

Assessing the sensitivity of UK water demand to climate change

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Introduction

To date, there have been few studies that have examined the sensitivity of water demand to climate variability and change. This study uses Anglian Water's *Survey of Domestic Water Consumption* (SODCON) dataset for the East of England to examine the sensitivity of metered water demand micro-components to climate variability and change. The sensitivity analysis will show the extent to which climatic and non-climatic drivers could shape future peak demands and hence the degree to which demand can be managed. The study will also inform wider debates about balancing water supply and demand as well as providing a basis for testing the robustness of Anglian Water Services strategic water planning.

Hopefully, the UK climate projections (UKCP09) can ultimately be applied to the relationships determined between micro-components and climatic variables to evaluate the range of uncertainty in water demand projections under climate change. It is also important that this study considers the transferability of our findings to other regions where no such detailed data exists. Additionally, the findings from this study will inform and provide case study material for a regional assessment of the resilience of water supply, distribution and demand to climate change in SE England (ESPRC-ARCC water). ARCC water is a multi-institutional collaboration between UK water engineers, researchers, government bodies and the water industry to address aspects of UK water management within a changing climate.

Context

Anthropogenic climate variability and change threatens UK water security through such factors as altered drought frequency and intensity, changing water demand profiles and damage to infrastructure (Arnell and Delaney, 2006; Arnell, 1998). These potentially could alter water availability for storage, abstraction and supply as well as present new challenges for the UK water sector. Furthermore, climate change sits amongst a host of other pressures to the water system such as socio-demographic change and population growth (Blöschl and Montaanari, 2010; Wilby and Dessai, 2010). Mitchell (1999) states that increases in demand (attributed to an absolute growth in both household numbers and household water consumption) along with climate change threats to supply are forcing UK water resources closer to sustainability limits than ever before.

Water management is essentially about balancing water supply and demand whilst being mindful of wider environmental consequences (McDonald *et al.*, 2003). Each side of this balance composes of many different aspects (population, demographics, pollution, leakages). Historically water planning techniques used to make the implicit assumption that a system which can maintain supply through a repeat of the climate of the last fifty or hundred years can provide sufficient security of supply for the future (all other factors being constant). Climate change modifies the problem of water supply planning by removing the climatic 'stationarity' that underpins this assumption (Milly *et al.*, 2008). Planning thus requires numerical models and forecasts to predict the hydrological response of the catchment to changes in climate (McDonald *et al.*, 2003). However, hydrological models and climate change projections can yield different results depending on the methods and observed data used for calibration. In addition there are uncertainties associated with our understanding of groundwater recharge rates and capacities, population and demand behaviour forecasts and future technological change. As a result of all these uncertainties it is important that our water management approach is both socially and ecologically adaptive and flexible to reorganise in response to climate change and its observed impacts (Lopez *et al.*, 2009; Watts, 2009; Wilby and Dessai, 2010). Intelligent monitoring and reporting are also needed to track emergent trends and evaluate adaptation interventions (UNDP, 2007; Parry *et al.*, 2009).

Presently the majority of focus in water management from both the water industry and academic research is on the supply side. Considerations of the impact of climate change on future water supply side and demand side are unbalanced; to date relatively few studies have examined potential water demand impacts. The narrow long-term demand forecasting literature base can be attributed to the difficulty in recording, understanding and predicting the complex nature of domestic demand alongside the fact that it was not until recently that the importance of demand management and the possibilities it holds for controlling water resources was acknowledged. (McDonald *et al.*, 2003; Memon and Butler, 2006; Medd & Chappells, 2008).

In the UK, OFWAT now requires water utilities to estimate and forecast water demand as part of the annual June Returns, 5 year Periodic Review process and hold a responsibility to provide cost effective and defined levels of service. Currently when assessing the impact of climate change on demand most water companies apply factors from the Climate Change and Demand for Water Revisited project (Downing *et al.*, 2003). It states an average per capita consumption (PCC) prediction for the UK, ~2-3% PCC increase under climate change for the next 25 years. Limitations of this study are that it is now 7 years old and that its use of average PCC masks inter-house variations in water-use habits resulting from different variables such as climate occupancy rates, cultural-values, and bill payment methods i.e. metering or tariff (Herrington, 1998; Gleick, 2002). PCC also assumes that water use is linearly dependent upon occupancy, i.e. it masks subtle differences in micro-component uses which reflect water using practices (Edwards and Martin, 1995).

There is a need to develop methods for forecasting demand and supply with a high degree of accuracy due to increasing population, constraints on freshwater supply and the growing economic and environmental costs involved in the development of new water resources (Memon and Butler, 2006). In a context of climate change and the need to ensure sustainability of water resources, demand management could be a highly valuable tool (MacDonald et al., 2003). Furthermore, household water demand management is increasingly being viewed as a robust and 'low regret' adaptation option considering the uncertainties surrounding climate change and other threats to the UK water sector (Memon and Butler, 2006; Wilby and Dessai, 2010).

However, domestic water use is inherently complicated to understand and forecast being shaped by political, social and economic influences (Memon and Butler, 2006). The influence and interplay of these variables on a person's water-use behaviour and attitudes makes current domestic demand very temporally and spatially variable and extremely difficult to understand and model (McDonald *et al.*, 2003). The same average PCC can be obtained via multiple water consumption pathways (Gleick, 2002; Medd and Chappells, 2008). Predicting the nature in which the relationship between people's water using habits and these variables will change in the future is a further problem. Additionally, predictions of population growth, uptake of demand management measures and technological advances (i.e. introduction of new household technology with various water consumption volumes) are uncertain (Shove, 2003). These uncertainties alongside those associated with climate change projections, hydrological models and supply (reservoir) calculations means that domestic demand forecasting is extremely problematic (McDonald *et al.*, 2003).

Method

The methodology of this study is in its early stages and will employ an iterative approach being determined and refined through pilot and feasibility testing. A pilot PCC regression model and data analysis is presented in this paper to demonstrate how the intended methodology can be used to investigate the sensitivity and nature of domestic demand's relationships with climatic and non-climatic variables. The use of multiple regression models within this study will have two applications to undertake sensitivity analysis on household water demand. It can be used as a diagnostic tool to highlight variables of interest for further exploration and data analysis. It can also be used as a predictive tool to identify and explore relationships between domestic demand and climatic and non-climatic variables.

Data preparation

Initially a set of rigorous quality assurance checks, developed through an iterative process, were applied to the SODCON dataset. The next stage in data preparation was to stratify the dataset to reduce the scatter and noise within the multiple regression models and improve their explanatory power. There are numerous ways in which the dataset can be stratified to investigate the impact of different variables on household water use. For example, it can be stratified by region, a Classification of Residential Neighbourhoods (ACORN), occupancy rate, tariff or metering, day of week, month of the year, season or/and by bank holiday or non-bank holiday.

Pilot and feasibility testing

The possibilities of using multiple regression analysis to 'mine' the vast dataset and inform further analysis was investigated by undertaking pilot data analysis into PCC and its relationship with non-climatic and climatic variables. Within this pilot analysis the data was stratified by region so that only the Ruthamford participants were analysed. It was further stratified into metered and unmetered households to enable an investigation into the impact of metering on domestic water consumption. Finally it was stratified by occupancy rate. Single and four occupancy household samples were selected to analyse at this stage. The reason for this was that four occupancy households are the 'average family' member quantity according to the national census in 2001. Therefore in this example four occupancy samples are considered to represent an average 'family' household's water use allowing for a comparison of single and family occupancy households' water use. This enables an investigation of the previously mentioned limitations of PCC (i.e. masking variabilities in water use practices within a household).

This pilot PCC regression model demonstrates the general methodological approach of this study. Many intriguing questions emerge from its coefficients shown in figure 1 which can be explored with further data analysis. Some analyses have been applied and are presented here after. In addition to quantitative analysis it is intended that social scientists within the ARCC water project will be consulted about the underlying causes of these different behaviours and suggest ways of interrogating the regression models.

Variable	unmetered 1 occupancy	metered 1 occupancy	unmetered 4 occupancy	metered 4 occupancy
Intercept	24689.0	2160.3	8347.9	39301.7
CosMonth	11.1	4.0	-10.5	7.9
SinMonth	2.9	-2.5	-5.6	-2.4
Mon. (relative to Sun.)	-27.5	-55.8	-33.1	-97.4
Tue. (relative to Sun.)	-23.4	-54.4	-34.6	-79.4
Wed. (relative to Sun.)	-25.0	-49.2	-43.5	-74.7
Thu. (relative to Sun.)	-22.7	-43.5	-38.5	-124.5
Fri. (relative to Sun.)	0.3	-41.0	-31.9	-93.2
Sat. (relative to Sun.)	-4.4	-8.3	-18.8	-15.8
Bank holiday flag	1.6	42.6	16.9	42.0
Year	-12.3	-1.0	-3.9	-19.4
Min temp (l/°C)	0.0	-0.4	0.5	-4.9
max temp (l/°C)	0.1	1.4	0.3	6.5
Sunshine (hrs/d)	1.2	0.5	2.3	-1.8
rain ^0.25 (mm/d)	0.2	-1.8	-5.5	0.1
3-d rain (mm)	-0.1	0.4	-0.2	0.1
7-d rain (mm)	-0.1	-0.3	0.3	-1.5

Fig. 1- Table of coefficient results from pilot PCC multiple linear regression model for Ruthamford single and four occupancy households. Significant coefficients are shown in grey (p<0.05).

Weekly cycle

In figure 2 PCC relative to Sundays' PCC was plotted against the day of the week. There is a clear weekly cycle in water use within this dataset as shown in figure 2. Suggestions for this might be that people spend less time in the house during the week than at weekends and are thus likely to use more water midweek. The amplitude of this cycle depends on the occupancy of the household and whether it is metered or unmetered. Metered households' water use is more depressed during midweek in relation to Sunday than unmetered. Similarly, four occupancy households show a more pronounced weekly cycle than single. Raising questions such as which water practices are these differences associated with and how might this behaviour be affected by climate change?

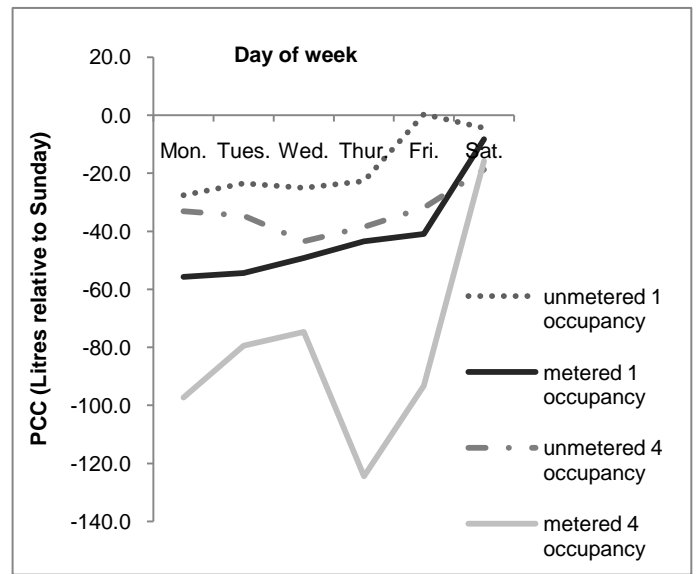


Fig. 2- Average PCC in litres per day relative to Sunday.

Bank holidays vs. Non-bank holidays

The multiple regression model coefficients (see fig. 1) highlighted the impact that bank holidays have on household water consumption compared to non bank holiday days. All modelled houses consume more water on a bank holiday than at other times (see fig. 3). This raises questions as to how this behaviour might be affected by climate change? The coefficient results from the regression analysis suggest that metered single and four occupant households use ~160 litres more water on a bank holiday than at other times. Will metered households' water use always be so responsive to bank holidays in the future? It is questions like these that future quantitative and qualitative analysis within this study can begin to explore. Further preliminary analysis examining the individual micro-components PCC values gives some indication of how household water consumption habits change on bank holidays to cause such a marked increase in PCC. On bank holidays metered single occupancy households in particular use much more water in the kitchen sink and for WCs. What behaviours or habits lead to this trend?

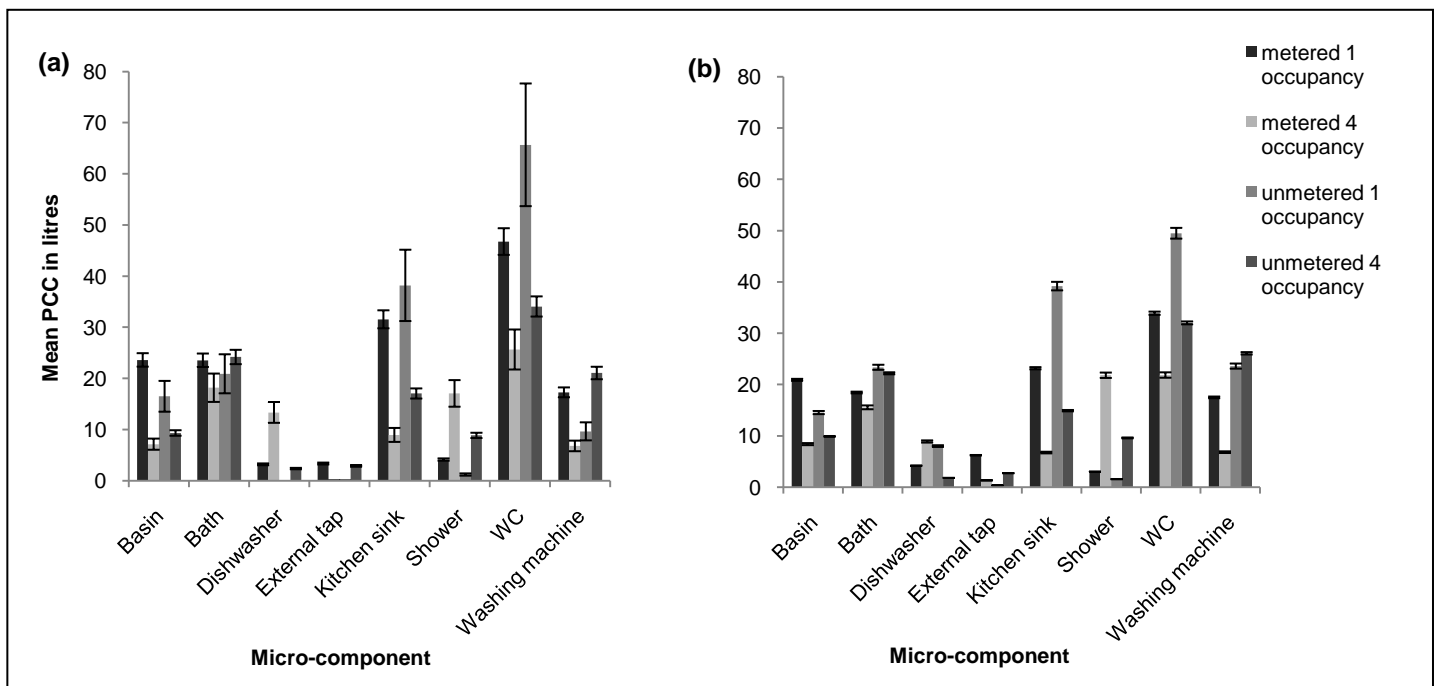


Fig. 3- Average microcomponent PCC in litres for a) bank holidays and b) non-bank holidays. Results are presented with the standard error of the mean.

Metering

Worth noting from figure 1 is that metered four occupancy households consume a maximum of 6.5 litres water per 1°C rise in air temperature compared with single occupancy households which consume 1.5 litres per 1°C. This value is based on historical data but if this relationship and all other factors remain constant, an average 2°C temp rise would result in a 52 litre increase in household water-use per day in a four occupancy household. This poses the question; why is the PCC in four occupancy households so much more responsive to temperature than single occupants?

The differential metered response of single and four occupant households to temperature suggests that the use of average PCC could conceal a lot of subtle variation at the level of the micro-components of demand. Consequently questions emerge as to which water practices these differences are associated with and whether PCC is the best method for assessing water demand? Answers to these and similar questions could be important to inform management of household demand by targeting high micro-component CC related practices.

From analysis of the micro-component PCC (see fig. 4) it is evident that four occupant metered households consume more water than single occupancy metered households in the practice of showering. Single occupancy metered households appear to use more water in the kitchen sink per capita than four occupant households.

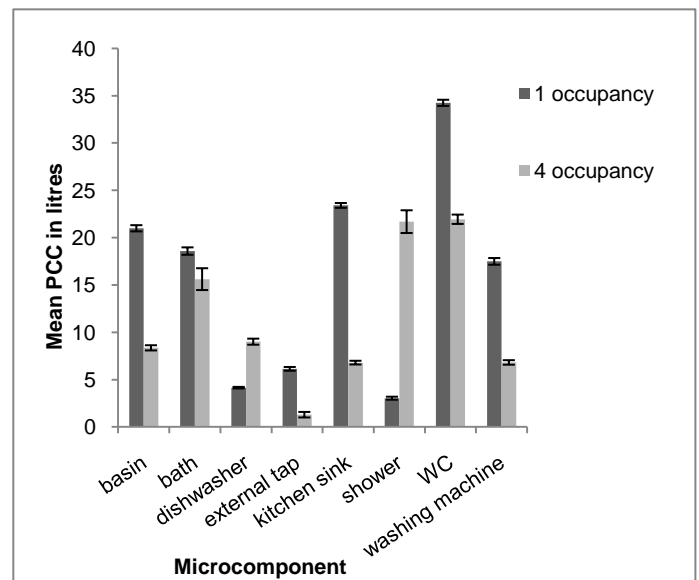


Fig. 4- Average microcomponent PCC in litres. Results are presented with the standard error of the mean.

Longer-Term Study Goals

The pilot analyses results presented within this report are based on average historic conditions. However, the SODCON data covers several years so it may be possible to evaluate time-dependency in the most important loadings of micro-component water demand. It would be interesting to apply the UKCP09 projections to relationships determined between micro-components and climatic variables to evaluate the range of uncertainty in water demand projections under climate change. Finally, it is important that the transferability of our findings to other regions for which there are no such detailed data is considered.

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