Draft Water Resources Management Plan 2024

Appendix B: The Demand for Water

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Appendix B: The Demand for Water

Appendix B provides an overview of the different uses of water supplied in our area and an explanation of the methodology we use to make projections of how demand will change over the next 60 years. We make our projections for the following scenarios:

- dry year conditions as we are required to do so by Natural Resources Wales (NRW) for water supply planning purposes
- critical period conditions where we expect supply demand challenges, and
- a normal year demand forecast which reflects the demand in an average year.

The demand scenarios incorporate the policy assumptions specified in the Environment Agency (EA), Natural Resources Wales (NRW) and Ofwat jointly published Water Resources Planning Guideline (2021). We also produce our demand projections in two stages:

- a baseline demand forecast
- a final planning demand forecast.

The baseline assumes that as a minimum we will continue existing demand management activity and leakage reduction. The baseline demand forecast to 2085 therefore:

- assumes a continuation of optional metering at current rates
- maintains leakage at the 2024-25 level
- assumes a continuation of water efficiency base activity delivered in AMP7.

We then test the costs and benefits of additional leakage reduction and demand management measures to produce our final planning demand forecast.

We have produced demand forecasts based on assumptions about how water consumption will change over the next 60 years, including an assessment of the impacts of climate change. We have also taken account of Government water efficiency and demand management policies and aspirations. We have used the summary of current Government policies and aspirations presented in the WRMP guiding principles to inform the assumptions incorporated into our forecast of demand.

The chapters in Appendix B cover the following elements of water demand:

- household consumption
- non-household consumption
- leakage
- water efficiency.

B1 Recent demand for water in our region

Distribution input (DI) is the term we use to describe the total quantity of treated water that we put into supply, and is composed of:

- demand from measured household and unmeasured household customers
- demand from measured non-household and unmeasured non-household customers
- leakage from our underground infrastructure, such as mains, distribution systems and communication pipes, the sum of which is known as distribution losses (DL)

- leakage from the underground supply pipes owned by our customers (which is referred to as underground supply pipe losses (USPL))
- minor components, such as water taken unbilled and distribution system operational use.

Recent trends in DI have shown an upward shift. The hot summer of 2018 resulted in the household consumption component of DI rising to dry year levels. More recently the COVID-19 pandemic has affected AMP7 demand and potentially longer-term consumption patterns. In March 2020 people throughout the UK were told they must stay at home and were only allowed to leave their homes for a small number of purposes to control the spread of COVID-19. This was the start of a lengthy period of lockdown through to July 2020, followed by easing of lockdown measures and subsequent phases of lockdowns and restrictions to control the spread of COVID-19.

At the start of the lockdown, we could not have foreseen the impact on water consumption in homes, which when combined with the hot and dry weather resulted in some of the highest peaks in water demand that water companies have ever seen.

In our area, we observed an uplift in household demand because of the COVID-19 pandemic. Factors causing this increase include the health advice on hand washing, more people staying at home as we moved into the lockdown period, home schooling and home working along with periods of hot weather.

Following the easing of lockdown and subsequent return of a degree of normality, household consumption has reduced from the peak of 2020-21 lockdown levels. However, household consumption remains high which is likely to be due to customers adopting hybrid working arrangements, customers continuing to practice health advice and residual behavioural change impacts from changes during the covid lockdown periods. Uncertainty remains over what a ‘new normal’ looks like regarding COVID-19 impact on water consumption and this presents a challenge for the future. We have developed this plan against this COVID-19 uncertainty and our successful leakage and demand management record, and household metering programme from 2020 to 2025 gives us a strong platform on which to build the ambitious reductions set out in this latest dWRMP24.

We will continue to participate in industry wide research to better understand water use practices of our customers and use such learning to inform longer term projections.

B2 Forecasting household demand for water

B2.1 Regulatory requirements for the household demand forecast

Natural Resources Wales (NRW) sets out its expectations and guidance for household demand forecasts in the Water Resources Planning Guideline.

The guideline states that water companies should produce an estimate of demand for water in the base year and produce a forecast of their household demand over the planning period. The planning period is a minimum of 25 years.

The guidance sets out the methodology water companies should follow, with reference to further relevant technical guidance:

- UKWIR (2016) WRMP19 Methods – Household Consumption Forecasting
- UKWIR (2016) Population, Household Property and Occupancy Forecasting
- UKWIR (2006) Peak Water Demand Forecasting Methodology

The broad needs of the regulators are:

- Clearly explain the assumptions, risks and uncertainties associated with the results.
- State why a particular method has been chosen, the assumptions made, and the uncertainty associated with the demand forecast.
- Show how uncertainty is allocated in the rest of the plan.
- Consider the impacts of prolonged dry weather and droughts and the resulting high demand where it affects the supply-demand balance.
- Consider whether there are alternative methods to define dry year demand.
- Consider the results of water industry project on 'Water Demand Insights from 2018' (Artesia 2020).
- If the plan includes a critical period of high demand, it should be informed by recent peak demand years, including 2018 and 2020. It should include weather dependent demand, seasonal population changes and other factors as appropriate.
- Clearly describe the assumptions and supporting information used to develop population, property and occupancy forecasts, and any uncertainties.
- Explain the methods used to forecast property figures after the planning period used by local councils.
- Demonstrate how other information sources have been included and amended the forecast accordingly.
- Clearly describe any limitations in the forecast.
- Clearly describe how you have worked with regional groups (where applicable), neighbouring companies and those involved with strategic water resource solutions to align your forecasts.
- Explain the assumptions about how unaccounted populations have been derived.
- Describe how populations have been allocated to the geographically different water resource zones (such as using neighbourhood plans or census data to further subdivide the populations).

B2.2 Household consumption forecasting methods

Household consumption forecasts need to take account of factors such as population growth, climate change impacts, the effect of year-to-year weather variation, and peak demands which occur within years. Such plans have been required for about 20 years.

Household demand can be derived at the property level (per household consumption – PHC) or at the individual level (per capita consumption – PCC). The PHC or PCC household consumption values are then multiplied by either the number of households (for PHC) or the number of people (PCC) in a region to obtain total household demand, which is measured in megalitres per day (Ml/d). Producing household-based forecasts reduces the error of occupancy being introduced into the forecasts.

The process by which household demand is determined and forecasts produced, are generally based on one of two modelling approaches:

1. Micro-component (MC) models
2. Multiple linear regression (MLR) models.

MC models have been used for water demand forecasting in England and Wales since the late 1990s. They quantify the water used for specific activities (e.g., showering, bathing, toilet flushing, dishwashing, garden watering, etc.) by combining values for ownership (O), volume per use (V) and frequency of use (F). For example, per-capita (PCC) or per household consumption (PHC) can be modelled as:

$$PCC\ or\ PHC = \sum_i (O_i \times V_i \times F_i) + pcr$$

Where:

O is the proportion of household occupants or households using the appliance or activity for micro-component i,

V is the volume per use for i,

F is the frequency per use by household occupants or households for i,

pcr is per capita residual demand.

MLR models use standard statistical processes to develop relationships between historic demand and the explanatory factors that influence demand, typically including household occupancy, property type/size and some measure of socio-demographics. The resulting model has a number of model parameters, and each has a coefficient that is derived from the model, and there is residual error term. The residual is essentially the consumption component that cannot be explained by the model parameters. Residuals are used for estimating error and developing further modelling refinements.

Some of the model parameters will vary over time, whilst some are static over time.

Depending on the data available, problem characterisation, challenges that already exist and length of forecast required, either the MLR or MC models may be more appropriate.

An overall modelling framework has been developed which outlines the steps needed to develop the forecast. This is shown Table B2.1.

Table B2.1: Household consumption forecasting framework for MLR and MC models

<table>
<tr><th>Phase</th><th>Task No.</th><th>MLR</th><th>MC</th></tr>
<tr><td rowspan="4">A. Data Collection and formatting</td><td>1</td><td colspan="2">Discuss the project requirements, finalise scope and produce a data specification</td></tr>
<tr><td>2</td><td colspan="2">Collect and organise the data, considering data management protocols</td></tr>
<tr><td>3</td><td colspan="2">Data formatting and submit data queries</td></tr>
<tr><td>4</td><td colspan="2">Quality assurance of the data</td></tr>
<tr><td rowspan="5">B. Population and property separation / exploratory analysis</td><td>5</td><td colspan="2">Finalise model segmentation (e.g., umHH, mHH, etc)</td></tr>
<tr><td>6</td><td colspan="2">Split the property and population forecasts into defined segmentations</td></tr>
<tr><td>7</td><td colspan="2">Select and agree the modelling method following risk assessment</td></tr>
<tr><td>8</td><td>Exploratory data analysis of consumption data, explanatory factors and weather</td><td>-</td></tr>
<tr><td>9</td><td>Outlier removal and gap analysis for each variable</td><td>-</td></tr>
<tr><td rowspan="3">C. Model build and testing</td><td>10</td><td>Undertake variable selection and develop the base year household consumption forecasting (HHCF) model</td><td>Apply ownership, volume and frequency (OVF) values to forecast</td></tr>
<tr><td>11</td><td colspan="2">Test the model</td></tr>
<tr><td>12</td><td colspan="2">Calibrate the model to the base year per area/zone</td></tr>
<tr><td rowspan="5">D. Model Refinement and forecast</td><td>13</td><td>Residual modelling and testing (spatially and temporally)</td><td>-</td></tr>
<tr><td>14</td><td>Select final model</td><td>-</td></tr>
<tr><td>15</td><td>Apply normal year correction</td><td>-</td></tr>
<tr><td>16</td><td colspan="2">Forecast the model</td></tr>
<tr><td>17</td><td colspan="2">Apply agreed trends to the forecast</td></tr>
<tr><td rowspan="3">E. Weather modelling and peak factors</td><td>18</td><td>Compute dry year factors at required granularity</td><td>Compute normal year and dry year factors at required granularity</td></tr>
<tr><td>19</td><td colspan="2">Select return period and peak factor duration</td></tr>
<tr><td>20</td><td colspan="2">Compute critical period factors per area/company, as required</td></tr>
<tr><td rowspan="4">F. Scenarios, climate change and uncertainty</td><td>21</td><td colspan="2">Collate outputs to company level</td></tr>
<tr><td>22</td><td colspan="2">Apply climate change factors</td></tr>
<tr><td>23</td><td colspan="2">Undertake uncertainty analysis</td></tr>
<tr><td>24</td><td colspan="2">Run appropriate steps from 5-23 again, for any agreed scenarios to be tested</td></tr>
<tr><td rowspan="3">G. Baseline outputs</td><td>25</td><td colspan="2">Micro-component outputs and EA table</td></tr>
<tr><td>26</td><td colspan="2">Output forecast in a format specific to original requirements</td></tr>
<tr><td>27</td><td colspan="2">Audit reporting</td></tr>
</table>

By producing a framework in this way, we ensure that:

- no step is omitted,
- there is full transparency in the method,
- allows consistency between the company outputs,
- the process can be streamlined for automation resulting in complete auditability and repeatability of the outputs.

Best practice guidelines (detailed in Figure B2.1) have been followed in deriving the baseline household demand forecast.

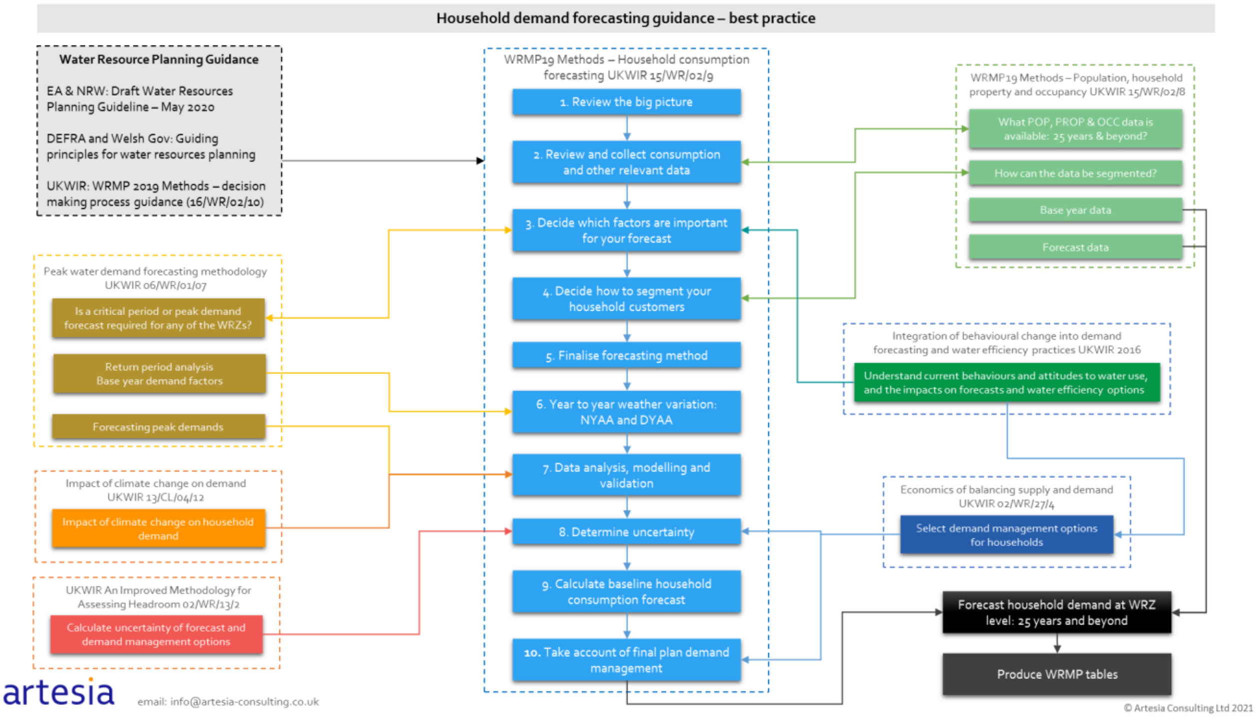


Figure B2.1: Best practice guidelines for household demand forecasting

This following sections provide an explanation of the household consumption forecasting (HHCF) method, including any assumptions made, split by the phases in the modelling framework.

B2.3 Base year and forecast population and properties

Base year population

Base year Resource Zone population estimates have been developed using the latest population estimates from CACI, a specialist demographic data provider. Household occupancy estimates are mapped geographically to water resource zones to produce household population estimates at water resource zone level.

Adjustments are made for estimates of additional hidden and transient population. To account for population in properties on private water supplies, private water supply data is gathered direct from local authority records.

Non-household population data is derived from the Census 2011 communal population (prisons, hospitals etc.) data at postcode sector level which is geographically mapped to the water resource zones. Non-household population data is assumed to only occupy measured non-households. Unmeasured non-household population is assumed to be zero as all communal establishments will be metered.

Base year properties

For the base year 2019-20, the numbers of unmeasured household, measured household and void household properties are taken from our company billing system, TARGET. Property records are allocated to Water Resources Zones using their postcodes. These data form the base year numbers from which we forecast property numbers for each future year.

Forecast population

Estimates of future population have been built up from Office for National Statistics (ONS) 2018 based local authority (LA) population projections. For household population we have used the Welsh Government projections and have applied these to our base year data. These projections are taken from the 2018 base sub-national population projections for Wales from the ONS. The annual percentage rates of change for local authorities are applied to the base year population estimates at postcode level and then aggregated up to water resource zone level. This approach follows the WRMP Guideline and gives the underlying change in population due to births, deaths, and migration in our region. Local Authorities do not provide their own population projections but reference the use of the latest ONS projections. The ONS 2018 base projections of population extend to 2044 while we are required to project to 2085 – to extend our growth projections we assume population trends in the latter years of the ONS forecast continue to 2085.

Having derived the overall population trend for our region, we next allocate future population changes across different property categories (unmeasured and measured households) and take account of population movement between these categories.

It is necessary to allocate the population forecast between property types as this defines the property occupancies which influence the level of water use in each household. Section B2.4.1 details the population forecast allocation methodology.

Forecast properties

The WRPG 2021 instructs companies supplying customers in Wales to base property forecasts on local authority (LA) property projections published by the Welsh Government. We have adopted the Welsh Government projection for Local Councils in our area for the dWRMP24 central housing growth forecast and assumed trends from the latter part of the projection continue to 2084-85.

B2.4 Forecasting household water consumption

B2.4.1 Method selection

The Water Resources Planning Guideline identifies the need for water companies to use methods for supply and demand analysis that are appropriate to the level of planning concern in their water resources zones (WRZs).

The overall problem characterisation for our region for the dWRMP24 is ‘low’ (see Appendix F).

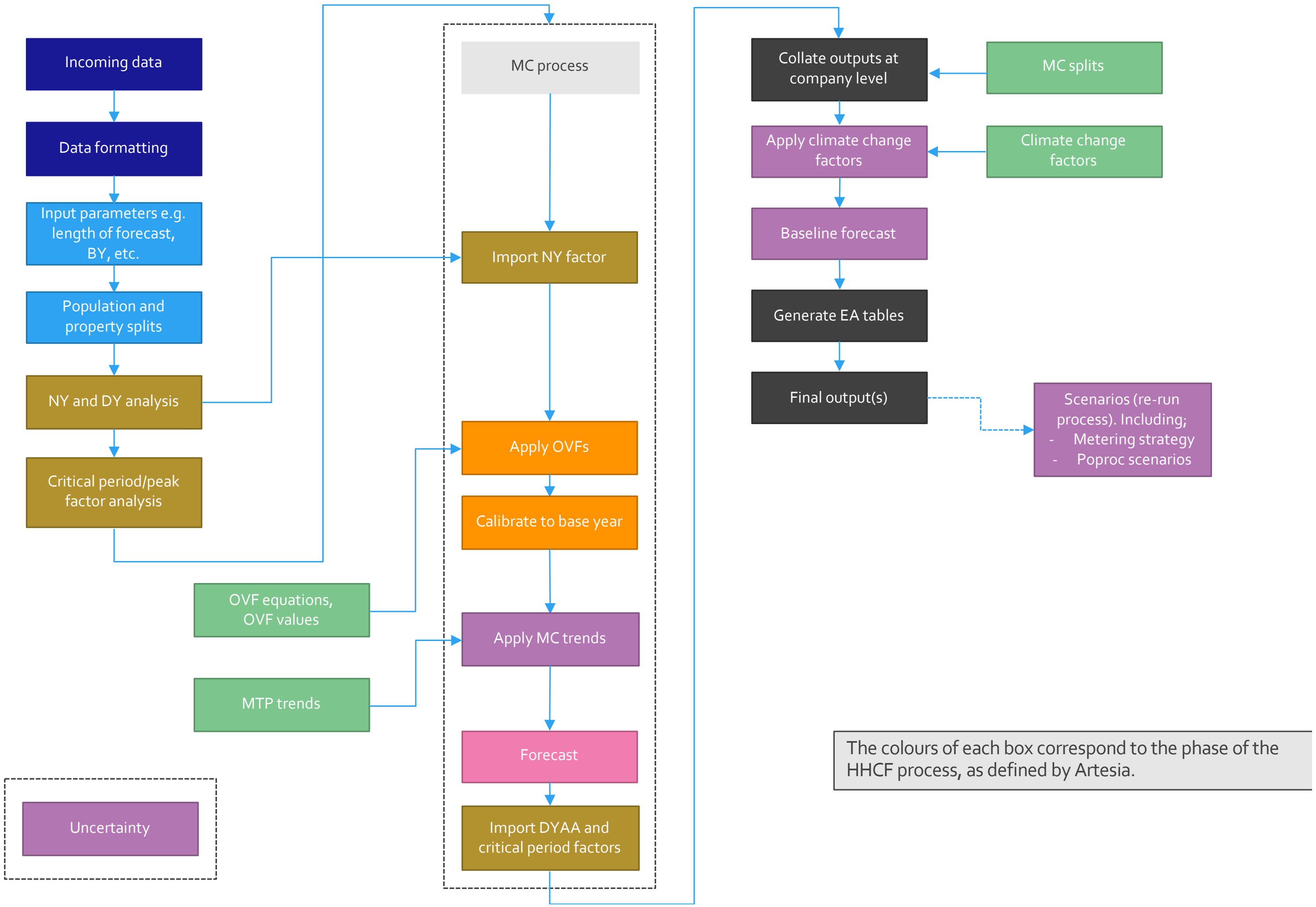
Guidance on the selection of appropriate household consumption forecasting methods were developed by UKWIR (UKWIR, 2016), along with guidance on the application of these methods. For regions with a high-risk problem characterisation, more complex methods of forecasting are appropriate, and for regions of lower risk, it is acceptable to adopt less complicated approaches to forecasting. Despite the low characterisation, we have chosen to follow a micro-component forecasting methodology as it is a well understood method that has a greater level of complexity to ensure more robust forecasts than other methods like macro-components, macro-simulation, or proxies of consumption. Pursuing a multiple linear regression model was not possible due to data limitations.

The following sections provide an explanation of the complete HHCF method, including any assumptions made, split by the phases in the modelling framework.

Each subsection (phase) starts with the relevant steps from the modelling process to provide clarity.

The MC model largely follows the process described in Figure B2.2.

Note that the boxes in Figure B2.2 that are coloured in green are not specifically related to a particular phase but represent external data sources or analyses which are used in the corresponding process. For example, the “MC splits” which are used to separate the resulting consumption predictions into the components required for the data tables were derived from a previous piece of work by Artesia to map from one to the other. Similarly, the “ownership/volume/frequency (OVF) equations and OVF values” form the basis of the micro-component model with the data used to generate the OVFs coming from a combination of studies by UKWIR and Water Research Centre (WRc).



The colours of each box correspond to the phase of the HHCF process, as defined by Artesia.

Figure B2.2: Flowchart showing the stages of the MC model build coloured by the stages in the HHCF framework

B2.4.2 Data collection and formatting

There are four tasks that we carry out in Phase A of our household consumption forecasting framework. These are shown in Table B2.2.

Table B2.2: Phase A of household consumption forecasting framework

Task No.	
1	Discuss the project requirements, finalise scope and produce a data specification
2	Collect and organise the data, considering data management protocols
3	Data formatting and submit data queries
4	Quality assurance of the data

The amount of data required to build a household consumption forecast is vast. The premise of a forecast is to collect enough historic data to understand the relationships between different factors and extrapolate this forward with confidence.

To streamline this process, the data requirements in Table B2.3 were used to accurately capture all necessary information.

Table B2.3: Data requirements for MC methodology

MC Data requirements
All household property and population forecasts, split into the same granularity as the forecast requires (e.g., zonally, company, regionally, etc).
Metering strategy property forecasts. E.g., optant and compulsory metering forecasts split into the same granularity as the forecast requires.
Base year property and population data, split into the forecast granularity (e.g., WRZ) as well as split into the forecast segmentation (e.g., measured, optants, unmeasured).
Historic population and property data split into the forecast granularity (e.g., WRZ) as well as split into the forecast segmentation (e.g., measured, optants, unmeasured).
Different population and property forecast scenarios, ***if applicable***. This should be at the same granularity/segmentation as the baseline population, property (poproc) forecast.
Annual return consumption data (PCC, PHC and Mld) for the base year, split into the required segmentation at the forecast granularity.
Annual return consumption data (PCC, PHC and Mld) for historic years, split into the required segmentation at the forecast granularity.
Weather data, including as a minimum; temperature, rainfall and sunshine using at least monthly granularity.
Historic DI data, preferably after the removal of leakage and non-household usage, to leave domestic consumption. This should be using the same granularity as the forecast.

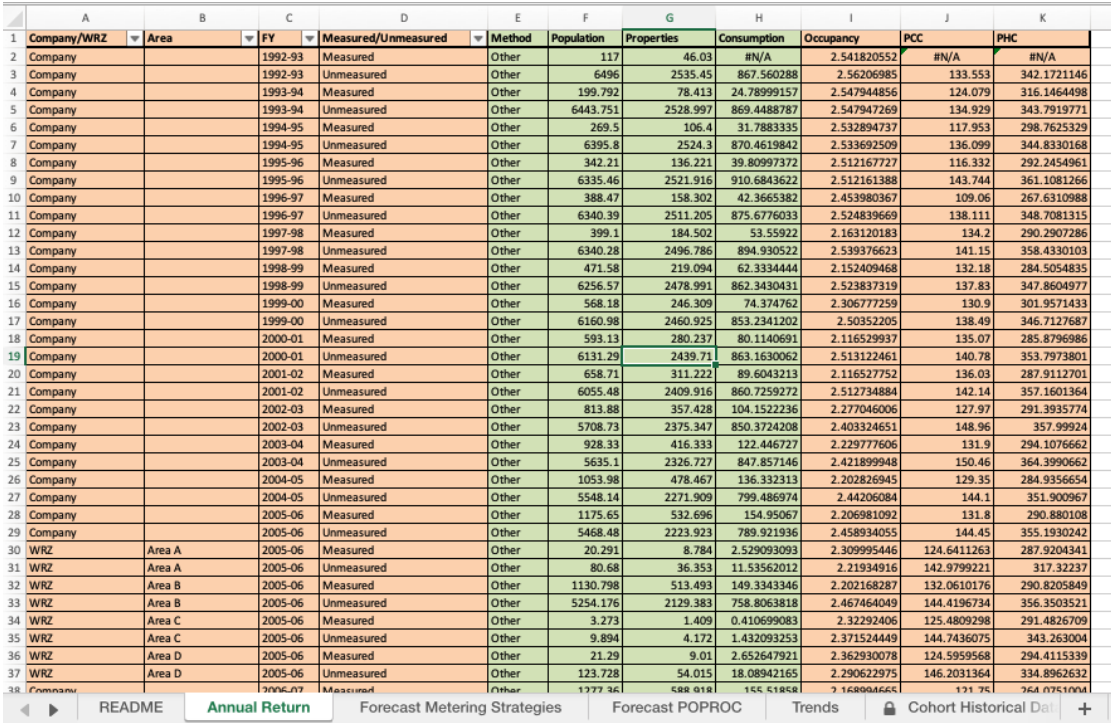
In addition to the data given in Table B2.3, it may sometimes be appropriate for us to collect additional data from open-source locations, such as the Office for National Statistics (ONS) or the Met Office. This may be necessary if company specific weather data is unavailable, or if there is still a high level of uncertainty in the forecast which may be explained using external data sources. If this is the case, this will be explicitly stated.

To adhere to the fully transparent and auditable process that the framework offers, an input template has been put together to collate all the data required in Table B2.3 to allow a simple way to sense check the outputs, as well as ensuring that all of the data units are consistent and visible. Figure B2.3 shows an extract of this template with tabs specifically for the following data:

- Annual return
- Metering strategy forecast

- Population, property, occupancy (POPROC) forecast
- Forecast trends
- Historic meter strategy data
- Weather
- DI

Figure B2.3: Extract of the data input template



	A	B	C	D	E	F	G	H	I	J	K
1	Company/WRZ	Area	FY	Measured/Unmeasured	Method	Population	Properties	Consumption	Occupancy	PCC	PHC
2	Company		1992-93	Measured	Other	117	46.03	#N/A	2.541820552	#N/A	#N/A
3	Company		1992-93	Unmeasured	Other	6496	2535.45	867.560288	2.56206985	133.553	342.1721146
4	Company		1993-94	Measured	Other	199.792	78.413	24.78999157	2.547944856	124.079	316.1464498
5	Company		1993-94	Unmeasured	Other	6443.751	2528.997	869.4488787	2.547947269	134.929	343.7919771
6	Company		1994-95	Measured	Other	269.5	106.4	31.7883335	2.532894737	117.953	298.7625329
7	Company		1994-95	Unmeasured	Other	6395.8	2524.3	870.4619842	2.533692509	136.099	344.8330168
8	Company		1995-96	Measured	Other	342.21	136.221	39.80997372	2.512167727	116.332	292.2454961
9	Company		1995-96	Unmeasured	Other	6335.46	2521.916	910.6843622	2.512161388	143.744	361.1081266
10	Company		1996-97	Measured	Other	388.47	158.302	42.3665382	2.453980367	109.06	267.6310988
11	Company		1996-97	Unmeasured	Other	6340.39	2511.205	875.6776033	2.524839669	138.111	348.7081315
12	Company		1997-98	Measured	Other	399.1	184.502	53.55922	2.163120183	134.2	290.2907286
13	Company		1997-98	Unmeasured	Other	6340.28	2496.786	894.930522	2.539376623	141.15	358.4330103
14	Company		1998-99	Measured	Other	471.58	219.094	62.3334444	2.152409468	132.18	284.5054835
15	Company		1998-99	Unmeasured	Other	6256.57	2478.991	862.3430431	2.523837319	137.83	347.8604977
16	Company		1999-00	Measured	Other	568.18	246.309	74.374762	2.306777259	130.9	301.9571433
17	Company		1999-00	Unmeasured	Other	6160.98	2460.925	853.2341202	2.50352205	138.49	346.7127687
18	Company		2000-01	Measured	Other	593.13	280.237	80.1140691	2.116529937	135.07	285.8796986
19	Company		2000-01	Unmeasured	Other	6131.29	2439.71	863.1630062	2.513122461	140.78	353.7973801
20	Company		2001-02	Measured	Other	658.71	311.222	89.6043213	2.116527752	136.03	287.9112701
21	Company		2001-02	Unmeasured	Other	6055.48	2409.916	860.7259272	2.512734884	142.14	357.1601364
22	Company		2002-03	Measured	Other	813.88	357.428	104.1522236	2.277046006	127.97	291.3935774
23	Company		2002-03	Unmeasured	Other	5708.73	2375.347	850.3724208	2.403324651	148.96	357.99924
24	Company		2003-04	Measured	Other	928.33	416.333	122.446727	2.229777606	131.9	294.1076662
25	Company		2003-04	Unmeasured	Other	5635.1	2326.727	847.857146	2.421899948	150.46	364.3990662
26	Company		2004-05	Measured	Other	1053.98	478.467	136.332313	2.202826945	129.35	284.9356654
27	Company		2004-05	Unmeasured	Other	5548.14	2271.909	799.486974	2.44206084	144.1	351.900967
28	Company		2005-06	Measured	Other	1175.65	532.696	154.95067	2.206981092	131.8	290.880108
29	Company		2005-06	Unmeasured	Other	5468.48	2223.923	789.921936	2.458934055	144.45	355.1930242
30	WRZ	Area A	2005-06	Measured	Other	20.291	8.784	2.529093093	2.309995446	124.6411263	287.9204341
31	WRZ	Area A	2005-06	Unmeasured	Other	80.68	36.353	11.53562012	2.21934916	142.9799221	317.32237
32	WRZ	Area B	2005-06	Measured	Other	1130.798	513.493	149.3343346	2.202168287	132.0610176	290.8205849
33	WRZ	Area B	2005-06	Unmeasured	Other	5254.176	2129.383	758.8063818	2.467464049	144.4196734	356.3503521
34	WRZ	Area C	2005-06	Measured	Other	3.273	1.409	0.410699083	2.32292406	125.4809298	291.4826709
35	WRZ	Area C	2005-06	Unmeasured	Other	9.894	4.172	1.432093253	2.371524449	144.7436075	343.263004
36	WRZ	Area D	2005-06	Measured	Other	21.29	9.01	2.652647921	2.362930078	124.5959568	294.4115339
37	WRZ	Area D	2005-06	Unmeasured	Other	123.728	54.015	18.08942165	2.290622975	146.2031364	334.8962632
38	Company		2006-07	Measured	Other	1277.36	588.918	155.51858	2.168994665	121.75	264.0751004

We have used the following historic data, corresponding to the data requirements in Table B2.3.

- Annual return (AR) data from 2005 until 2020 including zonal consumption, property, population, and occupancy values.
- Historic optant numbers per zone.
- Population and property forecasts by zone.
- Optant forecasts per zone.

Once this data was collated, it was subjected to quality assurance checks to ensure the following:

- The units were known and consistent.
- No missing data.
- The data format was as expected (e.g., if a numeric value is expected, this is not formatted as text or as an image).

Statistical quality assurance checks are conducted during the model build stage, and so are not appropriate here. The purpose of the initial checks is to verify that the data matches the requirements list, and there is no ambiguity in the meaning of the data or units.

Finally, the configurations given in Table B2.4 were set within the household consumption forecast and are therefore assumed throughout the remainder of the document.

Table B2.4: Model configurations for the HHCF

Data requirement	Response
Forecast base year	2019-20
Length of forecast	Until 2085
Granularity of the model	By water resource zone
Model segmentation	Split by meter status, measured and unmeasured. Measured properties further split into; compulsory metered, optants, existing measured and new properties.
Baseline growth forecast	Welsh Government projections for Local Authorities

B2.4.3 Population and property separation and exploratory analysis

There are subsequent tasks that we carry out in Phase B of our household consumption forecasting framework. These are shown in Table B2.5.

Table B2.5: Phase B of household consumption forecasting framework

Task No.	
5	Finalise model segmentation (e.g., umHH, mHH, etc)
6	Split the property and population forecasts into defined segmentations
7	Select and agree the modelling method following risk assessment
8	-
9	-

Once the data collection and formatting are complete, and the configurations of the model selected, the next task of the framework is to split the property and population forecasts into the defined segmentations.

Population and property splits

Typically, population and property forecasts are supplied at total property level for each water resource zone. We require the HHCF at meter status (measured and unmeasured) level, it is necessary to split the population and property (POPROC) forecast into the required segments. As the POPROC information supplied for this project contains multiple growth forecasts, this is complicated further as this is required for each version.

This is not a simple task, particularly for population and occupancy, due to the number of cohorts required (unmeasured, existing measured, compulsory metered, optants, new properties) as well as the complexity in the behaviours between these properties.

In order to split the forecasts, further data is required, including:

- Data describing the company at the base year.
    - Total number of properties, and how many of these are measured/unmeasured.
    - The number of new properties that will join the company's water supply network annually.
    - The occupancy of measured/unmeasured properties.
    - How the measured cohort is divided into new, compulsory and optant cohorts.
- Yearly forecast data. For each June return this must include:
    - The number of properties which will opt onto a meter (optants).
    - The number of properties which will be required to have a meter (compulsory).
    - A global occupancy forecast.
    - A global property count forecast.
    - The number of properties which will be demolished.

All of this data has been acquired during the data collection stage, a method can be developed to segment the forecasts. The basis of the method is illustrated in Figure B2.4.

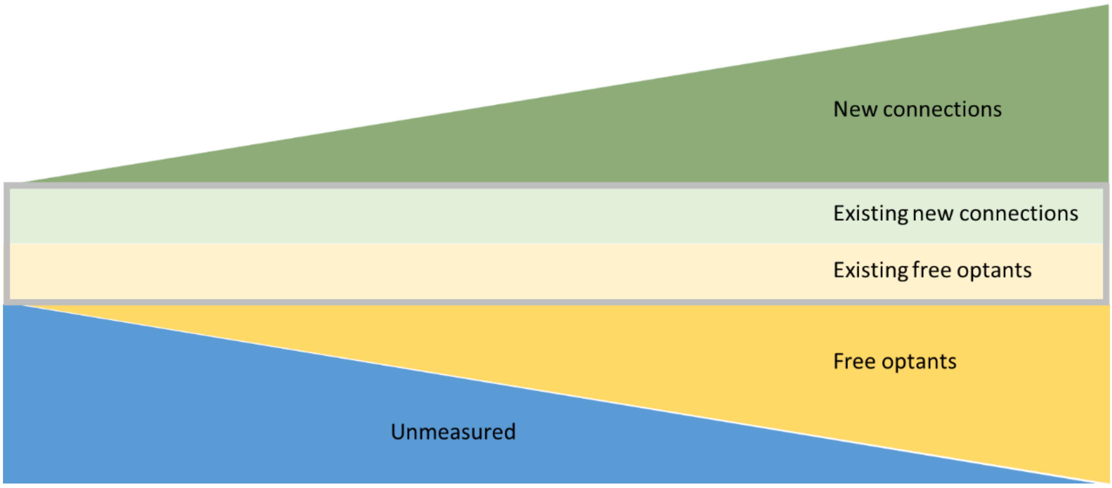


Figure B2.4: Illustration of splitting POPROC forecast into required cohorts, to the point of 100% meter penetration

To achieve this, the following assumptions have been made.

- New households will always be measured.
- Free optants move directly out of the unmeasured property segment.
- Voids are forecast to remain constant throughout the forecast period, in that there are no further voids added beyond the base year. Voids have not been included in the baseline forecast due to their negligible consumption.
- Despite 100% penetration being unlikely in practice, the year in which this point is reach is needed for the mathematical calculations in order to balance the population figures.
- Demolitions are distributed evenly across the cohorts.

As well as mapping the properties into each of the segments, population must also be distributed, which is more complex. Figure B2.5 demonstrates that as meter penetration increases, the occupancy of the unmeasured and optant properties increase until full meter penetration. Throughout the forecast, the sum of the population for the optants plus unmeasured properties remains the same (this assumes that each year optants come from the unmeasured pool). Meanwhile the average occupancy of all the segments must follow the change in occupancy from the property and population forecasts.

In summary, the assumptions in respect of splitting population are:

- Measured households have lower occupancy than unmeasured households.
- Optants have the lowest occupancy, on average.
- New properties are assumed to have the same occupancy as the average across all properties.
- Compulsory properties are assumed to have the same occupancy as unmeasured households.
- The optant households are taken from the lower end of the unmeasured occupancy distribution.
- As optants leave the unmeasured pool, the average occupancy of the households that remain will increase.

These assumptions provide an estimate of the change in occupancy within the household segments over time, which are applied in an iterative manner. There will of course be a complex movement of population within these segments, reflecting births, deaths, people moving into the region, people moving out of the region, and people moving within the region. However, the intra-cohort variation is not required for the forecast.

Finally, each year the segments are calibrated to consider the company (or zonal) level occupancy changes throughout the forecast period. To ensure the segmented households and populations sum to the company own forecast, various calibration steps and data validation checks are also included in the calculations.

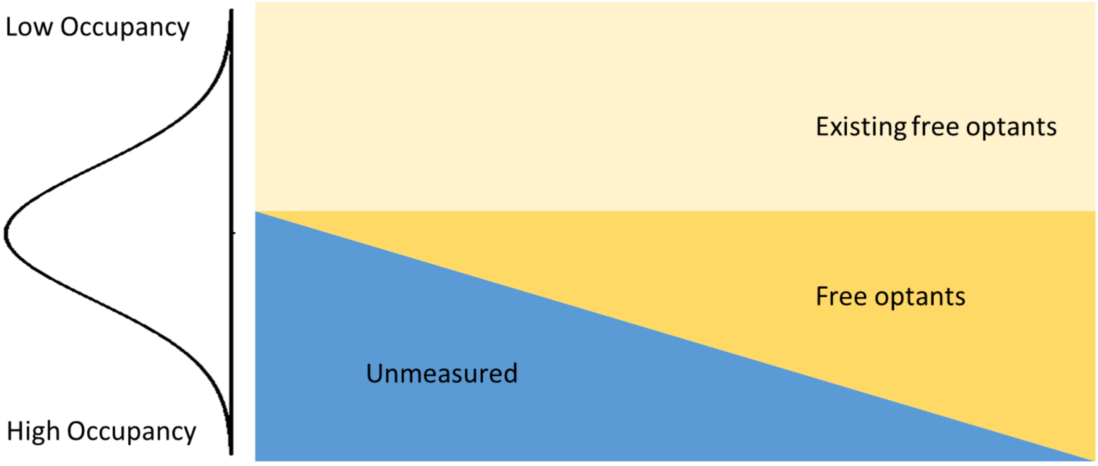


Figure B2.5 Illustration of the change in occupancy as meter penetration tends towards 100%

B2.4.4 Model build and testing

This section explains the method and approach used to build the MC model required for the forecast as set out in Table B2.6.

Table B2.6: Phase C of household consumption forecasting framework

Task No.	
10	Apply ownership, volume and frequency (OVF) values to forecast
11	Test the model
12	Calibrate the model to the base year per area/zone

MC models have been used for water demand forecasting in England and Wales from the late 1990s. They quantify the water used for specific activities (e.g., showering, bathing, toilet flushing, dishwashing, garden watering, etc.) by combining values for ownership (O), volume per use (V) and frequency of use (F). For example, per-capita (PCC) or per household consumption (PHC) can be modelled as:

$$PCC\ or\ PHC = \sum_{i} (O_i \times V_i \times F_i) + pcr$$

Where:

O is the proportion of household occupants or households using the appliance or activity for micro-component i,

V is the volume per use for i,

F is the frequency per use by household occupants or households for i,

pcr is per capita residual demand.

By applying this together with the population or property data, a water demand model can be formed. By forecasting changes in each of the variables (O, V, F or daily water use for each micro-component) over time, a water demand forecast can be created. Hence the micro-component forecast model requires estimates of changes in these variables, to reflect future changes in technology, policy, regulation, and behaviour.

Below is a description of how this modelling process has been applied, and how the inputs have been generated for:

- Base year micro-components from a micro-component occupancy model.
- Final year micro-components from an occupancy model. This allows a rate of change of micro-component daily water use to be derived due to the change in occupancy over the planning period. This is how the forecast is generated.

Selection of the modelling unit

Two commonly used methods of consumption forecasts are based on Per Capita Consumption (PCC) and Per Household Consumption (PHC).

In the case of PHC modelling, occupancy needs to be included as an explanatory variable, and PHC is composed of a consumption allotted to the house based on its characteristics, and an additional consumption assigned to each occupant.

PCC modelling assigns a different consumption value per person based on the characteristics of the property they inhabit.

In the former case, the model is property driven, which aligns with the data collection based on household meter reads.

The latter case introduces all the error associated with the household occupancy figure into the model at the very first step. If the model is based on PCC, the PCC is calculated from estimated occupancy (for which there is an error), so there is no part of the consumption modelling that is independent of occupancy error; all the error in population forecasting is propagated through the zonal forecast if it is based on PCC.

Modelling by PHC makes occupancy-driven household consumption components implicit in the model whereas PCC-driven modelling would need to incorporate a correction for changing occupancy rates in PCC forecasting.

For these reasons, PHC is used as the basis for modelling and aggregating up to a zonal consumption forecast.

MC occupancy modelling

Whilst the forecast is built at household level, there is an influence on several of the micro-components from occupancy. For example, it is expected that dishwasher usage increases linearly with occupancy but washing machine use will not hold a linear relationship. Therefore, in calculating the base year and final year PHC values, we use a set of linear models that relate either daily use or frequency of use to occupancy in each year.

Because of the segmentation of the forecast required, the model is also used to provide the base and final year values for the different metered property types; existing metered, optants, new properties and compulsory metered.

Once the occupancy model is built, this forms the central part of the MC model, and when combined with the rates of change for each micro-component, a forecast can be generated.

Several national datasets have been used in building this model, to increase the understanding of historic and recent micro-component consumption. Historic micro-components are extracted from the WRc CP187 report (WRc, March 2005) and recent micro-components are extracted from an UKWIR study, (UKWIR, 2016).

This is micro-component data that has been collected by measuring the different micro-components used within the household (as opposed from survey questions and assumptions). This allows ownership (O), volume per use (V) and frequency of use (F), to be calculated for each micro-component. There were two main sources of data for this:

1) 2015-16 data collected using the Siloette system:
    - A sample of measured billed households, with associated occupancies and demographic information on the households, collated during an UKWIR Study (UKWIR, 2016). This contains 62 households from around England and Wales.
    - A sample of unmeasured billed households, which do not have associated demographics (collated from other anonymous Siloette studies carried out by Artesia Consulting, from England and Wales).
2) 2002 – 2004 O, V, and F data collected using the Identiflow system (a sample of unmeasured billed households, (WRc, March 2005)).

Both the Siloette and Identiflow systems measure the flow into a property and compute the individual micro-components through pattern recognition (although the detailed methodology of the two systems is different).

The UKWIR micro-component data for measured billed households were used for the modelling, because this dataset has a complete set of occupancy data for each household over the logging period. The total number of households in the sample was 62.

The following micro-components were used as part of this model:

- WC flushing
- Shower use
- Bath use
- Tap use
- Dishwasher use
- Washing machine use
- Water softener use
- External use
- Miscellaneous use (including internal plumbing losses)

Each of the micro-components were investigated to determine whether the daily volume per use, frequency of use or ownership varied significantly with occupancy. The following micro-components showed relationships where occupancy was a significant factor:

- WC flushing (toilets)
- Shower use
- Bath use
- Tap use
- Washing machine use

For each of these micro-components (toilets, showers, baths, washing machines and taps) a linear model was developed using occupancy as the predictive factor.

To illustrate this, Figure B2.6 shows the variation of toilet flushing per day with occupancy, with the mean frequency of use per day plotted against occupancy. The model is a logarithmic relationship of frequency of use against occupancy with the following equation.

$$Frequency\ of\ use\ (uses\ per\ day) = 6.143 + 3.744 \times \ln\ (occupancy)$$

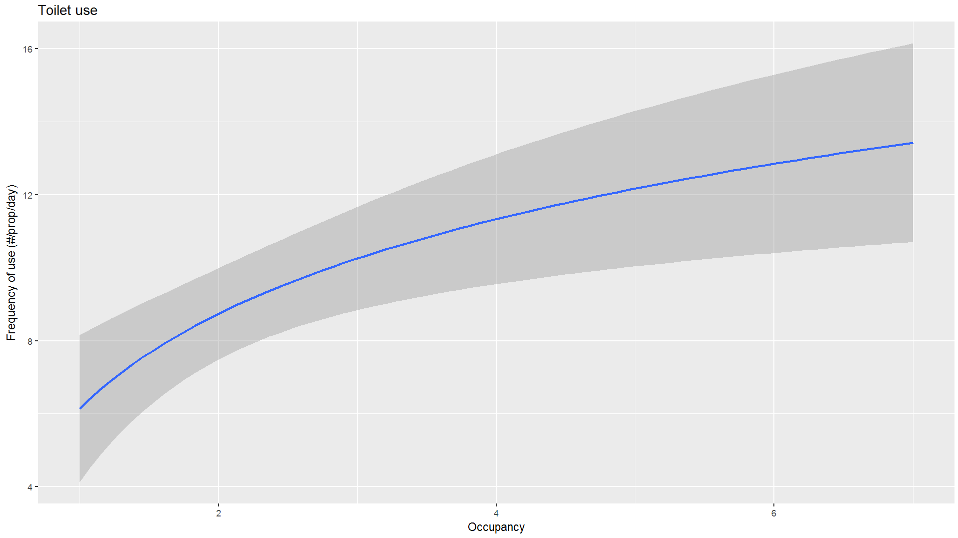


Figure B2.6: Variation of toilet flushing frequency (uses per day) with occupancy

This same exercise was repeated for showers, baths, washing machines and taps to generate frequency of use equations (or total daily volume equations) for the MC model, which are shown in Table B2.7.

Table B2.7: Use equations using occupancy driven micro components

Micro-component	Use/Volume equations	Equation reference
Toilet	$Uses\ per\ day = 6.143 + 3.744 \times \ln(occupancy)$	1
Shower	$Volume\ per\ day = 15.47 + 57.47 \times \ln(occupancy)$	2
Bath	$Volume\ per\ day = 7.181 + 7.378 \times \ln(occupancy)$	3
Washing machine	$Uses\ per\ day = 0.3242 + 0.43705 \times \ln(occupancy)$	4
Tap	$Volume\ per\ day = 27.92 + 62.89 \times \ln(occupancy)$	5

The final step is to separate out the relationships between the micro-components and the metering status of the property, based on the cohorts being modelled. Table B2.8 shows the variations of the toilet, washing machine, dishwasher, and plumbing losses micro-component volumes with meter cohort type. Toilets contain the largest variation, with new builds having the smallest flush volumes, consistent with new build regulations. Unsurprisingly, unmeasured properties have the highest toilet flush volumes, which by default causes compulsory metered properties to have the same value (as compulsory metered properties are taken from the unmeasured pool).

However, there is typically a consumption saving when a property moves from unmeasured to compulsorily metered. Therefore, as part of this process, there is an additional compulsory saving of 15% applied.

Table B2.8: Micro-component volumes dependent on meter status

Property type	Toilet flush volume (mean l/flush)	Washing machine volume/use (mean l/use)	Dishwasher volume/use (mean l/use)	Wastage / plumbing losses (frequency of occurrence)
Unmeasured household	7.58	54.19	16.7	0.825
Existing measured	7.26	54.19	16.7	1.55
Optant	6.0	54.19	16.7	0.275
New build	5.5	50.0	15.0	0.275
Compulsory metered	7.58	54.19	16.7	0.275

Bringing all of this information together, Table B2.9 shows the final ownership (O), volume (V) and frequency (F) values for each micro-component, and these are combined to give daily use per micro-component in the model. This is sometimes referred to as the "OVF" model.

Table B2.9: MC occupancy model parameters

Micro-component	Weighted Ownership 'O'	Volume per use 'V' (l/use)	Frequency of use 'F' (uses/day)	Daily use (l/prop/day)
Toilets	1	See Table	See Equation 1	$O \times V \times F$
Showers	-	-	-	See Equation 2
Baths	-	-	-	See Equation 3
Taps	-	-	-	See Equation 5
Dishwashers	0.42	See Table	0.5	$O \times V \times F$

Washing machines	0.95	See Table	See Equation 4	$O \times V \times F$
Water softeners	0.02	52.06	0.97	$O \times V \times F$
External use	0.18	285.18	0.07	$O \times V \times F$
Plumbing losses	0.22	37.2	See Table	$O \times V \times F$
Miscellaneous	0.95	1.63	3.74	$O \times V \times F$

These values can be used to define an MC model to calculate the micro-component daily use (and hence the per household consumption (PHC)) for the following property types based on the occupancy assigned to each property type, in the base year and in the final year of the forecast:

- Unmeasured households
- Existing metered billed households
- Optant households
- New build metered households
- Compulsory metered billed households

Using the base year and final year PHC values, a rate of change in PHC due to occupancy change can be calculated for each household metered status. This is what enables the forecast to be generated. These are in addition to any technology and behaviour trends described in section headed 'Applying additional trends'

However, before the forecast is created, the data requires calibration to the base year, to ensure that there are not any large gaps or deviations from the annual return data in the selected base year, 2019-20.

Base year calibration

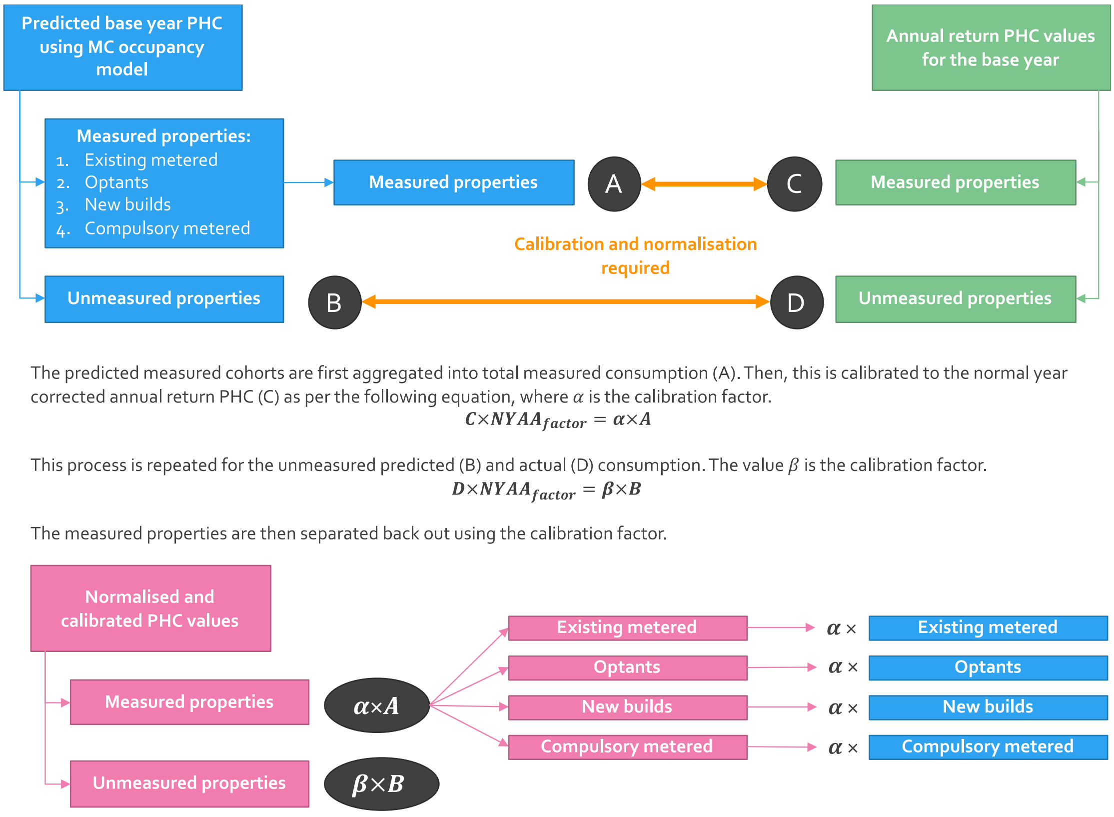
At this point, the base year and final year PHC values have been generated from the occupancy model. This model relates each micro-component to known household behaviours using occupancy as a variable. For each of the household segments, the OVF models are applied using the base year occupancy values. However, it is entirely possible that the annual return data does not match the base year PHC values generated by the model. Therefore, a calibration is required before the rates of change are computed and a forecast generated.

There are two approaches that can be taken to calibrate the base year, and these are either before or after the application of the normal year factors. The normal year factors are values (typically around 1) that are designed to remove any influence of abnormal weather from the base year PHC/PCC values. This kind of normalisation is required so that the forecast does not contain any additional weather-related influences, making future scenarios difficult to apply.

Therefore, it is important that the normal year annual average (NYAA) factor is applied within the base year calibration to ensure that the subsequent rates of change over time for each component is not affected by annual variation that might by contained within the base year.

So, instead of calibrating the predicted base year PHC values to the annual return data and applying the normal year correction afterwards, the AR data is normalised and then the calibration takes place. This is the approach that has been taken in this model.

Since the Annual Return (AR) data is only given at measured and unmeasured granularities, the first stage is to combine the predicted measured PHC values to "total measured" before the calibration takes place. The PHC values for the non-reported figures; existing measured, new builds, optants and compulsory metered, are calculated proportionally based on the NYAA measured calibration factor, using the OVF values in each segment. This is illustrated in Figure B2.7.



The predicted measured cohorts are first aggregated into total measured consumption (A). Then, this is calibrated to the normal year corrected annual return PHC (C) as per the following equation, where α is the calibration factor.

$$C \times NYAA_{factor} = \alpha \times A$$

This process is repeated for the unmeasured predicted (B) and actual (D) consumption. The value β is the calibration factor.

$$D \times NYAA_{factor} = \beta \times B$$

The measured properties are then separated back out using the calibration factor.

Figure B2.7: Illustration of the base year normalisation method

B2.4.5 Model refinement and forecast

Now that the MC model has been produced, the final step is to compute the baseline micro-component trends (rates of change) to apply on top of the PHC values from the occupancy model and generate the forecast as per Table B2.10.

Table B2.10: Phase D of household consumption forecasting framework

Task No.	
13	-
14	-
15	-
16	Forecast the model
17	Apply agreed trends to the forecast

Note that this forms the basis of the baseline scenario. It is possible to alter these rates of change based on differences in technological and behaviour trends as touched on in the next section, but these are added separately and are explained in more detail in the following section titled 'Applying additional trends'.

Micro-component trends

The baseline micro-components trends due to technology change, policies and regulation, and behaviour change, have been computed using the same data sets from the UKWIR and WRc studies, (UKWIR, 2016) (WRc, March 2005) as used in the occupancy model. However, we also use the data from Defra's Market Transformation Programme (MTP)1.

The MTP produced predictions of water use for different water using appliances in 2030 for three different scenarios:

- Reference scenario (equivalent to the baseline scenario)
- Policy scenario (assuming more effective implementation and accelerated take-up of more sustainable products)
- Early best practice (EBP) which assumes a more positive impact than the policy scenario and an early take up of innovative water efficient products.

We focus on the "reference scenario" to define the baseline trends. This has been done for all the micro-components, though this is just provided for toilet flushing here, to give an example of the process used.

Toilet flush volumes

For the toilet flush volume trend, we assume that ownership and frequency of use remains constant, with the volume per use changing due to market transformation.

Using the available data, we created a histogram of the volumes per flush. These are shown in Figures B2.8 and B2.9. This shows that for 2002-04 the mean flush volume was 9.4 litres per flush, with a range of flush volumes from 5 litres to more than 15 litres. In 2015-16 the mean flush volume had reduced to around 7.3 litres with a range from 3 litres to about 13 litres per flush.

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[1] For example, Defra (2011) BNWAT01 WCs: market projections and product details. Note that the MTP reports do not appear to be available online anymore.

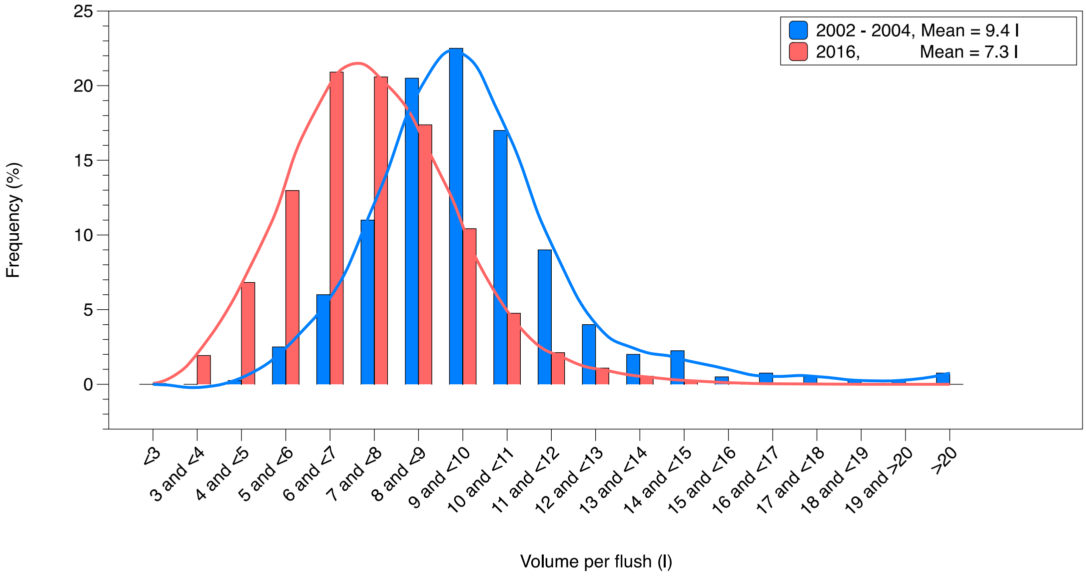

Figure B2.8: Histogram of historic flush volumes

The reason for this reduction in flush volumes is due to the replacement of larger volume toilet cisterns with smaller volume cisterns, due to market transformation based on regulatory policies. The schematic in **Error! Reference source not found.** B2.9 shows the change in maximum flush volumes over time due to changes in regulation. From 12 litres in 1910 to a 6-litre single flush (or 6/4 or 6/3 litre dual flush) in 2000 to date. The reason we see larger flush volumes in the histogram is due to incorrectly setting up the fill height or over filling during the flush period.

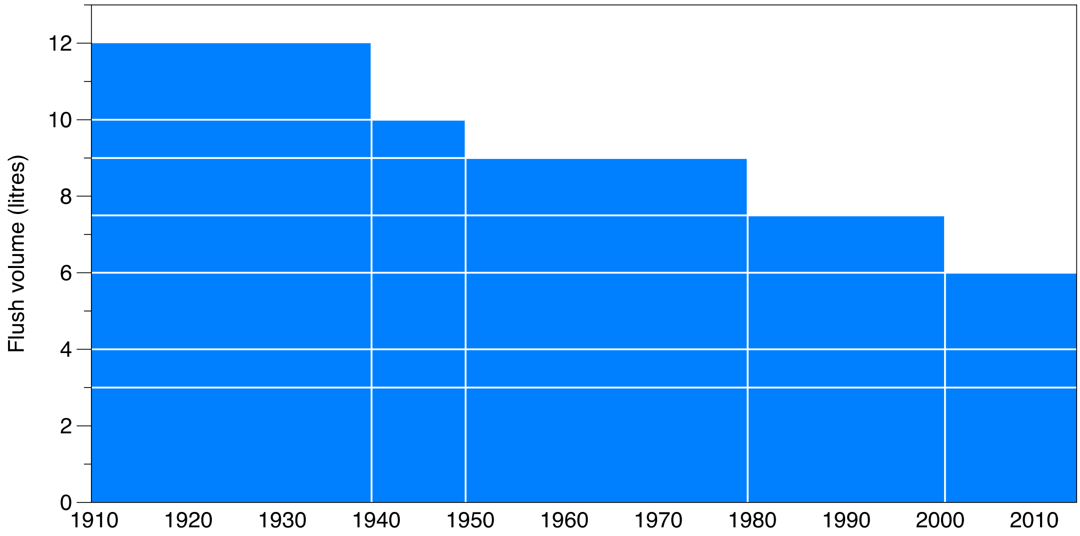

Figure B2.9 Regulatory changes in flush volumes

The latest projections for toilet flush volumes[2] in 2030 for the reference scenario is 4.8 litres/flush. Figure B2.10 shows the mean 2002-04 (CP187), the 2015-16 flush volumes and the flush volume from the MTP scenarios in 2030. The blue line shows the linear fit from the 2002-04, 2015-16 and MTP Reference scenarios.

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[2] Source: http://efficient-products.ghkint.eu/spm/download/document/id/954.pdf

If we assume that the market transformation continues at the current rate (a reasonable assumption for baseline forecasts, as there are no planned regulatory changes in toilet flush volumes), then the flush volume in 2028 will be approximately 5.1 litres (shown by the intersect of the grey lines in Figure B2.10). This provides some confidence in the MTP reference scenario for toilet flush volumes.

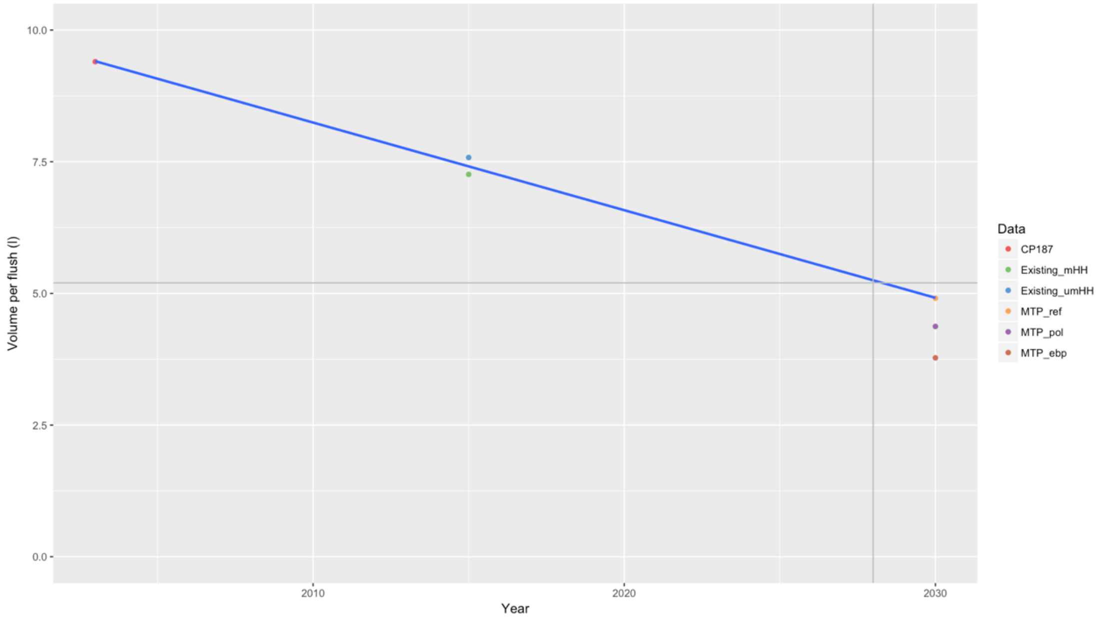

Figure B2.10: Historic, current and future flush volumes

We have therefore created future trends for toilet volumes per flush (see Figure B2.11) using:

- the base year volumes per flush in
-
-
-

- Table for different property types,
- the 2030 projection for toilet flush volumes from the MTP reference scenario,
- an assumption that all property types will have achieved the MTP Reference scenario between the forecast base year and 2030 (for the baseline forecast assuming no change to current WC flush regulations),
- and an assumption that the volume per use will then remain relatively constant until 2050.

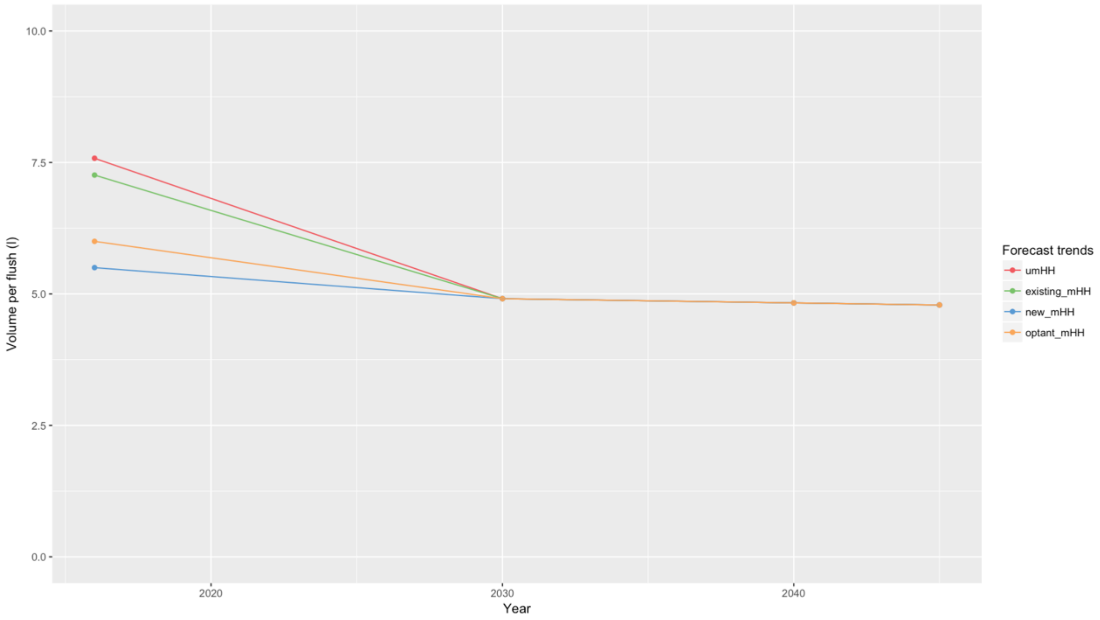

Figure B2.11: Trends for toilet flush volumes

From these trends, annual rates of change have been produced for each of the property types. The rates of change are then incorporated into the model to produce the forecast.

Note that since the final year of the forecast is 2085, these trends are held flat for all micro-components from 2050 until 2085. This is because there is a much higher level of uncertainty of these continued rates of change this far into the future.

Applying additional trends

The previous section describes the process used to determine the future micro-component trends which is required to produce the forecast. However, this is focused on the “reference scenario”, (or the baseline scenario). Sometimes, it is necessary to include stricter assumptions about the micro-component trends to include within the baseline scenario. Or more likely, other trends are required for the generation of additional scenarios.

For our forecast, the reference scenario is to be used for the baseline outputs, however time was spent producing additional trends using the alternative MTP values[3] for the scenario outputs.

These two additional trend scenarios based on micro-component trends to account for variations within the future predicted rate of change in consumption. These are:

- **Sustainable Development:** This scenario assumes that the current paradigm of regulatory driven incremental technological efficiencies will continue past 2045 and arrive at an endpoint that is conceivable with existing technologies but currently not economically viable. Artesia consider that this represents the 10th percentile trend.
- **Market Forces:** This scenario assumes that the projected trend in micro components does not continue beyond 2022. This would require a situation such as Brexit where UK building regulations may be decoupled from current standards and the logical decline in flush volumes is curtailed. The

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[3] For example, Defra (2011) BNWAT01 WCs: market projections and product details. Note that the MTP reports do not appear to be available online anymore.

observed upward trend in showering continues to increase. Artesia consider that this represents the 95th percentile trend.

The variation in the trends are shown in Figure B2.12, for both measured and unmeasured, assuming a baseline of “no trend”. As per the baseline trend, these trends are applied until 2050 (only in the scenario where they are selected) and held flat until the final year of the forecast, as the uncertainty is far greater that far into the future.

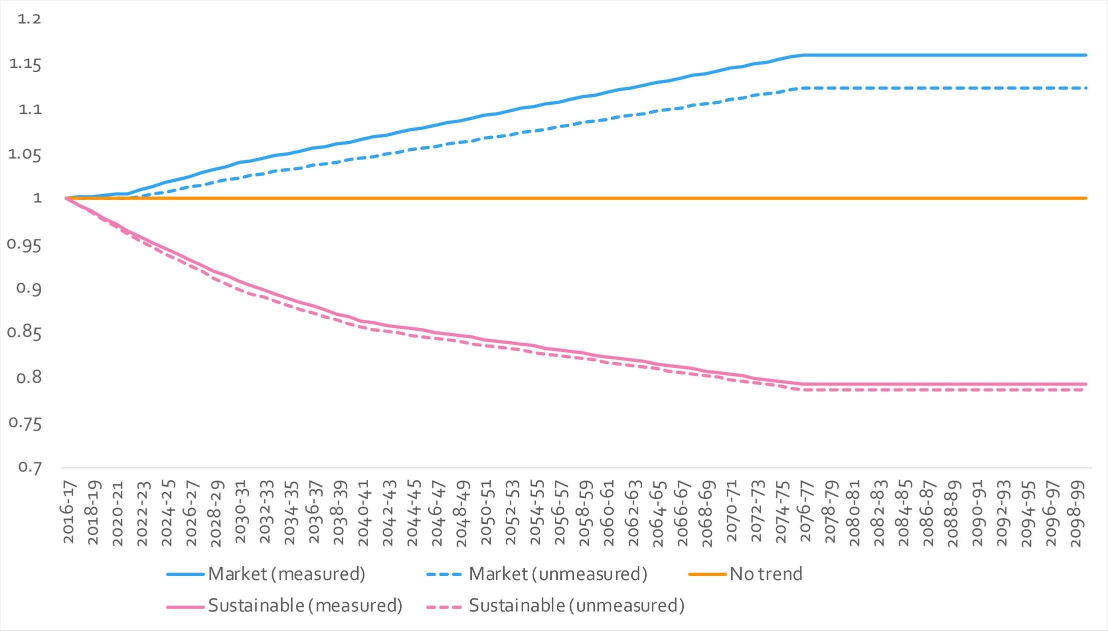


Figure B2.12: Variation in trends assuming a fixed baseline – factor of change relative to no trend

The application of these trends is designed to be applied on top of the baseline micro-component rates of change, so they do not double count.

B2.4.6 Weather modelling and peak factors

Table B2.11: Phase E of household consumption forecasting framework

Task No.	
18	Compute normal year and dry year factors at required granularity Compute normal year and dry year factors at required granularity
19	Select return period and peak factor duration
20	Compute critical period factors per area/company, as required

Household consumption is dependent on a range of variables such as practices, behaviours or attitudes that need to be accounted for in order to develop reliable forecasts. Weather has proven to be a driver of consumption and the inter-annual variation in consumption due to its effect needs to be understood and accounted for in water resources planning as shown in Table B2.11. Historic demand forecasting methods deal with this by:

- Analysing historic data to determine how annual average consumption differs between typical 'normal' and 'dry years'
- Comparing this to recent actual consumption and
- Producing factors or uplift volumes based on this comparison which are then applied to the consumption forecast

This enables a suitable consumption value to be determined for the first year of the forecast, and production of dry year forecasts from this starting point. In WRMPs, demand should be calculated as Dry Year Annual Average (DYAA). We have used outputs of weather-consumption analysis of historic Severn Trent consumption data by the Met office that produced a long-term historic view of weather related demand, presented in Figure B2.13), to estimate a dry year uplift factor for our region. Data limitations meant the analysis could not be completed for our region specifically.

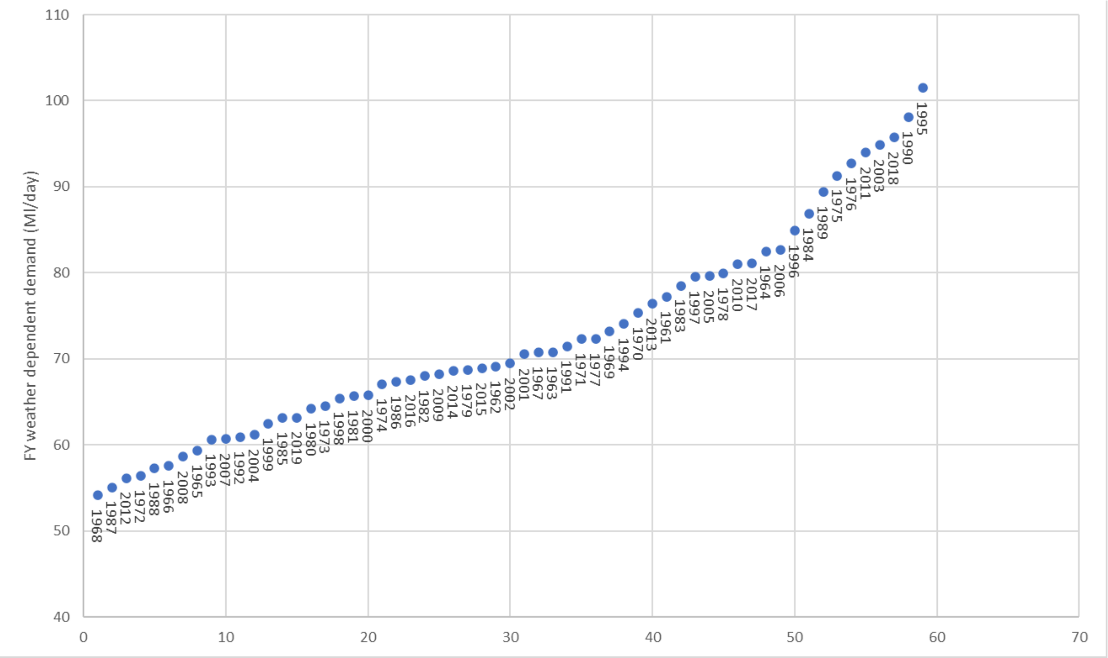


Figure B2.13: Long term historic weather related demand from Met office analysis

The analysis results can be used to derive the dry year and normal year factors for any historic year to equate to the 95th and 50th percentile (respectively) of long-term weather-related demand. The DYAA uplift for the base year is 2.98%, and we have applied this factor to the duration of the forecast

In addition to the dry year adjustment, we have also applied a COVID-19 uplift to reflect the effects of the COVID-19 pandemic and expected long term impact. In March 2020 people throughout the UK were told they must stay at home and were only allowed to leave their homes for a small number of purposes to control the spread of COVID-19 from the novel coronavirus SARS-CoV-2. This was the start of a lengthy period of lockdown through to July 2020, followed by easing of lockdown measures and subsequent phases of lockdowns and restrictions to control COVID-19 spread through the remainder of the year.

At the start of the lockdown, we couldn’t have foreseen was the impact on water consumption in homes, which when combined with the hot and dry weather resulted in some of the highest peaks in water demand that water companies have ever seen.

We observed an uplift in household demand because of the COVID-19 pandemic. Factors causing this increase include the health advice on hand washing, more people staying at home as we moved into the lock down period, home schooling and home working along with periods of hot weather.

Following the easing of lockdown and subsequent return of a degree of normality, household consumption has reduced from the peaks of 2020-21 lockdown levels. However, household consumption remains high which is likely to be due to customers adopting hybrid working arrangements, customers continuing to practice health advice and residual behavioural change impacts from changes during the covid lockdown periods. Uncertainty remains over what a ‘new normal’ looks like with regard to COVID-19 impact on water consumption and this presents a challenge for the future. Table B2.12 shows the assumed factors in our baseline household demand forecast. We have considered the outputs of an industry collaborative project led by Artesia that analysed the impacts of COVID-19 lockdown in 2020-21. Uncertainty regarding longer term impacts of COVID-19 have been assumed in our headroom assessment.

Table B2.12: Household COVID-19 factor assumption in baseline forecast

	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26 to 2084-85
Household consumption COVID factor	9%	6%	4.5%	3 %	3%	3%

B2.4.7 Scenarios, climate change and uncertainty

Table B2.13: Phase F of household consumption forecasting framework

Task No.	
21	Collate outputs to company level
22	Apply climate change factors
23	Undertake uncertainty analysis
24	Run appropriate steps from 5-23 again, for any agreed scenarios to be tested

Once the HHCF model has been built, the POPROC data segmented and the weather modelling complete, the final stage (Table B2.13) is to apply the climate change adjustments, before running different scenarios and uncertainties.

The concepts of uncertainty and scenarios are often used interchangeably and partially overlap in terms of meaning. Both represent unknowns that may affect water consumption forecasts. For the dWRMP24 household demand forecasts we separate the concepts through definitions:

- Uncertainty refers primarily to the variability we have in the forecasts due to data uncertainty and unexplainable variability uncertainty. Uncertainty is non-zero, even in the present, and grows with time in a gradual way due to uncertainty propagation. Uncertainty can be described by probability distributions and derived statistics, like mean, standard deviation, or quantiles.
- Scenarios refer to the variability in future projections due to foreseeable (at least in terms of happening) events. Scenarios’ variability is only applicable to future figures, not to the present, and can grow or decrease in time according to the specific events being considered. Scenarios are usually represented by a discrete number of alternative forecasts.

The section below explains the method for applying the climate change factors.

Climate change factors

The household consumption forecasting guidance describes the requirement that all HHCFs should be provided with and without the addition of climate change impacts. To achieve this, we have used the methods and models provided in the UKWIR report, "Impact of climate change on water demand", (UKWIR, 2013). The aim of this project was to provide climate change demand factors to account for the impact of climate change to be used in the WRMP process.

More specifically, this report contains demand factors for each UKCP09 river basin, describing the percentage change in household demand for two case study relationships, Severn Trent and Thames, and three demand criteria (annual average, minimum deployable output and critical period). The demand factors are given for the 10th, 25th, 50th, 75th and 90th percentile to reflect the uncertainty in the climate projections.

The values provided as part of this project have been used to define the climate change factors.

The first step is to select the correct model for use. Based on proximity, the selected model for our region is the Severn Trent case study relationship. The default percentiles selected are the 50th percentile, with the annual average values used for the normal year (NYAA) and dry year (DYAA) demand criteria, and critical period values being used for the peak demand (critical CP) demand criteria.

The selection of the correct river basin is the final step in determining the correct climate change factors. This selection has been made using the geographical distance between our region and the river basin options and is shown in Table B2.14.

Table B2.14: Climate change factors and river basin selected

Area	Planning scenario	Company cc figure	Climate change percentile	River basin	River Basin coverage	River basin cc figures
STW	NYAA	0.905	p50	Severn	50%	0.92
				Humber South	50%	0.89
STW	DYAA	0.905	p50	Severn	50%	0.92
				Humber South	50%	0.89
STW	DYCP	2.38	p50	Severn	50%	2.42
				Humber South	50%	2.34

Once the climate change factors are selected, the final step is to generate the values by year. This is achieved by linearly interpolating the values from the base year point of zero, to the final climate change factor in Table B2.14 for 2045 and continuing this trend until the final year of the forecast.

Scenarios and uncertainty

As described at the start of this section, scenarios are defined as the variability in future projections due to foreseeable events. These are typically due to different growth forecasts in the POPROC data, or changes to the metering strategy (i.e., rates of optants or compulsory metering).

In this context, the estimated uncertainty represents the variability within a given, foreseeable scenario. For each scenario, the uncertainty can be estimated and is represented as buffer intervals around the central forecast, usually represented by quantiles (e.g. between the 5th and the 95th quantile or between the 25th and the 75th quantile).

B2.4.8 Baseline household consumption forecast outputs

Table B2.15: Phase G of household consumption forecasting framework

Task No.	MC
25	Micro-component outputs and EA table
26	Output forecast in a format specific to original requirements
27	Audit reporting

The complete modelling process has now been completely described, with the only remaining step being putting all the steps together (Table B2.15), applying a company level collation and producing outputs suitable for the EA, NRW and UKWIR templates and guidelines.

The method for separating the outputs into the macro-components specified by the EA is simply based upon combining the micro-components into the following categories based on a simple ratio approach.

- Toilet flushing
- Personal washing
- Clothes washing
- Dishwashing
- Miscellaneous internal use
- External use

The baseline household consumption forecasts for each water resource zone are published in our data tables.

B3 Forecasting non household demand for water

We have, alongside other companies from Water Resources West (Severn Trent and United Utilities) have worked with Artesia, a leading statistical analysis/data science company and water industry experts, to produce forecasts of non-household water demand to 2085.

We have produced a set of non-household demand forecasts for all WRZs (Water Resources Zone) for our region from 2019-20 out to 2084-85. These are presented for metered and unmetered properties at company level, water resource zone level and disaggregated by industrial sector.

The approach used follows existing industry best practice. Robust multiple linear models have been produced for four cohorts of industrial sectors for each company in WRW, using explanatory factors that include population, gross value-added metrics, employment rates, population density and other factors.

Since the last set of non-household forecasts were completed for WRMP19, the non-household retail sector has undergone a transformation with the introduction of retail competition in England. A significant impact from this is that metered non-household consumption data is now the responsibility of new retailers, managed by the Market Operator Services Ltd (MOSL). We have observed a change in data quality and consistency since the change in 2017 for English water and waste companies. This has complicated the joint modelling approach for us (which relies on a consistent set of time series data) and has increased the uncertainty around the demand forecasts. This has been taken into account in the models, uncertainty and scenario estimates.

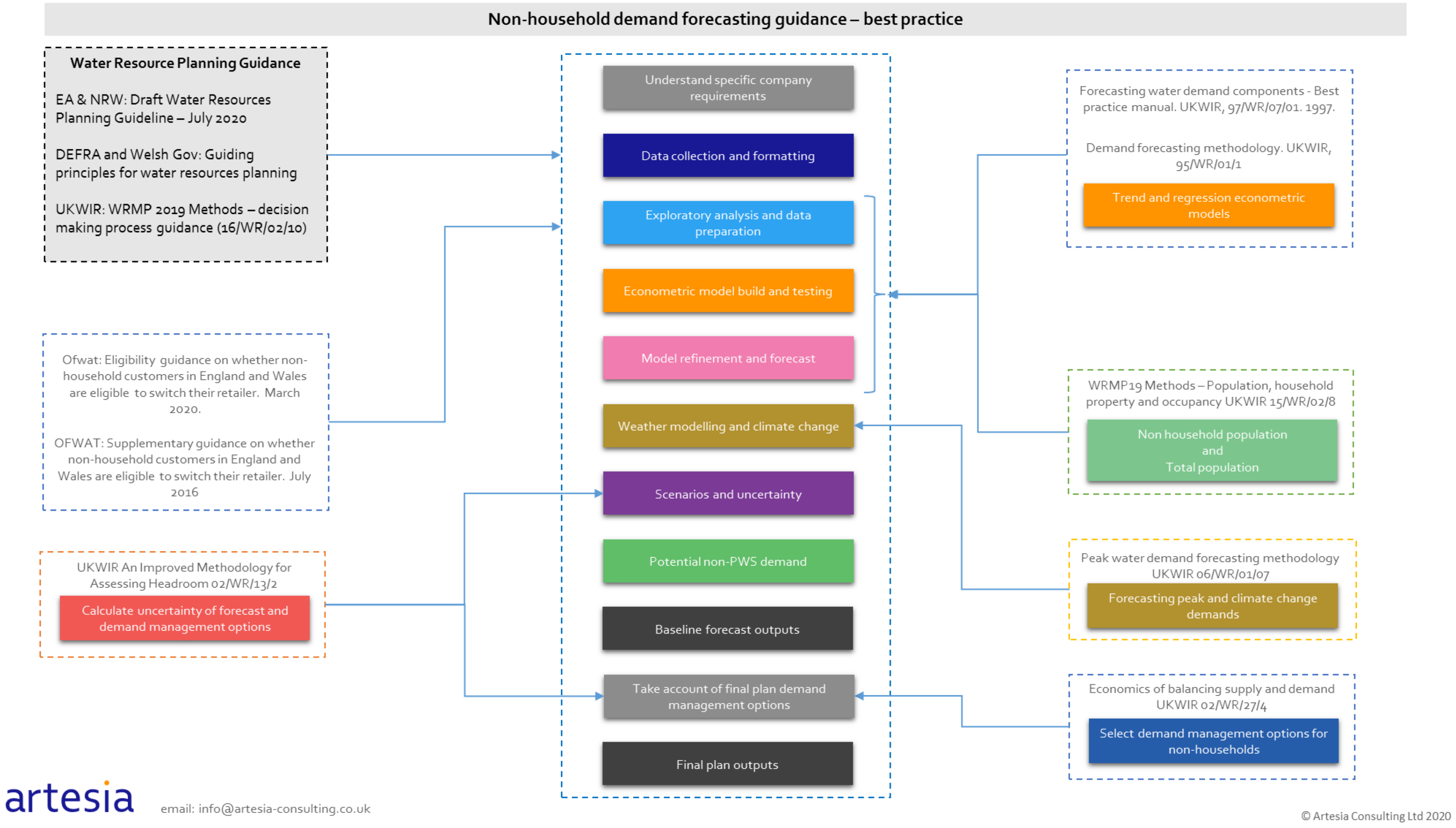
The first year of the forecast (2019-20) has seen an unprecedented change in non-household demand due to the policies introduced to combat the COVID-19 pandemic. This increases uncertainty going forward as we still do not fully understand what the enduring impacts will be from changes in working practices, such as increased working from home. Therefore, we have included the COVID-19 impact in the scenarios and uncertainty estimates.

The sector also faces a number of future unknowns in demand from non-households, such as population change, Brexit, climate change and how water efficiency will be delivered in the non-household sector. Therefore, these have also been included in the scenario and uncertainty modelling.

The following section details this approach.

B3.1 Best practice for developing non-household demand forecasts

There are a series of best practice documents in addition to the regulatory requirements, and an overview of these is presented in Figure B3.1. We have followed this best practice framework in producing our non-household water consumption forecast.



Non-household demand forecasting guidance – best practice

Water Resource Planning Guidance

EA & NRW: Draft Water Resources Planning Guideline – July 2020

DEFRA and Welsh Gov: Guiding principles for water resources planning

UKWIR: WRMP 2019 Methods – decision making process guidance (16/WR/02/10)

Ofwat: Eligibility guidance on whether non-household customers in England and Wales are eligible to switch their retailer. March 2020.

OFWAT: Supplementary guidance on whether non-household customers in England and Wales are eligible to switch their retailer. July 2016

UKWIR An Improved Methodology for Assessing Headroom 02/WR/13/2

Calculate uncertainty of forecast and demand management options

Understand specific company requirements

Data collection and formatting

Exploratory analysis and data preparation

Econometric model build and testing

Model refinement and forecast

Weather modelling and climate change

Scenarios and uncertainty

Potential non-PWS demand

Baseline forecast outputs

Take account of final plan demand management options

Final plan outputs

Forecasting water demand components - Best practice manual. UKWIR, 97/WR/07/01. 1997.

Demand forecasting methodology. UKWIR, 95/WR/01/1

Trend and regression econometric models

WRMP19 Methods – Population, household property and occupancy UKWIR 15/WR/02/8

Non household population
and
Total population

Peak water demand forecasting methodology UKWIR 06/WR/01/07

Forecasting peak and climate change demands

Economics of balancing supply and demand UKWIR 02/WR/27/4

Select demand management options for non-households

artesia email: info@artesia-consulting.co.uk

Figure B3.1: Non-household demand forecasting best practice overview

The following sections provide additional details on the methodology we implemented to meet the requirements of the non-household forecast. The methodology described in this section was applied consistently for our region and Water Resources West companies.

B3.2 Data collection and formatting

The first stage of the project was to collect/format customer data and agree modelling inputs for which a consistent data requirement specification was agreed as displayed in Table B3.1.

Table B3.1 Data requirements for the non-household demand forecast

Ref	General Data requirements	Data Type
1	Data transfer preferences (e.g email, Sharepoint, Drop Box etc)	Information
2	Key data contact	Information
3	Forecast granularity	Information
4	Number of areas	Number
5	Base year	Year
6	Population (total) forecast by WRZ (from Base year)	Population
7	Non-HH property forecast by WRZ (from Base year) – Split measured and unmeasured	Property
8	Historic annual return: non-HH property numbers split by measured and unmeasured by WRZ	Property
9	Historic annual return: total population numbers by WRZ	Population
10	Pre 2017 annual non-HH consumption data (per property or per segment or industry code)	Consumption
11	2017 to 2020 annual non-HH consumption data (per property or per segment or industry code)	Consumption
12	Data to link non-HH consumption to industry code (SIC, ABP or Land registry)	Data Link
13	Data to link non-HH consumption to WRZ	Data Link
14	Weather data for each WRZ: monthly (or finer) mean temperature and mean rainfall	Weather
15	GVA and employment data by WRZ and industry segment (historic and forecast)	Economic Activity
16	Historic annual return consumption data up to and including base year	Consumption
17	Base year consumption data for each property linked to WRZ and Segment (maybe included in ref 11)	Consumption
18	Climate change scenario predictions for temperature and rainfall	Climate
19	Scenario trend data	Trend
20	Non-PWS demand prediction	Non-PWS
21	WRMP19 non-household consumption forecast outputs	Information

This data was assessed and formatted consistently for each water resource zone.

B3.3 Exploratory analysis and data preparation

The outputs from the exploratory analysis and data preparation, were a set of consistent data frames. These consisted of:

- Segmented consumption
- Explanatory variables
- Annual return data.

B3.3.1 Consumption data

Consumption data was provided at individual property level. Having consumption data at property level allows us to identify and exclude large users, which may have a significant impact on consumption at WRZ level. We also hold data on specific large users which was used to determine a consumption threshold value above which we could classify users as a large user. We determined that this threshold should be set at 2%, i.e. if a single user consumes greater than 2% of the WRZ non-household consumption then we would flag this property as a large user.

Data quality checks were performed, looking at the following:

- Proportion of properties that were unclassified or unmatched to a Standard Industrial Classification (SIC) group, split by year, as presented in Table B3.2
- Percentage of reported (annual return) volume that is contained within either classified or unclassified consumption data.

B3.3.2 Population data

Population forecast data and annual return by year and WRZ were imported and combined to create a joint population dataset. Populations for overlapping years for both historical and forecast data were compared to check data accuracy.

The populations used for the baseline scenarios are presented in Section B3.6.3

B3.3.3 Industry sector mapping

SIC classifications were mapped to industry grouping using various mapping files. We developed mapping files for the historic version of SIC groups from 1980 to 2007. These were then used to group the properties' consumption into the industrial sectors shown in Table B3.2:

Table B3.2: Industry groupings

Industry grouping	SIC_2007 sections	Reference
Agriculture	A	1
Non-service industries	B, C, D, E, F	2
Service industries – population driven	O, P, Q, R, S, T	3
Service industries – economy driven	G, H, I, J, K, L, M, N	4
Unclassified		5

The sector groups were chosen using the recommendations in the review of current practice[4]. They represent a compromise between the previous approach of splitting non-household customers into service and non-service categories, and a more ambitious approach of allowing the exploratory analysis to define the industry groupings based on their usage characteristics.

Table B3.3 shows the proportion of properties and the proportion of consumption for each company that falls into each of the industry groupings identified in Table B3.2.

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[4] Ovarro (2020) Review of Non-Household Demand Forecast Methods. Final Report. Document No: J2017\GD008\01. Version: 1

Table B3.3: Proportion of properties and consumption in each industry group in 2019-20

Industry grouping	Proportion of properties in group	Proportion of consumption in group
Agriculture	22.3%	23.73%
Non-service industries	6.24%	18.51%
Service – population driven	4.12%	3.98%
Service – economy driven	39.38%	36.32%
Unclassified	27.89%	17.46%

B3.3.4 Weather data

Compiled weather data sourced from the Met Office was loaded with average rainfall and average maximum temperature by year.

B3.3.5 Econometric data

Historic econometric data was provided by Oxford Economics (OE) from 1991 to 2020, and forecasts to 2040. We formatted this data into employment and Gross Value Added (GVA) by SIC group and region, and we mapped our region to the statistical area of Wales.

B3.3.6 Data collation

A maximal theoretical dataset was produced by creating all combinations of year (from OE, weather, consumption, and population datasets), WRZ (weather, consumption, and population) and SIC/industry groups (consumption), with all variables joined to these where available.

This was then aggregated to industry grouping level, with group-specific numerical variables summed (consumption, employment, GVA) and other numerical variables re-joined at aggregated level (weather and population).

B3.4 Model build, testing and refinement for baseline forecasts

B3.4.1 Non-household forecast modelling

The non-household forecast modelling was carried out in line with best practice.

Choosing the right modelling process is a complex task that needs to take into consideration statistical model performances, but also many other variables that require the modeller expert judgement (availability of variables, reliability of data, overfitting problems, and more). Therefore, the modelling process is based on offering all the statistical tools to the modeller, who then takes a decision based on all considered aspects.

The NHH forecast modelling process is divided in the following steps:

1. Build the multi linear regression (MLR) model based on past aggregated consumption data, considering Oxford Economic variables and potentially other factors.

2. Calibrate the model for the base year, in this case 2019-20, first by industry sector using the property consumption data, then by WRZ using the Annual Return (AR) consumption.

3. Apply the MLR model and the calibration to future explanatory variables to estimate future NHH consumption.

The MLR modelling is done at company level but considering industry groups independently. Calibration is instead performed at WRZ level.

At each stage adjustments and improvements can be made, depending on the specifics of the data. In Section B3.7.1 there is a modelling report which identifies all the specific modelling details.

B3.4.2 MLR modelling

Multi linear regression (MLR) modelling aims at finding a linear relationship between the observed consumption and explanatory variables. Firstly, all available explanatory variables are considered. Subsequently, the model is refined choosing only the significant variables. The choice is based on:

- model performances excluding the variables one by one
- interaction between variables
- logical inclusions/exclusions based on the relationship between the expected effect of each variable on consumption, and the estimated coefficients
- exclusion of outliers
- other modellers' considerations.

Results for each MLR model for each industry sector (Section B3.7.1) include the following:

- model term
- estimate
- standard error
- p value.

B3.4.3 Calibration

The joint MLR model is based on our company data and MOSL data in the base year, which may not represent the total annual reported NHH Measured consumption. For this reason, the results of the model need to be calibrated against the Annual Report (AR) data for the base year, in this case 2019-20. This also helps accounting for differences between WRZ, not accounted for when building the model at company level.

To ensure the proportion between different sectors is maintained, the calibration has been further refined:

- First modelled consumption is calibrated against property consumption for each industry group and WRZ, deriving an additive factor
- Then the total measured consumption is calibrated against AR data at WRZ, deriving a multiplicative factor.

Section B3.7.2 includes the calibration factors for each company and WRZ for each industry sector.

B3.4.4 Baseline forecasts

Final NHH baseline forecasts are obtained separately for the measured and the unmeasured components.

For the Measured component, NHH is forecast with the following steps:

- apply the MLR model separately for each industry group and WRZ
- apply the two-step calibration

- forecasts are then extended as a flat line from 2040-41 to 2084-85. This is because the econometric forecasts, upon which the NHH forecasts are based, only extend to 2040, and to infer any trends after this point would be over-optimistic
- minimum consumption is set to 10% of the observed years' average, with exclusion of 2020-21 that is allowed to go to zero considering the COVID-19 crisis.

Given its uncertainty, the unmeasured sector is forecasted as constantly equal to the base year value.

The baseline forecasts are presented in our published data tables.

B3.5 Scenarios and uncertainty

B3.5.1 Concepts of uncertainty and scenarios

The concepts of uncertainty and scenarios are often used interchangeably and partially overlap in terms of meaning. Both represent unknowns that may affect water consumption forecasts. For the purpose of the dWRMP24 non-household demand forecasts we need to separate the concepts through definitions:

Uncertainty refers primarily to the variability we have in forecasts due to data uncertainty and unexplainable variability uncertainty. Uncertainty is non-zero even in the present figures and grows with time in a gradual way, due to uncertainty propagation. Uncertainty can be described by probability distributions and derived statistics, like mean, standard deviation, or quantiles.

Scenarios refer to the variability in future projections due to foreseeable (at least in terms of happening) events. Scenarios' variability is only applicable to future figures, not to the present, and can grow or decrease in time according to the specific events we are considering. Scenarios are usually represented by a discrete number of alternative forecasts.

As the dWRMP24 non-household (NHH) forecasts are derived through a complex process, the sources of uncertainty can be many, and very little is known about the quantification of uncertainty. Similarly, the number of factors that can affect NHH water consumption can be large and unexpected events and technologies may alter the way we will consume water; therefore, it is very difficult to consider all plausible scenarios.

In this work, we introduce some approximations to overcome the unknown quantification and the technical limitations involved in modelling both the uncertainty and the scenarios. We first proceed in delineating a large number of foreseeable scenarios, from which we derive plausible central, lower and upper thresholds. Then we proceed in applying uncertainty estimations for quantifiable factors on the three selected thresholds.

Details of the scenarios' definition and the uncertainty quantification are reported in following sections.

B3.5.2 Scenario development

There are multiple and complex links between non-household demand and a wide range of factors, from international and national macroeconomic trends to local investment strategies and population growth. This complexity could present challenges for forecasting; in terms of what factors to consider and the range of scenarios needed to capture a suitable range of futures. Therefore, we have developed seven scenarios to reflect the impact from a broad range of drivers and pressures. The scenarios each result in a different mid-century non-household forecast. These scenarios help to take account of a range of uncertainties and risks and help identify opportunities for resilient responses.

We chose to adopt this scenario approach because of the specific short-term impacts likely as a result of COVID-19 and Brexit, alongside other medium to long term impacts associated with the other factors considered and discussed in this section. This combination of timescales and magnitude of impacts suggest a simple Monte Carlo approach would not be appropriate for analysing these factors. However, the results from this analysis, combined with the uncertainty analysis presented in Section B3.5.4 can be used as inputs to Monte Carlo analysis, for example for headroom modelling.

The scenarios have been developed using a 'DPSIR' framework to identify and assess how the scenarios are related to and perform in terms of Drivers, Pressures, States, Impacts and Responses.

In this section we describe the background to the DPSIR model, the approach to scenario development and the scenarios themselves. This section also provides an evaluation and summary of the scenarios.

The use of a DPSIR model for context and assessment of scenarios

One of the most common analytical frameworks for scenario development is the Drivers, Pressures, State, Impact, and Response (DPSIR) model that depicts how socioeconomic development impacts ecosystem services and the environment[5]. The DPSIR model is a flexible framework that can be used to assist decision-makers in many steps of the decision process. DPSIR was initially developed by the Organisation for Economic Co-operation and Development[6] and has been used by the United Nations and European Environmental Agency to relate human activities to the state of the environment.[7]

The DPSIR model describes a general chain which triggers environmental issues between socioeconomic origins and the results. This chain indicates that societal, economic and population development act as drivers (D) on the environment, thus producing pressure (P) on it, which gives rise to a change in its status (S) and thus affects it. All of these effects then either cause humans to respond (R) to the environmental status (S), changing the complex systems which consists of society, economics and population, or directly act on environmental pressure (P), status (S) and impacts (I).[8]

To support optimal consideration of the factors impacting on non-household demand, we have adapted this framework for this dWRMP so that the 'drivers' are:

- Macro-economic growth/decline, driven by factors including globalisation, the COVID-19 pandemic and Brexit
- Population change
- Regional policy for development and investment
- Commercial factors within sectors (e.g. operating costs, investment requirements, market competition, etc)

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5 Kelble CR, Loomis DK, Lovelace S, Nuttle WK, Ortner PB, Fletcher P, et al. (2013) The EBM-DPSER Conceptual Model: Integrating Ecosystem Services into the DPSIR Framework. PLoS ONE 8(8): e70766. https://doi.org/10.1371/journal.pone.0070766

6 OECD, 1994. OECD core set of indicators for environmental performance reviews. OECD

774 Environment Monographs No. 83. OECD, Paris. http://www.oecd.org/env/indicators775 modelling-outlooks/31558547.pdf

7 https://archive.epa.gov/ged/tutorial/web/pdf/dpsir_module_2.pdf

8 Shikun Sun,Yubao Wang,Jing Liu,Huanjie Cai,Pute Wu,Qingling Geng,Lijun Xu (2016) Sustainability assessment of regional water resources under the DPSIR framework. Journal of Hydrology Volume 532, January 2016, Pages 140-148. https://doi.org/10.1016/j.jhydrol.2015.11.028

- Technology and technological change (e.g. the potential increase in the use of hydrogen and therefore water to replace fossil fuels)
- Water availability
- Climate change impacts on supply and demand.

Pressures are expressed in terms of:

- Changes in non-household demand
- Changes in abstraction and resultant environmental impact
- A change in available headroom in the supply-demand balance, and the need for interventions to maintain this at an acceptable level
- Water availability becoming a constraint on economic growth.

The 'state' (i.e. the state that the scenarios should be measured against) is 'resilience'[9]. Impacts are the effects of drivers on non-household demand. Responses can be seen as measures that can be taken by WRW, wholesale and retail water companies and others, including:

- Legislative and policy drivers (e.g. water regulations and quality requirements, water efficiency or water reuse targets)
- Identify other potential sources of supply
- Increased water efficiency (through reducing leaks and wastage, new technology, water labelling, pricing/ tariffs and behaviour change)
- More water reuse (e.g. using clean process water for cooling)
- More use of non-potable sources (e.g. rainwater for cooling or other suitable processes)
- More co-ordination between non-households (e.g. using cooling water from one premises in another nearby customer's process). This could be part of wider 'circular economy initiatives'
- More water trading (e.g. using spare/unused irrigation water for a nearby process).

There are also responses which are either outside the control of WRW and others, or may be secondary outcomes, such as the development of waterless processes or companies relocating (or not moving in at all) due to lack of access to water supply.

Scenarios can be used to systematically investigate future impacts on non-household water demand, and set out how coherent and plausible alternative futures could affect future water use.

We have developed seven scenarios taking account of the following inputs to this project:

- The effects of specific drivers including COVID-19 , Brexit, HS2, and other drivers identified earlier in this section
- The response measures identified earlier in this section

The scenarios take the current 'landscape' of non-household demand in summer 2020 as a starting point. They are characterised in terms of two of the main drivers of future water availability/consumption – economic growth and environmental protection. These form the axes in Figure B3.2, and help 'position' the scenarios. Whilst other drivers could be used for the axes, this would not fundamentally impact the scenarios, which are designed to represent a range of plausible future 'states of the world'.

There are seven different scenarios within 5 main headings, each is briefly described below.

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[9] Specifically, "resilience is the ability to cope with, and recover from, disruption and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future" (Ofwat, Resilience in the Round).

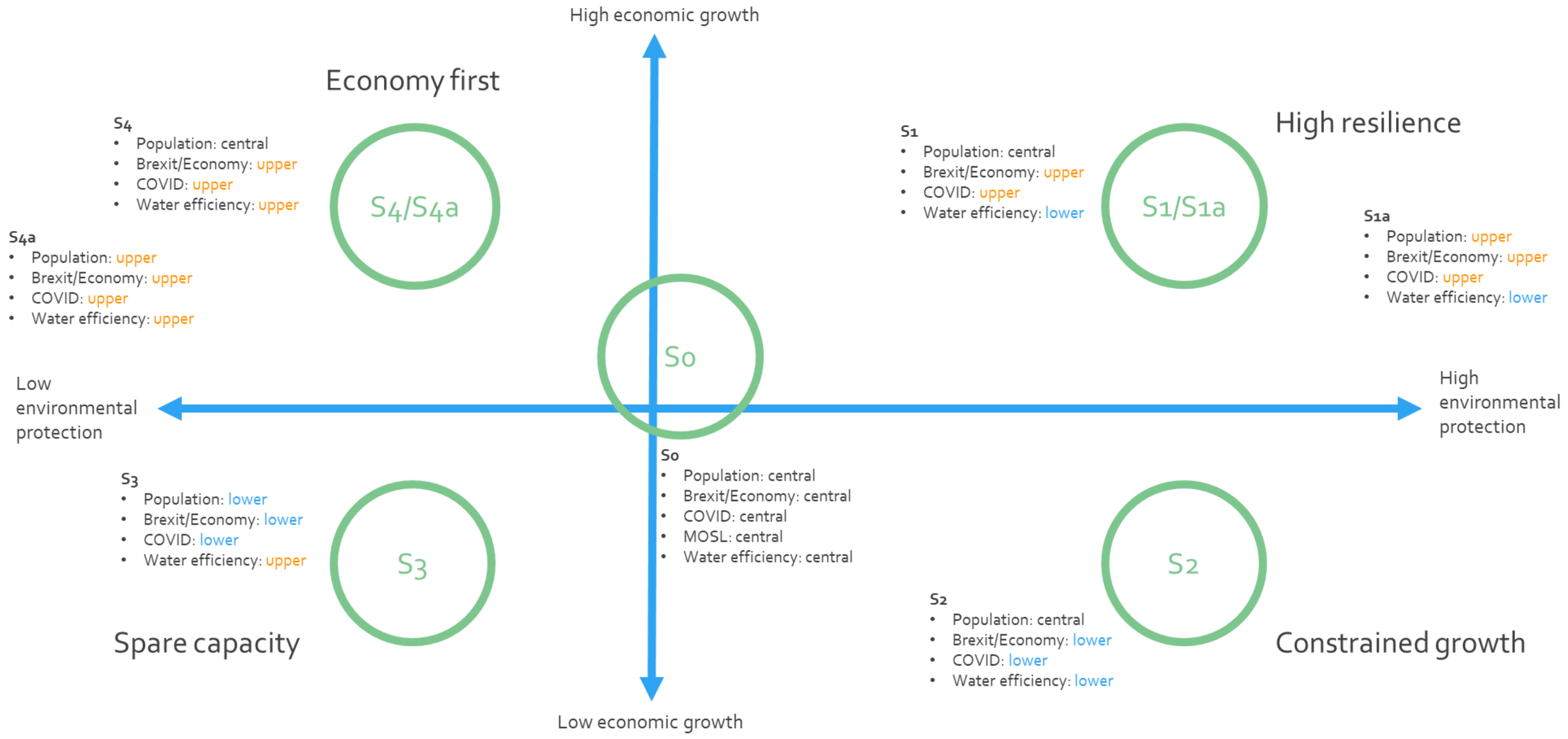
S0: Current landscape
Existing (summer 2020) non-household demand for water. This is suppressed (lower than usual) because of the COVID-19 pandemic.

S1: High resilience
Economic growth is partly driven and facilitated by technological change and innovation. This is matched by high environmental standards aimed at addressing increased water scarcity, leading to a greater focus on water efficiency, reuse and collaborative working. There are two variants (S1 and S1a) of this scenario using the central and upper population forecast.

S2: Constrained growth
Economic growth is heavily impacted by the COVID-19 pandemic and Brexit, as well as by the need to protect and enhance the environment, leading to legislative and regulatory policies that drive more efficient water use, and by the use of pricing and tariffs.

S3: Spare capacity
Economic growth is heavily impacted by the COVID-19 pandemic and Brexit, as well as by low levels of innovation and low population growth. Environmental protection is given a low priority and there is spare capacity in the provision of water services, with water efficiency and demand management measures deemed largely unnecessary.

S4: Economy First
Economic growth is prioritised, resulting in higher than average growth in both the service and non-service sectors. Water companies need to identify new potable and non-potable sources to maintain the supply demand balance. Collaboration, among water companies and between sectors, is limited, with a greater focus on competition. There are two variants of this scenario (S4 and S4a) using the central and upper population forecast.



S4
- Population: central
- Brexit/Economy: upper
- COVID: upper
- Water efficiency: upper

S4a
- Population: upper
- Brexit/Economy: upper
- COVID: upper
- Water efficiency: upper

S1
- Population: central
- Brexit/Economy: upper
- COVID: upper
- Water efficiency: lower

S1a
- Population: upper
- Brexit/Economy: upper
- COVID: upper
- Water efficiency: lower

S0
- Population: central
- Brexit/Economy: central
- COVID: central
- MOSL: central
- Water efficiency: central

S3
- Population: lower
- Brexit/Economy: lower
- COVID: lower
- Water efficiency: upper

S2
- Population: central
- Brexit/Economy: lower
- COVID: lower
- Water efficiency: lower

Figure B3.2: Scenario summary

B3.5.3 Modelling scenarios

The seven scenarios described were agreed to be the main focus of the scenario analysis.

Population scenarios

Population scenarios used are presented in Table B3.4.

Table B3.4: Scenario to population scenario mapping

Scenario	Scenario type	Scenario name
S0	central	Baseline
S1	central	Baseline
S1a	high	SC Completions
S2	central	Baseline
S3	low	ONS Low
S4	central	Baseline
S4a	high	SC Completions

The choice of population scenario is illustrated in Figure B3.3

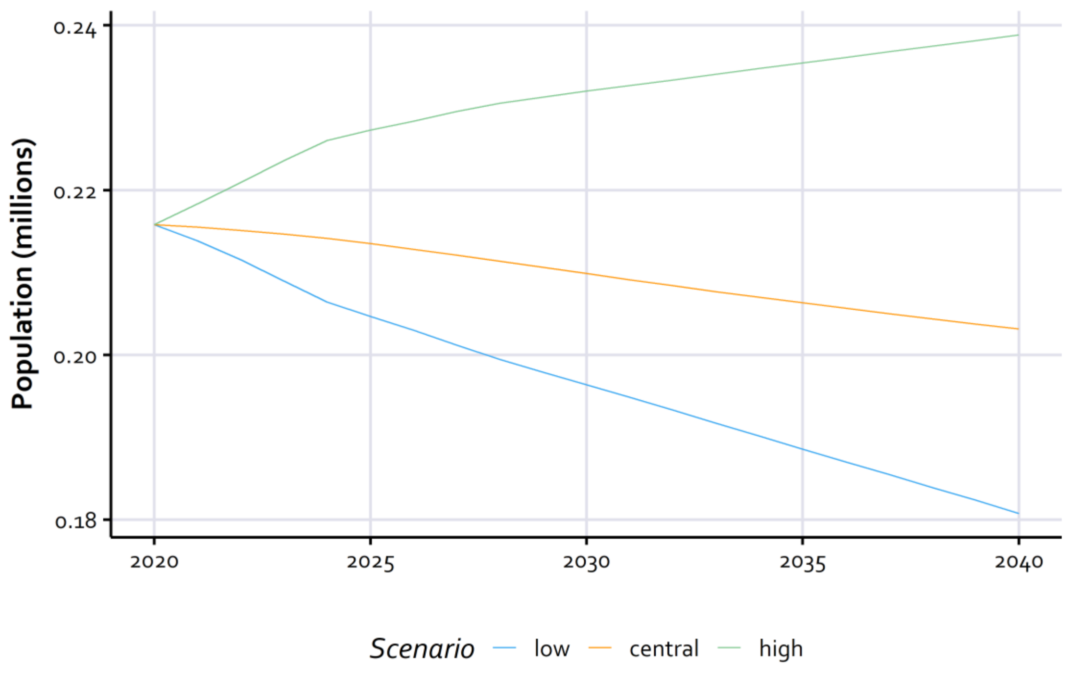


Figure B3.3 Basis for choice of population scenarios

Brexit

The United Kingdom left the European Union on 24 December 2020. The two parties agreed a trade deal for goods and movement between the UK and EU27. The impact of this deal on the economy and immigration remains unknown at present, for both the short and the long term. However, the short-term forecasts consider both Brexit and Covid-19 impacts on the economy, and these two factors are difficult to separate. So, we decided to apply only the long-term impacts for the Brexit scenarios, as the short-term effects are already represented in the three COVID-19 scenarios.

NHH water consumption is modelled considering GVA, employment and population among other factors, and these factors are the ones impacted by Brexit.

The impact on population is estimated from Lomax, (2019)[10], considering the percentage variation between the three reported Brexit scenarios: EU-membership, soft Brexit and hard Brexit. Considering our baseline as the middle scenario, we can consider a change in population of +2.6% by 2040 under the upper Brexit scenario, and a decrease of -2.6% under the lower Brexit scenario.

For employment estimates, we considered the HM Government report entitled HM Treasury analysis: the long-term economic impact of EU membership and the alternatives[11], which states that "unemployment would reach 7% to 8% in 2020, compared with a projected rate of 5% if the UK remained in the EU". Assuming our estimates correspond to the central, we can consider a variability around 3%, so +/- 1.5% for the upper and lower scenarios. Not having further temporal information, we keep this steady in time.

In terms of GVA (proportional to Gross Domestic Product (GDP) if fixed taxation is assumed), the report proposes wider ranges, going between 1.2% and 2.8%, considering the uncertainty. For consistency we consider 1.5% like for the employment estimates. The summary of Brexit impacts is presented in Table B3.5

Table B3.5: Brexit scenarios and their impact

	Population	GVA	Employment
Upper Brexit scenario	+2.6% by 2040	+1.5% fixed	+1.5% fixed
Central Brexit Scenario	baseline	baseline	baseline
Lower Brexit Scenario	-2.6% by 2040	-1.5% fixed	-1.5% fixed

COVID-19

COVID-19 has had a strong negative impact on the economy and on NHH water consumption, due to lockdown measurements and economic recession, as well as due to remote-working measurements. The impact of COVID-19 is modelled in three different ways:

1. GVA and Employment are modified on the short term, according to the expected impact on the economy
2. Water consumption is reduced across all sectors
3. Water consumption is shifted between sectors.

COVID-19 impact on GVA and Employment

The impact of COVID-19 on GVA and Employment is estimated from the Forecasts for the UK economy 2020 by the HM Treasury[12]. The report compares independent forecasts. The baseline was estimated using the Oxford Economic (OE) forecasts for GVA and Employment. From the report the upper and the lower thresholds are estimated for GVA (derived from GDP, Table M1 of the report, with the assumption of proportionality) and for employment (derived from unemployment forecasts, table M5 of the report), using the upper and the lower independent estimate. For GVA, OE is a central forecast, therefore is used as the central scenario, while for employment OE is already the upper forecast, so it is used as the upper scenario. The result is a set of percentage changes to apply to the baseline for years 2019-2024. These estimates also include the short-term impact of Brexit.

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[10] Lomax, N., Wohland, P., Rees, P. & Norman, P. The impacts of international migration on the UK's ethnic populations. J. Ethn. Migr. Stud. 46, 177–199 (2019).

[11] HM Government. HM Treasury analysis: the long-term economic impact of EU membership and the alternatives, 2016, Cm 9250, Web ISBN 9781474130905

[12] HM Treasury, Forecasts for the UK economy: a comparison of independent forecasts, 2020, No. 397, ISBN 978-1-913635-61-9

NHH water consumption reduction due to COVID-19

Beyond the effects on the economy, COVID-19 has an effect on water consumed by businesses and non-household properties due to different operations and remote working. Artesia has conducted an independent study on the impact of COVID-19 on the NHH sector. Figure B3.4 shows the reduction in water consumption during summer 2020 compared to the previous year, considering weather, holidays, and other influencing factors. Figure 3.5 shows the estimated reduction in consumption during 2020 for each COVID-19 period.

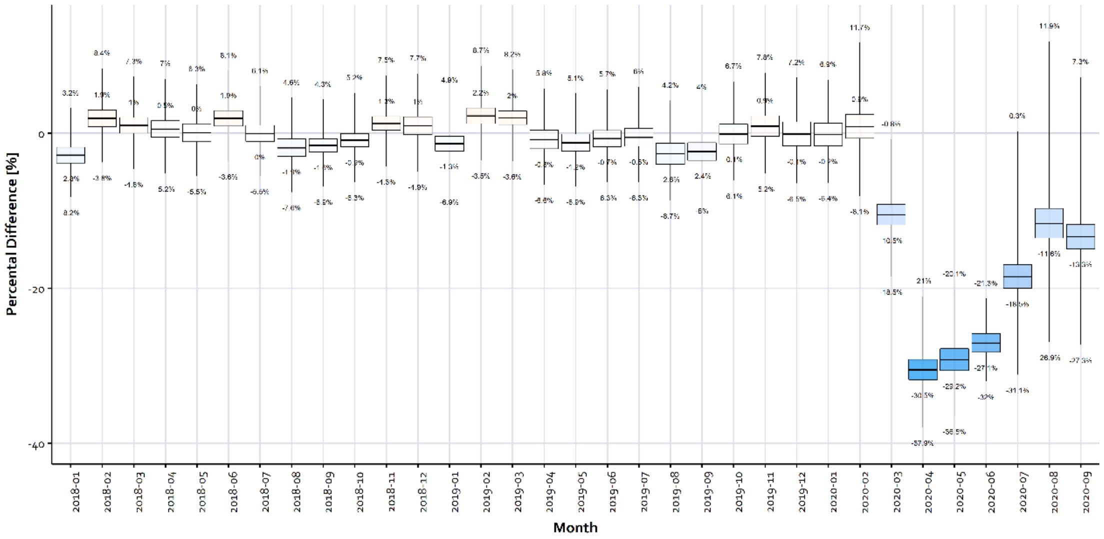

Figure B3.4: Estimated reduction in NHH water consumption during 2020 for each COVID period

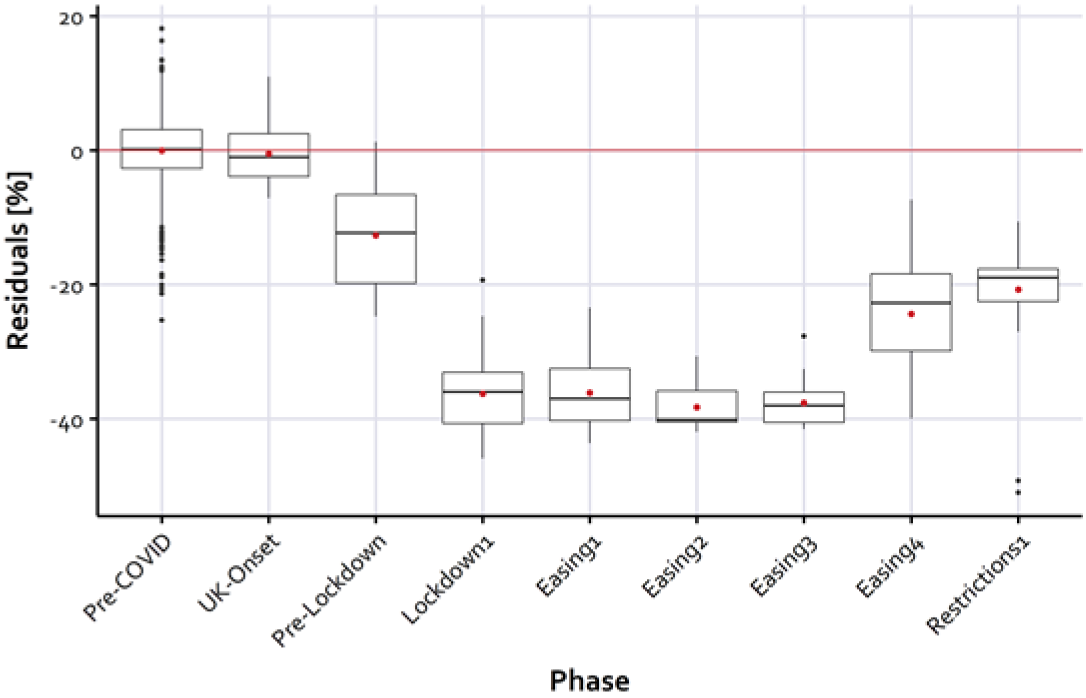

Figure B3.5: Estimated reduction in NHH water consumption during 2020 for each COVID period

The three scenarios are considered as follows:

- Upper COVID-19 scenario: no variation on the baseline
- Central COVID-19 scenario: -12% in 2020-21 and -6% in 2021-22, then baseline
- Lower COVID-19 scenario: -20% in 2020-21 and -10% in 2021-22, then -3% on the baseline.

Shift between sectors due to COVID-19
The economic impact of COVID-19 and the change of operations due to a mass remote-working approach affected water consumption. Both these factors, quantified above as a total effect, have varying affects on different economic sector. Therefore, a final step of the modelling is to shift water consumption between sectors.

To do so, we use data from the ONS Business Impact of COVID-19 Survey (BICS) from September 2020[13] (assumed to be the best representation to date to the post-lockdown COVID-19 scenario). The dataset reports both the changes in turnover and the percentage of workers working remotely, by sector. Combining the two factors we could derive that under the September 2020 conditions, NHH water consumption is likely to have shifted:

- Agriculture +0.4%
- Non-service +9.1%
- Service-economy -4.1%
- Service-population -5.8%
- Unclassified +0.4%.
- The shift is only considered in the lower COVID-19 scenario, where long term impact of remote-working is considered.

Summary of COVID-19 scenarios
Table B3.6 lists the summary of the COVID-19 scenarios and their impact.

Table B3.6: COVID-19 scenarios and their impact

	GVA	Employment	Consumption reduction	Sector shift
Upper COVID-19 scenario	Upper independent forecast	OE forecast	baseline	baseline
Central COVID-19 Scenario	OE forecast	Central independent forecast	-12% in 2020-21 -6% in 2021-22 then baseline	baseline
Lower COVID-19 Scenario	Lower independent forecast	Lower independent forecast	-20% in 2020-21 -10% in 2021-22 then -3%	Agric: +0.4% Non-serv: +9.1% Serv-eco: -4.1% Serv-pop: -5.8% Unclass: +0.4%

- [13] ONS, BICS Wave 14 edition of this dataset 7 September to 20 September 2020.

Climate change - Modelling residuals

Building the residual models for each WRZ independently is correct theoretically, but due to the low number of points in time it can result in unstable models. Therefore, generalised models covering other regions which contained more stable data points were used. To make the residuals comparable, we standardised them, dividing them by the consumption itself:

$$residuals = \frac{(consumption - prediction)}{consumption}$$

Using this method, the resulting model predicts standardised residuals in the future as a function of weather variables (average rainfall and average maximum temperature). The residuals can then be adapted to each WRZ by multiplying them by the mean consumption of past years.

Climate change - Modelling historic weather trends

The first step in the analysis is to establish the change in weather patterns that are occurring due to climate change. The weather variables under examination are average maximum temperature and average rainfall. Figure B3.6 and Figure B3.7 show that the trends of these variables over the years can be well represented with linear regressive models.

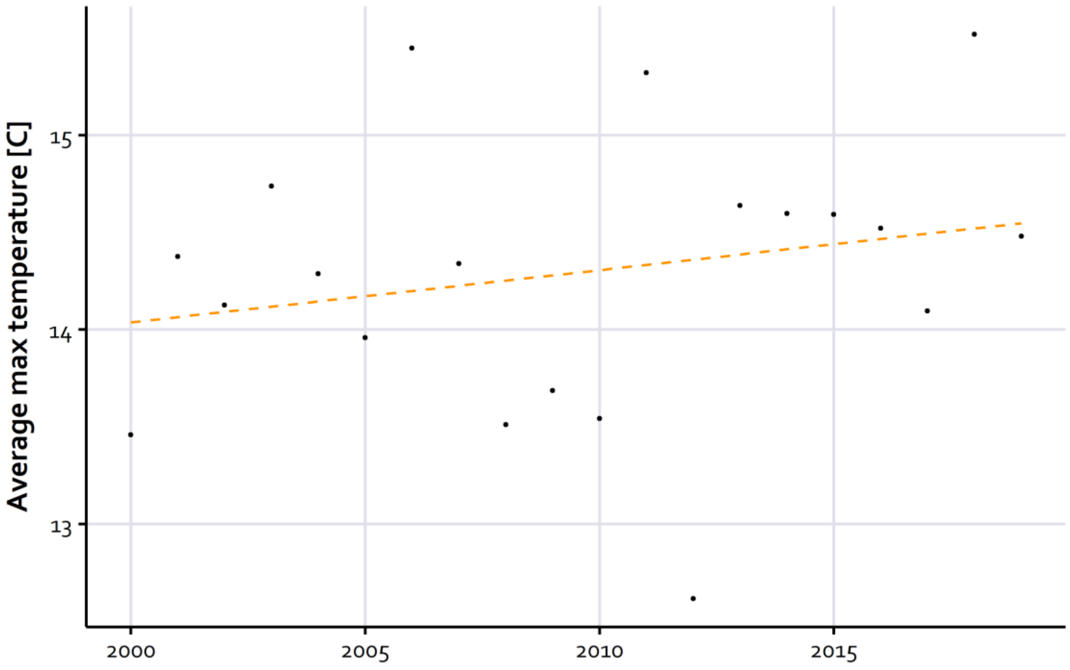

Figure B3.6: A plot showing the trend of average max temperature

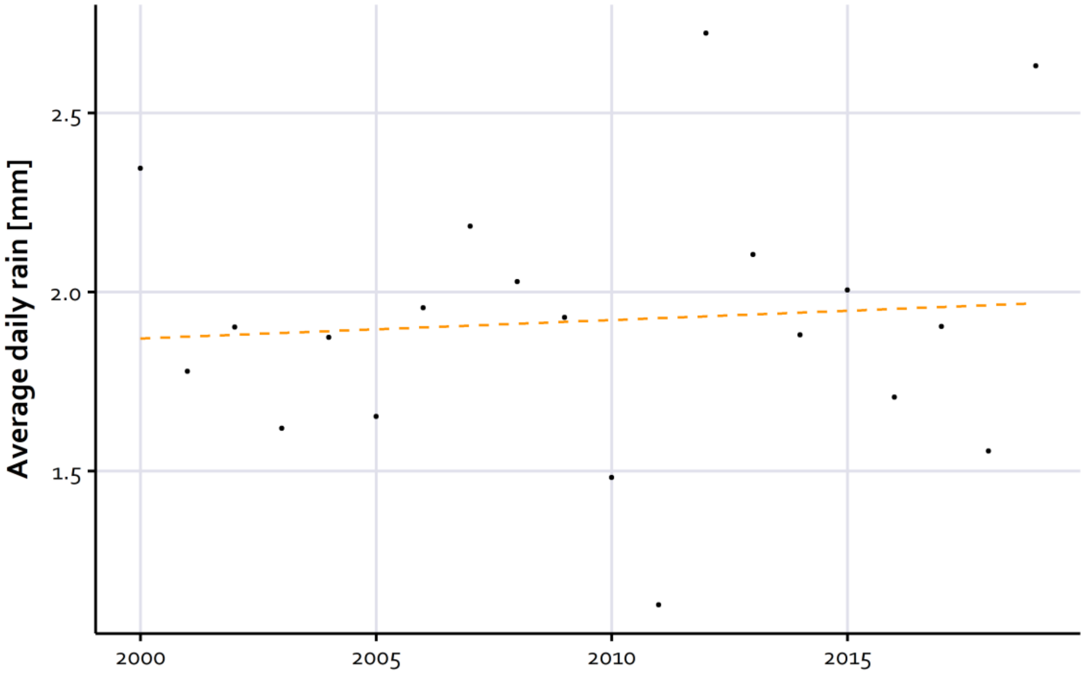

Figure B3.7: A plot showing the trend of average daily rainfall.

Forecasting Weather and Climate Change Residuals

The weather models developed in Figure B3.4 and Figure B3.5 are used to forecast average maximum temperature and average rainfall through the forecast period.

We used additive climate change models in conjunction with the weather forecasts. These models provide 12 scenarios of potential temperature and rainfall patterns.

The forecasts of the weather variables are each summed with the 12 relevant climate change scenarios to produce 12 forecasts for average maximum temperature and average rainfall. The 12 scenarios for each are then fed into the residual model to obtain residual forecasts.

However, all 12 scenarios are not required for this analysis, only a low, central, and high scenario. To extract three scenarios from the 12, the 10th, 50th, and 90th quantile of the scenarios are taken for each financial year.

The climate change scenarios only go up to the year 2080, whereas we need forecasts up to the year 2085. To extend to this timeframe, a linear regressive model is fit to each of the low, central, and high scenarios and used to predict to 2085.

Water efficiency

The evolution of technology and regulations is expected to contribute to reducing NHH water consumption, by improving water efficiency.

The three water efficiency scenarios below were selected in consultation with the WRW steering group:

- Upper water efficiency scenario: water consumption is reduced by 2% by 2050-51
- Central water efficiency scenario: water consumption is reduced by 7.5% by 2050-51
- Lower water efficiency scenario: water consumption is reduced by 16% by 2050-51.

B3.5.4 Modelling uncertainty

Every single element of the complex dWRMP24 NHH forecasts is affected by a certain degree of uncertainty, but the quantification is difficult. Therefore, we decided to focus on the elements that have the biggest impact on the forecasts:

- the explanatory variables used in the model
- the model
- climate change
- MOSL reporting.

The quantification of uncertainty for each component is described in the following sections.

Explanatory variable uncertainty

Each explanatory variable is affected by a different degree of uncertainty. It is not easy to separate the uncertainties and to evaluate the effects of each on the resulting water consumption. However, thanks to the linear nature of the model, if we consider the explanatory variables to have the same uncertainty, e.g. ±10%, we can derive that the same uncertainty will affect water consumption. The following explanatory variables are considered for uncertainty:

- GVA
- Employment
- Population.

Other minor explanatory variables are expected to have a lower uncertainty and to affect the water consumption estimations to a smaller degree.

Observing the population scenarios, we can observe that their uncertainty is very small in the present and grows steadily in the future, reaching a value of ±6% to ±12% depending on the scenarios we consider.

In terms of GVA and employment as we can observe in the Forecasts for the UK economy 2020 by the HM Treasury, the larger uncertainty is actually in the short term and varies between ±30% to ±50% for GVA to ±1.5% to ±3% for employment.

Considering the uncertainties estimated above, the general uncertainty for the explanatory variables is estimated as:

- ±8% of the water consumption in 2019-20
- Growing to ±12% of the water consumption in 2025-26
- Growing to ±17% of the water consumption in 2084-85.

Model uncertainty

Model uncertainty is estimated separately for the considered industry groups and companies, as different models are used. A model's R2 value represents the variability in the data that the model is able to explain. We estimate the model uncertainty as 1 – R2, i.e. the variability in the data that the model is not able to explain. This is a simplification, as effects like overfitting can increase the R2 value beyond what the real capabilities of the model are, but overall it is a good proxy for the model uncertainty.

Climate change uncertainty

Climate change uncertainty has been estimated from the UKCP18 Climate Change Over Land infographic, that estimates the following:

- Rainfall is expected to show a variability up to ±25-30% in summer and ±12-19% in winter by 2060-79. It can be approximated as a ±20% on a yearly basis by 2060-79.
- Temperature is expected to show a total variability between 2.5-3.5 °C in winter and 3.3-4.7 °C in the summer, so about 4 °C on a yearly basis by 2060-79. Assuming an average yearly temperature around 15°C, that is about 15°C±2°C, i.e. ±13%, by 2060-79.

Combining the two estimates, we can consider a climate variability of about 16% by 2070, which we extrapolate to an effect in 2085.

B3.5.5 Application of uncertainty

Once the uncertainty of the single components is defined as in the previous sections, they are then combined in a quadratic way:

$$u = \sqrt{u_{EV}^2 + u_{model}^2 + u_{climate}^2}$$

The resulting uncertainty, estimated at company level, WRZ, industry group and year, is applied on the three derived scenario thresholds.

B3.6 Potential non-PWS demand

The non-PWS demand for our area only includes abstraction licence data located in the former WRZs of Wrexham and Llandinam & Llanwrin. Our initial assessment was carried out as part of the WRW non-PWS project and we are currently working on a collaborative project to improve the assessment. The results presented here are a best estimate of the total non-public water supply demand in our region, and will be updated as we conclude ongoing projects.

B3.6.1 Data

For the calculation and forecast of non-PWS demand we used the output created for the Wood plc study for Welsh Government[14] and the NRW, specifically the spreadsheet:

- swabs_gwabs_extract_v05_West_Unedited.xlsx

From this spreadsheet we used data from the Existing_Abstractions_All worksheet, which contains combined surface water abstractions (SWABS) and groundwater abstractions (GWABS) point-purpose licence (extracted from WRGIS database February 2019) including multiple GWABS entries where impacts are apportioned to multiple surface water bodies.

B3.6.2 Analysis

Firstly, we removed all the public water supply abstractions by filtering them out using the "PWS" flag in the "secondary code" column. We then segmented the non-PWS observations into industrial sectors. This was done using the codes shown in Table B3.7.

The data was then checked for duplicates and any duplicates removed.

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[14] http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20172

Table B3.7: Sector segmentation – existing abstractions

Ref	Sector	How to reference
E1	Spray irrigation	Use the following Tertiary codes: 380 390 400 410 420
E2	Paper and pulp	Use secondary code: PAP
E3	Chemicals	Use secondary code: CHE
E4	Food and Drink	Use secondary code: FAD
E5	Power	Use primary code: P
E6	Agriculture (non-spray irrigation)	All remaining agriculture after E1 is removed.
E7	Navigation	Use secondary code: NAV
E8	Minerals and extraction	Use secondary codes: EXT and MIN
E9	Other	Anything that is left

The abstractions were then grouped by industry code and WRZ. For each WRZ, we then summed the following:

- Recent actual point purpose annual quantity in m3/year, consumptive quantities only (RAPTPANQM3)
- Consumptive only - Best Estimate Growth Factor Applied to RAPTPANQM3
- Consumptive only - 75th Percentile Growth Factor Applied to RAPTPANQM3.

The derivation of the “Best estimate growth” and the “75th percentile growth” factors are described in the Wood plc report.

Annual predicted non-PWS needs projecting from 2025 to 2085. For 2025 to 2050 use a linear interpolation between baseline and growth to 2050. For 2051 to 2085 we keep the non-PWS flat for this first iteration (alternative scenarios for post 2050 growth could be applied).

B3.7 Modelling results

B3.7.1 MLR modelling

The MLR models developed are reported in the Tables B3.8 to B3.11.

Table B3.8: MLR model summary for the industry group "nonservice"

term	Estimate	std.error	p.value
(Intercept)	-0.2	0.03	0
mosl	0.048	0.043	0.2845
population	0.000012	0.00000054	0

Table B3.9: MLR model summary for the industry group "serviceeconomy"

term	Estimate	std.error	p.value
(Intercept)	-0.24	1.5	0.8769
mosl	-0.21	0.14	0.1484
employment	0.00068	0.0025	0.7941
population	0.000021	0.0000015	0

Table B3.10: MLR model summary for the industry group "servicepopulation"

term	Estimate	std.error	p.value
(Intercept)	0.035	0.02	0.0898
mosl	0.025	0.012	0.0523
GVA	-0.000011	0.000004	0.0169
population	0.0000024	0.00000014	0

Table B3.11: MLR model summary for the industry group "unclassified"

term	Estimate	std.error	p.value
(Intercept)	-0.19	0.034	0
mosl	0.2	0.05	0.001
population	0.0000091	0.00000062	0

B3.7.2 Calibration

The joint MLR model is based on our company data and MOSL data inputs , which may not represent the total of the NHH Measured consumption. For this reason, the results of the model need to be calibrated against the Annual Report data for the base year, in this case 2019-20. This also helps accounting for differences between WRZ, not accounted for building the model at company level.

To ensure the proportion between different sectors is maintained, the calibration has been further refined:

- First modelled consumption is calibrated against property consumption for each industry group and WRZ, deriving an additive factor
- Then the total measured consumption is calibrated against AR data at WRZ, deriving a multiplicative factor

The calibration factors are reported below in Table B3.12.

Table B3.12: Calibration factors for the considered WRZs.

WRZ	Group	factor1	factor2
Llandinam & Llanwrin	Agriculture	0.118	1.020
Llandinam & Llanwrin	nonservice	-0.130	1.020
Llandinam & Llanwrin	serviceeconomy	0.216	1.020
Llandinam & Llanwrin	servicepopulation	0.029	1.020
Llandinam & Llanwrin	unclassified	-0.120	1.020
Llanfyllin	agriculture	0.164	1.111
Llanfyllin	nonservice	0.026	1.111
Llanfyllin	serviceeconomy	-0.047	1.111
Llanfyllin	servicepopulation	-0.030	1.111
Llanfyllin	unclassified	-0.047	1.111
Saltney	agriculture	-0.307	2.759
Saltney	nonservice	0.043	2.759
Saltney	serviceeconomy	-0.081	2.759
Saltney	servicepopulation	0.011	2.759
Saltney	unclassified	0.069	2.759
Wrexham	agriculture	-0.079	1.558
Wrexham	nonservice	0.135	1.558
Wrexham	serviceeconomy	-0.299	1.558
Wrexham	servicepopulation	0.003	1.558
Wrexham	unclassified	0.120	1.558

B5 Water Efficiency

Overview

In line with our understanding of our statutory water efficiency under s93A Water Industry Act, and those of customers, government, and regulators we will continue to offer a range of water efficiency services to our customers which we will adapt over time.

To inform our WRMP we have assessed the viability of a range of potential water efficiency activities and continue to explore some of these through ongoing trials and engagement with thirds parties. The activities we have assessed and continue to assess are:

- Provision of free and subsidised products to household customers. We intend to increase promotion of these to drive an increase in uptake.
- Carrying out home water efficiency audits (HWEC)
- in partnership with housing associations to offer their tenants a HWEC,
- Through this activity we offer customers:
- advice on reducing the volume of water they use,
- install water efficient devices where appropriate
- repairing leaks on internal fittings where it is simple to do so.
- To continue to provide advice to our customers on how to reduce their water use which includes continuing our work with schools - site visits and online sessions and interactive bus.
- Free water efficiency devices
- Subsidised higher value water efficiency devices
- Social housing water efficiency audits in customers' homes to include advice, installation of water efficient devices and the repair of leaks on internal fitting where it is simple to do so
- Provide education and advice to consumers on how to use water more wisely through our regular communications team output and our Get Water Fit customer portal
- Offering home water efficiency checks to
- Our highest consumers
- Customers who contact us about high bills
- Self-reported internal leaks through Get Water Fit
- Offering home water efficiency checks by postcode

Baseline water efficiency plan

In developing our proposals, we have referred to the relevant guidance including:

- Water Resources Planning Guideline July 2021
- Meeting our Future Water Needs: A National Framework for Water Resources
- A Green Future: Our 25 Year Plan to Improve the Environment

We also referred to:

- Waterwise Evidence Base Reports
- Data from our own water efficiency programmes which we expect to update for the final plan with full years data from 2020-22.

To meet our statutory water efficiency duty, we have included the following water efficiency options in our Baseline Plan.

Products

We will continue to offer both free and subsidised water efficient product to our customers although we think that we will phase these out by 2039-40 as we expect that the water label and anticipated more stringent building regulations take effect and customers will have water efficient fittings in their homes either as standard in new properties or when they replace existing fittings.

Prior to 2039-40 we have assumed that we will continue to offer the same range of products as now, but we continue to explore opportunities for introducing new innovative products as they become available. In the past year we have made three new products available to our customers.

- Kitchen stream
- Toothy timer
- Garden kit

Free products
In 2020 we made a change to how customers could order free water saving products with the requirement that they now complete a short number of questions on our customer portal GetWaterFit (GWF) so we are able to understand current use which enables us to offer advice on how to reduce the water they use and, understand the current fittings in their property so we can tailor which products they are able to order thus reducing waste an given greater certainty that products are installed.

We have based our expectations of the number of orders, cost per order and savings per order on data reported in the first 6 months of 2021-22 which we assumed was half the number for the year. We will update this in our final plan when we have a full year's data.

Subsidised products
The only subsidised products we currently offer are water butts as the cost of showerheads has fallen so we now offer these free of charge. These orders do not appear to have been impacted by COVID to the same extent of free product orders, but as they fell slightly, we have assumed that the number sold in each year of AMP 7 is the same as in 2020-21.

Schools Education
We will continue to offer our well-established schools education programme where we offer visits, online resources, and interactive buses.

Other Education
Advice to our customers on how to use water more wisely delivered through our schools' education programme and for individual household customers using the Get Water Fit portal (GWF).

Home water efficiency checks (HWEC)

We also continue to trial other HWEC opportunities by offering these:

- To our highest consumers
- To customers who contact us about high bills
- To customers who self-report leaks on internal fittings at their property
- By postcode area

These latter options sit outside our base plan, but we are exploring increasing demand reduction options to help meet our PCC commitment.

Decay of water efficiency savings

As we have previously done, we have assumed demand savings from water efficiency activity will reduce over time (decay). This is because we assume that:

- Fittings will naturally be replaced as customers update their bathrooms with more water efficient ones.
- The water label and changes to building regulations will dictate that fittings that are bought are more likely to be more water efficient, and we have already accounted for these demand savings in our calculations.

B5 Leakage

Annual reductions in leakage continue in our region with a 0.8Ml/d reduction in 2021-22, an out performance of 5.3%. This delivered the three-year average leakage target for 2021-22 with a 0.3Ml/d reduction from the previous year rolling average. Figure B5.1 shows our performance to 2021-22 and forecast.

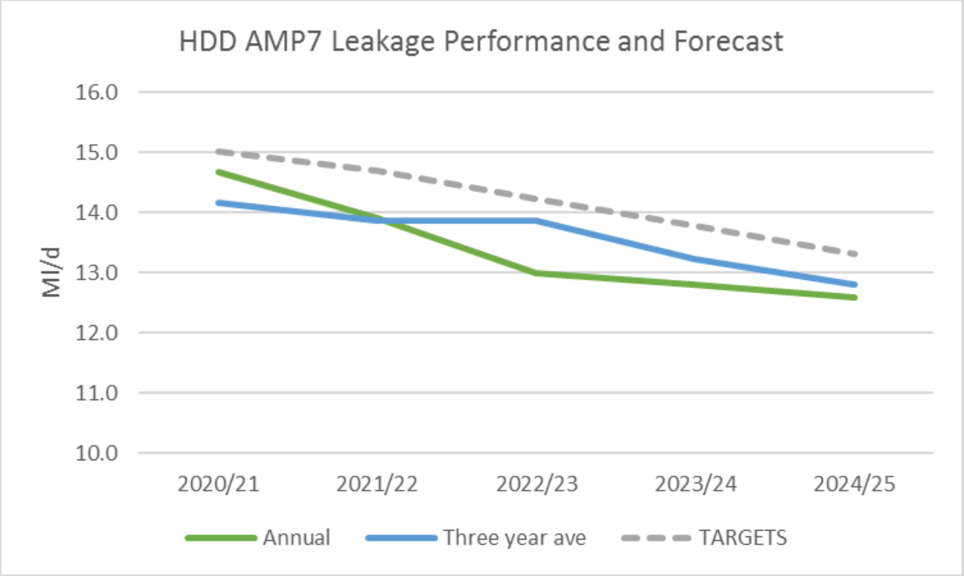

Figure B5.1: Leakage performance and forecast

The annual performance reductions need to be sustained in year 3 in order to maintain a reducing three year rolling average. Our operational performance was strong in 2020-21 with a reduction of 9% across our distribution and trunk mains network. We brought in additional resource to support an intensive programme of work. We have achieved the lowest ever leakage in Wrexham and a 10% reduction in Powys in the second half of 2021. We surveyed 11% of our upstream large diameter network for leakage and condition assessment. This work will continue into future years. We have now installed 1400 individual household meters in order to establish an unmeasured PCC monitor dedicated to our customers. Previously we had relied on Severn Trent monitoring to derive an estimate for our region.