

IMPACT OF CLIMATE CHANGE ON WATER DEMAND

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KEYWORDS

Climate Change, Weather, Water Demand, Resilience, Modelling

ABSTRACT

Climate change impacts weather and changes in weather is the single largest factor influencing fluctuations in water demand. Therefore, it would be natural to expect climate change to impact on demand, quantifiable by integrating the outputs of climate models with Sydney Water's demand forecasting model. However, most climate models typically do not produce a single forecast, but rather produce an ensemble of equally likely scenarios. The high variation between these projections lead to different estimates of demand, leaving decision makers with the task of selecting one projection to use. On the other hand, there exists no scientific way of doing this, as they are all equally likely, meaning selecting one would be as good as the other. The paper describes the way Sydney Water approached the problem, which was to use a two-staged process; developing a mathematical solution to integrate the output of global models with Sydney Water's demand forecasting model, and developing an approach based on the risk tolerance levels of the decision it informs to select the most appropriate output from a climate model, to arrive at the most appropriate estimations of the marginal-impact of climate change on demand as, 2.14% in the near-future (2020-2040) and 4.42% in the far-future (2060-2080).

INTRODUCTION

Weather is the single most significant factor that influences day-to-day variations in water demand. Weather driven variations in Sydney is estimated to be as high as 50 Giga Litre; most of which is the result of extreme weather conditions such as heat waves and droughts,

which are increasing in severity and frequency with climate change. In 2016 Sydney Water entered into a research partnership with the Centre for Climate Change of the University of New South Wales to bring together the expertise, knowledge and resources of both organisations, to develop a method of quantifying the impact of climate change on demand. As a result of this, Sydney Water has now able to successfully integrate the effect climate change has on demand forecasts, and for the first time has incorporated this into pricing recommendations made to the Independent Pricing and Regulatory Tribunal, and other infrastructure planning processes such the Metropolitan water planning process.

The methodology used, involves integrating a mathematical demand forecast model developed by Sydney Water with climate projections of the New South Wales / Australian Capital Territory Regional Climate Modelling (NARCLiM), via a Stochastic Weather Generator developed by the University of New South Wales. The integrated model estimates, in addition to the interactive effect of the predictor variables including population growth, dwelling type mix and climate change, the marginal impact of each of these factors on water demand. Thus, it is also possible to quantify the relative impact of climate change in comparison to population growth and dwelling type mix.

For a complete technical explanation of the methodology refer Barker, et al (2018a).

The purpose of this paper is to give an overview of the approach and how some of the challenges, both to do with the science, and policy development were overcome.

The key challenges involved in estimating the impact of climate change on long term demand are;

- Climate models typically predict averages, whereas demand is mostly driven by extreme events (severity and frequency)
- Climate Models (NARCLiM) does not produce single projection, but generate 12 member ensembles, based on –
 - four climate models and,
 - three downscaling methodologies
- the difficulty of estimating the uncertainty surrounding secondary impacts (eg, demand driven by the use of water in mitigation programs such as urban cooling).

The first challenge is overcome by building a 'weather generator' which develops Monte-Carlo simulations of weather scenarios based on climate average projections of NARCLiM, and integrating the weather generator with Sydney Water demand model to produce demand forecasts taking climate change into account.

The second has more to do with decision making than science; the challenge here is to have the right decision-making framework for incorporating climate change into government decision-making and policy development. We propose a risk based approach; selecting an ensemble member of the model, based on the risk tolerance profile of the decision it informs.

Secondary impacts of climate change on demand, likely to be mainly constituted by demand from outdoor irrigation, greening and urban cooling has not been properly estimated at this stage and is out of the scope of this paper.

SIMULATION /EXPERIMENT

The scientific component involves integrating the NARCLiM projections with the Sydney Water Consumption Model (SWCM), by developing a series of weather scenarios using a Stochastic Weather Generator and using them as inputs to SWCM.

Sydney Water Consumption Model

The Sydney Water Consumption Model is a statistical-forecasting-model based on a dynamic panel regression methodology (Woolridge, 2010; Bun and Sarafidis, 2015) based on the work of Abrahams Et al (2012). The model forecasts metered water use - which constitutes 90% of all consumption (the rest is either leakage or undermetered usage, which amounts to approximately 57 GL a year) - based on population change, dwelling types, whether or not a property has water efficiency programs such as BASIX, and five weather variables, which are;

1. average daily precipitation,
2. number of days in a month when precipitation exceeds 2 mm,
3. average daily maximum temperature,
4. number of days in a month when temperature exceeds 30° C
5. average daily pan evaporation.

Historic recordings from 12 weather stations operated by the Bureau of Meteorology were used in developing the model. For full technical details of SWCM, please refer Barker et al (2018a)

New South Wales / Australian Capital Territory Regional Climate Modelling Project (NARCLiM).

The NARCLiM project provides temperature and precipitation data based on four different global climate models (GCMs) for the present (1990-2010), near-future (2020-2040) and far-future (2060-2080). The GCMs used are CCCMA3.1, CSIRO MK 3.0, ECHAM5 and MIROC 3.2. All simulations were based on Intergovernmental Panel on Climate Change's Special Report on Emission Scenarios, scenario A2.. Data is available on 10km x 10 km grids for the whole of Eastern Australia including Sydney Water's areas of operation. Three runs are produced for each period/GCM, with each run generated using different physics assumptions for the downscaling process.

The NARCLiM data was bias corrected, so that the temperature and precipitation have the same yearly averages as the Australian Water Availability Project (AWAP) data, over the same period.

Stochastic Weather Generator.

A stochastic weather generator developed by Barker et al. (2018a) was used for the generation of weather scenarios as inputs for the SWCM. A

weather generator was used to overcome the problem that each NARCLiM member only produces a single realisation of a stochastic process (i.e. weather). The weather generator enables multiple (in this case 100) realisations to be generated, each consistent with a NARCLiM ensemble member, to examine the statistical distribution of weather and water consumption forecasts.

For each period/GCM/run combination, the stochastic weather generator was calibrated to produce weather scenarios with statistical properties similar to those of the NARCLiM data. NARCLiM weather data from the closest grid point to each of the 12 weather stations was used to calibrate the stochastic weather generator. Each weather scenario contains data for the 11 financial years from 2014/15 to 2024/25 and 100 weather scenarios were generated for each period/climate model/run combination.

In total 13 sets of 200 years of data were generated for each time period (present, near future, far future) allowing quantification of the variance due to changing weather. All weather variables were assumed not to have a yearly trend within the 20 year NARCLiM period. It should be noted that estimates of water demand by SWCM requires pan evaporation, a variable not generated by most weather and climate models including the NARCLiM project. Instead, the evaporation model described by Barker et al. (2018a) was used to generate evaporation data as a function of precipitation and maximum temperature.

The output from this was used as the five weather related inputs to the SWCM.

Experiments performed

The consumption forecast generated through the above reflects changes in population, dwelling types, and changes in weather patterns that are likely to occur in relation to climate change.

The population inputs were approved by the NSW Government. The weather data associated with a forecast is taken from a stochastic weather generator simulation based on data from a NARCLiM ensemble member in one of the present, near or far future periods. We can vary the NARCLiM ensemble member and time period represented, with weather reflecting the present, near or far future. Therefore, we can examine the consumption forecasts for combinations of populations between 2014/15 and 2024/25 with weather for

the present, near future or far future. We therefore undertook three analyses, each for the present, near and far-future:

1. Isolate the effect of climate change on water consumption. Here, population is held at 2019/20 levels and the dwelling type mix uses the population estimates;
2. Isolate the effect of population change on water consumption. Here, population is allowed to vary from 2014/15-2024/25, with a dwelling type mix associated with that population change.
3. Isolate the effect of dwelling type mix. Here, population varies from 2014/15-2024/25 and the dwelling type mix varies between the dwelling type mix estimate, simulations with no single dwellings, and simulations assuming all single dwellings.

However, for the purpose of this paper, we will discuss only (1); the marginal impact of climate change.

The process was repeated for each NARCLiM period, GCM and run leading to 12 forecasts altogether.

RESULTS

The results, (Figure 1, Table 1 & Table 2), suggest a large variation between the different ensemble members of NARCLiM. However, there is no direct scientific way of selecting one of these forecasts over the other, because the different GCM outputs which lead to the different demand forecasts, are all considered equally likely. They are scenarios, rather than members of a probability distribution. This means using a central tendency such as a median or average would be equally useless, in mathematical terms, these would not yield anything more accurate than arbitrarily choosing one of the ensemble outputs.

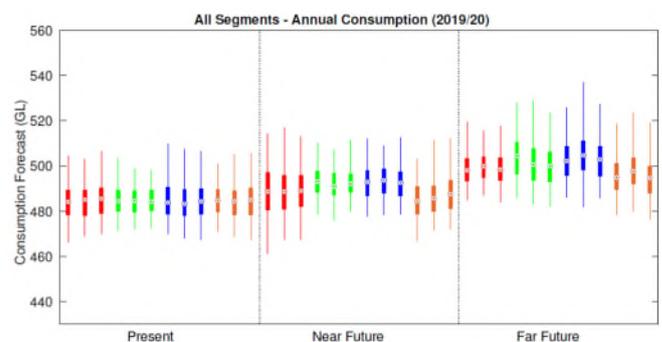


Figure 1: Annual Demand
Red CCMA3.1, Green CSIRO-MK 3.0, Blue ECHAM5, Brown-MIRCO3.2 (reproduced from Barker et al (2018b))

Table 1 Total Annual Consumption (2019/2020)
- Period: 2020-2040

Model run	Median demand GL	% increase from base year
CCCMA3.1	488.7	0.93
CCCMA3.1	488.7	0.75
CCCMA3.1	489.0	0.72
CSIRO-MK 3.0	493.0	1.79
CSIRO-MK 3.0 ²	490.9	1.32
CSIRO-MK 3.0	492.1	1.62
ECHAM5	492.9	1.90
ECHAM5 ¹	493.6	2.14
ECHAM5	492.5	1.69
MIROC3.2	484.4	-0.06
MIROC3.2	485.6	0.27
MIROC3.2	487.4	0.51

Table 2 Total Annual Consumption (2019/2020)
- Period: 2060-2080

Model run	Median demand GL	% increase from base year
CCCMA3.1	498.0	2.86
CCCMA3.1	499.8	3.06
CCCMA3.1	498.4	2.65
CSIRO-MK 3.0	504.3	4.12
CSIRO-MK 3.0 ²	500.5	3.31
CSIRO-MK 3.0	500.0	3.24
ECHAM5	502.2	3.82
ECHAM5 ¹	504.6	4.42
ECHAM5	502.9	3.85
MIROC3.2	494.9	2.10
MIROC3.2	497.7	2.75
MIROC3.2	494.7	2.00

¹ Suggested for infrastructure investment

² Suggested for price determination

DISCUSSION

The differences between the outputs from the different ensembles is so large that it would be hard, if not impossible to plan for all of them, Which, makes it a necessity to select one.

That solution to this does not lie in the science, but in the way the science is incorporated into decision making. We argue that there is no

need to use a single scenario to inform all decisions. Planning against different scenarios depending on the risk profile of the decision involved, is commonly used across government and industry. For example, governments typically plan for high impact situations such as national security or preventing deadly diseases against worst case scenarios, while they plan for things like economic turns against medium term scenarios. We propose something similar, choosing a projection scenario, based on;

- the impact of error, i.e, the impact of 'getting it wrong'
- potential to respond to an error in terms of capability and speed to respond
- how equitably the impact of error is distributed among stakeholders.

We demonstrate this through the example of the following two decisions.

1. Determining the optimal retail price of water to recommend to IPART.
2. Plan/determining investments in building future infrastructure.

Table 3 Risk profile of decision framework

Decision	Direction of error	Impact of error on NSW Govt. / SW	Impact of error on customer	Potential/ability & speed to respond	Most appropriate projection
Retail price determination	Over forecast	Loss of revenue		High	Middle case
	Under forecast		High price	High	
Infrastructure/water security planning	Over forecast	Wasted investment		Potential to catch up in time	Worst case
	Under forecast		Service failure/constrain	Slow	

In the case of the retail price determination, over-forecasting and under-forecasting, more or less have the same impact. Over forecasting can lead to lower retail prices (as prices are usually set to achieve retail targets) and hence loss of revenue to Sydney Water, whereas under forecasting can lead to higher cost to consumers. However, the degree of loss or gain is more or less the same in both cases.

Therefore, the most appropriate forecast to use would be the ensemble member in the middle of the range. In the case of determining investments in future infrastructure, the consequences of under-forecasting, which could lead to supply constraints or shortages, most would agree is of graver consequence than wasted investments, building unnecessary excess capacity. Further, responding to under-forecasting would be harder as building

infrastructure takes time, whereas excess capacity in infrastructure could be absorbed in time as natural growth takes place. It could also be argued that the cost of error would be felt more by consumers than Sydney Water.

Therefore, in the case of determining investments in infrastructure, the ensemble member providing the worst case projection scenario should be used. Thus, given informing long-term planning decisions is the purpose of the long-term demand forecasting, we recommend ECHAM5, as appropriate for this purpose.

Therefore, percentage increase in the near term is, 2.14% and percentage increase in the far term is 4.42%

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