Report

Kapiti Water Supply Project: Demand Modelling for River Recharge with Groundwater

Prepared for Kapiti Coast District Council (Client)

By CH2M Beca Limited

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Revision History

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Appendices

1 Introduction

In preparation for the next round of groundwater modelling for the Kapiti Water Supply Project we have reviewed historic demands for the Waikanae and Paraparaumu-Raumati (WPR) water supply and developed an algorithm to predict daily water demands based on climate variables. The objective of developing the algorithm was to produce a time series of demand that matches the 36-year historic record of Waikanae River flows for input to surface water and groundwater modelling to assess the sustainable yield for the river recharge with groundwater solution under different scenarios of population growth. This modelling will also aid in understanding the likely frequency and duration of river recharge occurrences.

The demand algorithm has been incorporated into a demand model with a 36-year climate record, such that a 36-year time series of demand can be generated. Additionally, the demand model has been set up to modify the predicted demand to account for the introduction of universal metering together with ongoing water loss reduction and water conservation measures.

This report documents the demand modelling work and the proposed demand scenarios for surface water and groundwater modelling. Refer to separate reports for the results of the surface water and groundwater modelling.

2 Demand Algorithm

Using multiple linear regression analysis (MLRA) an algorithm has been developed for each of the two water supply schemes (Waikanae and Paraparaumu-Raumati) to predict water demand based on climate variables. The algorithm was developed using daily demand records for the two schemes and daily climate data from NIWA for the period 1 March 2005 to 21 October 2011. Refer Appendix A for the details of the algorithm development.

The final algorithm incorporates the following variables:

- Potential evapotranspiration (PET)
- Days since rainfall
- Previous day rainfall
- Weekend or weekday
- Change in soil moisture
- Previous day demand

The demand calculated from the algorithm is daily gross demand[1] in L/person/day.

The largest contributor to the modelled demand is the previous day's demand. A number of different climate variables were trialled in developing the algorithms, but the best fit was achieved when the previous day's demand was also included as a parameter. However it is noted that the previous day's demand is also calculated from the algorithm and so it has the influence of earlier climate conditions incorporated within it.

[1] Gross demand includes residential, commercial and industrial use as well as losses.

The demand algorithms developed using MLRA provide a very reasonable, but by no means perfect, method for predicting demands. The R^2 values indicated that 53% and 75% of the variability in demands for Waikanae and Paraparaumu-Raumati could be explained by the algorithms developed using climate variables and the previous day's demand.

This suggests that the algorithms may not be useful as an operational tool without further understanding of the non-climate factors affecting demand (eg, demographics, socio-economic influences, demand management) and refinement of the algorithms, especially for Waikanae. This may also include disaggregating demand into use components (eg, residential, commercial, industrial) and treating the different components separately as each component will vary differently with the climatic factors.

Nevertheless the R^2 values are comparable with those determined from other linear regression analyses of water demands[2], and the algorithms are considered valid for our ultimate purpose of generating demand inputs that correlate with the other inputs used for the surface water and groundwater modelling. For this modelling it is the periods of peak demands that are of primary interest and the error between predicted and actual peak demands is generally less than 10%. Also, because the responsiveness of the groundwater resource is very gradual it will be the trends in demand rather than the day to day variation that is important for the groundwater modelling. In addition the inclusion of headroom in the yield modelling will provide contingency for any under-prediction of demands.

3 Population Forecast

Population projections through to 2032 under various scenarios (MERA, 2012) were provided by Council. The WPR water supply area does not exactly correspond to Census area units, but for the majority they are similar and as such the Waikanae, Paraparaumu-Otaihanaga and Raumati area unit totals were used for the WPR water supply population. The two population projection scenarios considered for the Waikanae and Paraparaumu-Raumati water supply up to 2032 are:

- 03 Medium Growth, Baseline (this matches the population projection included in Council's draft LTP 2012-2032, Table B.3.2b)
- 07 High Growth, Baseline

These projections were extended to 2060 using growth rates from the long-term population projections for the Kapiti Coast district provided by MERA in 2009. A key assumption in extending the forecasts from 2032 to 2060 is that growth in the Waikanae and Paraparaumu-Raumati supply areas will be the same as forecasted for the district as a whole.

The high and medium growth population forecasts for the WPR water supply are shown graphically in Figure 1. The solid lines represent the population forecasts from the MERA 2012 data, while the dashed lines represent the forecasts derived using the growth rates from the MERA 2009 data.

[2] For example: Blakemore & Burton (2007); Aitken, Duncan & McMahon (1991); Gutzler & Nims (2005)

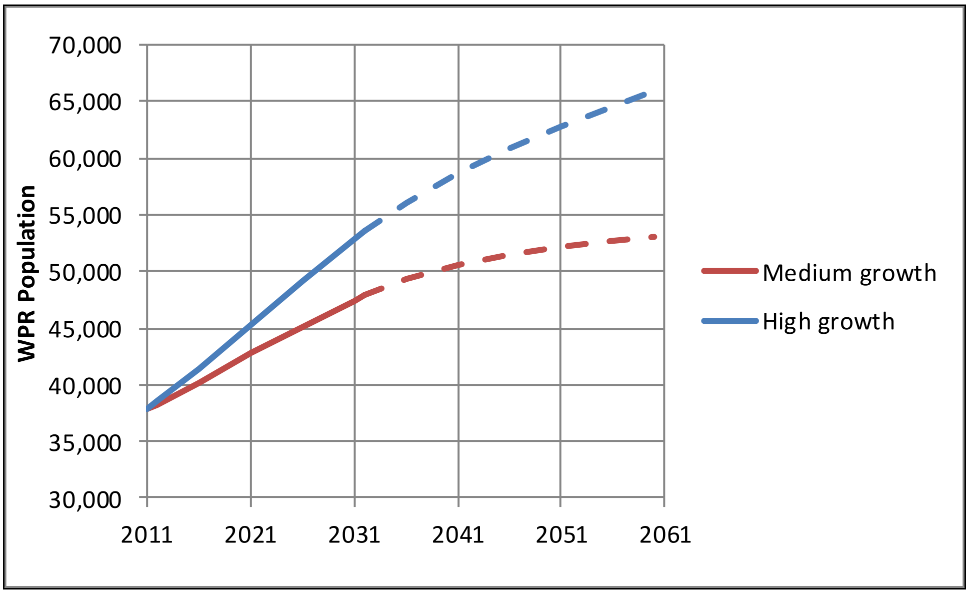


Figure 1 – Population Forecast for WPR Water Supply

Refer Appendix B for the population data. It is noted that the 2012-2032 population projections show the growth rate in Waikanae being approximately twice that in Paraparaumu-Raumati.

4 Demand Headroom

For the purposes of consenting and meeting the overall project objective of securing an enduring water supply solution for 50 years, the river recharge with groundwater solution includes an allowance for headroom. Headroom is included to account for uncertainty in the demand forecasting. As agreed with Council, the headroom used will be the difference between the demands calculated from the high and medium growth population forecasts. This means demand headroom of 0% in 2011 increasing to 24% in 2060. The demand headroom in 2060 equates to about 6,000 m^3/day – refer Table 2.

The demand modelling considers both the medium and the high population growth scenarios to enable assessment of how the headroom affects staging and cost forecasting.

Note this headroom does not account for uncertainty in source water availability (ie, supply side issues).

5 Changes to Demand

5.1 Peak day

Council has requested that the future gross peak day demand for the WPR water supply be set at 490 L/person/day for the demand modelling. This peak day demand is consistent with the demand used in the August 2010 Stage 3 report and assumes that universal metering, water conservation and loss reduction work will achieve savings to reduce peak demands to at least this amount. Council expects that this target will be attained by July 2016; two years after volumetric water charging is introduced in July 2014.

5.2 Average demand

It is judged that the gross *average* per person demand for the WPR water supply will be reduced by 15% as a result of universal metering and other demand reduction work. A key input to this decision was Council's universal metering modelling which assumed a 15% reduction in average residential demand (CRAG report, 2012). The CRAG report noted that this figure was extrapolated from the experience of other Councils such as Tauranga and Nelson and that this is a conservative assumption. We have assumed that the total average demand will be lowered to the same degree.

5.3 Minimum demand

It is assumed that the minimum demand will be reduced by 5% to match Council's savings target for loss reduction.

5.4 Demand components

The demand model could be enhanced by splitting the predicted demand into its various components (eg, commercial, losses, residential indoor and residential outdoor) and then adjust each of these components differently to account for the impacts of universal metering, water conservation and loss reduction. It has been decided not to undertake this work at this stage.

5.5 Climate change

At Council's request no allowance has been made for climate change effects on water demands. The potential impacts of climate change are not well known and Council considers that any increase in demands could be managed with universal metering.

6 Demand Modelling

6.1 How the demand model works

The user selects a year (between 2011 and 2060) and population growth scenario (medium or high). From these inputs the model looks up the forecasted population and generates a time series of predicted demand for the WPR supply corresponding to the period of historic climate data. The demand model uses daily climate data sourced from the NIWA Cliflow database for Virtual Climate Station number 30229. This is the same climate station used to develop the demand algorithms. To ensure a corresponding river flow data set is available, the period of climate data used in the demand modelling is 4 March 1975 to 1 November 2011.

Within the WPR water supply the two schemes of Waikanae and Paraparaumu-Raumati have different historic demand patterns, with the average per person demand in Waikanae approximately 1.5 times the average per person demand in Paraparaumu-Raumati[3]. The Waikanae demand pattern is considered to be higher because of higher losses and higher outdoor water use. To better account for this difference, a demand algorithm was developed for each scheme. However if each scheme were to achieve a peak day demand of 490 L/person/day, the reduction in demand required for the Waikanae scheme would be significant whereas only modest savings would be required for the Paraparaumu-Raumati scheme. Instead the target of 490 L/person/day is applied to the WPR water supply as a whole rather than the two individual schemes.

[3] For analysis of historic demands refer to: *Benchmarking the water loss estimate for Waikanae, Paraparaumu-Raumati Water Supply 2010* (CH2M Beca, 2011).

To do this, the demand model calculates the predicted demand for each scheme (using historic climate data and the relevant algorithm) and then determines the average predicted demand across the WPR supply based on the forecasted population for each scheme. The WPR demand is then altered according to the anticipated changes in demand outlined in Section 5 and the logic outlined in this section.

The demand model modifies the predicted demand for each day using a linear relationship between the predicted demand and anticipated percentage reduction in demand (from Section 5). The demand model identifies the maximum predicted demand in the time series and determines the percentage reduction required in order to bring this demand down to 490 L/person/day (this is typically around 25%). Predicted demands greater than the average predicted demand are reduced by a percentage between 15% and the peak demand reduction. Predicted demands less than the average predicted demand are reduced by a percentage between 5% and 15%.

The demand model has been set up so that the user can alter the anticipated changes in demand (ie, the target peak demand and percentage reductions in average and minimum demand) if they wish.

An allowance for wastewater at the Waikanae WTP is added to the modified predicted demand to derive the required daily abstraction from the river. The wastewater allowance is for draw off from the clarifier and filter backwashing. The model uses an allowance of 300 m^3/day, which was the average volume discharged to sewer from the WTP between 13 December 2010 and 9 January 2011 (CH2M Beca, 2011), but this figure can be altered in the model.

6.2 Synthesised climate data for 50-year low flow

To simulate the conditions leading to a 50-year low river flow, climate data from March and April 2003 has been modified to match the synthetic extension of the observed river flow recession in early 2003 through until the 50-year low flow of 603 L/s[4]. Refer to Appendix C for a comparison of the actual and synthesised climate data.

The user is able to select whether to use the actual 2003 climate data or the modified data inserted in the historic climate data set.

6.3 Demand scenarios

The demand model will be run with the following scenarios and the results from these model runs will be used as an input to surface and groundwater modelling:

- 36 year time series (1975-2011), with modified climate data in 2003 for 50-year low river flow of 603 L/s:
  - 1) Population at 2049
    - a) with medium population growth, and
    - b) with high population growth
  - 2) Population at 2060
    - a) with medium population growth, and
    - b) with high population growth

[4] Note this 50-year low flow differs to that reported on the Greater Wellington website (517 L/s). Refer to the surface water report (CH2M Beca, 2012) for further information about analysis of historic river flows and the revised 50-year low flow.

The first scenario uses the year 2049 because this would be the end of a 35 year consent period (starting in 2014). The second scenario uses the year 2060 because this was the original planning period for the water supply project.

6.4 Modelling results

6.4.1 Peak and minimum demand

Using the 36-year climate record with projected demand figures, the demand model predicts that the peak demand across the 36-year period occurs in early February 2008. The high demand is caused by a period of 26 days without rainfall, with an average PET over this period of 4.5 mm/day and a corresponding high rate of declining soil moisture.

Interestingly the minimum predicted demand across the 36-year period is also in the summer of 2008. There was a storm on 7-8 January 2008 with 188.5 mm of rain in 48 hours recorded at the Waikanae WTP monitoring site; this rainfall event had an estimated return period of more than 25 years (GWRC, 2008). The high amount of rain from the storm with the resulting rapid increase in soil moisture and low PET levels leads to a dramatic reduction in the predicted demand, but it quickly recovers and after 4 days is back at a similar level to before the storm.

The year 1998/99 has the most number of days with elevated demand (>95%ile) with 42, followed by 2007/08 (34 days), 1977/78 (33 days) and 2010/11 (33 days). The year 2007/08 has the longest continuous period of elevated demand (17 days), followed by 1987/88 (16 days).

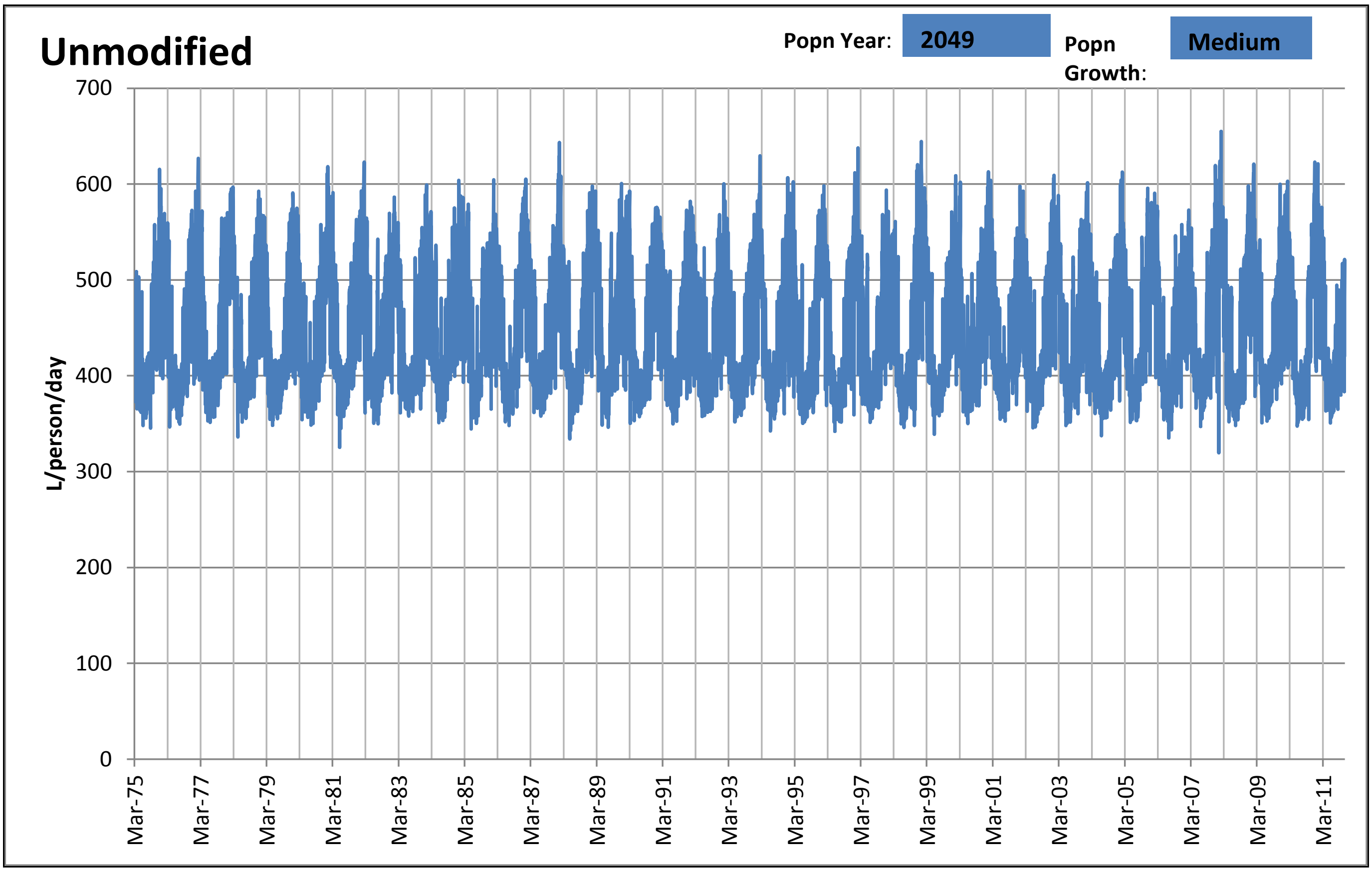
6.4.2 Demand reduction

Table 1 and Figure 2 compare the original predicted demand series using the 2049 medium growth population projection against the demand series resulting from the anticipated changes in demand with the introduction of universal metering.

Table 1 – Predicted Demands
(2049 population with medium growth, 1975-2011)

		Original	Reduced
Peak day demand	L/person/day	655	490
Average day demand	L/person/day	449	383
Minimum day demand	L/person/day	320	304
PDD/ADD		1.46	1.28

Blakemore and Burton (2007) reported that in Tauranga the introduction of metering resulted in a reduction in both average and peak day gross demand but the ratio of peak to average gross demand (1.44) was similar to the ratio prior to universal metering (1.46). This suggests that we might be conservative in the assessment of the reduction in average demand at 15%, but we consider it is better to be more conservative about future demands at this stage. A greater reduction in average demand would likely reduce the total volume of groundwater needed for river recharge during periods of low river flow, but the maximum required yield would not change (as this is dependent on the peak day demand).



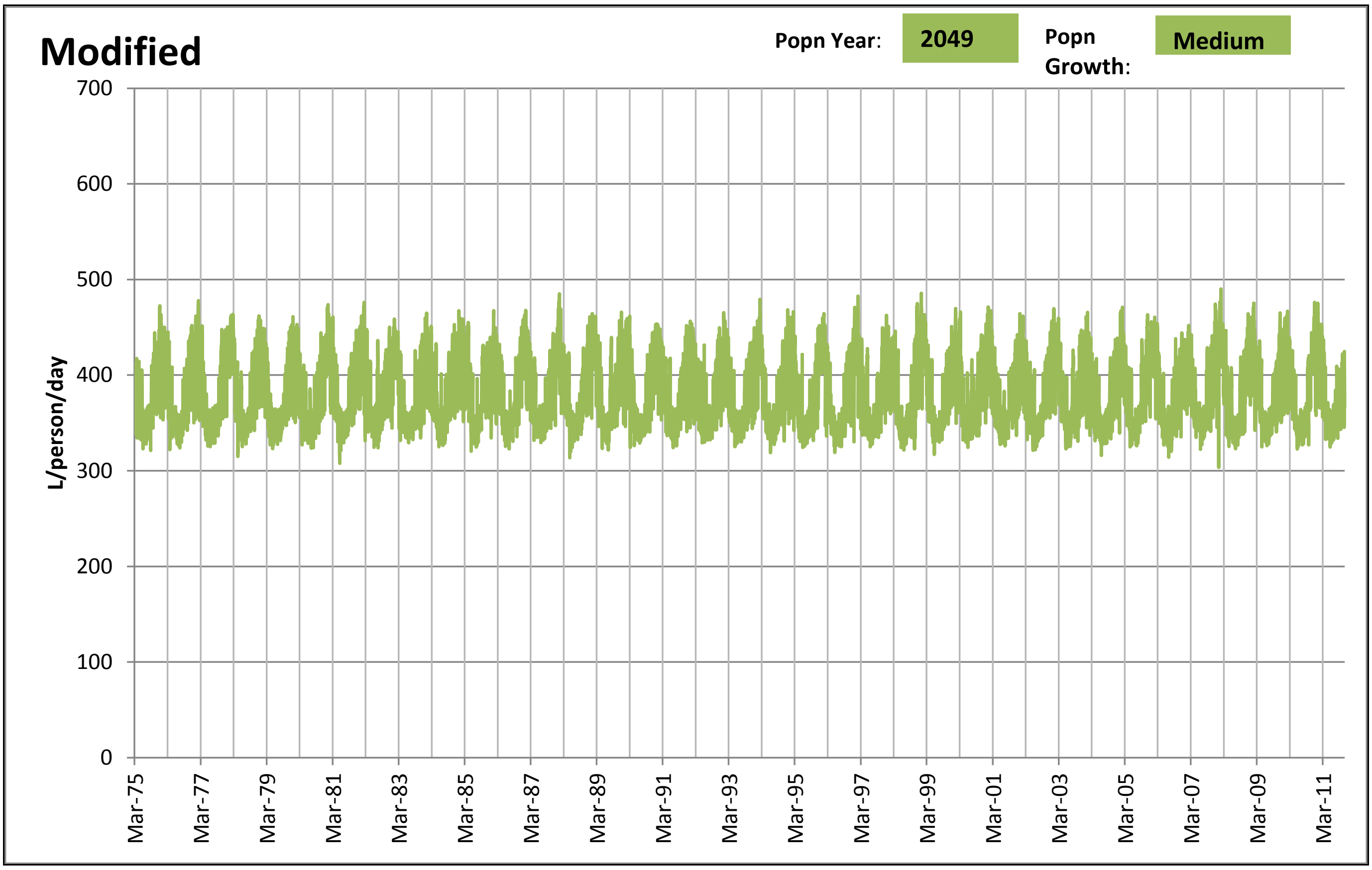


Figure 2 – WPR Predicted Demand: Unmodified and Modified

6.4.3 Effect of 2003 synthesised climate data

Figure 3 shows the change in predicted demand in 2003 that results when the synthesised climate data for the 50-year low flow is used instead of the actual climate data. With the modified climate data, demand continues to increase (because of the absence of rainfall) until around 12 April 2003 when the drought breaks and predicted demand drops. The insertion of a rainfall event into the climate record to break the drought (when the 50-year low river flow of 603 L/s is reached) leads to lower predicted demand than the demand predicted using the actual climate data.

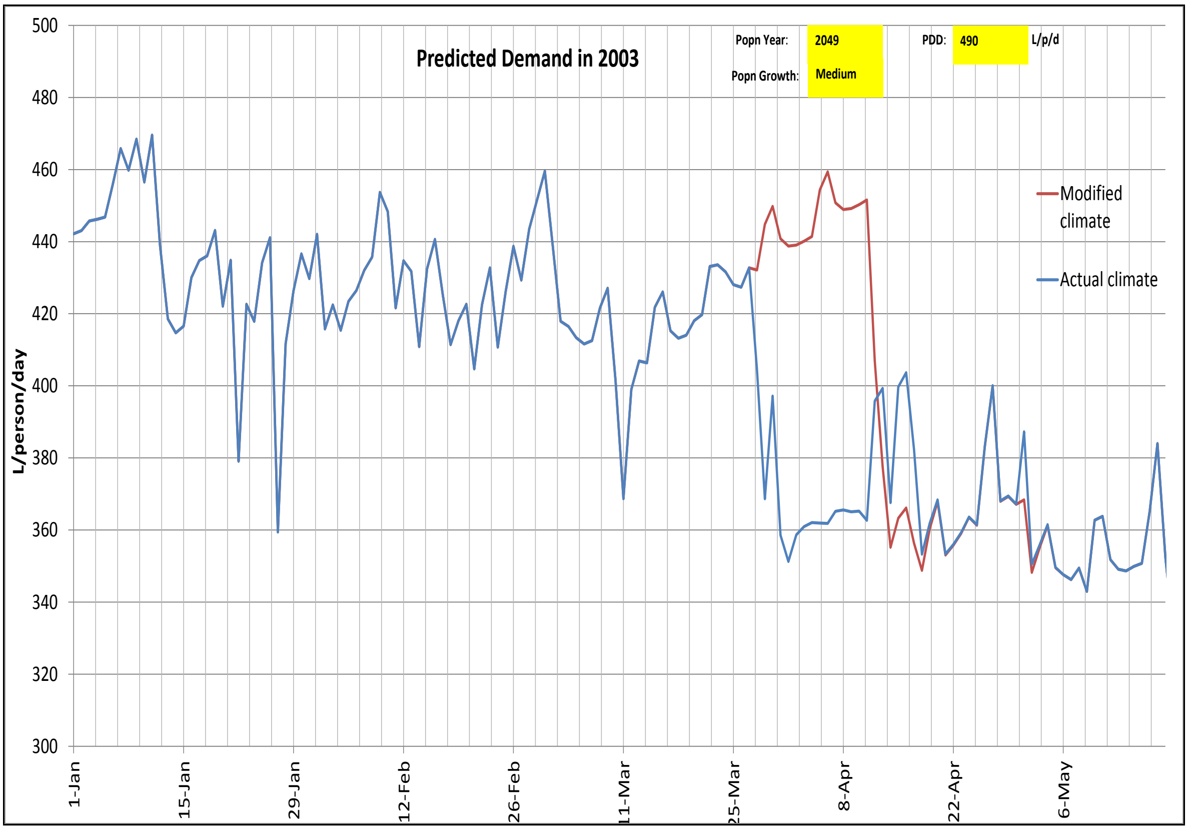


Figure 3 – Predicted demand in 2003 with actual climate data and synthesised climate data

6.4.4 Outputs for surface water modelling

Refer to Appendix D for graphs of the data for the four scenarios that will be input to the surface water modelling.

7 Peak Demands for Staging

Figure 4 plots the forecasted annual peak day demands through to 2060 using 490 L/person/day gross peak day demand and the medium and high growth population projections. Council anticipates that it will take 2 years from the first water bill (July 2014) for peak demand to reduce from current levels to the target of 490 L/person/day. The table below presents the forecasted peak day demands for key years within the planning period for the river recharge with groundwater solution. The forecasted peak day demands are used to determine the peak yield required from the borefield and to develop the staging of river recharge with groundwater through to 2060.

Table 2 – Forecasted Peak Day Demands for WPR Water Supply

Year		Peak day demand (m^3/day)	
		Medium popn growth	High popn growth
2016	demand savings achieved	19,700	20,300
2032	20 year LTP period	23,500	26,300
2049	35 year consent period	25,400	30,400
2060	50 year solution	26,000	32,300

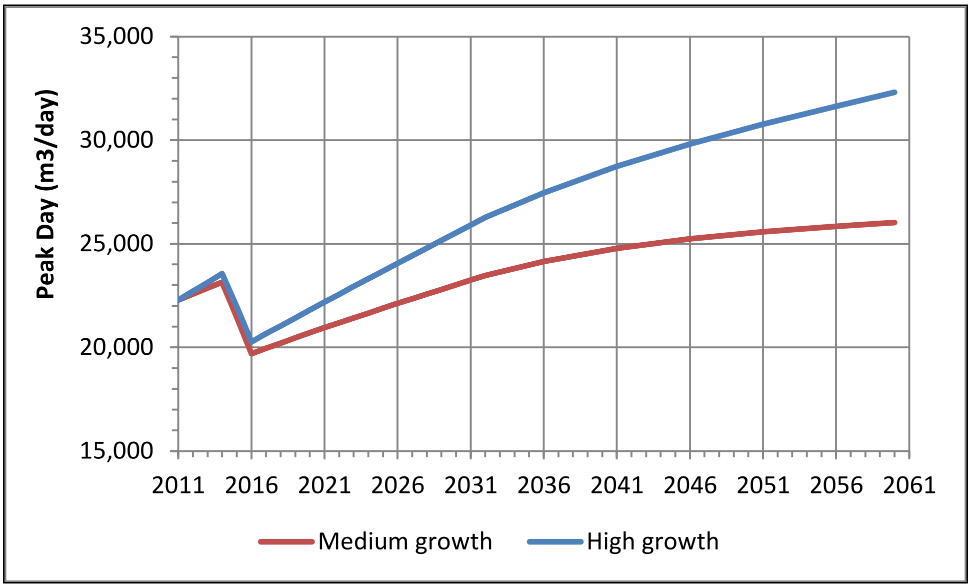


Figure 4 – WPR Peak Day Demand Forecasts with 490 L/person/day

The demands in the graph and table above do not include the 300 m^3/day allowance for wastewater at the Waikanae WTP.

8 Next Steps

The modelling outputs will be applied to the surface water model to determine the quantity of groundwater needed for river recharge and also to assess the frequency and duration of river recharge. The results of the surface water modelling will be a key input to the groundwater modelling.

9 References

Aitken CK, Duncan H and McMahon TA, 1991. A cross-sectional regression analysis of residential water demand in Melbourne, Australia. *Applied Geography*, Vol. 11, Issue 2, April 1991, p157-165

CH2M Beca, 2012. *Kapiti Water Supply: Hydrology and yield modelling*

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Blakemore R and Burton S, 2007. *An Assessment of Peak Daily Demand in Tauranga City and Implications for Water Supply Management.* 49th Water New Zealand Annual Conference and Expo

Gutlzer DS and Nims JS, 2005. Interannual Variability of Water Demand and Summer Climate in Albuquerque, New Mexico. *Journal of Applied Meteorology*, Volume 44, December 2005, p1777-1787

GWRC, 2008. *Annual hydrology monitoring report for the Wellington region, 2007/08*

CRAG, 2012. *The Charging Regime Advisory Group Report to Kapiti Coast District Council on a Recommended Water Charging Formula*, p12&14

MERA, 2009. *Kapiti Coast District: Summary of 2006-2009 trends in a longer term context*

MERA, 2012. "Copy of KCDC_n255023_v1_Jan2012rev_MERA_PROJECTIONS_Population.xls". Provided by KCDC, February 2012.

Appendix A

Demand Algorithms

Appendix A – Demand Algorithms

1 Data Inputs

1.1 Climate Data

Daily climate data was obtained from the NIWA Cliflo database for a Virtual Climate Station[1] located in the vicinity of Tui Crescent, Waikanae.

The following table lists the data parameters taken from NIWA's database.

Climate Data

Parameter	Description	Unit	Start Date
MSLPress	Mean sea level pressure at 9am local day	hPa	1 January 1972
PET	24-hour Penman potential evapotranspiration total from 9am local day	mm	1 January 1972
Rain	24-hour rainfall total from 9am local day	mm	1 January 1960
RH	Relative humidity at 9am local day	%	1 January 1972
SoilM	24-hour soil moisture index total from 9am local day positive = runoff negative = soil moisture deficit	mm	1 January 1972
TempEarth10cm	Earth temperature at 10cm depth at 9am local day	degC	1 January 1972
Radn	24-hour global solar radiation total from midnight local day	MJ/m^2	1 January 1972
Tmax	Maximum temperature over 24 hours from 9am local day	degC	1 January 1972
Tmin	Minimum temperature over 24 hours to 9am local day	degC	1 January 1972
VapPress	Vapour pressure at 9am local day	hPa	1 January 1972
WindSpeed	Average wind speed at 10m above ground level over 24 hours from midnight local day	m/s	1 January 1997

The end date for the climate data is 7 November 2011.

A number of derived parameters were created based on the parameters above and seasonal/time parameters. These were also used to create the demand algorithm, and included:

- Days since rainfall
- Previous day rainfall
- Rain today? yes/no
- Is Tmax above 24°C? yes/no

[1] Virtual climate station 30229, latitude -40.875, longitude 175.075

- Number of days in the last week with Tmax above 24°C
- Change in SoilM from yesterday
- Variation in EarthTemp from monthly average
- Number of days SoilM less than -140mm
- Is it a weekend day? yes/no
- Month
- Is it a summer day? yes/no (summer is defined as November to March[2])
- Previous day demand

1.2 Demand Data

Actual demand records for WPR are available going back to 1 July 2000, but only data from 1 March 2005 onwards (to 21 October 2011) was used to create the final demand algorithm. The data prior to March 2005 was discounted due to an apparent increasing trend in per capita demand in Waikanae between 2003 and 2005 which was unrelated to climate variables. This was adversely affecting the modelling results for more recent years. Previously[3], a distinct change in water use in Waikanae was noted around 2003 which was postulated as due to water conservation measures in response to the 2003 drought and an apparent permanent change in behaviour of consumers. Because of this change in water use it was felt there was little value in using data prior to 2003.

The daily demand data collected by KCDC is the total demand for the previous 24 hours from midnight to midnight. In the model, the demands were shifted back one day, so that the demand related to the day being considered and not the day after.

The demand data was converted from m^3/day to m^3/person/day to eliminate the effect of population increase on demand. The population data used was taken from the 2011 KCDC population predictions for 2006 and 2011[4], and from the MERA data for 2001[5]. A linear increase in population was assumed between these years.

Waikanae demand was assumed to be the daily flow from the Kakariki Reservoir. Paraparaumu-Raumati demand was assumed to be the daily flow from the Riwai Reservoir. It is noted that although the Otaihanga zone is not served by the Riwai Reservoir, the Otaihanga population has been included when determining the per person demand for Paraparaumu-Raumati. This is because there is no separate population data for Otaihanga, and due to the small size of the population (approximately 400 people[6]), the results would not be significantly altered by excluding the Otaihanga population when determining the per person demand.

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[2] To match Council definition for summer, and also the Ministry for the Environment's bathing season monitoring period

[3] From the Beca report *"Benchmarking the Water Loss Estimate for Waikanae, Paraparaumu-Raumati Water Supply 2010"*

[4] Council report SP-11-118, 24 March 2011, Table 1

[5] MERA, *Kapiti Coast District: Summary of 2006-2009 trends in a longer term context*, Dec. 2009.

[6] Based on 174 connections and 2.3 people/property.

2 Demand Algorithm Development and Results

2.1 Algorithm Development

Multiple linear regression analysis (MLRA) was used to create the demand algorithm. MLRA is a well-recognised method for predicting an outcome from a number of variables based on observed data. MLRA assumes that there is a linear relationship between each of the climate parameters and the demand for water. Graphs of many of the parameters listed in Section 1.1 against demand were plotted to check this assumption. In almost all cases the distribution of data was large and not particularly well correlated, however a linear relationship was judged to be the best fit in all cases. It was noted in some cases, particularly soil moisture and temperature, that below a certain threshold value, demand was fairly constant, but rose more steeply once that threshold value was reached.

The output from multiple linear regression analysis is an equation of the form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_nx_n$$

Where in this case, y is demand, $\boldsymbol{b_n}$ is a set of coefficients determined by the modelling and $\boldsymbol{x_n}$ is the set of climate parameters chosen.

Microsoft Excel's built in multiple linear regression analysis package was used to create the algorithm. Two algorithms were created, one for Waikanae and one for Paraparaumu-Raumati. The two algorithms used identical parameters (i.e. $\boldsymbol{x_n}$ was the same for both algorithms).

The significance of each of the parameters can be determined from the model output by comparing the ratio of the coefficient to the standard error for each parameter to the t-statistic (at 0.05 significance). If the absolute value of the ratio is greater than the t-statistic value then that parameter is considered significant. If it is less, it may be discounted.

The closeness of the modelled demand to the actual is indicated by the R^2 value. The closer the R^2 is to 1.0, the better the model is at recreating the actual data.

Several iterations were carried out to test the MLRA on different combinations of climate parameters. Each iteration was refined by adding parameters to attempt to improve the R^2 value, or by removing parameters based on their apparent lack of significance. Promising iterations were cross-checked between Waikanae and Paraparaumu-Raumati to ensure that the set of parameters ($\boldsymbol{x_n}$) chosen are suitable for both supplies.

It was found during the modelling that the equations produced by the MLRA worked well during periods of average demand, but underestimated peaks in demand. To address this a peak day scaling factor was introduced which was only applied when demand is above the average day demand for each supply (calculated from historical data).

2.2 Results from Modelling

After several iterations and much agonising, the following table summarises the final output from the MLRA.

Results from Multiple Linear Regression Analysis – Modelling Demand on Climate Data

Parameter	Waikanae Value	Paraparaumu-Raumati Value
Intercept (b_0)	0.2850	0.2077
PET	0.0179	0.0181
Days since rainfall	0.0022	0.0027
Previous day rainfall	-0.0002[7]	-0.0005
Weekend yes/no	0.0247	0.0186
Change in soil moisture	-0.0004	-0.0004
Previous day demand	0.3838	0.2952
R^2 prior to scaling factor application	0.53	0.75
Peak day scaling factor	1.09	1.09
R^2 after peak day scaling factor applied	0.22	0.57

By far the largest contributor to the modelled demand is the previous day's demand parameter, as can be seen from the coefficients in the table above. It generally contributes 30%-40% of the demand estimate. A number of different climate variables were trialled in developing the algorithms, but the best fit was achieved when the previous day's demand was also included as a parameter. However it is noted that the previous day's demand is also calculated from the algorithm and so it has the influence of earlier climate conditions incorporated within it.

Application of the peak day scaling factor improves the modelled demand at times of peak demand, but also has the effect of shifting all demands higher than the historical average daily demand upwards. Because of this, the R^2 value following application of the peak day scaling factor drops.

Although the R^2 values seem low for both of the models, it was considered appropriate for the purpose, considering the number of influences on demand (not all of which are climate related) and the fact that we are primarily interested in peak day demands[8] rather than average day demands, as these are the determinant of the pressure on the surface and groundwater resources.

The following table compares actual peak day demands with the modelled peak day demands (with peak day factor applied).

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[7] In the model for Waikanae, previous day rainfall is identified as being an insignificant parameter. However, it was significant for the Paraparaumu-Raumati model so was kept as a parameter for consistency.

[8] Peak day demands generally occur during warm periods with low rainfall, when surface water levels are expected to be at their lowest. It is at these times that the water supply will be under greatest pressure, and thus these are the periods we are the most interested in for the purposes of the surface water and groundwater modelling and how best to manage the water supply infrastructure.

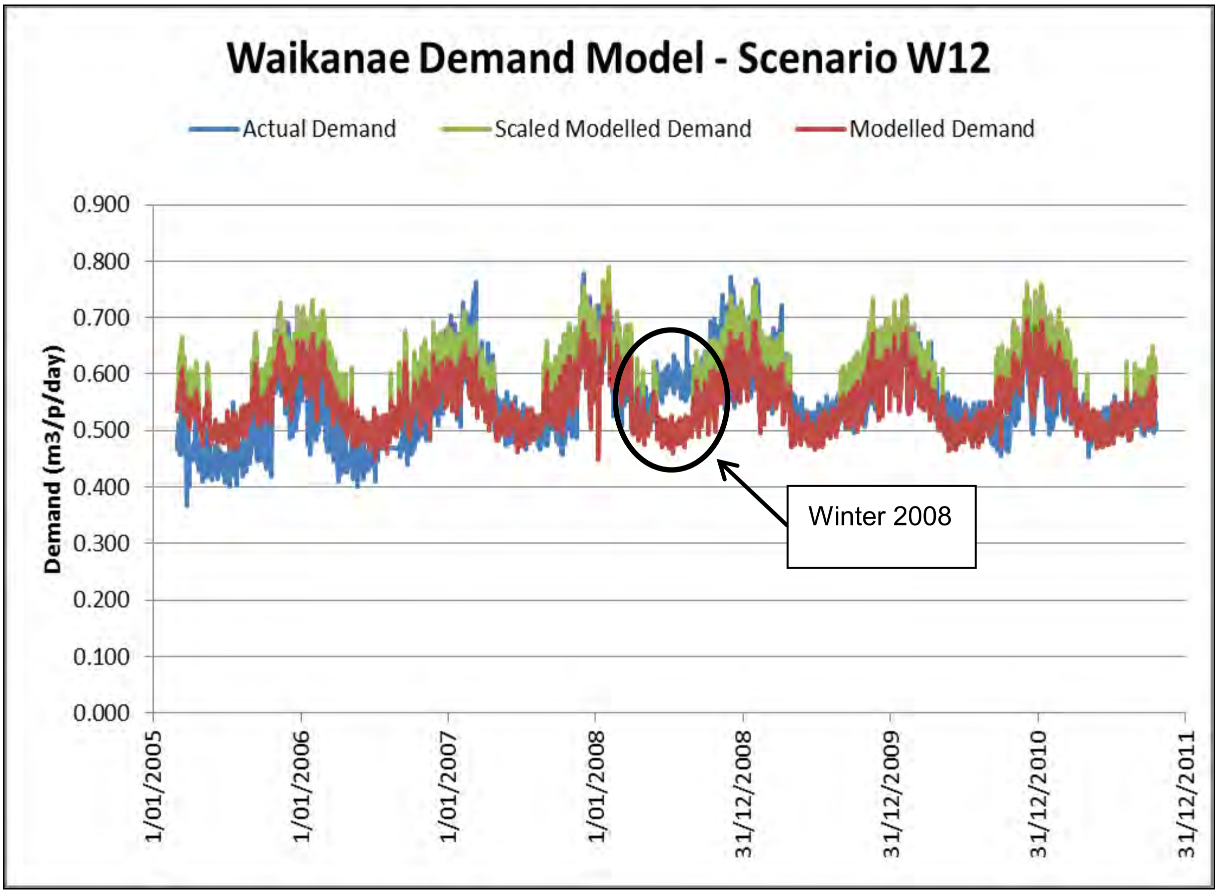
Comparison of Actual and Modelled Peak Day Demands

	Waikanae PDD (m^3/person/day)			Paraparaumu-Raumati PDD (m^3/person/day)		
Year	Actual	Modelled	Error	Actual	Modelled	Error
2005	0.699	0.727	5%	0.550	0.530	-4%
2006	0.677	0.730	10%	0.536	0.519	-3%
2007	0.778	0.755	-4%	0.576	0.551	-4%
2008	0.771	0.789	3%	0.549	0.588	7%
2009	0.767	0.755	-2%	0.522	0.553	6%
2010	0.677	0.759	15%	0.583	0.555	-5%
2011	0.666	0.757	17%	0.526	0.553	5%

The graphs below outline the results from the modelling for both Waikanae and Paraparaumu-Raumati.

Modelling the demand in Waikanae proved to be more challenging than for Paraparaumu-Raumati. This is reflected in the lower R^2 values obtained for the Waikanae demand model. While we would have liked to have achieved a higher R^2 value for Waikanae (closer to that of Paraparaumu-Raumati), there were a number of periods when actual water demand for Waikanae does not behave as might be expected. For example, during the winter of 2008, demand does not drop off as expected and remains relatively high. This cannot be explained by climate factors alone, and hence is not well predicted by the model. A possible explanation is errors in flow measurement or data transmission during the period.

While the prediction of Waikanae demand is not as reliable as Paraparaumu-Raumati demand, the fact that Waikanae is about a third of the total WPR population, some of the error is dampened once the two demands are combined into an overall WPR demand. However in the longer term, because the forecasted growth for Waikanae is greater than that of Paraparaumu-Raumati, there will be lesser dampening.


Waikanae Demand Model - Scenario W12
Actual Demand
Scaled Modelled Demand
Modelled Demand
Demand (m3/p/day)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1/01/2005
1/01/2006
1/01/2007
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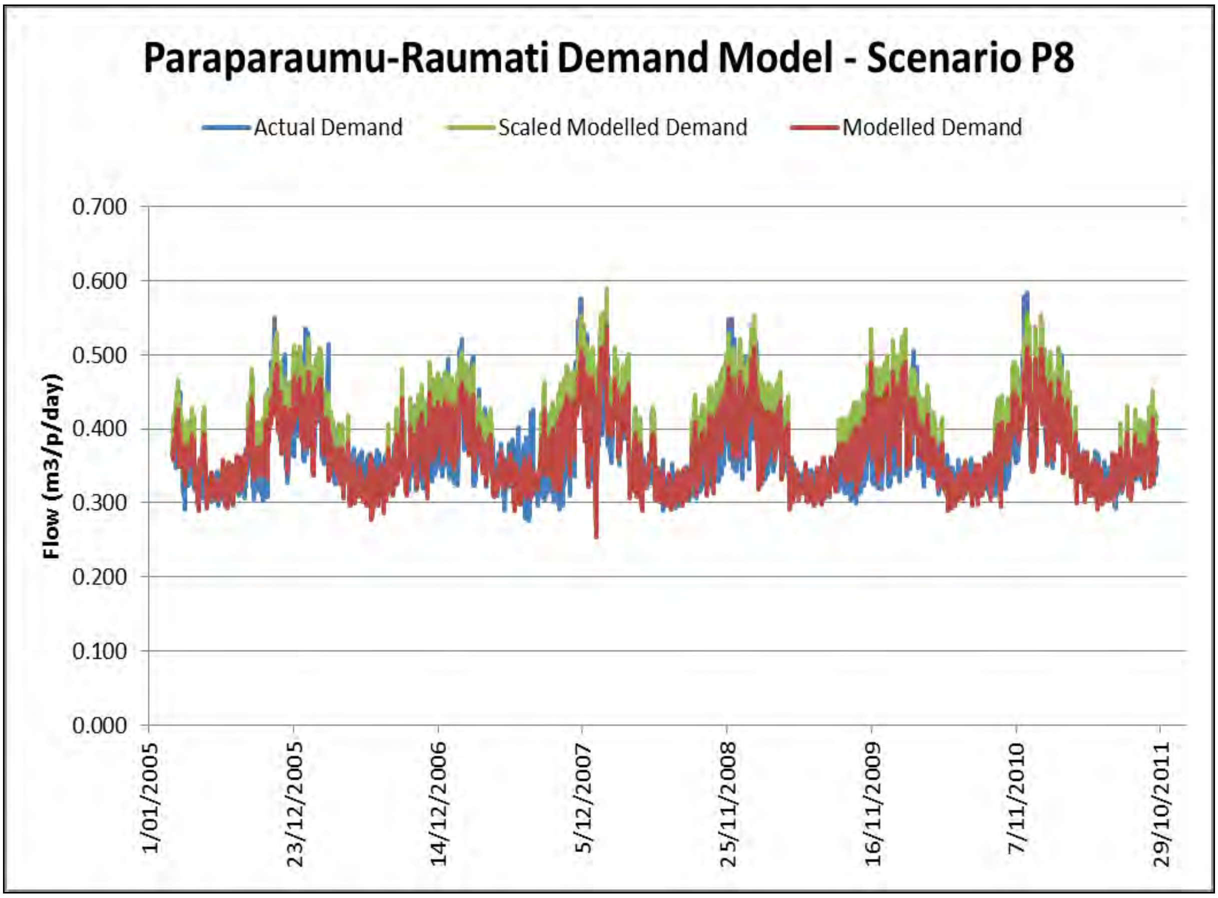
31/12/2008
31/12/2009
31/12/2010
31/12/2011
Winter 2008


Paraparaumu-Raumati Demand Model - Scenario P8
Actual Demand
Scaled Modelled Demand
Modelled Demand
Flow (m3/p/day)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1/01/2005
23/12/2005
14/12/2006
5/12/2007
25/11/2008
16/11/2009
7/11/2010
29/10/2011

2.3 Limitations

Reasons that the modelled demand does not match the actual demand well, and consequently for the low R^2 values may include:

- A number of random factors influencing each household's demand that are impossible to account for in a high-level model.
- The different components of demand (ie, residential use, commercial use and losses) vary differently with the climatic factors.
- Unreliability of flow data. For example, it is known that the Kakariki Reservoir meter was mis-reading from sometime in 2007/2008 until January 2010.

It is noted that several of the parameters used to form x_n may be correlated, for example rainfall and change in soil moisture. This may lead to a degree of multicollinearity within the model. Multicollinearity is only a problem if the purpose of the model is to estimate the contributions of individual predictors. In this case, we are only interested in the predicting the dependent variable, demand, from a set of climate parameters, and the multicollinearity will not reduce the accuracy of the model.

3 Sensitivity Analysis

The model as described in the table above was used to predict demand for the entire historical climate record, going back to 1972.

In order to do this, initial values had to be chosen for a number of parameters:

- Previous day demand – the average day demand for 2005 – 2011 was used
- Previous day rainfall – assumed to be zero
- Days since rain – assumed to be zero
- Change in soil moisture – assumed to be zero

A sensitivity analysis was carried to assess the impact of the assumptions listed above. The results are presented in the tables below. Note that the sensitivity analysis was carried out on demands prior to application of the peak day factor.

Results of Sensitivity Analysis - Waikanae

	Previous Day Demand (m^3/ person/ day)	Previous Day Rainfall (mm)	Number of days since rain	Change in soil moisture	R^2	Length of influence (days)
Base	0.549	0	0	0	0.526	NA
Low previous day demand	0.200	0	0	0	0.527	4
Moderate previous day demand	0.500	0	0	0	0.523	4
High previous day demand	0.900	0	0	0	0.527	0
Moderate previous day rainfall	0.549	10	0	0	0.527	0
High previous day rainfall	0.549	30	0	0	0.527	1
Moderate number of days since rain	0.549	0	4	0	0.526	5
High number of days since rain	0.549	0	15	0	0.524	6
Moderate negative change in soil moisture	0.549	0	0	-1	0.526	0
Large negative change in soil moisture	0.549	0	0	-30	0.526	1
Moderate positive change in soil moisture	0.549	0	0	1	0.526	0
Large positive change in soil moisture	0.549	0	0	30	0.527	2

Results of Sensitivity Analysis – Paraparaumu-Raumati

	Previous Day Demand (m^3/ person/ day)	Previous Day Rainfall (mm)	Number of days since rain	Change in soil moisture	R^2	Length of influence (days)
Base	0.370	0	0	0	0.749	NA
Low previous day demand	0.100	0	0	0	0.746	3
Moderate previous day demand	0.400	0	0	0	0.749	1
High previous day demand	0.800	0	0	0	0.747	3
Moderate previous day rainfall	0.370	10	0	0	0.749	1
High previous day rainfall	0.370	30	0	0	0.748	1
Moderate number of days since rain	0.370	0	4	0	0.749	4
High number of days since rain	0.370	0	15	0	0.748	5
Moderate negative change in soil moisture	0.370	0	0	-1	0.749	0
Large negative change in soil moisture	0.370	0	0	-30	0.749	1
Moderate positive change in soil moisture	0.370	0	0	1	0.749	0
Large positive change in soil moisture	0.370	0	0	30	0.748	1

The results from the sensitivity analysis shows that changes to any of these four parameters have little impact on the R^2 value and take a relatively short time to adjust (in the order of one week). In the context of the 36 years of time series that the model will produce, the impact of a week until the model settles down is considered insignificant.

4 Conclusions

The demand algorithms developed using MLRA provide a reasonable, but by no means perfect, method for predicting demands. The R^2 values indicated that 53% and 75% of the variability in demands for Waikanae and Paraparaumu-Raumati could be explained by the algorithms developed using climate variables only.

This suggests that the algorithms (may not to be useful as an operational tool without further understanding of the non-climate factors affecting demand (eg, demographics, socio-economic influences, demand management) and refinement of the algorithms, especially for Waikanae. This may also include disaggregating demand and treating the different components separately as each component will vary differently with the climatic factors.

Nevertheless the R^2 values are comparable with those determined from other linear regression analyses of water demands[9], and the algorithms are considered valid for our ultimate purpose of generating demand inputs that correlate with the other inputs used for the surface water and groundwater modelling. For this modelling it is the periods of peak demands that are of primary interest and the error between predicted and actual peak demands is generally less than 10% (apart from 2010 and 2011 for Waikanae). In addition the inclusion of headroom in the yield analysis will provide contingency for under-prediction of demands. Also, because the responsiveness of the groundwater resource is very gradual it will be the trends in demand rather than the day to day variation that is important for the groundwater modelling.

[9] Blakemore & Burton (2007); Aitken, Duncan & McMahon (1991); Gutzler & Nims (2005);

Appendix B

Population Data

Appendix B – Population Data

MERA 2012

03 Medium Growth, Baseline

Area Unit Total	2011	2012	2016	2021	2026	2031	2032
Waikanae	10,838	11,073	12,012	13,227	14,439	15,699	15,951
Paraparaumu-Otaihanga	18,614	18,780	19,446	20,296	21,062	21,679	21,802
Raumati	8,317	8,404	8,751	9,249	9,636	10,061	10,146
WPR Total	**37,769**	**38,257**	**40,209**	**42,772**	**45,136**	**47,439**	**47,899**

03 High Growth, Baseline

Area Unit Total	2011	2012	2016	2021	2026	2031	2032
Waikanae	10,838	11,140	12,348	13,908	15,546	17,305	17,656
Paraparaumu-Otaihanga	18,614	18,889	19,989	21,599	23,104	24,410	24,672
Raumati	8,317	8,461	9,038	9,775	10,450	11,144	11,283
WPR Total	**37,769**	**38,490**	**41,375**	**45,282**	**49,100**	**52,859**	**53,611**

MERA 2009

Kapiti Coast District growth per annum (%)

	Medium	High
2031-2036	0.71	1.11
2036-2041	0.52	0.91
2041-2046	0.37	0.75
2046-2051	0.27	0.63
2051-2056	0.20	0.56
2056-2061	0.18	0.52

Forecasts 2011-2060

Resulting population projections for the two schemes and WPR total using the data above

Medium Growth

	2011	2012	2016	2021	2026	2031	2032	2036	2041	2046	2051	2056	2060
Waikanae	10,838	11,073	12,012	13,227	14,439	15,699	15,951	16409	16840	17154	17387	17561	17688
Paraparaumu-Raumati	26,931	27,184	28,197	29,545	30,697	31,740	31,949	32866	33730	34358	34824	35174	35428
WPR Total	37,769	38,257	40,209	42,772	45,136	47,439	47,900	49,275	50,570	51,512	52,211	52,735	53,116

High Growth

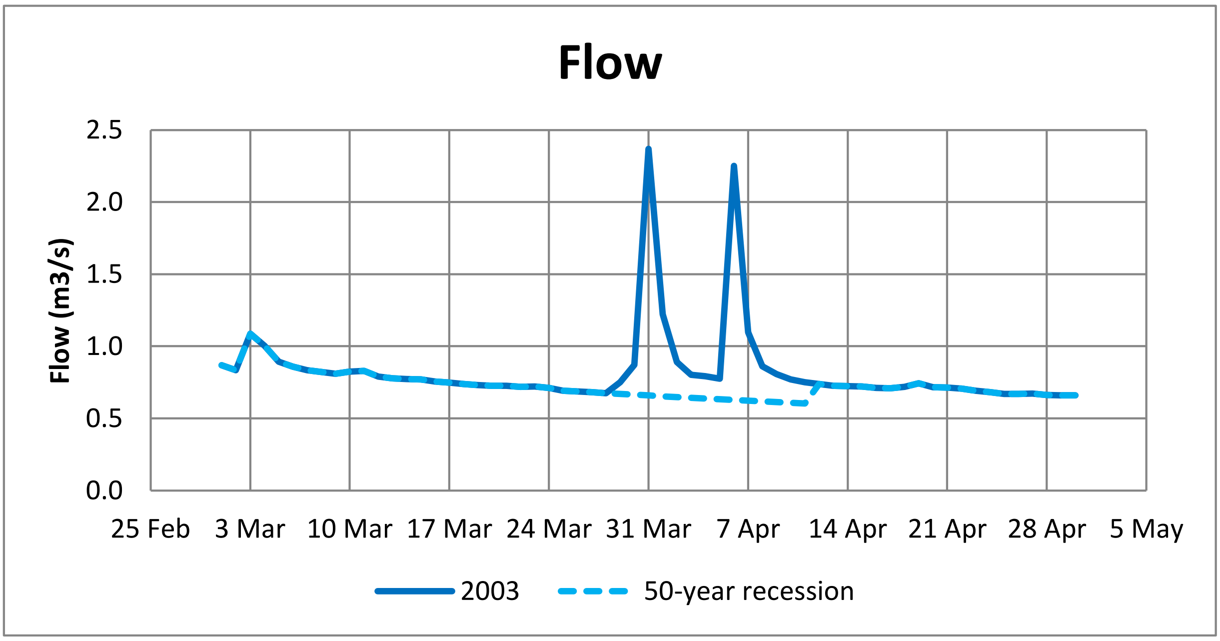
	2011	2012	2016	2021	2026	2031	2032	2036	2041	2046	2051	2056	2060
Waikanae	10,838	11,140	12,348	13,908	15,546	17,305	17,656	18,453	19,308	20,043	20,682	21,268	21,715
Paraparaumu-Raumati	26,931	27,350	29,027	31,373	33,554	35,555	35,955	37,578	39,319	40,816	42,118	43,311	44,221
WPR Total	37,769	38,490	41,375	45,281	49,100	52,860	53,611	56,031	58,627	60,859	62,800	64,579	65,936

Appendix C

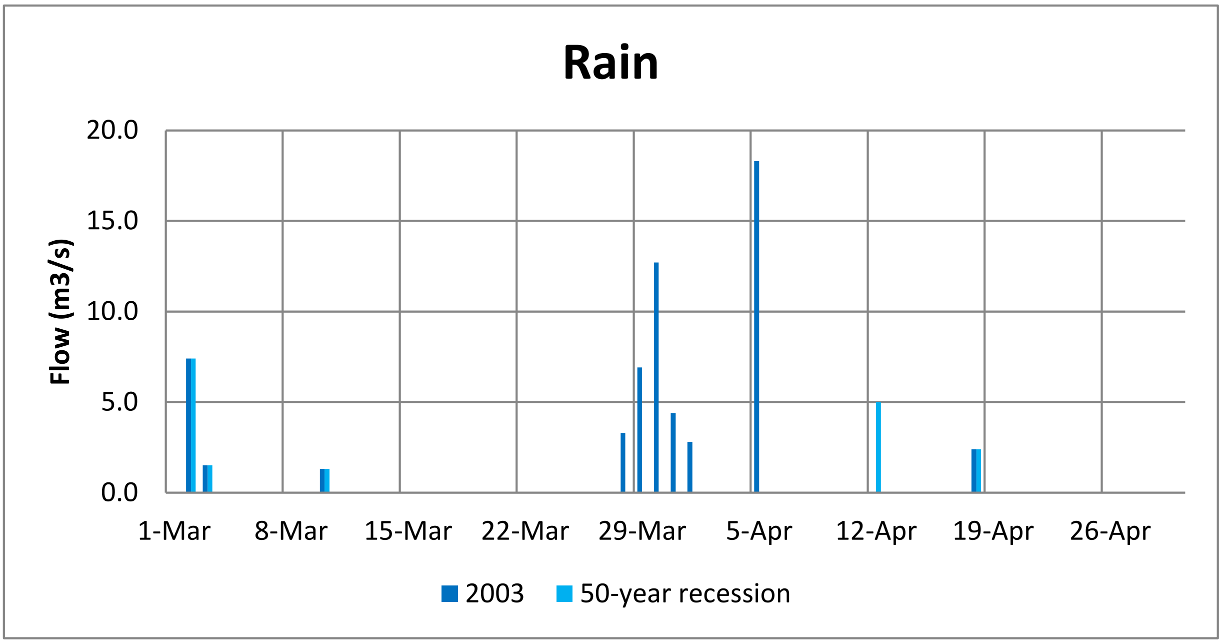
Synthesised Climate Data for 50-Year Low Flow

Appendix C – Synthesised Climate Data for 50-Year Low Flow

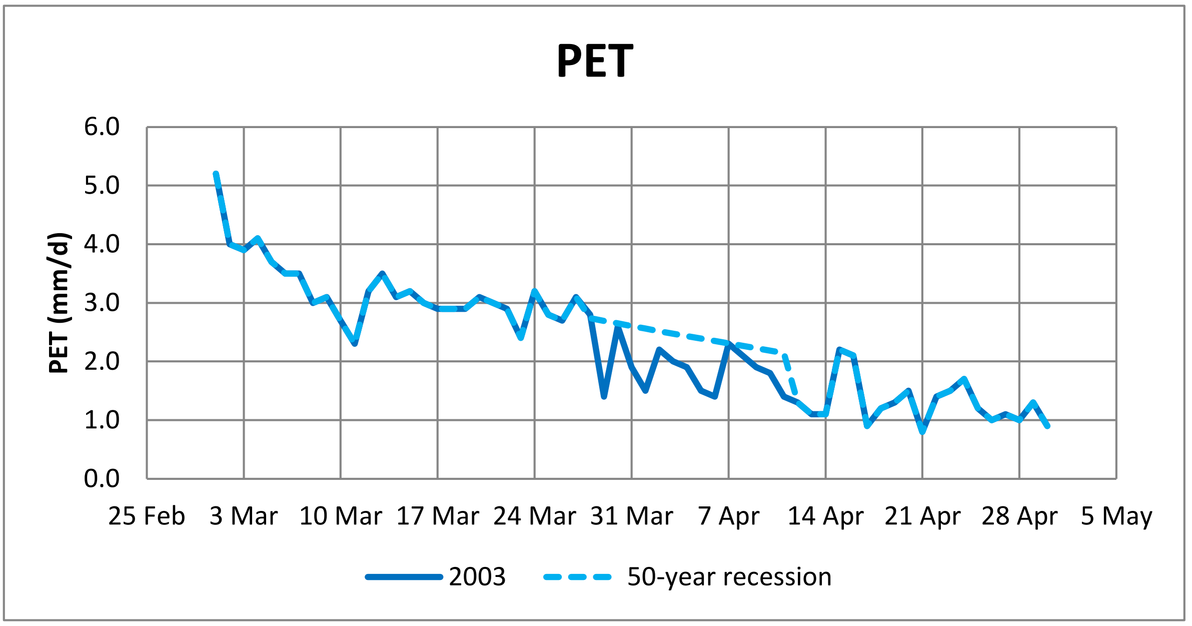
In order to model the 50-year low flow, the observed flow recession in early 2003 was extended through until the 50-year low flow of 0.603 L/s was reached, as shown below. This was achieved by removing the two small flood events that occurred around the beginning of April and extrapolating the underlying recession curve through to the end of the month. Refer to the surface water report for further information on river flows.



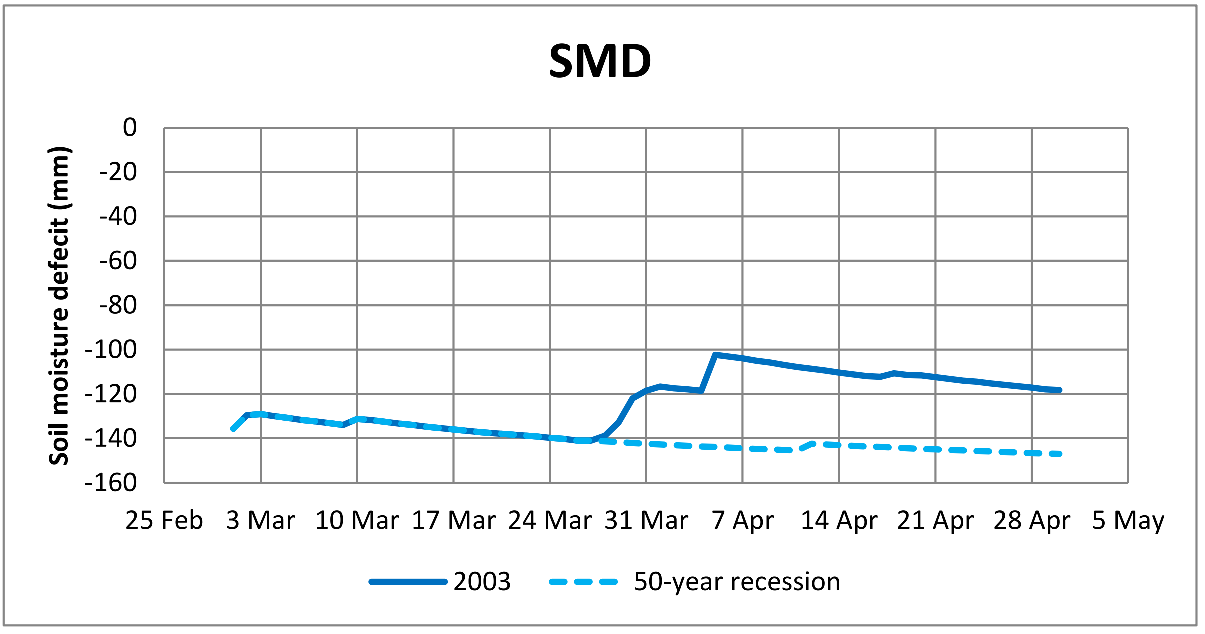
Correspondingly rainfall that occurred in early April was removed from the record, as shown by the plot below. Rainfall was added to the record on 12 April to represent the transition from the 50-year low flow back to the actual river flow (ie, breaking of drought).



Though there was not much rainfall in March/April 2003, the recorded potential evapotranspiration (PET) was not particularly high. In March 2003 the PET tended to fluctuate between the median and upper 75%ile for the month so the smoothed 75 percentile for April was used.



The minimum soil moisture deficit (SMD) values recorded are about -147 mm. For the 50-year low flow the soil moisture deficit has been increased steadily based on historic rates of increase. A small decrease is included in the record to account for the rain added on 12 April, and then the deficit continues to increase until it reaches the minimum value at the end of April.



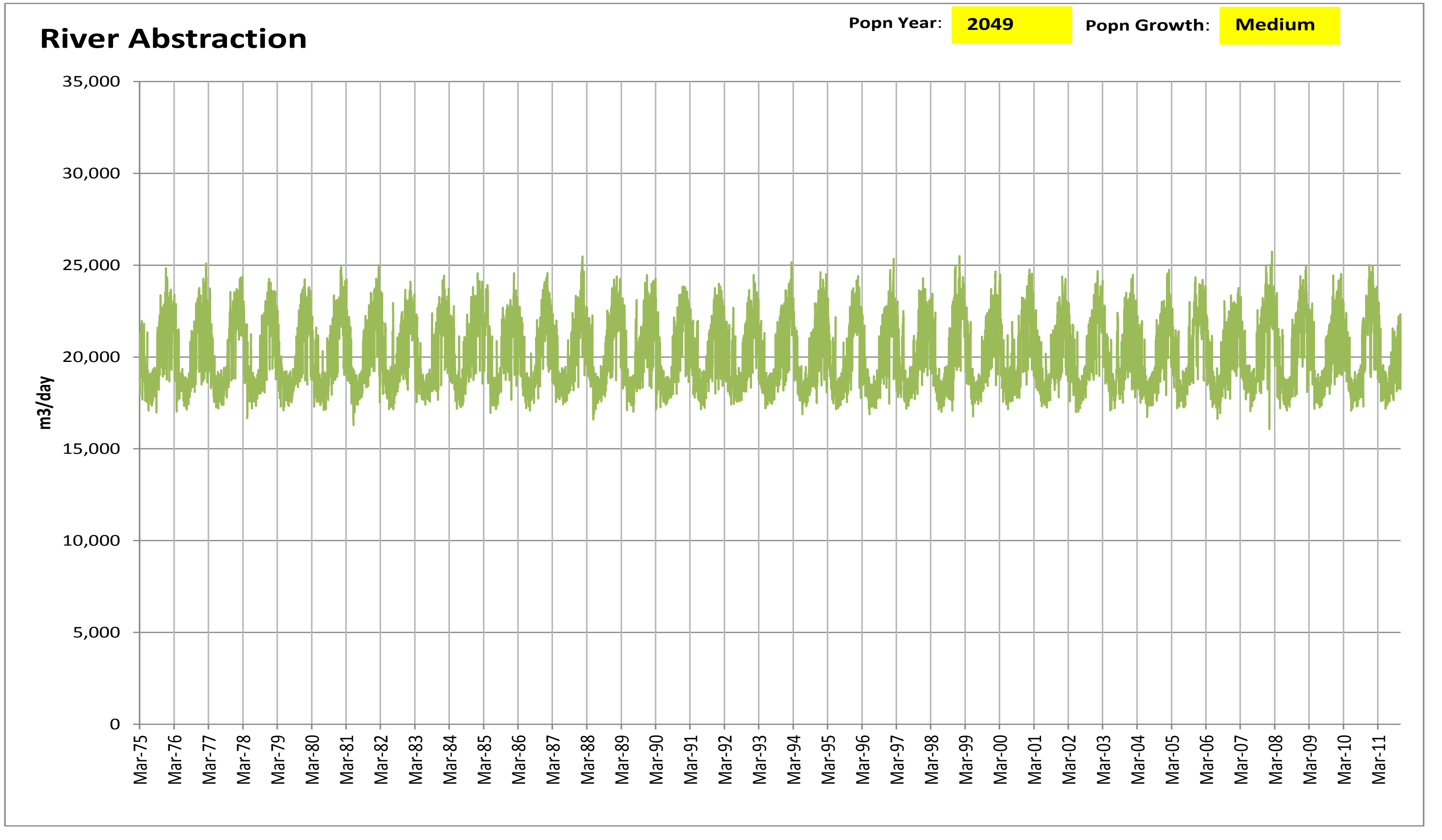
Appendix D

Modelling Outputs

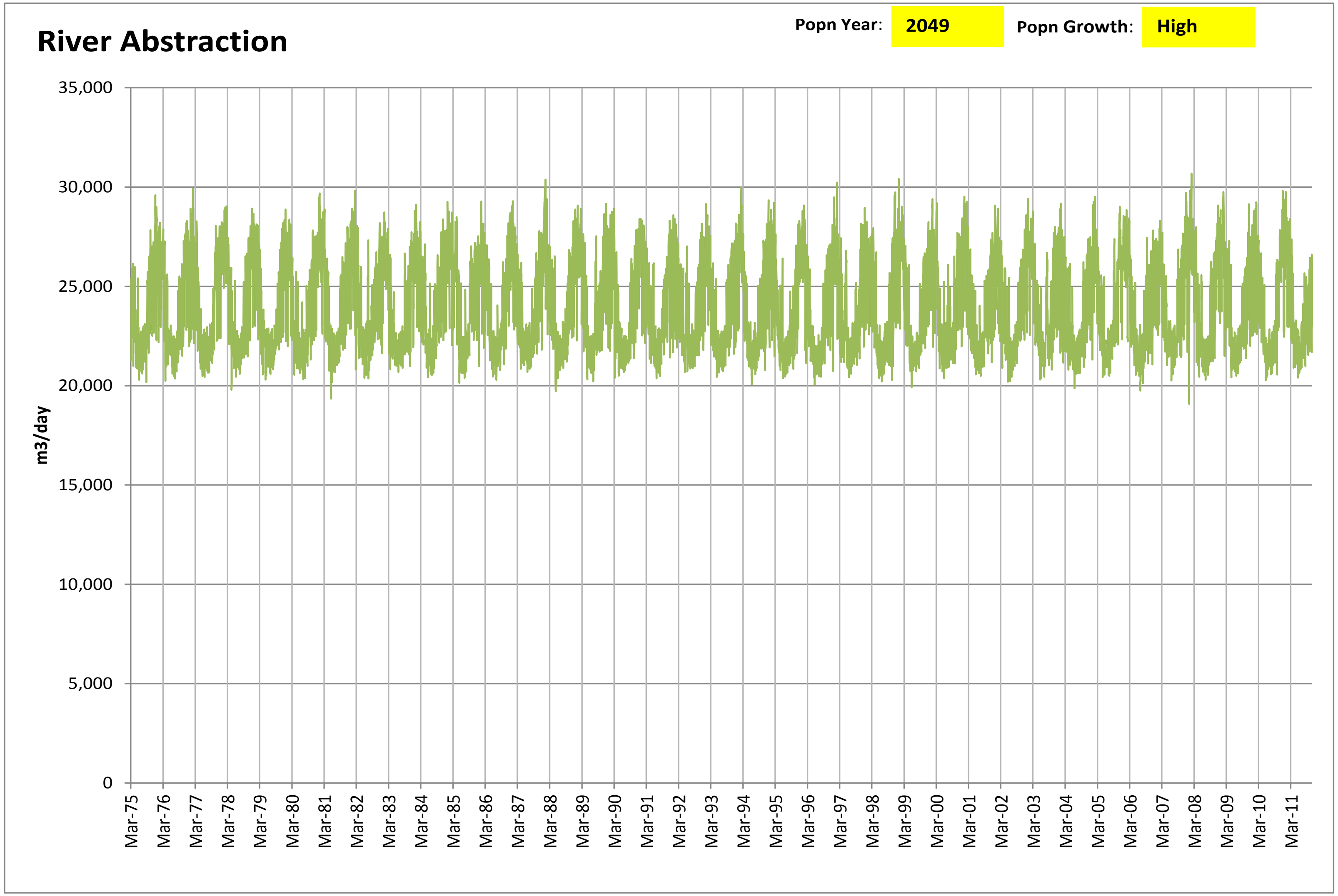
Appendix D – Modelling Outputs

1 36 year time series (1975-2011), with modified climate data in 2003 for 50-year low river flow of 603 L/s

a) Population at 2049, with medium population growth

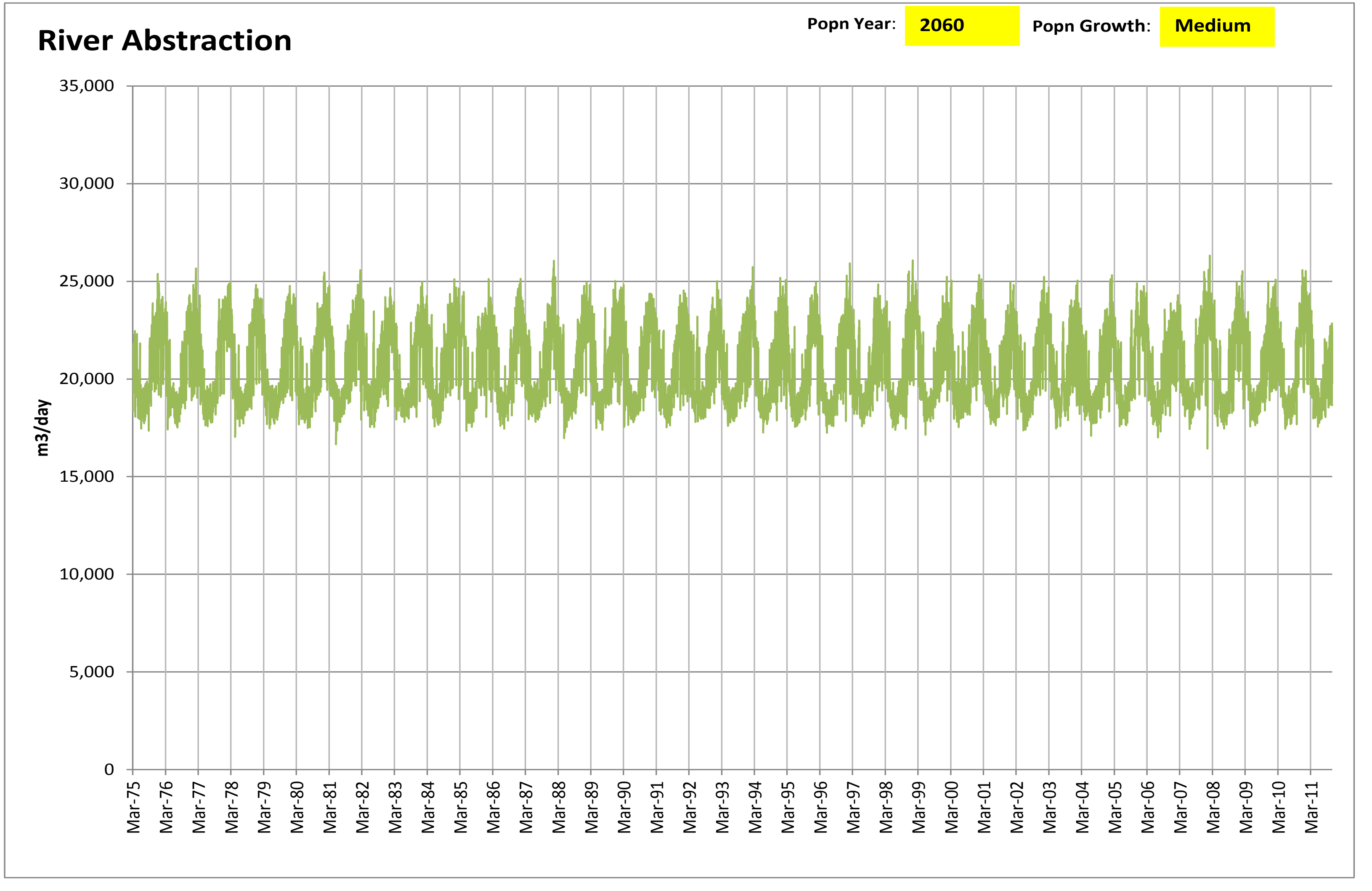


b) Population at 2049, with high population growth



2 36 year time series (1975-2011), with modified climate data in 2003 for 50-year low river flow of 603 L/s.

a) Population at 2060, with medium population growth



b) Population at 2060, with high population growth