Title:	**Report AR1206 Annex D** **Demand forecast model**		
Project no.:	2287	Date:	2nd May 2018
Author(s):	Shana Meeus Sarah Rogerson Rob Lawson Dene Marshallsay	email:	rob@artesia-consulting.co.uk

This document is one of five technical annexes that accompany the main report "The long term potential for deep reductions in household water demand" produced for Ofwat by Artesia Consulting.

1. Introduction

This annex describes the demand model used to forecast the deep demand reductions over 50 years for each of the scenarios presented in the main report. We will present the modelling approach, assumptions and modelling results for each scenario.

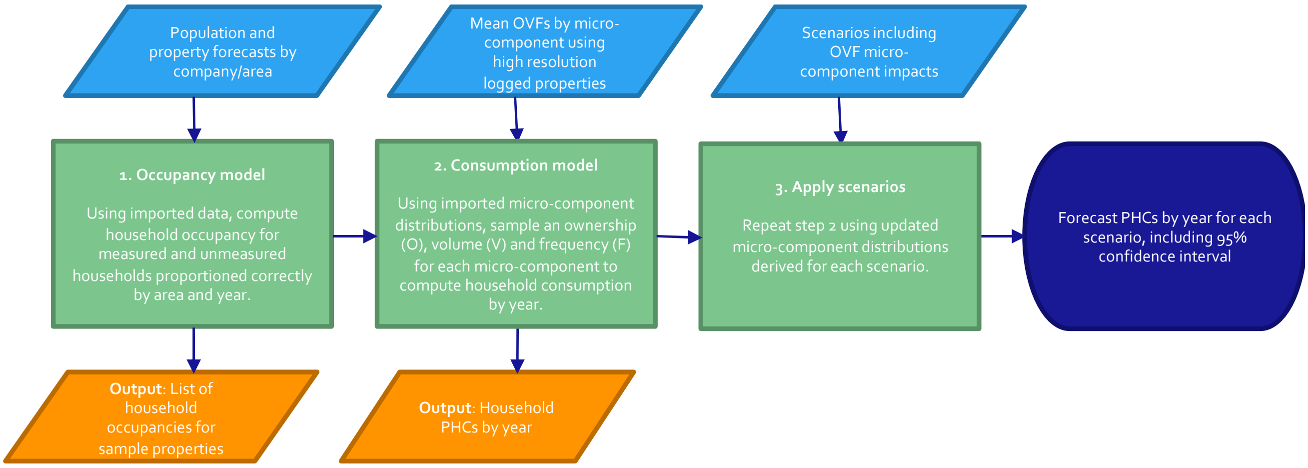
2. Modelling approach

Forecasting long term household consumption is a challenging task, as factors such as behaviour, technology and regulation can affect a consumer's response to water use. Therefore, to understand the long-term potential for demand management in domestic properties in England and Wales, a stochastic approach has been used to model the variation in responses effectively.

A stochastic approach differs from a deterministic model, since the model possesses inherent randomness which will lead to an array of results from which uncertainties can be derived. The model therefore produces outputs with defined confidence intervals, which will indicate how variable a specific scenario outcome is.

In order to model as many explanatory variables as possible, the model has been split into three stages, as shown in Figure 1. These stages will be discussed separately in this annex.

Figure 1: Overview of modelling process



2.1. Occupancy modelling

To begin, occupancy is modelled using the population and property forecasts for each company/area. This is important since it allows an occupancy trend to be included within the model, as this is understood to have a big impact on household consumption.

First, a probability distribution is assigned to occupancy making it possible to produce household level occupancy values which have a mean occupancy equal to that using all data combined. Producing household level data in this way will allow individual homes to be modelled, producing the final PHC distributions which can be used to derive confidence intervals.

2.2. Consumption model

The basis for modelling PCC stochastically is predicated on an understanding of micro-component usage in the home (WC flushing, showering, clothes washing, drinking, etc.), conditional on meter status and occupancy.

At this point household level occupancy has been output from the model, therefore the first stage of the consumption model is to analyse a large number of individual unmeasured and measured household's micro-component data. Using this, we can calculate current and future PCC using a micro-component model.

Each end-use is calculated using values for ownership, frequency of use and volume per use (O, V, F) which will differ by occupancy, and measured or unmeasured meter status. This deep understanding allows us to make assumptions about how each scenario will impact each element of water use in the home, which is important in the final stage of the model.

The basis for the model for household consumption (PHC) is:

$$PHC = \sum_{i=1}^{n} (O_i + V_i + F_i) + phr$$

Where:

O	is the proportion of the households using the appliance or activity, per micro-component 'i'
V	is the volume per use for 'i'
F	is the frequency per use (per household) for 'i'

phr is the household residual

The consumption model resulting from this micro-component analysis allows household level consumption to be predicted depending on occupancy and meter status. So, as average occupancy changes through time and meter penetration increases, so will average household consumption.

The 'phr' term represents the consumption that is not explained by the O, V and F parameters. This is the amount by which the model is calibrated in the base year. This makes the assumption that future years' 'phr' is proportionately the same as the base year, if this is not the case then there will be an additional error in the forecast that cannot be quantified.

2.3. Modelling the scenarios

Thus far, consumption will vary with changing occupancy and meter status, as well as varying within the parameters of the individual O, V and F micro-component distributions for each end use.

However, by varying the ownership, volume and frequency distributions based on the response measures identified in Section 4.2 of the main report, it is possible to output PCC distributions for each scenario revealing the effect on average household consumption, with an accompanying confidence level.

For each of the scenarios described in section 5 of the main report, a short narrative was produce to describe in qualitative terms how the scenario would impact the various micro-components. The narratives are described below:

Scenario 0: Current ambition

This scenario is simply a projection forward in time of the average rate of household consumption reduction (PCC) observed and forecast from 2015 to 2025 by water companies in England and Wales.

Scenario 1: Unfocussed frugality

Incremental changes to technology, households adopt the technology, this brings down the volume per use of toilets, washing machines and dishwashers. Up to 25 years things carry on pretty much as there are in the final plan and a drive for metered customers to use less water. After 50 years there are pressures on water supply, so the frequency of use for each micro-component is lower.

Scenario 2: Localised sustainability

Initially the frequency and ownership provides the reduction in water use. Behaviour and the requirement for lower water use drives technology at a later stage. When new technology comes in people have already changed their habits, so that the technology doesn't really change the frequency of use. There is a widespread take-up of rain and grey water use, meaning many homes are refitted with a dual water systems for flushing WCs and external use.

Scenario 3: Technology and service innovation

Innovation in water technology is encouraged and trend setters start to change products when the new one comes out. This drives the price of the entry level tech down and so that there is more widespread adoption of this technology. Initially behaviour isn't really effected too much as the technology provides the reductions. Different methods of 'buying' technology are developed, further encouraging adoption of low water use products. Therefore the majority households use far less water, but still maintain a high quality of living. Some users still use a significant amount of water that they can afford. There is 100% metering and apps to control water to different uses in the house.

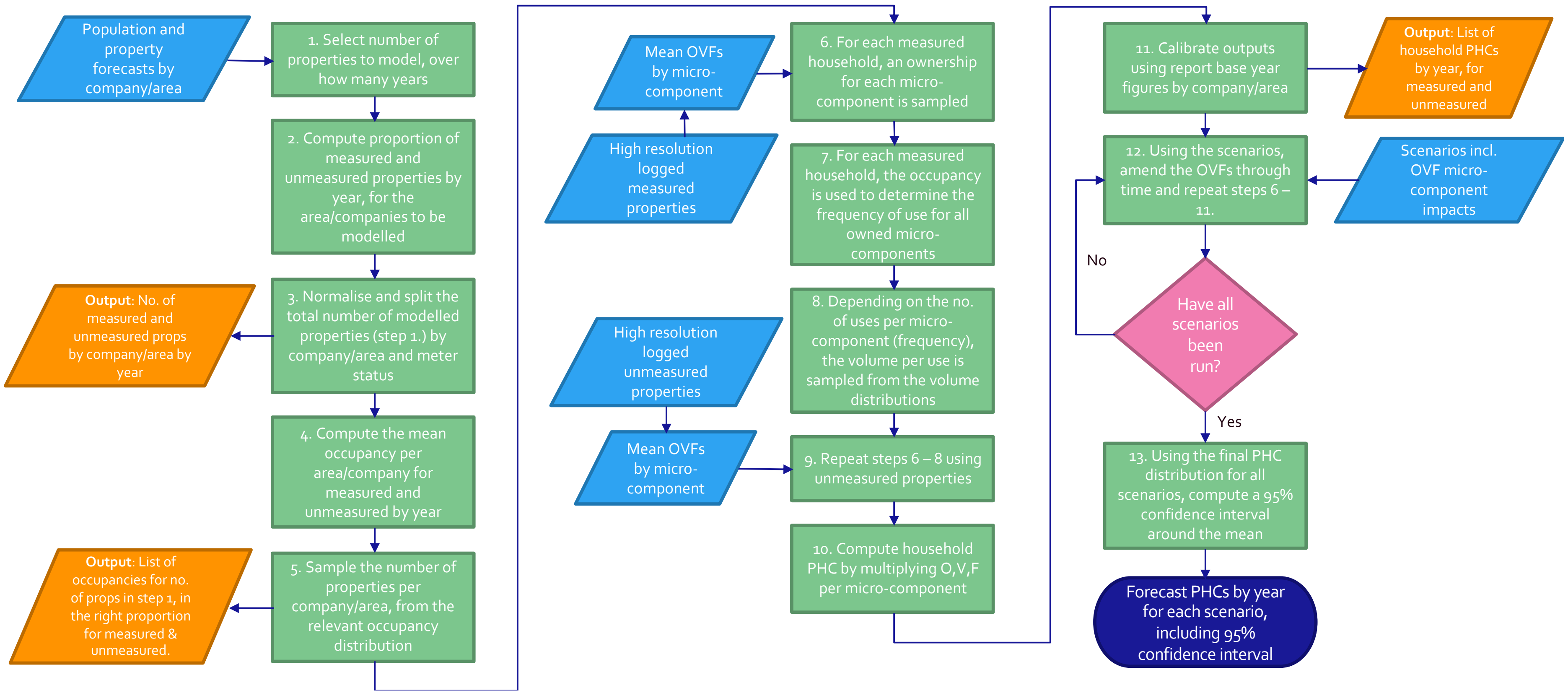
Scenario 4: Regulation and compliance

There are incremental changes to technology, and households are encouraged and incentivised to adopt the technology. This brings down the volume per use of toilets, washing machines and dishwashers. Up to 25 years things carry on pretty much as there are in the final plan and a drive for metered customers to use less water. After 50 years there are pressures on water supply, so the frequency of use for each micro-component is lower.

2.1. Detailed modelling approach

The detailed modelling process is presented in **Error! Not a valid bookmark self-reference.**.

Figure 2: Overview of modelling process



3. Model assumptions and requirements

Building a stochastic model requires various assumptions about the micro-components, distributions, and scenarios.

3.1. Micro-component assumptions

Firstly, the assumptions about the micro-components are set out in Table 1.

Table 1: Micro-component modelling assumptions

Assumption	Impact
Micro-components can be well described as well-known distributions.	With the exception of losses and external use, the micro-components are assumed to be well described by standard probability distributions. This allows the mean and standard deviations to be altered in the scenarios, but may not fully show the randomness of some micro-components.
Frequency of use only depends on occupancy.	Mean frequency of use has been determined per micro-component.
Volume per use varies per household, and is not fixed per micro-component.	A single household may be modelled as having differing toilet flush volumes, however this means that multiple appliances can be modelled, and reduces the probability of over-sampling from the extremes of the distribution.
The OVF distributions do not change in the scenarios, their mean and standard deviations do.	The micro-components are assumed to behave in the same way probabilistically, when considering scenarios, however they may have altered means and different variance.
All measured properties can be treated as one group.	The model currently only considers measured and unmeasured populations due to the high resolution data available. However, optants and compulsorily metered properties may behave differently, which are not modelled here.
Losses are assumed to be independent of occupancy.	This is largely true, however larger occupancy households are likely to be larger homes with more appliances. Having more appliances may mean a higher probability of an internal leak, which is not currently modelled.
External use is assumed to be independent of occupancy.	Within the data set analysed to derive the OVFs, this seems to be the case. However, if external use is related to occupancy, then this is not currently modelled.

3.2. Micro-component distributions

The distributions applied to each of the micro-components is shown in Table 2.

Table 2: Distributions used in the final model

Micro-component	Ownership	Volume	Frequency
Tap	Binomial	Lognormal	Poisson
Toilet	Binomial	Normal	Poisson
Bath	Binomial	Normal	Poisson
Shower	Binomial	Lognormal	Poisson
Washing Machine	Binomial	Normal	Poisson
Dishwasher	Binomial	Lognormal	Poisson
External use	Binomial	Custom	Poisson
Losses	Binomial	Custom	Poisson

3.3. Occupancy modelling

When modelling occupancy in stage one, a Poisson distribution was used, with mean occupancy for the area/company used as the distribution variable.

3.4. Model inputs

The model was built in the programming language R and requires the following inputs in order to produce an output distribution:

- The number of properties to be modelled each year (measured and unmeasured households).
- The mean occupancy for measured and unmeasured households each year.
- The change in each micro-component in response to the water efficiency measures under each scenario.

4. Model calibration

Before running the scenarios, the un-calibrated outputs of the model in the base year were assessed to ensure that the resulting household consumption values for measured and unmeasured households were sensible, and to check whether the difference in measured and unmeasured consumptions were statistically significant.

Figure 3 shows the distribution of measured and unmeasured household consumption before calibration using 10,000 sampled properties with an average occupancy of 2.56 for each group. Keeping occupancy the same for both groups is intended to highlight the differences in consumption independent of occupancy.

The shape and scale of measured and unmeasured PHC distributions vary, as expected, thus meaning that the prior micro-component analysis managed to capture the differences in usage. The measured consumption has a smaller mean, and the unmeasured consumption has a longer right hand tail, as we would expect.

Further, the calculated measured and unmeasured OVFs per micro-component are consistent with historic reported data, and the average unmeasured consumption is 17% higher than measured consumption, independent of occupancy. This is comparable with reported differences between measured and unmeasured households under universal metering conditions.

Significance testing showed that the mean consumption values are significantly different between the groups, with the 95% confidence limits and the mean household consumptions shown in Table 3.

Figure 3: Modelled distributions for measured and unmeasured households

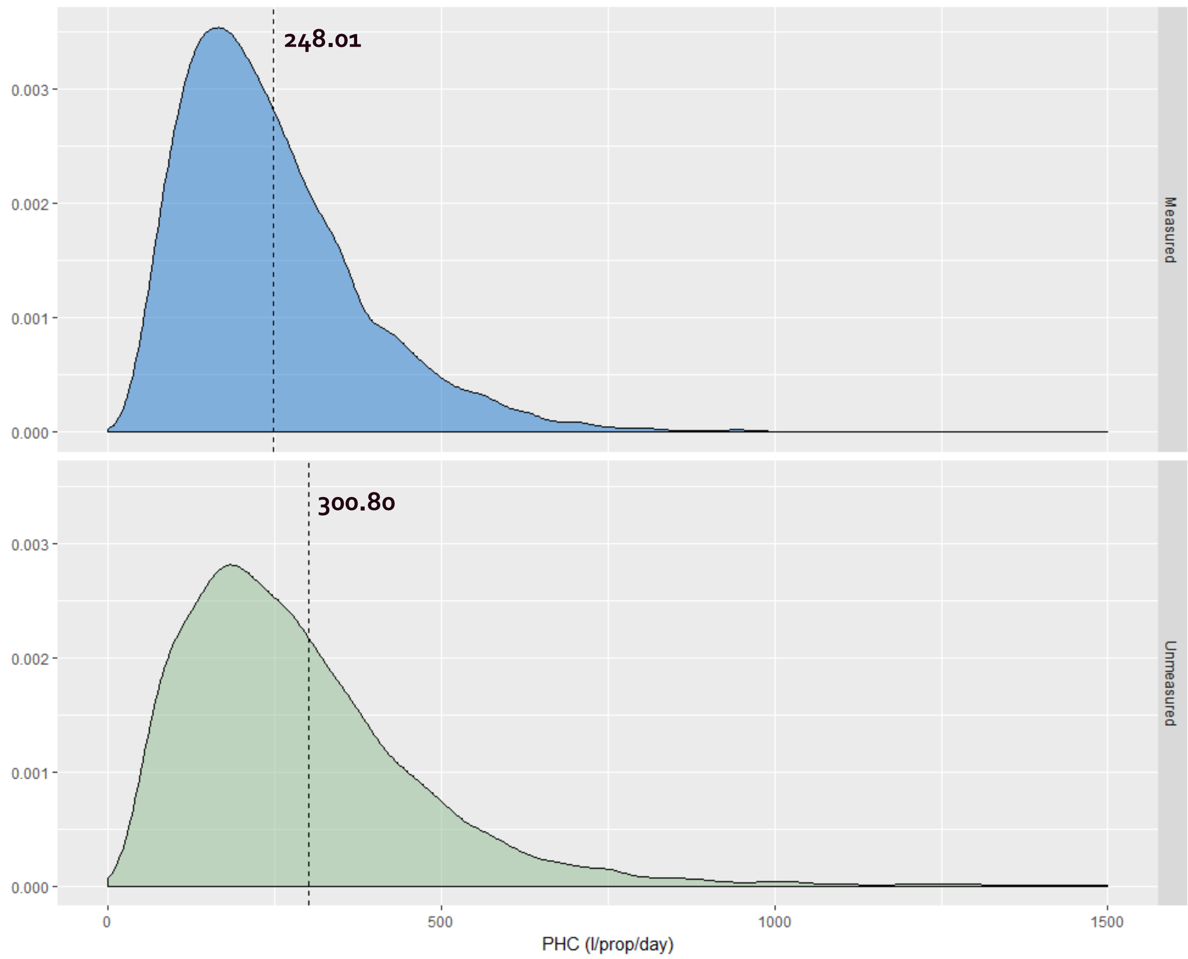


Table 3: Mean and 95% confidence limits for the two distributions

Bill type	Lower PHC – 95% confidence interval (l/prop/day)	Mean PHC (l/prop/day)	Upper PHC – 95% confidence interval (l/prop/day)
Measured	245	248.01	250
Unmeasured	294	300.8	306

5. Model results

After calibration, the model was run for each scenario at years 0, 15, 25 and 50 years into the future. The high level results for each scenario for England and Wales are shown in Figure 4.

Figure 4: Modelled results for each scenario at the England and Wales level

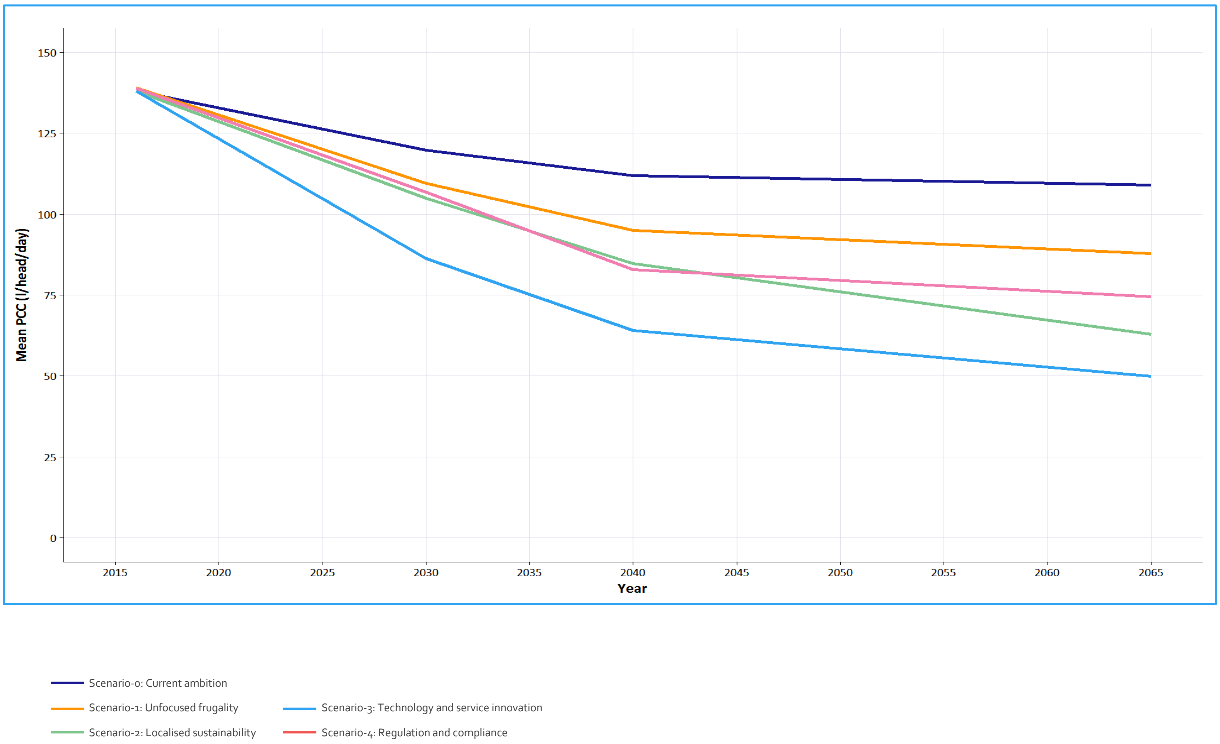


Figure 4 shows the predicted reduction in PCC over time. At 50 years into the future the scenarios result in the following mean PCC figures for each scenario:

- Scenario 0: Current ambition = 105 l/head/day
- Scenario 1: Unfocussed frugality = 83 l/head/day
- Scenario 2: Localised sustainability = 56 l/head/day
- Scenario 3: Technology and service innovation = 49 l/head/day
- Scenario 4: Regulation and compliance = 67 l/head/day

The values above are the mean values from Figure 4, with the range of the distributions shown in Figure 5 - Figure 9. The range of the resulting household consumptions are shown by the widths of each plot, the proportion of households at each PCC level are illustrated by the height of each plot.

Figure 5: 50 year PCC distribution for Scenario 0: Current ambition

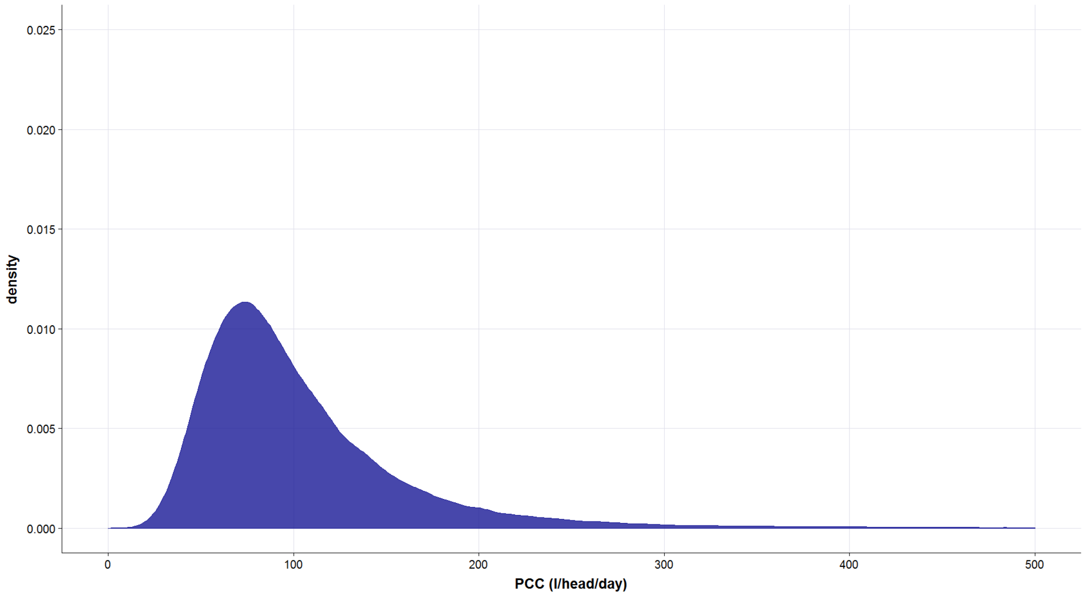


Figure 6: 50 year PCC distribution for Scenario 1: Unfocused frugality

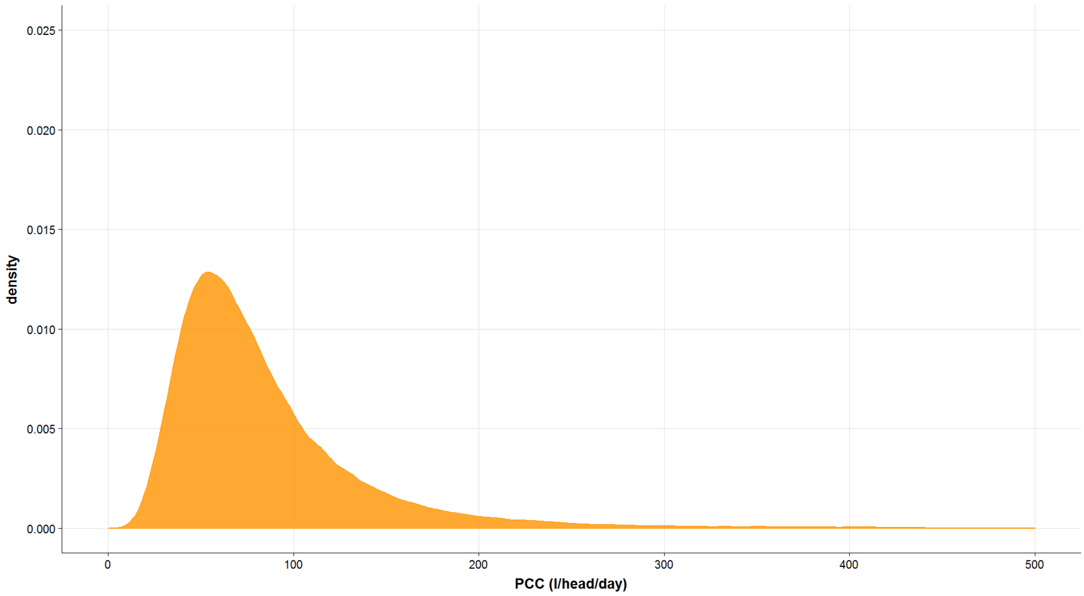


Figure 7: 50 year PCC distribution for Scenario 2: Localised sustainability

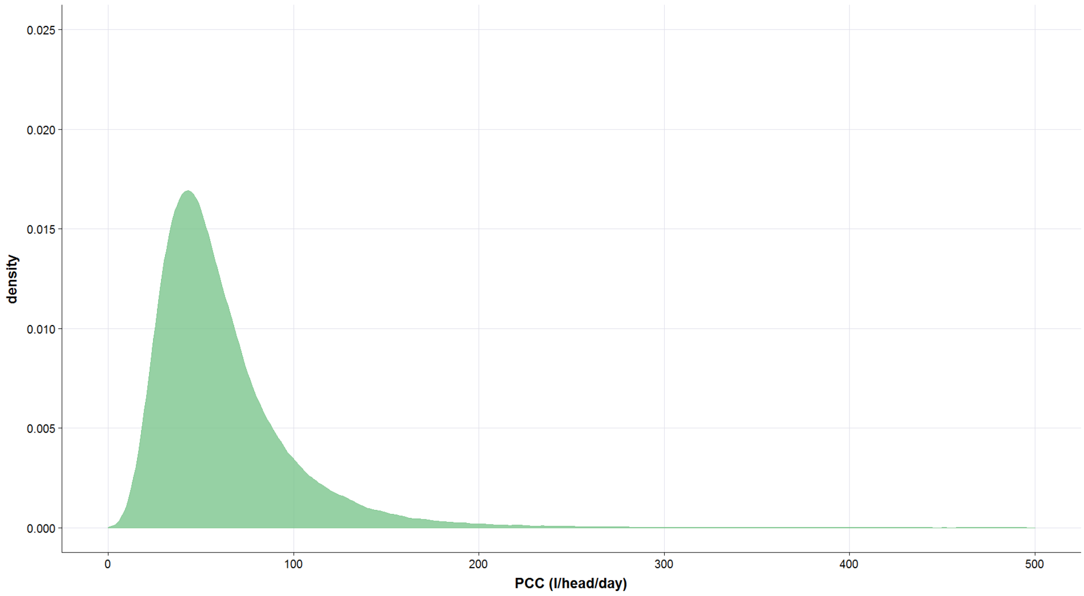


Figure 8: 50 year PCC distribution for Scenario 3: Technology and service innovation

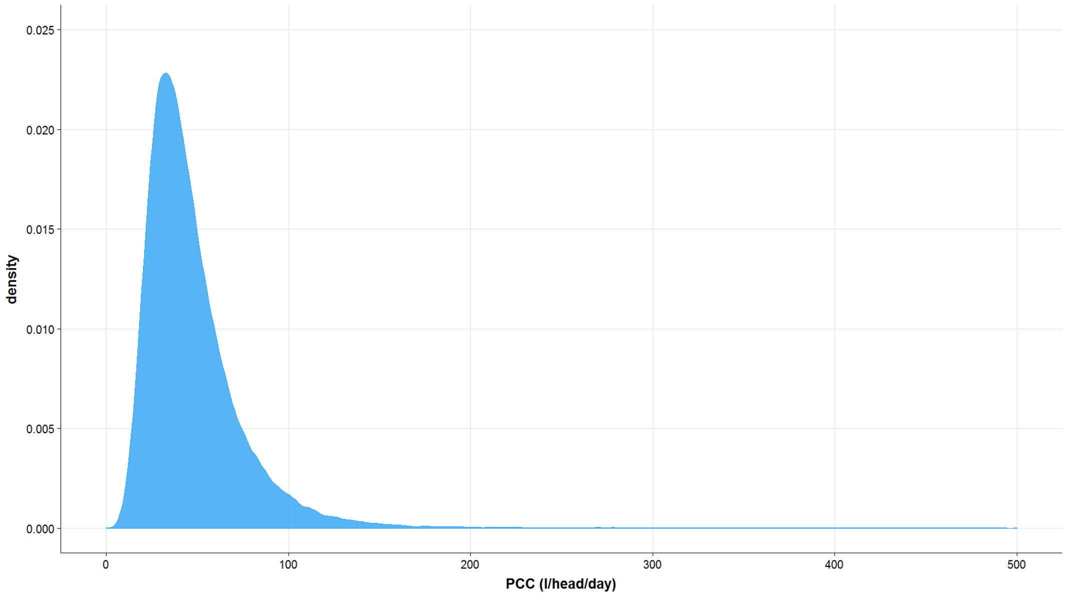


Figure 9: 50 year PCC distribution for Scenario 4: Regulation and compliance

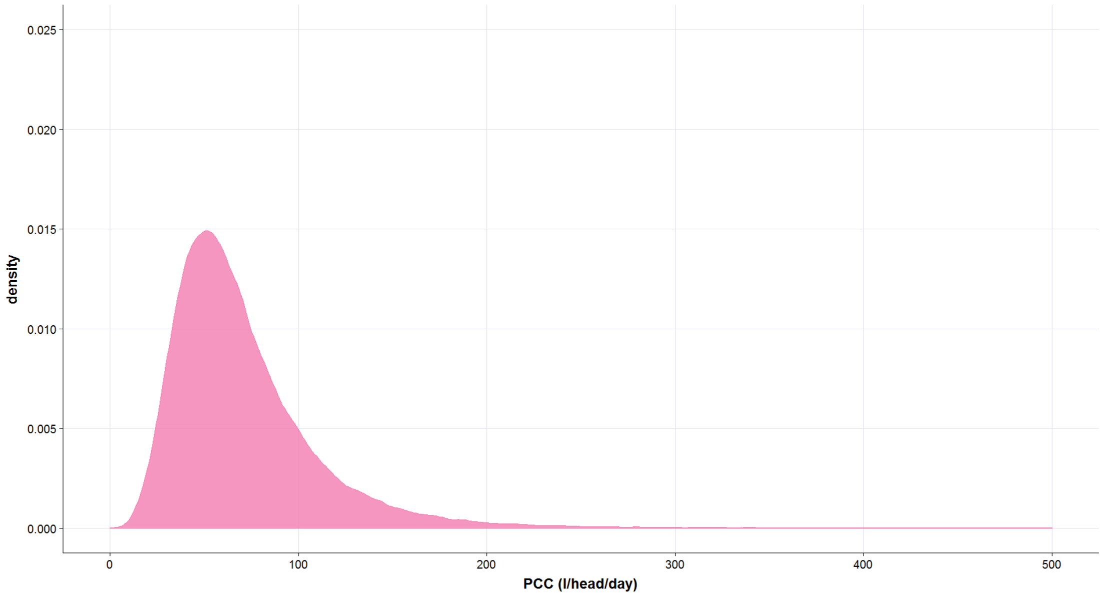
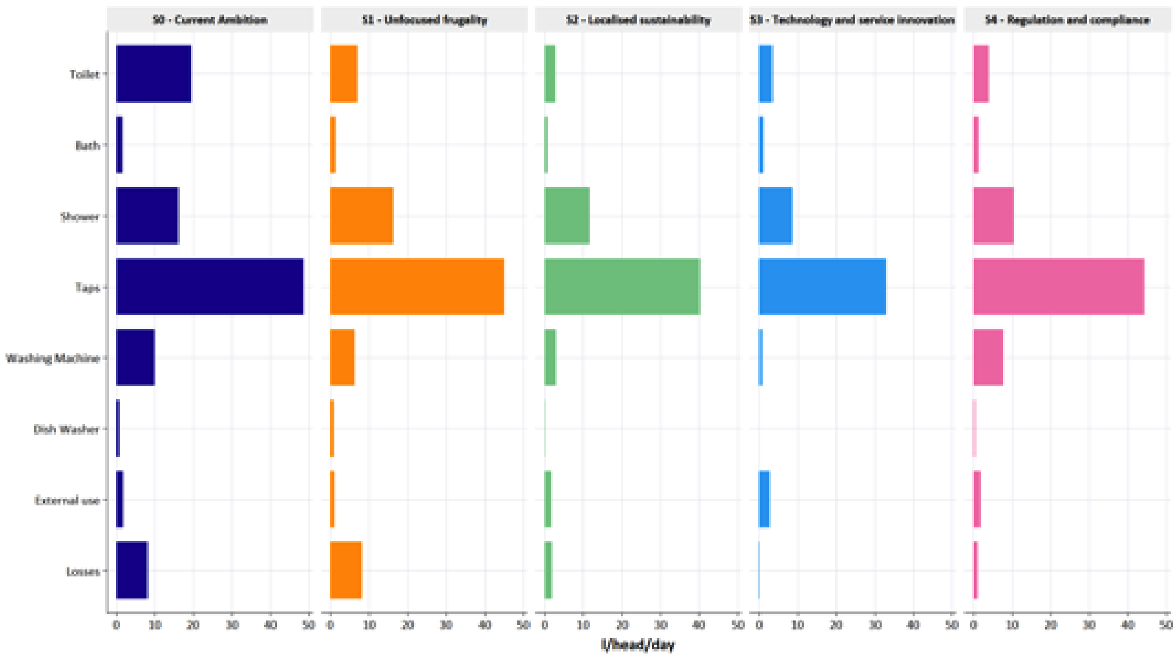


Figure 6 shows that the scenario with the widest range of variation in PCC at 50 years is Scenario 1 Unfocused frugality, and the scenario with the narrowest range of variation is Scenario 3 Technology and service innovation (Figure 8).

Figure 10 shows the breakdown of PCC into each of the modelled micro-components for each scenario.

Figure 10: Modelled micro-components of household water consumption in 50 years for each of the scenarios



The data for each of micro-components is presented in Annex E.