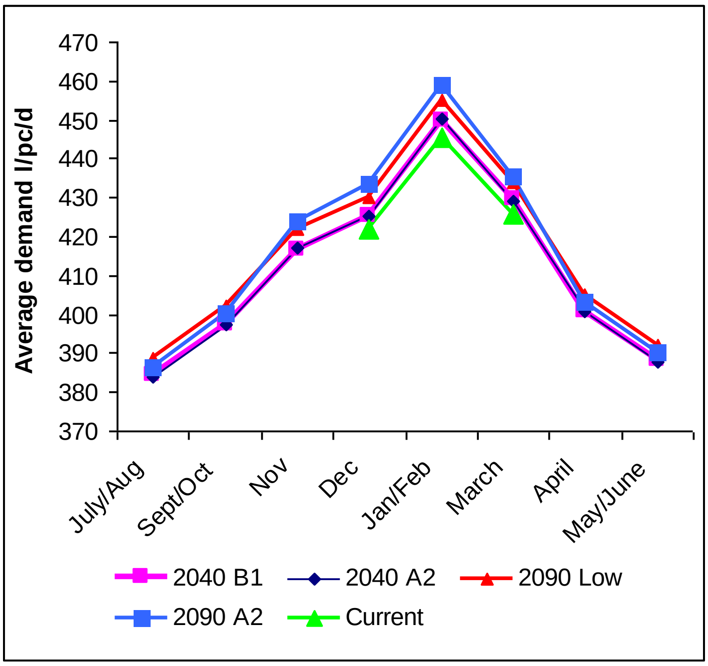


Figure 3.3: Average Per Capita Demand (PCD) 2040 and 2090 by month and IPCC A2, B1 and low carbon scenarios (Mod 12).

As shown in Figure 3.4, when the projected population increase for 2040 is taken into account, average supply and average demand overlap in February, indicating that even in an average year, storage of surplus water from winter would become essential for supplying water in the summer.

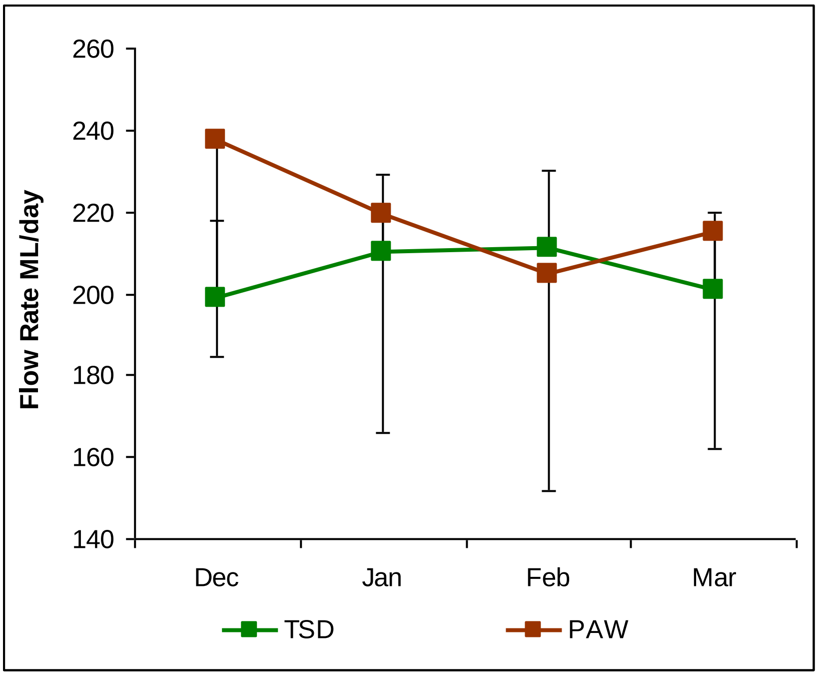


Figure 3.4: Average daily supply (PAW) -1 standard deviation, and average daily flow demanded (TSD) + 1 standard deviation in ML/day, from December to March under climate variability for 2040 A2 with population growth (Mod 12).

During a drier than average summer, daily demand may easily increase by more than one standard deviation from the mean with a concurrent decrease in supply. As a dry summer progresses, the deficit between demand and supply can grow considerably. Figure 3.5 shows the potential degree of annual variability for net-flow. As shown in Figure 3.5, with climate change, population growth and average PCD at 404 L/day, the mean running net-flow (supply less demand) is below zero for both the A2 and low-carbon scenarios by 2090. This indicates that even if balanced over a year and with large amounts of storage, the flow of water available to Wellington from current sources will be insufficient to meet projected demand. The minimum value for the 2040 box plot is close to zero, which indicates that even with as much as 20,000 ML of storage capacity to balance supply and demand flows over a year; there may not be enough water to meet projected demand in a particularly dry year by 2040.

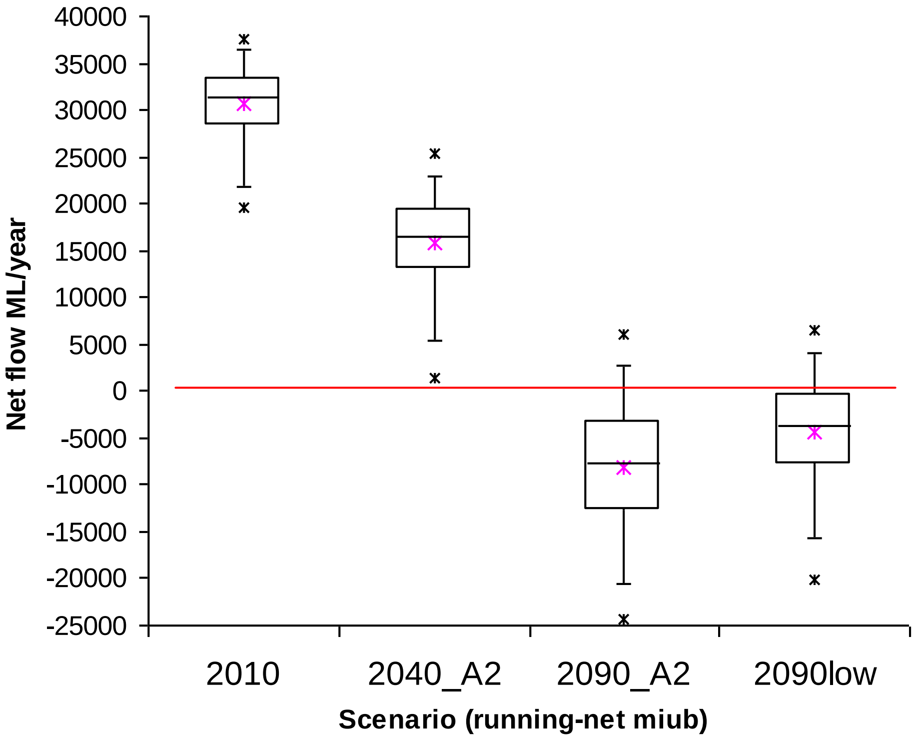


Figure 3.5: Running net-flows for 2040 A2, and 2090 A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 404 L/day.

Assuming average PCD of 404 L/day; population growth coupled with climate change pushes the mean running net-flow down by 15,000 ML/year by 2040 and then by another 25,000 ML/year between 2040 and 2090 (Figure 3.5). In Figure 3.6 the effect of population growth on the running net-flow has been removed by holding the population constant at 390,000. By holding population constant, the difference in net-flow shows the relative effect of climate change, with average PCD at 404 L/day. The mean annual net balance is 3144 ML/year less between 2010 and 2040 (equivalent to the capacity of the Stuart Macaskill storage lakes), and there is a 5850 ML/year difference between the 2040 and 2090 A2 scenarios (Fig. 3.6). In percentage terms climate change alone decreases mean annual net-flow by 10% from 2010 to 2040, and by 21% from 2040 to 2090.

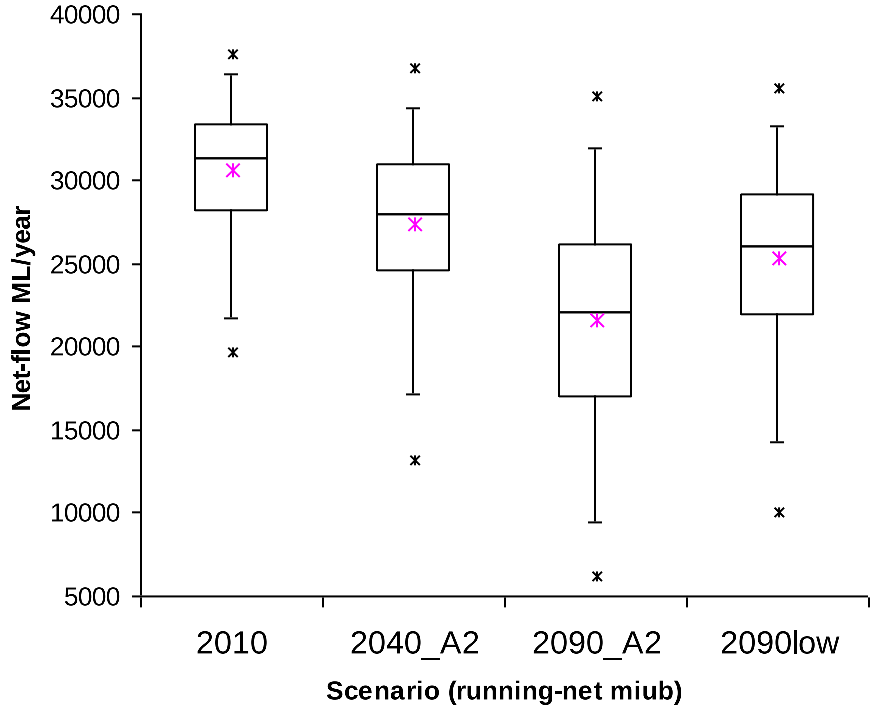


Figure 3.6: Running net-flows with no population increase for 2040 A2, and 2090 A2 and low-carbon scenarios.

3.2 Potential Impacts – with reduced water-intensity

Figure 3.7 presents a scenario where average PCD is reduced to 303 L/day by 2040. The data indicates that with this scenario there is sufficient water available for storage, enabling projected demand to be met in all but the most extreme summers under the 2090 A2 climate scenario. By 2040, with population growth, climate change and a reduction in average PCD to 303 L/day, the mean annual running net-flow increases relative to 2010 by 2700 ML/year, and then decreases by 19,000 ML/year between 2040 and 2090 for the A2 scenario (Figure 3.7).

In Figure 3.8 population has been held constant at 390,000 and average PCD is 303 L/day to show the relative effect of climate change for this scenario. There is a reduction in average net-flow of 3300 ML/day between 2010 and 2040, and 5,686 ML/day between 2040 and 2090. The relative contribution of climate change to the decrease in net-flow between 2010 and 2040 is 7%, and between 2040 and 2090 it is 13.5%.

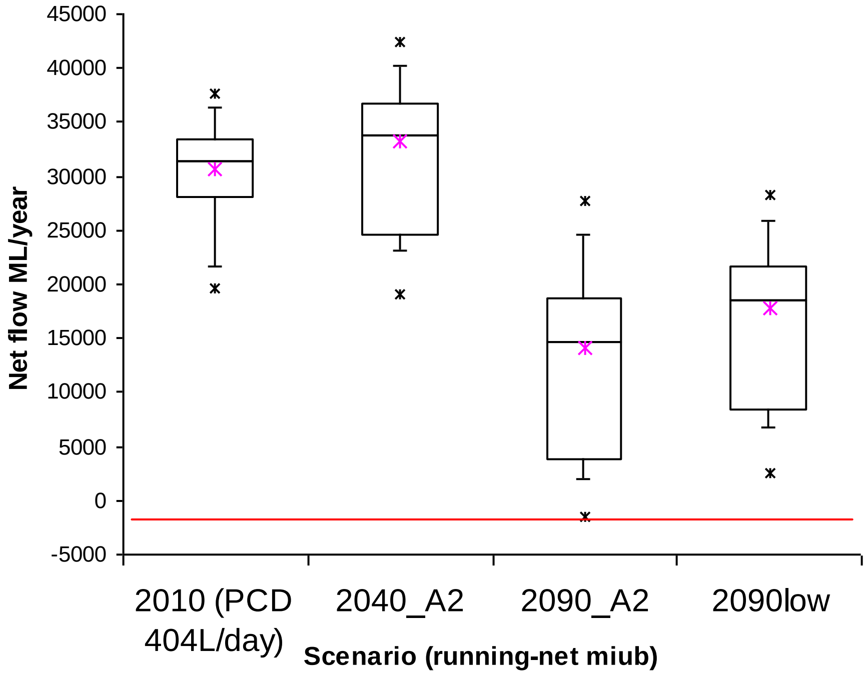


Figure 3.7: Running net-flows for scenarios 2040 and 2090 using both the A2 and low-carbon scenarios, for projected population growth with average aggregate per capita demand equivalent to 303 L/day.

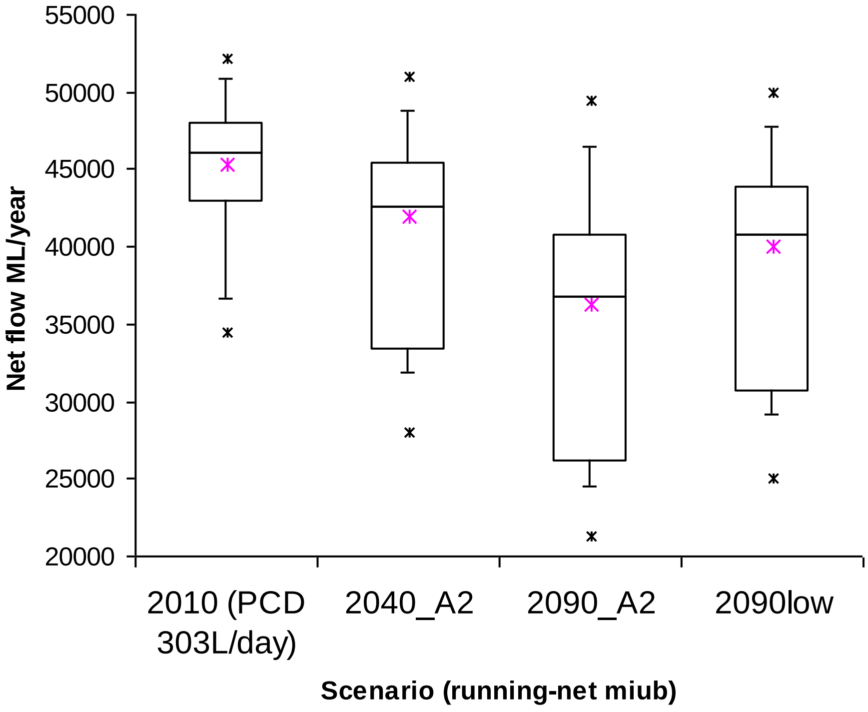


Figure 3.8: Running net-flows for 2040 A2, and 2090 A2 and low-carbon scenarios with average aggregate per capita demand equivalent to 303 L/day and no population growth.

3.3 Analysis of Extremes

Two events with deficits of 14,000 to 15,000 ML appear in the data (one per 57.5 years), one of which is shown in Figure 3.9. In addition there were five events with deficits of 12,000 to 14,000 ML (one per 23 years), and ten events with deficits of 10,000 to 12,000 ML (one per 11.5 years). In total there were 17 events (1 per 6.8 years) that with projected demand, and average PCD of 303 L/day could produce deficits of greater than 10,000 ML. Figure 3.9 shows that results for the 2040 scenario with 303 L/day PCD are similar to the 2010 scenario with PCD 404 L/day. This demonstrates the ability of reducing PCD to 303 L/day to 'offset' the effects of population growth and climate change on the water system. Figure 3.9 also shows a 202 L/day PCD scenario, which indicates a 'minimum bound' for a severe deficit event, such as might occur under optimal demand management conditions in 2040[10]. The actual average PCD for the section of the 202 L/day scenario shown is 210 L/day, with PCD at 271 L for the maximum day.

[10] The 202 L/day scenario provides a lower bound as it requires a reduction in PCD of nearly 50% from 2010.

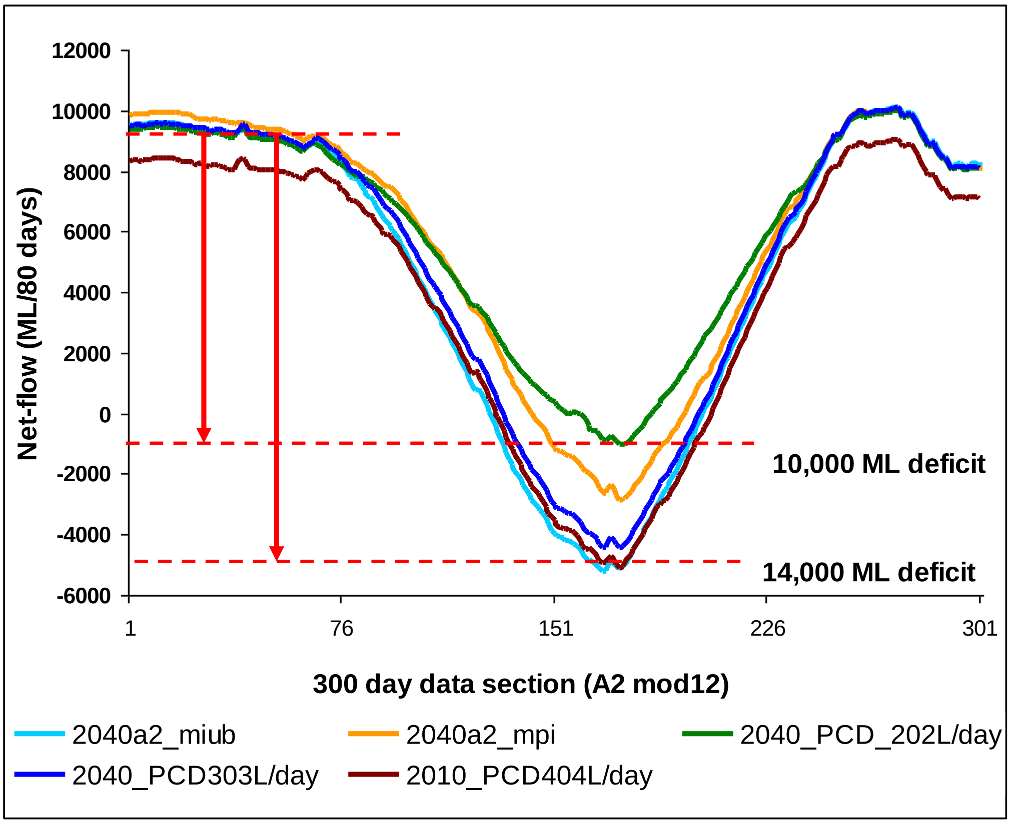


Figure 3.9: 300 day sequence of the largest deficit event generated for 2010 with PCD of 404 L/day, and 2040 with PCD of 303 L/day scenarios. The green line indicates a 'minimum deficit' with substantial and early demand management (A2 mod12, 80 day running-net). The miub (aqua) and mpi (orange) projections show the model range at the peak of the deficit.

The deficits generated by the largest seven events within the 115 year series are within the range of 12,000 to 15,000 ML (2010 with PCD 404L/day and 2040 with 303L/day), which suggests that 12000 ML of storage is required in order to meet Wellington's 2% or 1-in-50 year security of supply standard. This is potentially an upper bound, as the aquifer can be managed to provide short-term buffering capacity against a particularly dry month. However, as yet not enough is known about the aquifer to be able to accurately quantify how much buffering ability it can provide or for how long (Williams 2011, pers. comm.).

4. Discussion

4.1 Implications of General Trends

The general effect of climate change projected by 2040 is for a 5% decrease in potentially available water (PAW) and a 1% increase in per capita demand (PCD)

(PCD of 404 L/day). For the 2090 A2 scenario a 5.5% decrease in PAW and 3% increase PCD is projected. The net effect of population growth and PCD of 404 L/day is to reduce net-flow, or surplus flow available for storage to well below zero by 2090, in an average year. When the net-flow is below zero, increasing storage capacity to manage seasonally water availability is no longer an option, and new water supply sources are required. However reducing PCD to 303L/day is sufficient to 'offset' both projected population growth and climate change sufficiently to defer the need to augment supply until beyond 2090.

4.2 Implications for Managing Extreme Events

Extreme weather events are considered 'extreme' relative to the historic variability of the specific place affected. As illustrated in Figure 4.1, a change in climate increases the risk of extremes.

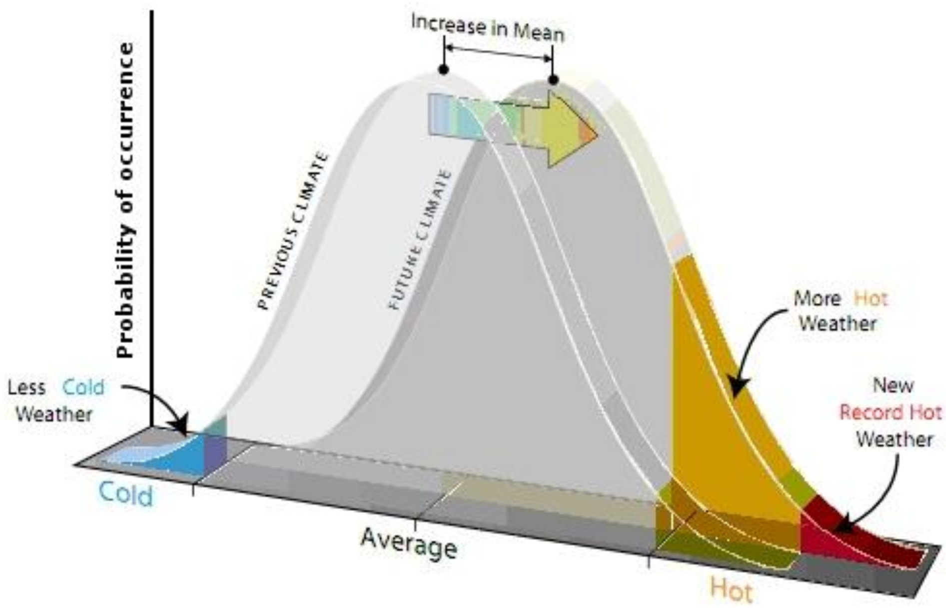


Figure 4.1. Climate change and increased risk of extremes. With regard to temperature, an increase in mean temperature within reference climate conditions results in a significant increase in the occurrence of hot weather, including record hot weather (Reisinger et al. 2010).

As stated in Section 2.3, a water shortage event is the net effect of both supply and demand factors. In practice water management generally focuses on supply management, and on meeting demand to an 'acceptable' level of risk based on engineering and financial parameters, whilst avoiding restrictions:

"Real-time system management requires decisions to be made on demand restrictions looking forward, whereas the severity and length of a drought is never

known until it is over. Therefore summer demand restrictions are likely to be imposed more frequently and be more onerous as the security of supply standard reduces, when in retrospect the level of restriction may have been unnecessary" (Shaw 2011, p.2).

However, this approach can give the community the unrealistic expectation that flow variability between PAW and total system demand (TSD) can usually be managed to enable 'unrestricted' summer water use. But just as it is not possible to know whether summer demand restrictions might retrospectively be seen as excessive, it is also not possible to exclude the possibility of a 1-in-50 or 1-in-200 year drought event for any coming summer. The expectation that summer water use will not be moderated is unrealistic since managing for extreme events requires a strategy to implement pre-emptive seasonal demand management.

Climate change is expected to increase the frequency and severity of droughts and floods, therefore increasing the size of the extremes that must be 'managed'. In addition, and as outlined in section 2.2, model projections tend to under-represent climate variability at the local level. This increases the level of uncertainty in the projections on which 'security of supply' decisions are based. An increased risk of extremes combined with the uncertainty regarding local level climate variability may compromise the rigour of risk management based planning (i.e. significantly increase the uncertainty of calculations for long-term infrastructure planning to meet a 1% or 2% water security standard).

From a resilience perspective, an informed community, who are aware that a drought is possible in any given summer, and therefore know they need to use water sensibly in summer, would be in a better position to cope with a particularly dry summer. The level of disturbance resulting from an extreme event will be more severe for a community that generally expects unrestricted use of water, compared to one that is generally active in reducing its water intensity, and understands the need to use water wisely in the summer. A resilient approach therefore is to 'expect surprises' and prepare for them.

4.3 Summary

Population growth, per capita demand, and total system demand are key variables within the water supply system that Wellington's water managers must contend with. Increased climate variability makes this job significantly more challenging.

The reduction in net-flow due to climate change and population growth represents a reduction in the amount of water available that can be stored to enable the water system to cope with seasonal flow variability. On the basis of balancing water availability over the year with storage, current supply (PAW) is sufficient to meet a PCD of 404 L/day to 2040, under the A2 scenario and with projected population growth. Towards 2090 the average net-flow from current supply sources is below zero. However, the need to augment supply can be delayed by increasing storage capacity and reducing the relative contribution of projected population growth by reducing average PCD to 303 ML/day.

Per capita demand is relatively high in Wellington, but it is falling. With sufficient demand management efforts, average aggregate PCD could be reduced to 303 L/day by 2025 and maintained at that level to 2040. In this case, and with sufficient storage, reduction of PCD to 303 L/day could delay the need to augment supply until after 2090. While increasing storage capacity is part of the solution, as TSD increases the surplus available for storage decreases to the point where the surplus flow is insufficient to fill reservoirs. However, once again reducing average PCD to 303 ML/day preserves the ability to use storage reservoirs to smooth out flow variability through to 2090, from present supply sources

The analysis above necessarily makes a number of assumptions, with greater than expected population growth being a key limitation, and the effect of sea level rise on water abstraction from the Waiwhetu aquifer a significant source of uncertainty. Nevertheless, a reasonable conclusion is that 10,000 ML of storage capacity may be required for managing flow variability in Wellington to 2040. This would require construction of approximately 7000 ML of storage to complement the existing Stuart Macaskill Lakes. 10,000 ML is the equivalent of 63 days supply at 158 ML/day, or 50 days at 200ML/day. Current storage provides 15 days at 200ML/day. Auckland's storage capacity provides 197 days (1-in-200 year standard), and Nelson 80 days (1-in-60 year drought standard) (MWH 2011). An 'expect surprises' or resilience approach would require the same storage capacity, designed around 'engineeringly' feasible and financially viable parameters, however in the event of a severe drought, the community would be much more prepared and better able to cope.

5. References

ADB (Asian Development Bank) 2011. Migration Due to Climate Change Demands Attention. News Release, 07 February 2011, viewed 27.02.11. http://www.adb.org/Media/Articles/2011/13473-asian-climates-changes/

Barnett, J. and S. O'Neill. 2010. Maladaptation. *Global Environmental Change,* Volume 20, Issue 2, May 2010, Pages 211-213.

Royal Society 2010. Sea-level Rise Emerging Issues. The Royal Society of New Zealand.

Capacity 2010. Annual Report 2009 – 2010. Capacity Infrastructure Services, Petone, Lower Hutt.

Climate Commission. 2011. The Critical Decade: Climate science, risks and responses. Commonwealth of Australia (Department of Climate Change and Energy Efficiency) 2011.

Grinstead, A., et al. 2009. Reconstructing sea-level from paleo and projected temperatures 200 to 2100AD", *Climate Dynamics,* 34:461.

GW 2008. Wellington Water Management Plan Technical Document. Version 5.4 Updated April-May 2008. Greater Wellington Regional Council.

GW 2008b. Technical Information: Waterloo Water Treatment Plant. Greater Wellington Regional Council.

GW 2010. Water Supply Annual Report 2010. Greater Wellington Regional Council.

Hennessy, K., B. Fitzharris, B.C. Bates, N. Harvey, S.M. Howden, L. Hughes, J. Salinger and R. Warrick. 2007: Australia and New Zealand. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Horton, R. et al. 2008. Sea-level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters, 35:02715.*

Ibbit, R. and B. Mullan. 2007. Potential effects of Climate Change on Sustainable Yield Model (SYM) outputs. NIWA Client Report. National Institute of Water & Atmospheric Research Ltd. Christchurch.

Jevrejeva, S., et al. 2010. How will sea-level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters*, 37:07703

Jones, R. 2010. A risk management approach to climate change adaptation. Chapter 1 in Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage, R.A.C., Wratt, D.S., Bornman, J.F., Jones, K. (eds), Wellington.

Kenway, S.J., A. Priestley, S. Cook, S. Seo, M. Inman, A. Gregory and M. Hall. 2008. Energy use in the provision and consumption of urban water in Australia and New Zealand. CSIRO: Water for a Healthy Country National Research Flagship.

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov, 2007: Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

MWH 2011. Wellington Metropolitan Bulk Water Supply Review of Security of Supply Standard. Prepared for Greater Wellington Regional Council.

Nicholls, R.J., A. Cazenave. 2010. "Sea-Level Rise and Its Impact on Coastal Zones". *Science*, 328: 1517.

Pfeffer, W.T., et al. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise, *Science*, 321:1340.

Rahmstorf, S. et al. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science*, 315:368.

Reisinger, A., B. Mullan, M. Manning, D. Wratt and R. Nottage. 2010. Global & local climate change scenarios to support adaptation in New Zealand. Chapter 2 in Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage, R.A.C., Wratt, D.S., Bornman, J.F., Jones, K. (eds), Wellington.

Shaw, T. and A. McCarthy. 2009. Stuart Macaskill Lakes seismic security upgrade. Greater Wellington Regional Council. Wellington

Shaw, T. 2011. Wholesale water supply - security of supply standard. Greater Wellington Regional Council. Wellington

Trenberth, K. 2011. The Russian Heat Wave and other Recent Climate Extremes. NZCCRI seminar, Wellington, 15 July 2011.

Vermeer, M. and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences* (USA) 106: 21527–21532.

WCC (Wellington City Council) 2009. Water Conservation and Efficiency Plan. Strategy and Policy Committee 15 October 2009.

Williams, G. 2010. Climate Change Study 2010, SYM Data Output. Greater Wellington Regional Council.