Section 5

Allowing for risk and uncertainty

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Allowing for risk and uncertainty

- In this section we describe how we have assessed risk and uncertainty relating to our supply demand balance to calculate an allowance called Target Headroom.
- The components of Target Headroom are explained and baseline values are presented for each water resource zone (WRZ) for both average and peak scenarios.
- The methodology for both baseline and final plan Target Headroom is described. However outcomes, including Target Headroom over the planning period and component graphs, are presented for baseline only; final plan Target Headroom outcomes are presented in Section 10: Programme appraisal and scenario testing.

A. Introduction

5.1 Uncertainties are inevitable in the planning process and how uncertainty is handled is important in the formulation of a supply demand programme. In water resources planning, uncertainty is handled through the calculation of 'Target Headroom', defined as:

> *'The minimum buffer that water companies are required to maintain between supply and demand in order to account for current and future uncertainties in supply and demand.'*[1]

5.2 Thus, Target Headroom is the minimum buffer that a prudent company should allow between supply and demand to cater for uncertainties in the overall supply demand balance and to meet its agreed level of service.

5.3 We use a statistical technique called Monte Carlo analysis to examine the uncertainty in specific elements of our supply and demand forecast.

5.4 In this process we examine the possible range of values (termed distribution) that elements of our forecast could take. We examine the uncertainty around both the supply and demand side forecasts and bring these values together to understand the range of uncertainty in our plan. We then choose a single allowance (Target Headroom) to allow for a proportion of this uncertainty.

5.5 This allows for the fact that we have more time to adapt to risks further into the future as they begin to become evident. Therefore we are able to accommodate more risk in our future plans. Our allowance for uncertainty is not fixed over time. We take less risk in the short term (5%) over the current AMP period and more risk in the long term (29%)[2]. The level of risk is fixed at

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[1] UKWIR, WRMP19 - Risk Based Planning Methods Guidance, 2016

[2] We make the choice about the level of risk we are prepared to accept as a business. The choice we believe is the best balance between the risks of supply failure and investing in assets before they are needed. Section G of

29% from 2044 as Target Headroom starts to decrease with an increase in the level of risk from this point onwards.

5.6 The remainder of this section is structured as follows:

- Introduction
- How the supply side uncertainty components are included in headroom
- How the uncertainty components of demand forecasting are included in headroom
- The baseline Target Headroom is presented for each WRZ

B. Methodology and approach

5.7 Target Headroom is the minimum buffer that a prudent company should allow between supply and demand to cater for uncertainties in the overall supply demand balance and meet its agreed level of service.

Methodology

5.8 We use the 'improved methodology' in our assessment for all WRZs. This Target Headroom concept, which utilises UKWIR methods from 2002[3,4] to address uncertainty, is a best practice method which links to Risk Composition 3. This is the risk composition we are following for our revised draft WRMP19 set out in Section 4: Current and Future Water Supply as described within the UKWIR (2016) guidance[5] and as referred to in the Water Resource Planning Guideline. We adopt this improved method to ensure we have an accurate estimate of uncertainty in our plan, given the importance of our plan to customer supply security and the number of customers we serve. The improved method uses a risk-based technique, full details of which are available in Appendix V: Risk and uncertainty. We are also addressing the vulnerability of our system to more extreme drought events through sensitivity analysis of the current Thames Water resource system and water resource options to different drought types than those in the historical record, as well as providing the basis for a more varied and robust assessment of climate change impacts through the modelling of stochastic weather patterns. This is explained in Appendix I: Deployable output and will be tested using various scenarios and development programmes.

5.9 The calculation of Target Headroom uses Monte Carlo simulation, a computerised mathematical technique that allows us to account for risk in quantitative analysis and decision making. Effectively it enables any chosen uncertain parameter, which up to this point would have had a deterministic (or specific chosen or calculated value), to be replaced with a range of potential values, defined by a statistical distribution. An example of a probability distribution is shown in Figure 5-1; it shows a probability density function (pdf). A pdf tells you the probability (value on the y-axis) that a random sample from the probability distribution will equal the

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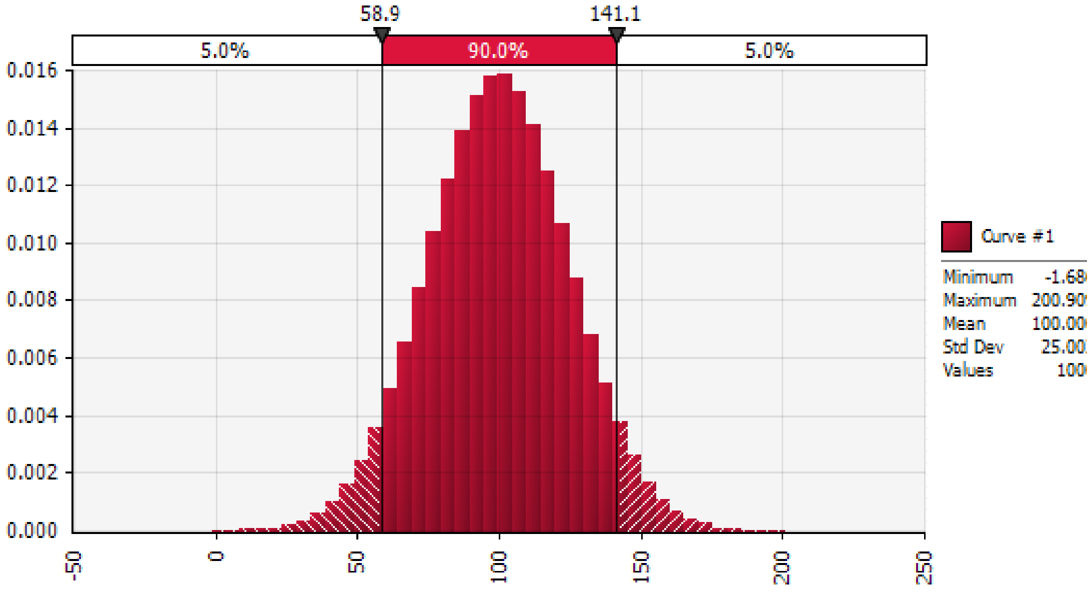
this document and of Appendix V: Risk and uncertainty provides an explanation of our decision making process surrounding setting the level of Target Headroom risk.

[3] UKWIR (2002) An Improved Methodology for Assessing Headroom
[4] UKWIR (2002) Uncertainty and Risk in Supply/Demand Forecasting
[5] UKWIR, WRMP19 - Risk Based Planning Methods Guidance, 2016

corresponding value on the x-axis. The data in Figure 5-1 is purely illustrative, but you could suppose the x-axis represents the volume of water produced by a single borehole in Ml/yr. The bar along the top (from left to right) shows there is a 5% chance that the borehole produces less than 58.9 Ml/yr, a 90% chance it produces between 58.9 and 141.1 Ml/yr and a 5% chance it produces more than 141.1 Ml/yr.

Figure 5-1: An example distribution used in headroom modelling



5.10 Once it has been decided which parameters are particularly uncertain and would better be defined by a probability distribution, models are used to run calculations thousands of times, taking a random sample from within the defined probability distributions.

5.11 This enables a probabilistic output to be produced (i.e. how likely is it that supply would be less than demand) and enables us to take an informed view on the level of risk we should allow for in our future planning. Should we take no risk and thus plan for sufficient headroom that even in an extreme case we will achieve our levels of service? Or is it more reasonable, particularly when looking decades into the future that we take more risk, confident that all the risk will not materialise, or that there will be time for us to act before the risk is realised?

5.12 Once calculated and a risk profile agreed, Target Headroom is added to the forecast of demand and compared with the water available for use (WAFU) to establish the available headroom or the gap in the baseline supply demand balance.

Approach

5.13 There are two stages at which Target Headroom is calculated. We assess uncertainty on both the supply side and the demand-side in separate models, and then draw them together using a Monte Carlo process to produce a combined uncertainty.

5.14 The initial assessment of headroom for the baseline supply demand balance does not include two of the headroom categories: S9 “Uncertain output from new resource developments”; and

"Uncertain outcome from demand management measures". The uncertainty associated with new resource developments and demand management measures is incorporated along with baseline uncertainty through the programme appraisal in the development of the preferred plan. This is described in Section 10: Programme appraisal.

5.15 The total volume of Target Headroom for a given WRZ in a given year may then be disaggregated into its component parts.

5.16 Below we discuss how we have accounted for the various supply side and demand side uncertainties acting on our plan.

C. Supply side uncertainty

Components of supply side uncertainty

5.17 The headroom components identified in the methodology that are supply-related are as follows:

- S1 - Vulnerable surface water licences
- S2 - Vulnerable groundwater licences
- S3 - Time-limited licences
- S4 - Bulk imports/exports
- S5 - Gradual pollution of sources (causing a reduction in abstraction)
- S6 - Accuracy of supply side data
- S8 - Uncertainty of impact of climate change on source yields
- S9 - Uncertain output from new resource developments

5.18 S1, S2 and S3 components are not included in the analysis following guidance from the Environment Agency, as set out on page 26 of the 2017 Water Resources Planning Guidelines (WRPG)[6]. With regard to S1 and S2 the guidance states 'You should not include any allowance for uncertainty related to sustainability changes to permanent licences'. With regard to S3 the guidance states 'You may include an allowance for uncertainty related to non-replacement of time-limited licences on current terms' however, following a review of our time-limited licences we have made a presumption of renewal with the exception of Bexley within our London WRZ where a risk of non-renewal has been identified and this has been included as an unconfirmed sustainability reduction (Section 4: Current and future water supply) and addressed through scenario testing during programme appraisal (Section 10: Programme appraisal).

5.19 Bulk imports/exports (S4): Our bulk supply imports and exports are subject to contractual agreements and as such we consider that the uncertainty around them is minimal. We do not include this component in our headroom assessment.

5.20 Gradual pollution (S5): With regard to gradual pollution we have reviewed the risk of our groundwater sources to gradual pollution and confirmed that there are no issues to include at this stage. This is due to the installation (or programmed installation) of suitable treatment

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[6] Environment Agency and Natural Resources Wales and also produced in collaboration with Defra, the Welsh Government, and Ofwat, Final Water Resources Planning Guideline, July 2018

processes for nitrates and cryptosporidium. In addition, we are working with the Environment Agency to develop suitable Catchment Management Plans that mitigate recognised issues. We also have a specific risk of bromate pollution in London which we deal with separately; this is discussed below under new resource development (S9).

5.21 Accuracy of supply side data (S6): Data inaccuracy and scarcity of information may render estimates of DO unreliable and this uncertainty needs to be included in headroom uncertainty. The impact of data inaccuracy affects all sources but depends on the factors that are constraining DO. The following issues have been assessed for impact on each of the resource zones:

- Pump or infrastructure capacity
- Abstraction licence limits
- Aquifer characteristics for groundwater
- Climate and catchment characteristics affecting surface waters

5.22 These issues are discussed in detail in Appendix V: Risk and uncertainty.

5.23 As part of the methodology for our Drought Plan we are required to introduce Temporary Use Ban (TUB) restrictions upon customers earlier than has historically been the case, based on the Lower Thames Control Diagram (LTCD). This is to allow time for the process of securing “regulatory permissions” such as Drought Orders and Drought Permits. As a result of imposing Level 3 restrictions (temporary use or hosepipe bans) in London at an earlier stage in a drought event, and earlier than in the defined methodology for determining DO, there will be a potential DO benefit.

5.24 However, the timing of the introduction of restrictions is subjective and the benefit will not necessarily always be there. By imposing restrictions upon customers earlier than in the methodology for determining the DO, a potential bias in favour of an increased DO is being introduced. To address this potential bias in the DO calculation and the supply demand balance, the “risk” can be included within the Target Headroom modelling with a negative skew, i.e. a reduction. The details are explained in Appendix V: Risk and uncertainty.

5.25 Climate change (S8): The uncertainty around climate change is discussed in the climate change sub-section below, with further detail contained in Appendix V: Risk and uncertainty.

5.26 New resource developments (S9): The uncertainty around new schemes has been assessed as part of the development of the final planning programme. Since no new resources are considered as part of the baseline this component has no impact on baseline Target Headroom. The risk around each scheme relates to changes in the DO of the scheme. Uncertainty is also estimated around the cost to deliver a new resource, but this does not contribute to Target Headroom and is discussed further in Appendix V: Risk and Uncertainty. A brief discussion of the process is provided in paragraphs 5.54 to 5.57 and the application of final plan Target Headroom is discussed in Section 10: Programme appraisal.

5.27 Northern New River Wells (NNRW): An additional uncertainty has been included within the Target Headroom modelling which relates to the risk to the NNRW sources from bromate pollution. The source of the bromate pollution is a former bromine chemicals factory at Sandridge, now redeveloped as a housing estate. The presence of bromate in the water pumped from the NNRW has meant that abstraction from these wells has had to be reduced in recent years to meet water quality standards. This is because current treatment facilities in north London cannot deal with the concentration of bromate in the water, which is also exacerbated by the ozonation process at two works. The combined licensed output from the sources average 100.5 Ml/d with an average Source Deployable Output (SDO) of 98.8 Ml/d.

5.28 In 2005, a scavenging remediation scheme was implemented in conjunction with Affinity Water from one of their groundwater sources. This was done to assist remediation of the bromate plume in the chalk aquifer and also to manage the concentration of bromate reaching the NNRW sources. There is however a risk that the NNRW would not be able to deliver its output should there be a problem, for whatever reason, with the scavenging remediation scheme. As this is not an outage issue but represents a real risk to our resources and with no recognized way within the methodology of including the risk, it has been included as a risk to our resources within Target Headroom. The impact of the reduced output from the NNRW was evaluated by inputting this data into the Water Resources Management System (WARMS2) and comparing it with the value of DO before the change; here the AR17 baseline London DO of 2,305 Ml/d, derived using the optimised LTCD, is used as the base run. The results from which is a reduction in DO of 12 Ml/d and for modelling expedience this is applied as the most likely impact in a triangular distribution within the Target Headroom analysis under the S9 functionality.

5.29 North London Artificial Recharge Scheme (NLARS): One of our strategic water resource schemes is the NLARS. This scheme abstracts water from a number of boreholes in the Lee Valley and discharges to the raw water system including from some boreholes to the New River and in some cases directly to reservoir. The nature of the scheme is to abstract water from the confined aquifer where output will decrease over time. Improved information on borehole performance, together with better information about the aquifer state of storage allowed an updated view of NLARS output at AR16; named NLARS Scenario 3. There remains a risk around what the scheme may actually be capable of during a drought thus two further scenarios of the output from NLARS have been evaluated (named 1 and 2) to aid the evaluation of the risk around NLARS. The impact of the modified output from NLARS for the two alternative scenarios was evaluated by inputting this data into WARMS2 and comparing with the value of DO before the change; here the AR17 baseline London DO of 2,305 Ml/d derived using the optimised LTCD is used as the base run. The risk is now in the range 15 Ml/d to 17 Ml/d and for modelling expedience these values are applied as the most likely and maximum impact in a triangular distribution within the Target Headroom analysis under the S9 functionality.

Climate change

5.30 Climate change is expected to lead to variations in patterns and frequencies of droughts, and other extreme weather events. The UK Climate Projections 2009 (UKCP09) reports that by the 2080s with medium emissions, “The biggest changes in precipitation in summer, are possibly down to about –50% by the 2080s, are seen in parts of the far south of England”[7].

5.31 The impacts of climate change will be felt throughout our business, as shown in Figure 5-2. The potential impact on water usage and abstraction is of concern. Reduced or extreme variation in annual rainfall rates may mean that the yields from river or groundwater sources could be

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[7] UK Climate Projections Online UKCP09 data

reduced and household water use could increase through increased garden watering and increased frequency of bathing and showering.

Figure 5-2: The impacts of climate change on our business

5.32 UKCP09 provides a large amount of information on how the UK climate may change over the next 100 years in response to different levels of greenhouse gas emissions. To understand the impact of the new scenarios on our assessments of supply and demand, HR Wallingford was engaged to develop a methodology to make the most use of the UKCP09 output data as practically possible. An outline of our climate change impact assessment is presented here and a detailed account of the methodology and how it has been applied is given in Appendix U: Climate change.

5.33 The updated climate change scenarios were launched by UK Climate Impacts Programme in June 2009 and provide 10,000 equally possible outcomes of future temperature and rainfall. The new projections are 'probabilistic' in that they encompass a wide range of possible changes in climate based upon the strength of evidence from observations, climate change models and expert opinion.

Basic vulnerability assessment

5.34 The first stage of the analysis by HR Wallingford was to undertake a basic vulnerability assessment (BVA) of all our WRZs (HR Wallingford 2017)[8]. This is the first phase of analysis in a tiered approach to climate change analysis as outlined in the Environment Agency/UKWIR

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[8] HR Wallingford, Thames Water climate change assessment and impacts on supply, March 2017

(2013) report[9]. Guildford and Henley WRZs have been identified as low vulnerability, Kennet and the Slough, Wycombe and Aylesbury (SWA) WRZs as medium vulnerability with the Swindon and Oxfordshire (SWOX) and London WRZs classified as high vulnerability, which required further “intermediate assessment”. Note the magnitude-sensitivity for SWOX was classified initially as medium vulnerability. However, given the interactions between London and SWOX, and SWOX’s vulnerability to short, intense droughts, it has been upgraded to high vulnerability.

Intermediate assessment

5.35 The intermediate assessment involves the identification of current system vulnerability through the analysis of the causes and mechanisms of historic droughts.

5.36 The Water Resources Management Plan 2014 (WRMP14) approach to assessing climate change impacts was based around using climatological drought indicators to identify a sub-sample of 20 climate change scenarios. When a similar approach was applied for the 2080s, the detailed analysis presented in the HR Wallingford report suggests that the resulting sub-sample may not be as adequate for identifying an appropriate sub-sample to take forward to the DO assessment.

5.37 In order to identify a more robust sample of climate change scenarios, simplified London and SWOX water supply system models were used to simulate the full 10,000 member UKCP09 ensemble for the 2080s, Medium Emission scenario. This allows the impacts of each climate change scenario on water supply system performance to be calculated using a system-based metric, as opposed to relying on the drought indicator methods which were shown to be less reliable for the 2080s. The climate change impacts simulated using the simplified water supply system model are considered to much better reflect what their relative impacts would be when used in WARMS2 and therefore provide a better basis for identifying a sub-sample to take forward into the draft Water Resources Management Plan 2019 (draft WRMP19) and carried forward to the revised draft WRMP19.

5.38 WARMS2 currently applies the Teddington flow factors to the Teddington and Days Weir natural inflows. It also uses a number of rainfall run-off models to simulate flows in various sub-catchments of the Thames. Thus when climate change factors of rainfall, evaporation and flows are input to the model, perturbed flows are generated and then used to calculate the flows of the various gauged and ungauged catchments throughout the model. It should be noted that in WARMS2, the greater proportion of flows are generated by rainfall-runoff models for gauged locations, where climate change impacts are simulated with the use of climate factors, and not through the use of flow factors. The simplified water supply system model demonstrates that by using only a single set of flow factors, as opposed to location specific hydrometric factors, the impacts of climate change on DO may be under-estimated by ~50 Ml/day for London. This is because WARMS2 is more detailed and generates and accumulates flows from various points throughout the Thames catchment rather than from a limited number of locations.

5.39 The output from the HR Wallingford study is a sub-sample of 20 UKCP09 climate change scenarios that are considered to provide the most appropriate representation as to the range and likelihood of the projected climate change impacts in the London WRZ. The sub-sample

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[9] Environment Agency/UKWIR, Climate change approaches in water resources planning – Overview of new methods, 2013

has also been shown to be valid for the SWOX WRZ and is therefore considered to represent the most robust sample of scenarios to use.

Emissions scenarios

5.40 The UKCP09 projections are available for three emissions scenarios; low medium and high, where for WRMP14 we used the medium emissions scenario to quantify the impact of climate change on our water resources. The Environment Agency's 2017 WRPG Supplementary Guidance[10], states that when using the Spatially Coherent Projections (SCPs) that a medium emission should be used as a minimum. This is also relevant when using the UKCP09 probabilistic scenarios that we used for the draft WRMP19 and carried forward to the revised draft, thus to be consistent with previous analysis at WRMP14 and be compliant with the guidance, the medium emission scenario has been used to assess climate change impacts for the 2080s.

5.41 Between the draft and revised draft WRMP19, we have investigated the climate change impacts of a High Emissions UKCP09 scenario for the 2080s within the London WRZ. On average, there is little change in the impact of a High Emissions 2080s scenario compared to a Medium Emissions 2080s scenario. Within the sample of 20 climate change scenarios from the High Emissions 10,000 member ensemble, the weighted average climate change impact is about 12Ml/d lower (i.e. less severe) with the impact of the very dry end of the sample quite significantly more severe and the impact of the very wet end of the sample significantly less severe.

5.42 It should also be noted that we understand that the UKCP18 data will include a medium emission scenario but not a high scenario. Updated climate change scenarios, UKCP18, were due to be launched by the UKCIP at a high level in May/June 2018. This has now been pushed back to November 2018 by the Met Office so will be launched too late for consideration in the revised draft WRMP19 and will instead be considered within the climate change analysis for WRMP24.

Assessment of climate change on groundwater

5.43 We have undertaken the analysis of our groundwater source drought performance based on the UKCP09 data for the 2080s. Five scenarios from the 20 were selected to assess the groundwater system sensitivity to each of the potential futures. The scenarios were selected, based on their percentiles, to focus on drier potential futures, but also to consider wetter scenarios. The percentiles used are 99, 95, 90, 50 and 10. The rainfall and temperature climate change factors for each of the five scenarios were used to generate recharge scenarios for input into Environment Agency regional groundwater models covering the major aquifers of London and the Thames Valley. These models were then used to undertake hydrogeological analysis of the climate change impacts on the aquifers, specifically the impact on groundwater levels.

5.44 The groundwater level changes derived from this regional analysis of five scenarios for each of the groundwater sources were then used to assess the impact on groundwater SDOs. The SDO for the remainder of the twenty climate change scenarios was derived by interpolation. This

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[10] Environment Agency, Estimating the impacts of climate change on water supply, April 2017

interpolation was based on a relationship between SDO and modelled baseflow change in the River Thames at Teddington for each of the five successive pairs of discretely defined SDOs. This data based on the UKCP09 data for the 2080s is used to assess the central or "best estimate" impact of climate change on DO.

Climate change impacts on deployable output

5.45 The amended groundwater SDOs together with the rainfall, potential evapotranspiration (PET) and flow factors were input to the WARMS2 to assess the impact on the DO for London and SWOX from the 20 climate change scenarios. The results of the groundwater analysis also provided the basis for the impact assessments for the other non-conjunctive use WRZs. The flow factors derived from the HR Wallingford work for the 2080s is the basis for the impact assessment on the Fobney DO in the Kennet Valley WRZ and Shalford DO in the Guildford WRZ, which are both river abstraction sources.

5.46 The methodologies developed have then allowed us to derive uncertainties around these possible outcomes such that Target Headroom can be calculated for London and the other WRZs. The uncertainty around the "best estimate" value is included in Target Headroom. We sought advice and peer review from notable experts in climate change including Professor Nigel Arnell (Director of the Walker Institute and Professor of Climate Science), Professor Jim Hall (Director of the Environmental Change Institute and Professor of Climate and Environmental Risk, University of Oxford) and Dr Steven Wade (Head of the Met Office's Scientific Consultancy). It was decided that consideration of a discrete distribution of the climate change impacts was most appropriate as it takes into account the full variability of the calculated impacts. A discrete distribution was built into the Target Headroom models to be able to determine the uncertainty around the "best estimate" of the impact on DO.

5.47 Using the sub-sample of 20 climate change scenarios to assess the impact on the London DO gives a range of change by 2080s from −485 Ml/d (dry scenario) to +204 Ml/d (very wet scenario) with a 'best estimate' of the impact of −187.15 Ml/d. This indicates that the more extreme changes could be highly significant for supply/demand long term planning. The 'best estimate' of the climate change impact has been calculated by modelling a discrete probability distribution function (pdf) using the variation in DO data and probability weightings. The Target Headroom model applies Monte Carlo techniques to determine the statistics from the discrete distribution and the mean impact value of -187.15 Ml/d has been calculated as the 'best estimate' by 2085.

Climate change uncertainty in Target Headroom

5.48 The Environment Agency specifies that the 'best estimate' of the modelled climate projection is applied as a reduction in DO and the uncertainty around this projection is handled in headroom. The impact of the 'best estimate' scenario for each of the WRZs average DO is shown in Table 5-1 and for peak DO in Table 5-2.

5.49 In our current forecast the impact of climate change is greatest in London. This is also the zone where we have most customers.

Table 5-1: Climate change impact on DYAA[11] DO

WRZ	Reduction in DYAA DO due to climate change (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	19.70	34.48	59.10	83.73	100.38	108.89	117.40
SWOX	1.12	1.96	3.35	4.75	5.69	6.18	6.66
Kennet Valley	1.26	2.21	3.79	5.37	6.44	6.99	7.54
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.36	0.64	1.09	1.55	1.85	2.01	2.17
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Reduction in DYAA DO due to climate change (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	125.90	142.92	159.93	176.94	193.96	210.97
SWOX	7.14	8.11	9.07	10.04	11.00	11.97
Kennet Valley	8.08	9.17	10.27	11.36	12.45	13.54
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.32	2.64	2.95	3.27	3.58	3.90
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

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[11] DYAA – Dry Year Annual Average

Table 5-2: Climate change impact on DYCP[12] DO

WRZ	Reduction in DYCP DO due to climate change (Ml/d)						
	2016/17	**2019/20**	**2024/25**	**2029/30**	**2034/35**	**2039/40**	**2044/45**
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	1.28	2.24	3.83	5.43	6.51	7.06	7.62
Kennet Valley	0.94	1.65	2.83	4.02	4.82	5.22	5.63
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.24	0.43	0.73	1.03	1.24	1.34	1.45
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Reduction in DYCP DO due to climate change (Ml/d)					
	2049/50	**2059/60**	**2069/70**	**2079/80**	**2089/90**	**2099/00**
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	8.17	9.27	10.37	11.48	12.58	13.69
Kennet Valley	6.04	6.86	7.67	8.49	9.30	10.12
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	1.55	1.76	1.97	2.18	2.39	2.60
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

5.50 The difference around this “best estimate” value is used to create discrete distributions for both groundwater and surface water climate change impacts for each year of the planning period within each WRZ. The uncertainty around the “best estimate” value is derived from the Target Headroom model and the results shown in Table 5-3 and Table 5-4.

5.51 A correction has been made to climate change scaling factors within the Target Headroom model between the draft and revised draft WRMP19 which explains the step in revised draft climate change uncertainty for the 2080s in Table 5-3. For AR17 the Target Headroom model was updated to reflect the updated climate change methodology used to assess climate change impacts for the draft WRMP19. This update was a step change from using climate change UKCP09 medium emissions impacts for the 2030s time slice (2035/36) to using the 2080s time slice (2085/86). The AR18 review has identified and corrected one omission to the Target Headroom model update namely ensuring that the model is using 2080s as opposed to 2030s scaling factors to scale the climate change impacts through the planning horizon. The impact of this correction is a reduction in the climate change component of Target Headroom uncertainty from 25.2 Ml/d AR17 (29.2 Ml/d AR17+) to 19.07 Ml/d for AR18.

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[12] DYCP - Dry Year Critical Peak

Table 5-3: Uncertainty around climate change in Target Headroom for DYAA

WRZ	Climate change uncertainty for DYAA Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	29.2	28.1	40.3	47.4	49.1	43.9	37.6
SWOX	2.30	2.14	2.98	3.27	3.38	3.05	2.71
Kennet Valley	0.61	0.49	0.82	1.11	1.21	1.13	1.06
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.36	0.36	0.53	0.65	0.71	0.65	0.62
Guildford	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WRZ	Climate change uncertainty for DYAA Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	37.6	37.6	37.6	37.6	37.6	37.6
SWOX	2.71	2.71	2.71	2.71	2.71	2.71
Kennet Valley	1.06	1.06	1.06	1.06	1.06	1.06
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.62	0.62	0.62	0.62	0.62	0.62
Guildford	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-4: Uncertainty around climate change in Target Headroom for DYCP

WRZ	Climate change uncertainty for DYCP Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	2.92	2.70	3.75	4.28	4.36	4.12	3.59
Kennet Valley	0.74	0.60	0.97	1.12	1.22	1.14	0.95
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.38	0.38	0.56	0.71	0.76	0.70	0.68
Guildford	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WRZ	Climate change uncertainty for DYCP Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	3.59	3.59	3.59	3.59	3.59	3.59
Kennet Valley	0.95	0.95	0.95	0.95	0.95	0.95
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.68	0.68	0.68	0.68	0.68	0.68
Guildford	0.00	0.00	0.00	0.00	0.00	0.00

5.52 Therefore it can be seen that the total impact of climate change on the supply demand balance for the DYAA conditions is as presented in Table 5-5 and for the DYCP conditions in Table 5-6.

Table 5-5: Total impact of climate change for DYAA

WRZ	Climate change impact for DYAA Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	48.90	62.58	99.40	131.13	149.48	152.79	155.00
SWOX	3.42	4.10	6.33	8.02	9.07	9.23	9.37
Kennet Valley	1.87	2.70	4.61	6.48	7.65	8.12	8.60
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.72	1.00	1.62	2.20	2.56	2.66	2.79
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Climate change impact for DYAA Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	163.50	180.52	197.53	214.54	231.56	248.57
SWOX	9.85	10.82	11.78	12.75	13.71	14.68
Kennet Valley	9.14	10.23	11.33	12.42	13.51	14.60
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.94	3.26	3.57	3.89	4.20	4.52
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

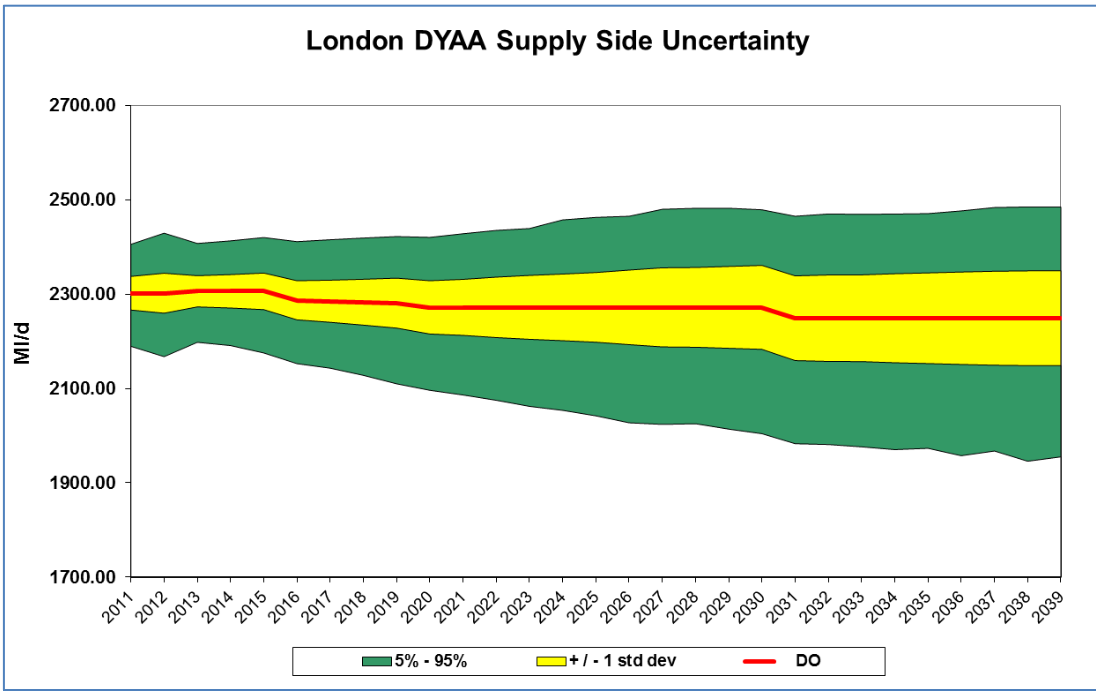
Table 5-6: Total impact of climate change for DYCP

WRZ	Climate change impact for DYCP Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	4.20	4.94	7.58	9.71	10.87	11.18	11.21
Kennet Valley	1.68	2.25	3.80	5.14	6.04	6.36	6.58
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.62	0.81	1.29	1.74	2.00	2.04	2.13
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Climate change impact for DYCP Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	11.76	12.86	13.96	15.07	16.17	17.28
Kennet Valley	6.99	7.81	8.62	9.44	10.25	11.07
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.23	2.44	2.65	2.86	3.07	3.28
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

5.53 The Target Headroom methodology shows climate change to be the most significant uncertainty on the supply side. In London the direct impact on average DO is around 19.7 Ml/d at the start of the planning period increasing to around 117.40 Ml/d by 2044 and climbing to 210.97 Ml/d by 2099. When the uncertainty on this is taken into account the combined impact is ~49 Ml/d at the start increasing to ~155 Ml/d by 2044 increasing to ~249 Ml/d by 2099. The range of potential uncertainty around DO is shown in Figure 5-3.

Figure 5-3: London DYAA supply side baseline headroom uncertainty



New resource development uncertainty

5.54 The volume of water delivered by new resources can often be uncertain. The uncertainty around existing resources is captured in the supply-side baseline uncertainty. But new resources included as a result of decisions made in this plan are not part of the baseline and must be included as part of a final plan re-assessment of Target Headroom. Section 10: Programme appraisal, presents a discussion of the application of final plan Target Headroom.

5.55 The inclusion of new resource schemes within the preferred programme will include elements of uncertainty over the actual DO produced by that scheme under the planning scenario delivered and also the cost of delivering the scheme. In essence the scope of the scheme, the assets constructed, are considered to be fixed and equal to that identified in Appendix R: Scheme dossiers. Note that cost uncertainty is not considered as part of the Target Headroom calculation and is discussed further in Section R: Scheme dossiers.

5.56 Between the draft and the revised draft WRMP19 we worked to replicate the approach to final plan Target Headroom followed for the draft WRMP19.

5.57 The draft approach involved assessing uncertainty around scheme yield (using the judgement of expert hydrologists and hydrogeologists supported by estimates and associated justification made by our engineering partner Mott MacDonald in Appendix R: Scheme dossiers) and characterising an uncertainty distribution, by percentile outputs in 5% increments, for each year of the 80 year planning horizon. The EBSD model then interpolated the value of the distribution between these points and sampled from the interpolated distribution. This analysis did not include uncertainty around scheme timing.

5.58 The results from this full appraisal for the revised draft WRMP19 were counterintuitive due to an underlying issue. This lead to an allowance of 5% of overall scheme yield being carried forward and added to baseline Target Headroom to calculate final plan Target Headroom.

Summary

5.59 We have used the 'improved methodology'[13] for calculating the impact of uncertainty on the supply side of our supply demand balance. The work shows that the impact of climate change is the most significant uncertainty on the supply side. We have undertaken considerable work to understand the impact.

D. Demand side uncertainty

Components of demand side uncertainty

5.60 The demand-related headroom components identified in the methodology are as follows:

- D1 – Uncertainty in base year data
- D2 – Demand forecast variation
- D3 – Uncertainty of climate change on demand
- D4 – Uncertainty of demand management measures

5.61 We have undertaken analysis of demand uncertainty using Monte Carlo simulation to understand the uncertainty around the deterministic demand forecast. We describe this briefly in the "Demand uncertainty overview" section below, before examining the individual components D1 to D4. For further detail see Appendix V: Risk and uncertainty.

5.62 The approach we have used is consistent with the current UKWIR guidance[14] which is recommended by the Environment Agency's 2018 WRPG.

Demand uncertainty overview

5.63 Specialist software is used to calculate the uncertainty associated with the demand forecasts that are described in Section 3: Current and future demand for water. The demand forecasts produce a single value for demand for each year of the forecast period. Underpinning the demand forecast is a series of values which are considered the best estimate. Like any estimate, there is scope for uncertainty and analysis of these uncertainties is used to produce the demand uncertainty, that is then used in the calculation of Target Headroom. Monte Carlo simulation is used to understand how the uncertainties from input variables translate into uncertainty in the overall demand forecast. An overview of this is shown in Figure 5-4.

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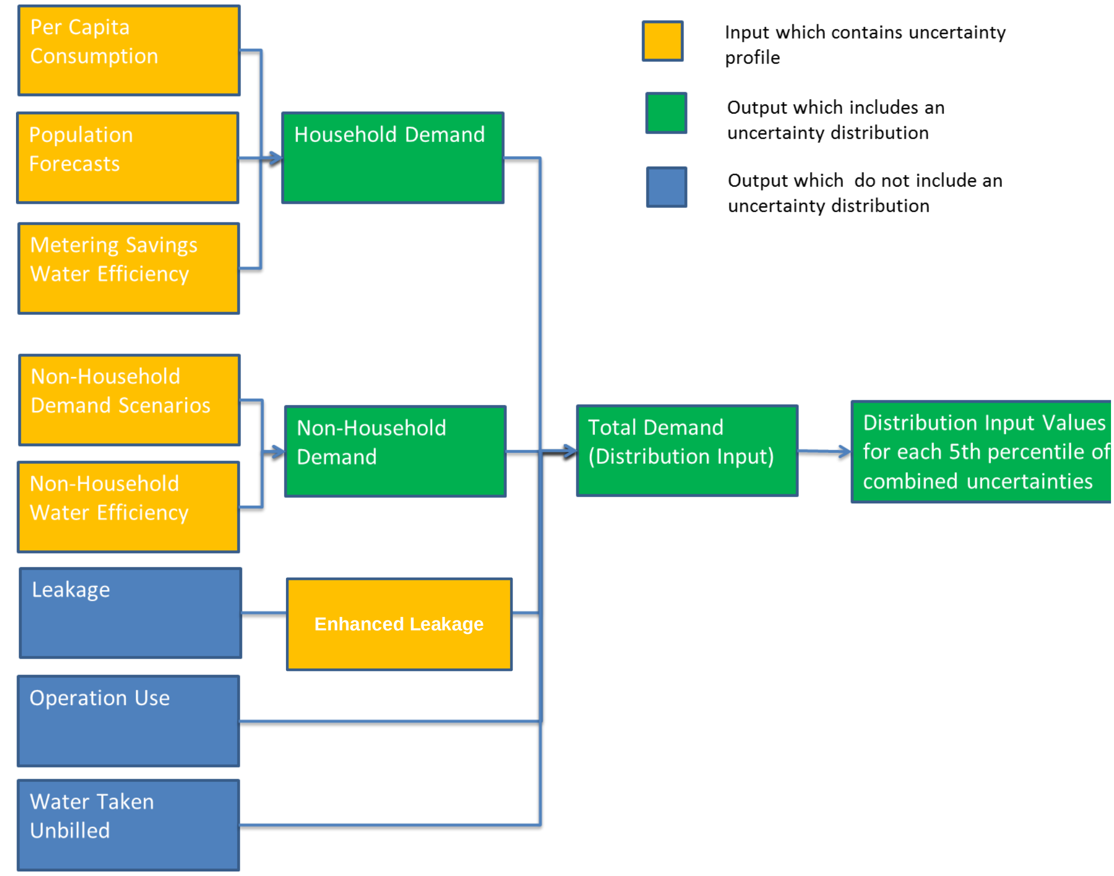
[13] UKWIR (2002) An Improved Methodology for Assessing Headroom
[14] UKWIR, WRMP 2019 Methods – Risk Based Planning, Appendix D7, (16/WR/02/11), 2016.

Figure 5-4: Overview of analysis of uncertainty in demand forecasts



5.64 Each demand component shown in orange is assigned a probability distribution according to the information available. Most of the uncertainty ranges around these components have been estimated based on studies where possible, and expert judgment or opinion where little information is available. Where judgment/opinion has been used output values have been examined to ensure that the uncertainty range is reasonable.

5.65 Traditionally, we have not considered uncertainties around leakage because the outturn value is, to a degree, within our management control to deliver. This does not mean there is no uncertainty. Weather, particularly cold winters, can cause metal pipes to contract and fracture, therefore increasing leakage. Furthermore, we have more than 30,000km of buried water network and, whilst we invest considerable effort in understanding and modelling how it deteriorates over time, it is not an exact science. For the revised draft WRMP we have adopted new and more stretching leakage targets and have now included uncertainties around the benefits of new enhanced leakage schemes (see component D4 below), while still excluding uncertainties around more standard activities or “base” leakage.

5.66 Uncertainty distributions for the following outputs are not included for demand components shown in blue in Figure 5-4:

- **Leakage** – For standard leakage management activities we consider the uncertainty in terms of the cost it will take for us to meet or out-perform our leakage target in each year through a mix of activities including finding and fixing leaks as they break out and replacing our old iron pipes with new plastic pipes. We do not include uncertainties in this “base” leakage in Headroom.

- **Operational use and demand from our properties** – This component reflects the water we use in operational activity such as flushing mains for water quality reasons or water used at out sites or offices for sanitation purposes. Similarly to leakage the outturn value for this component is, to a large degree, within our management control to deliver. Therefore the same logic applies around the inclusion of uncertainty in future forecasts. Note that these values are not actually forecast and are assumed to be constant at base year values over the planning period. As such the uncertainty around this output is part of the base year measurement uncertainty described in paragraphs 5.67 to 5.72. Additionally the total volume of this category is approximately 1% of total distribution input (DI) and therefore any reasonable uncertainty estimates around forecast values would be unlikely to have a material impact on the results of this analysis.
- **Water taken illegally or unbilled** – These values are not actually forecast and are assumed to be constant at base year values over the planning period. As such the uncertainty around this output is part of the base year measurement uncertainty described in paragraphs 5.67 to 5.72. Additionally the total volume of this category is approximately 1% of total DI and therefore any reasonable uncertainty estimates around forecast values would be unlikely to have a material impact on the results of this analysis.

D1 – Uncertainty in the base year data

5.67 The actual DI supplied in the base year is used as base data to support the forecast of demand for the 80 year planning period. DI is measured by meters, typically located at the outlet of a water treatment works. These meters are subject to a statutory verification programme, but there is still uncertainty about the results they record. This uncertainty is reflected in the calculation of the water balance as part of the annual performance report to Ofwat.

5.68 Here we have used the same uncertainty distribution for base year DI used as part of the water balance calculation. Base year DI is a random variable with a normal distribution where the mean is equal to the deterministic estimate of base year DI and the standard deviation is equal to 1.02%[15] of deterministic DI.

5.69 Uncertainty is also estimated around the uplift from the base year recorded value of DI to reflect the planning scenario in use[16]. This uplift reflects the weather and operational circumstance of the base year may have been more (or less) favourable than would be expected to be the case in a year typical of the planning scenario i.e. a dry year. For example, in London the recorded DI in the base year was 2,080.7 Ml/d. The weather in the base year was assessed to have suppressed demand below what it would have been in dry year conditions. An uplift of 24.6 Ml/d is applied to convert DI to the value expected if conditions in the base year had been equal to dry year conditions.

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[15] This is based on a 95% confidence interval for reported DI being +/- 2% and 95% confidence interval for a normal distribution being +/- 1.96 standard deviations. The 2% divided by 1.96 equals a standard deviation of 1.02%.

[16] E.g. Dry Year Annual Average basis for London.

5.70 There is uncertainty about the accuracy of the recording of conditions in the base year, the assessment of conditions in the dry year and the impact of those conditions on DI. Therefore we apply an uncertainty to the value of the uplift used. Because it is impossible to validate the accuracy of the uplift directly[17] we use expert judgement to set the uncertainty distribution used to reflect uncertainty around the uplift.

5.71 The value of the uplift in deterministic forecast is our best estimate and therefore we believe is also the most likely value. We do not have any reason to believe that the distribution is likely to be skewed and therefore we have used a normal distribution to characterise the uncertainty around the uplift. We chose to set standard deviation for the distribution at 5% of the value of the deterministic uplift value. This resulted in a distribution which best matched the expectation of a number of experts.

5.72 The impact of the uncertainty around base year estimates is then set the sum of both uncertainty distributions less the deterministic value of the base year DI in dry year conditions[18].

D2 – Demand forecast variation

5.73 The sources of demand forecast variation considered in the Demand Uncertainty Model are as shown in the list below. Each is discussed in a separate section which follows below:

- Household per capita consumption (PCC)
- Household population
- Non-household demand

Household PCC uncertainty

5.74 Household PCC is the average volume of water used by each person in a household. Typically it is reported in units of litres per head per day (l/h/d). PCC is a measure of customers' water use behaviour. In this section the PCC discussed is the baseline[19] value, meaning that it is the value prior to any demand management activity we might deliver to influence the value.

5.75 PCC uncertainty is calculated by using the household demand forecasting model produced by Artesia Consulting. The demand forecasting model uses a multiple linear regression approach, which produces standard errors around each of the input values that indicate uncertainties and can used to simulate confidence intervals around the central PCC forecast. The uncertainties related to the Artesia final model are illustrated in Figure 5-5, which shows that uncertainty in model coefficients alone translates to a PCC uncertainty range of +/- 3.4%[20]. It also shows that the number of adults and size of property are the key variables. This approach and the setup of the model are explained further in Section 3(C): Current and future demand for water (Household water use) and Appendix F: Household water demand modelling (Section 20

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[17] There is no opportunity to actually replicate the base year circumstances (population, customer water use behaviour, etc.…) in dry year weather conditions.

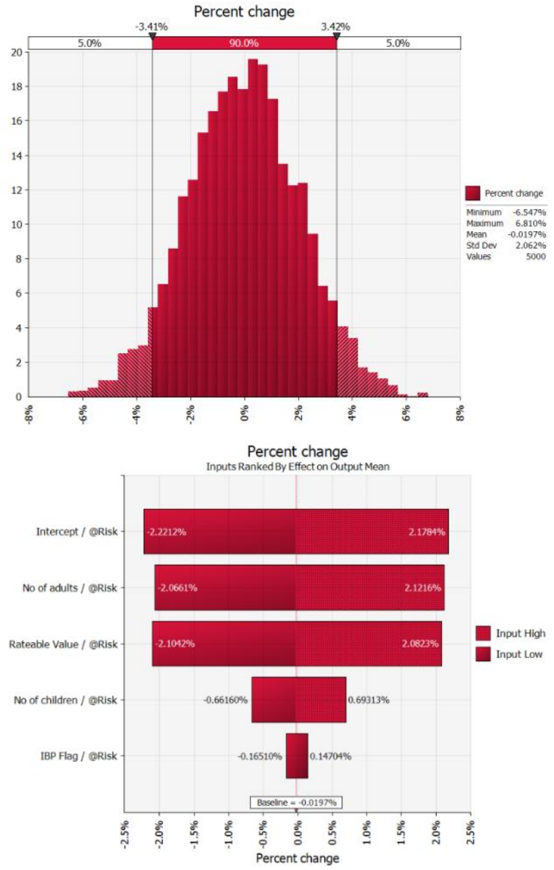
[18] Because of the properties of normal distributions this results in a normal distribution with a mean of zero and a standard error of the square route of the sum of the squared standard errors of the original distributions. For example, standard error of the distribution of the impact of uncertainty around the base year estimate is equal to the square root of the sum of 1.02% of the measured DI squared and 5% of the deterministic uplift value squared.

[19] For example, progressive metering or water efficiency Smarter Home Visits.

[20] This illustrative calculation is based on a household of 3 adults, one child with a rateable value of £283,000.

- uncertainties). This Section 20 discusses uncertainties where base year, model coefficients, property types and population uncertainties are combined to show impacts on water resource zone consumption in Ml/d.

Figure 5-5: Illustration of PCC model coefficient uncertainty on PCC (percentage) and sensitivity to input variables



5.76 An 80% confidence interval for forecasts of household PCC produced by applying the household demand forecasting model are used as inputs to the demand uncertainty model. The limits of this confidence interval along with the expected value used in the deterministic demand forecast are used to characterise a PERT probability density function[21] for household PCC for each year of the planning problem. Figure 5-6 shows the expected value, and the 10th percentile and 90th percentile values which form the 80% confidence interval for household PCC.

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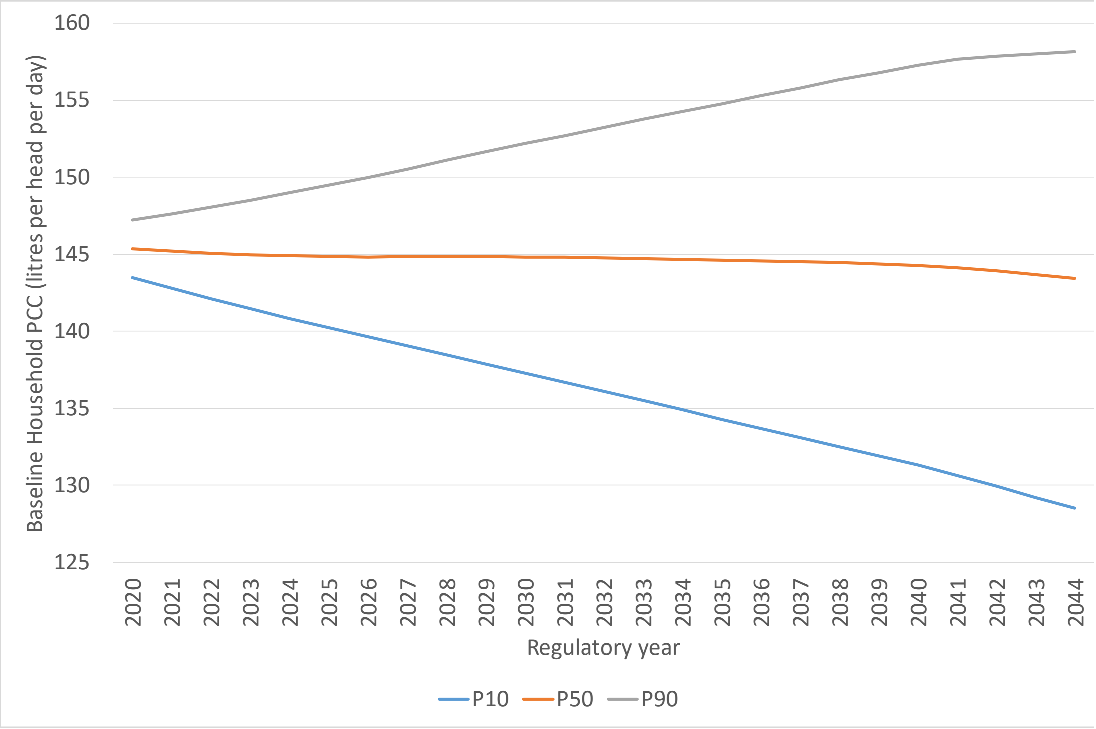
[21] More detail on how a probability density function is characterised in Target Headroom analysis can be found in Appendix V: Risk and uncertainty.

Figure 5-6: Baseline household PCC results from demand forecasting model



Household population uncertainty

5.77 The household population we serve is a key factor in forecasting demand. Population is the result of a myriad of uncertain components including, birth rates, death rates and net migration. Each of these components is influenced by a range of underlying factors such as macro-economic growth. As such it is easy to see why there is uncertainty in the forecast of population.

5.78 Population uncertainty has been estimated using the methodology suggested in the UKWIR report on population, household property and occupancy forecasting project[22]. The method uses three separate sets of normal uncertainty distributions for population uncertainty which are chosen on the basis of the relative scale of the population being forecast:

- Region (i.e. population of the order of 5 million)
- County (i.e. population of the order of 500,000)
- Local Authority (i.e. population of order of 100,000) or smaller

5.79 The report uses data from a number of Office for National Statistics population forecasts compared to the actual outturn population to calibrate the distributions. The results show that generally the smaller the population grouping being forecast the larger the inaccuracy of the forecast in percentage terms tended to be. The apparent logic is that for smaller population groups there is more of a chance for local effects to have a larger impact and less chance to be offset by counteracting effects in other parts of the area. More detail on the approach is provided in Appendix V: Risk and uncertainty.

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[22] UKWIR, WRMP19 Methods – Population, Household Property and Occupancy Forecasting (15/WR/02/8), 2015

5.80 We have applied the method at a WRZ level, which results in the following allocation of uncertainty distribution sets:

- Region: London
- County: SWOX, SWA, Kennet Valley
- Local Authority: Guildford, Henley

5.81 Figure 5-7 shows the 90% confidence interval over a period of 30 years for each of the three geographic scale types. The confidence interval is expressed in relative terms to the 50th percentile population forecast. Note that the region and county level values are highly similar. Figure 5-8 shows 50%, 80%, 90% and 95% confidence intervals for the region geographic scale type over 30 years.

Figure 5-7: Comparison of 90% confidence intervals for UKWIR population uncertainty

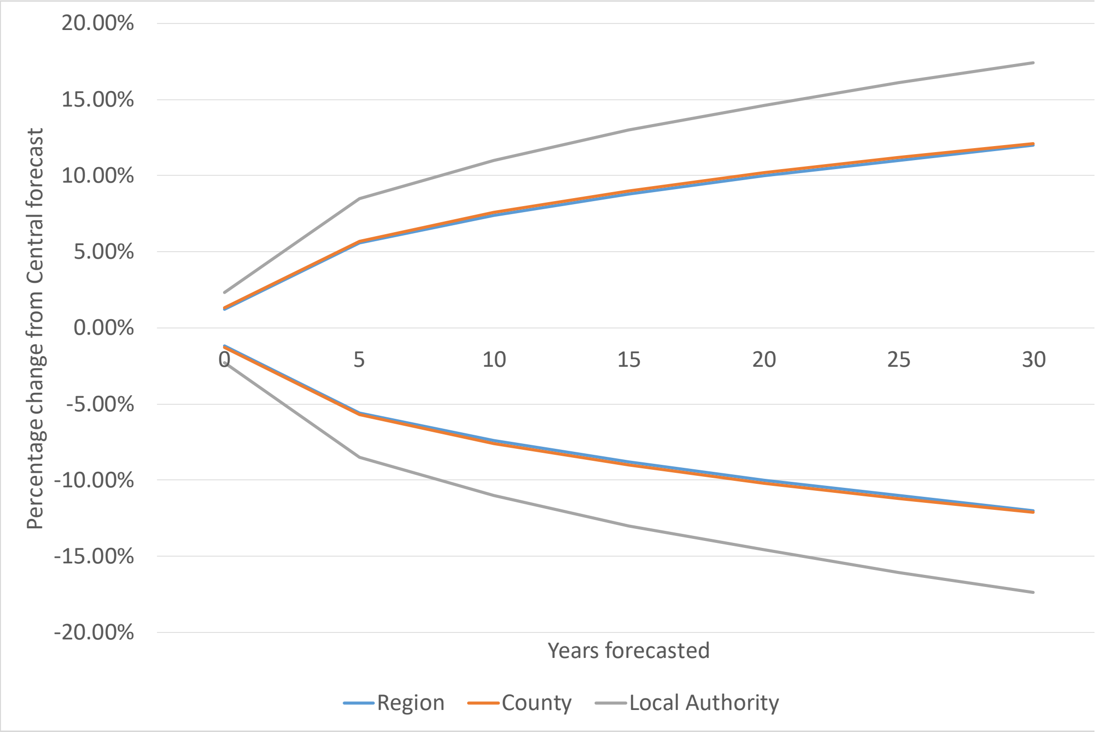
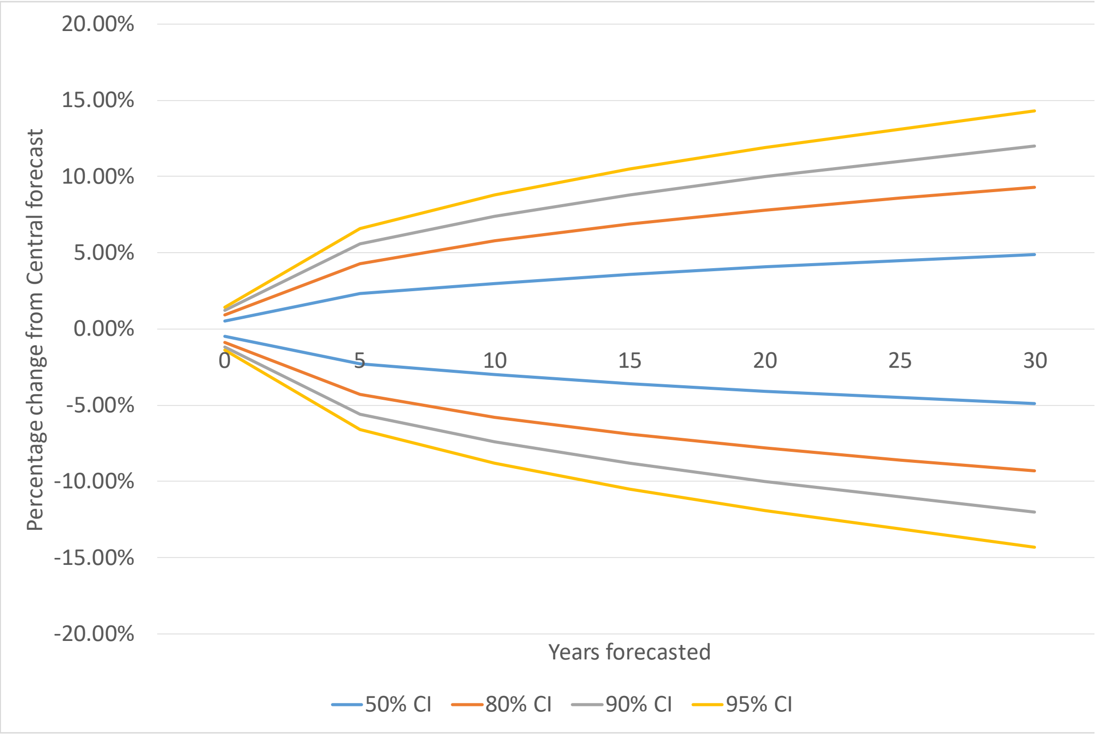


Figure 5-8: Confidence intervals for region level population forecasts



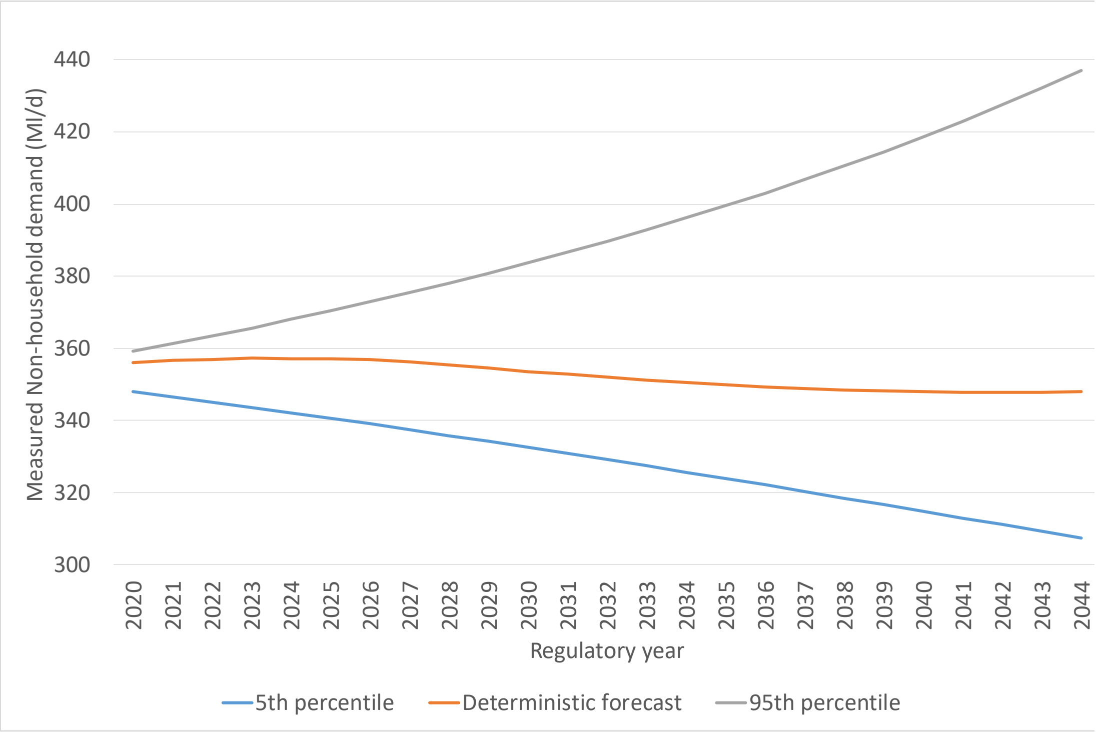
Non-household demand

5.82 Unmeasured non-household demand is a comparatively small component of total non-household demand, approximately 4% in London. We believe that measured and unmeasured non-household demand for water will tend to be well correlated as both are primarily driven by regional macro-economic factors. Therefore we have assumed that the uncertainty distribution for measured non-household demand can be applied proportionately to unmeasured non-household demand.

5.83 The deterministic forecast for non-household demand was produced by Servelec Technologies. As part of that work, using the same methodology and varying future macro-economic projections, they also produced lower and upper forecasts for measured non-household demand in each year. These estimates represent a 90% confidence interval for the value of non-household demand in each year.

5.84 We have fitted a PERT probability density function using the deterministic forecast as the 50th percentile value and the limits of the 90% confidence interval as 5th and 95th percentiles. More details on how distributions are fitted can be found in Appendix V: Risk and uncertainty. Figure 5-9 shows the values used to fit uncertainty distributions.

Figure 5-9: Measured non-household demand forecast uncertainty



D3 – Impact of climate change on demand

5.85 HR Wallingford carried out a study[23] to estimate the likely impacts of climate change upon household demand. Climate change effects are only considered for domestic water use. More information regarding the effects of climate change on demand can be found in Section 3: Current and future demand for water. The climate change ranges are summarised in Figure 5-10 for DYAA and Figure 5-11 for DYCP.

5.86 No allowance has been included for non-household demand based on the findings on the UKWIR report 13/CL/04/12 “Impact of climate change on water demand” which stated:

> *‘It was concluded that, except in the case of agriculture and horticulture in South East Water area, there is inadequate consistent evidence to justify making any allowance for climate change impacts on non-household demand.’*

5.87 The low, mid and upper scenarios presented in these figures are 10th percentile, 50th percentile and 90th percentile forecasts for the impact of climate change on demand. We have used these data points to fit a normal probability density function for each year in the planning period.

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[23] HR Wallingford, EX6828 Thames Water Climate Change Impacts and Water Resource Planning. Thames Water Climate Change Impacts on Demand for the 2030s, 2012

Figure 5-10: The impacts of climate change for the DYAA scenario

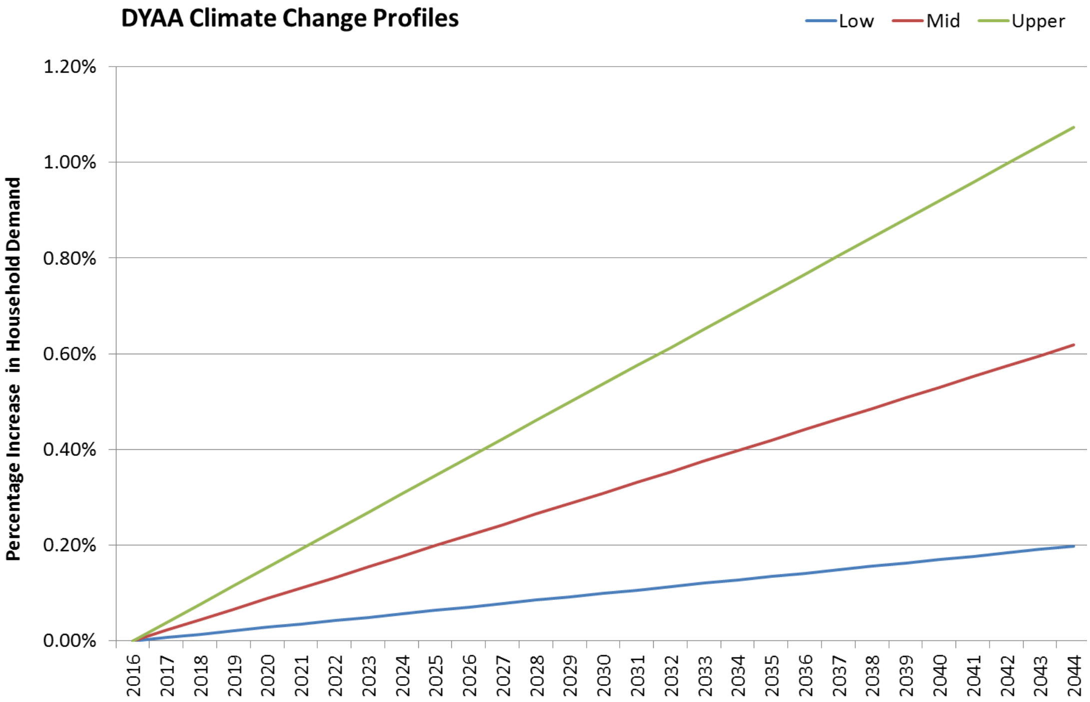
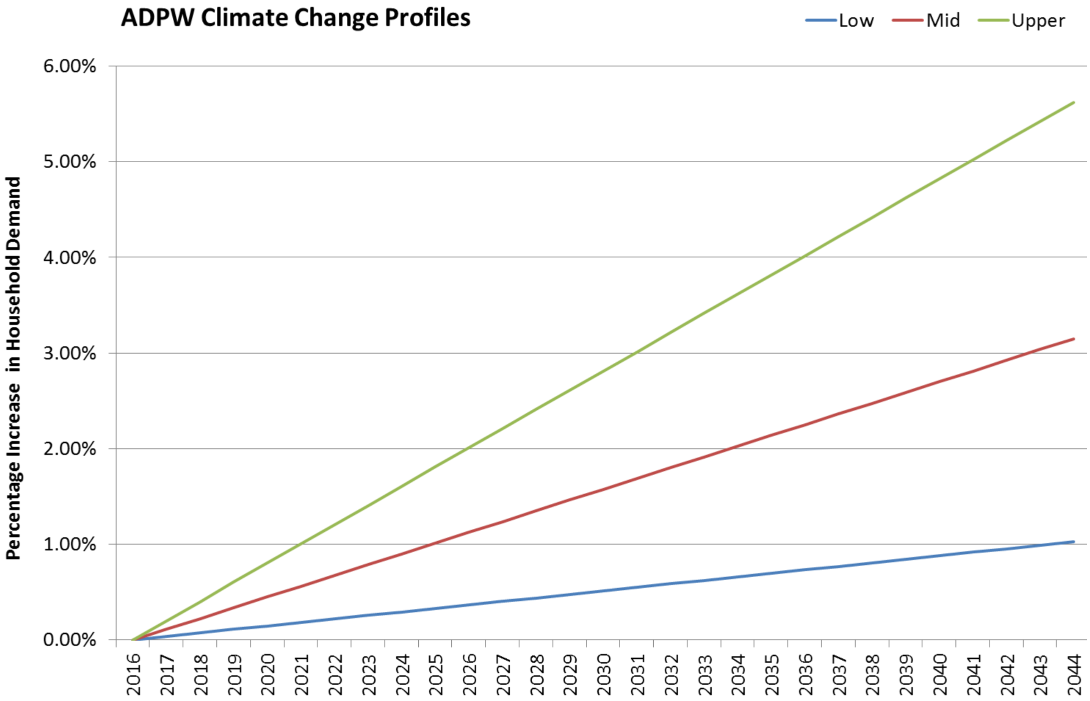


Figure 5-11: The impacts of climate change for the DYCP scenario



D4 – Uncertainty of demand management measures

5.88 These components are not part of the baseline Target Headroom calculation as the baseline position includes no demand management activity. These components are therefore only used as part of the assessment of Target Headroom of a candidate final plan as part of the programme appraisal. More detail can be found on the results of applying Target Headroom analysis on the final plan as part of programme appraisal in Section 10: Programme appraisal.

5.89 As stated in paragraph 5.66 uncertainty around "base" leakage is not considered as part of the assessment of Target Headroom. However, we have introduced uncertainties around new enhanced leakage activities in the revised draft plan. Uncertainty estimates for the material components of the demand management programme are produced separately:

- Metering savings from new meter installations.
- Water efficiency savings from smarter home visits for both household and non-household customers.
- The benefits of enhanced demand savings in Demand Management Areas (DMAs) due to Active Leakage Control (ALC) and other activities.
- The benefits of enhanced activities including mains replacement, further pressure management and customer supply line leakage.

Metering savings

5.90 The central estimate for progressive metering savings has been revised since WRMP14 based on the data collected from the delivery and subsequent monitoring of our progressive metering programme (PMP). Data from a sample of 9,567 households[24] were used in a report produced by expert statistical analysts from our Innovation team. The results of the analysis were controlled for the primary influencing factors:

- Housing type
- Occupancy
- Ethnicity

5.91 The analysis predicts household water use savings of 17.0% if the remaining unmeasured household population were to be metered. However, our experience in the delivery of our AMP6 PMP is showing that the percentage success rates when attempting to meter flats in London is in the low twenties. This is largely due to the complexity of plumbing in many converted flats precluding the ability of economically metering the supply to a single property. Adjusting the analysis to calculate savings for all unmeasured household properties but excluding 80% of flats results in an expected saving of 19.0%.

5.92 We have attempted to corroborate these results with data from other sources. We have been informed by Southern Water and Anglian Water that they have observed savings from their progressive metering programmes of 16.5% and 16.0% respectively. Note that the figure for Anglian Water includes a concurrent water efficiency programme.

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[24] 8,567 households which have been measured and a control group of 1,000 properties from the unmeasured domestic water use study

5.93 Triangulation from these sources has led us to use a deterministic forecast of 17.0% for progressive metering savings in the revised draft WRMP19.

5.94 Our internal analysis also produced a 95% confidence interval for the estimate of meter savings, shown in the Table 5-7.

Table 5-7: Progressive metering saving uncertainty parameters

WRZ	Unit	Upper estimate	Most likely	Lower estimate
London	%	79	81	83.2
Thames Valley	%	79	81	83.2

5.95 We have used the same width of confidence interval produced by our internal analysis to estimate the uncertainty around the deterministic value of 17.0%. Because the confidence interval is largely symmetrical and actual results will be delivered by many hundreds of thousands of households over likely more than a decade. We have assumed a normal distribution with a mean of the deterministic value and a standard deviation of the width of the 95% confidence interval (4.2%) divided by 3.92[25]. We have increased the amount of water efficiency activity in our revised draft plan but still assumed they will perform at the same level, Therefore we have applied the same uncertainty distribution through the whole planning period.

Smarter homes visit uncertainty

5.96 The uncertainty for water efficiency savings is based on a study of the activity carried out in AMP6. The results of this study are presented in Table 5-8. The upper and lower estimates are used as a 95% confidence interval for the most likely saving. This has been used to fit a normal distribution in the same manner as described for metering saving uncertainty in the section above. We have increased the amount of activity in our revised plan but still have used the same assumptions for AMP7 and beyond.

Table 5-8: Water efficiency savings uncertainty parameters for households and non-household

WRZ	Unit	Lower estimate	Most likely	Upper estimate
London	l/prop/d	9.1	10.6	12.1
Thames Valley	l/prop/d	9.1	10.6	12.1

Demand Management Areas (DMA Enhanced)

5.97 As outlined in section 5.65 we have included greater leakage reduction in the revised draft WRMP19 and now include uncertainties around the benefits of these activities. DMA Enhanced activities are planned for London, SWOX and Guildford only. Previous internal assessments for PR14 have assumed uncertainty ranges of +/-10-20% on the benefits of leakage activities[26]. Ongoing research with Artesia Consulting on the uncertainties associated with ALC suggested

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[25] Note the standard normal distribution has a 95% confidence interval bounded by the mean +/- 1.96 times the standard deviation.

[26] These uncertainties were not included in Headroom and managed as business risk in PR14 and in dWRMP, based on lower levels of ambition.

very wide-ranging uncertainties in the benefits. An internal workshop with the operational leakage team was used to estimate the likelihood of underperformance and exceedance of planned benefits. This suggested a moderate likelihood of not meeting planned targets for additional activities and a small chance of exceeding targets. Therefore, a simple triangular distribution was used with the 'most likely' value of 100% of the planned benefits, a minimum of 70% and a maximum of 105%.

Mains replacement, pressure management and customer supply line leakage.

5.98 In addition, we have included enhanced levels of main replacement, pressure management and customer side leakage (CSL) activities with ambitious targets. Previous internal assessments for PR14 have assumed uncertainty ranges of +/-16% on the benefits of these leakage activities. For AMP6 internal models assumed uncertainties of -25%/+10% on the benefits of these activities. An internal workshop with the operational leakage team was used to estimate the likelihood of underperformance and exceedance of planned benefits. This suggested a moderate to low likelihood of not meeting planned targets for additional activities and a small chance of exceeding targets. Therefore, a simple triangular distribution was used with the 'most likely' value of 100% of the planned benefits, a minimum of 80% and a maximum of 105%.

E. Accounting for correlation in demand side uncertainty

5.99 Some of the sources of uncertainty considered in this analysis will be influenced by similar underlying causes and hence their distributions will be correlated. We have completed a pairwise assessment of each source of uncertainty using expert judgement, the results of which are shown in Appendix V: Risk and uncertainty.

5.100 As a result of this analysis we have used a positive 0.75 correlation factor between the results of uncertainty for metering savings and water efficiency savings. These factors are both heavily influenced by customer attitudes to water use. This means that the model will reflect that if metering savings are higher than expected then water efficiency savings will also tend to be higher than expected. This has the effect of widening the overall uncertainty distribution from which Target Headroom is produced. Thus, it will marginally increase the resulting final plan Target Headroom over and above what would result from assuming the distributions are independent. In addition, we have assumed a lower positive correlation of 0.5 between AMP7 water efficiency and enhanced leakage activities.

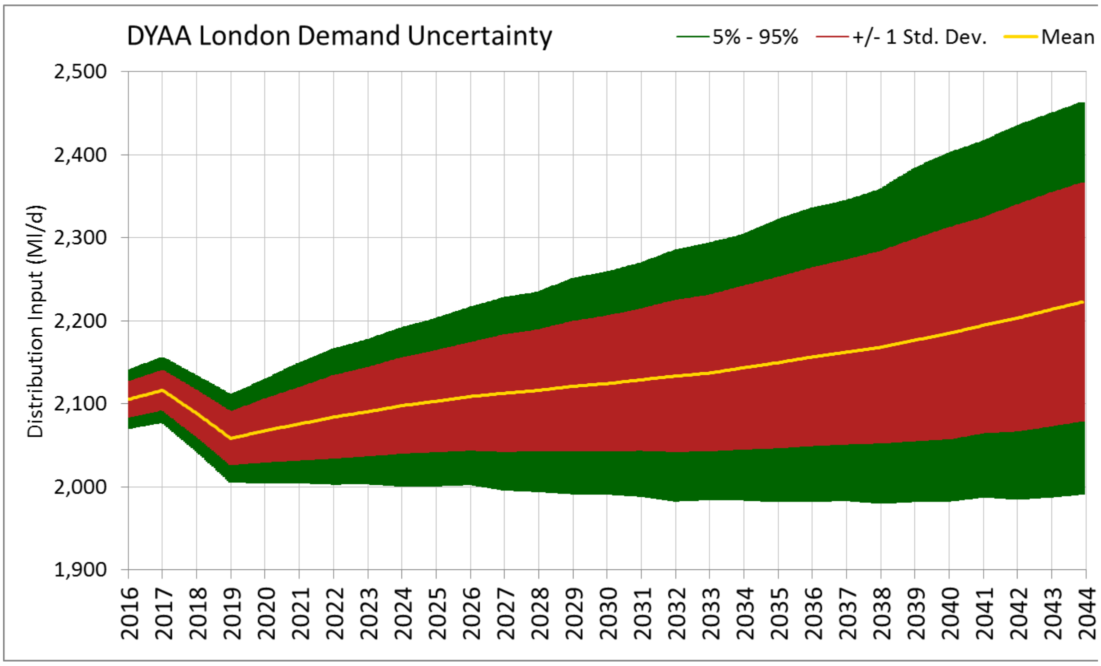
F. Sensitivity of demand side uncertainty

5.101 Climate change is the most important Headroom theme, but total demand side uncertainty is the second most important and a significant part of the plan. For Baseline Headroom both base uncertainty (D1) and population uncertainty (part of D2) are key components. Most uncertainty in future DI is due to uncertainty in population forecasts; over 40% of the variance in DI in 2044 is due to the population forecast alone. Introducing uncertainties for demand management measures (D4) for the final planning results increases the magnitude of uncertainty (by a maximum ca. 1% of DI) but population uncertainty remains the dominant factor. Further information on the contribution and impacts of demand uncertainty are included in Appendix V: Risk and uncertainty. In addition, further scenario testing and sensitivity analysis on population forecasts is completed in Section 10.

G. Model outputs

5.102 The output from the model, which is then used in the headroom model, is a table with a demand value for each 5th percentile. A graphical representation of the output can be seen in Figure 5-12.

Figure 5-12: Baseline demand forecast uncertainty spread - London WRZ



5.103 Results from the baseline model run are used as input into the headroom model to form an initial view of Target Headroom for the baseline forecasts.

H. Baseline Target Headroom and risk profile

5.104 Our baseline forecast has used a risk profile as shown in Table 5-9. A smaller allowance for uncertainty is made in the future as we consider the opportunity to review plans and adapt to changes. A profile has been adopted of 5% in AMP6, which then increases at 1% per annum until 2043/44. Thus the risk taken is increased from 5% to 29% by 2043/44 and is then held at this level over the remainder of the planning period till 2100. We have based our risk profile on a range of factors and made a judgement on what we consider is a reasonable balance of risk over the plan period[27]. Appendix V: Risk and uncertainty, Section G provides a detailed explanation of our decision making process surrounding setting the level of Target Headroom risk.

Table 5-9: Risk profile for Target Headroom assessment in WRMP14 and revised draft WRMP19

	Headroom Risk Profile (%)						
	2016/17	**2019/20**	**2024/25**	**2029/30**	**2034/35**	**2039/40**	**2043/44**
WRMP14	10	10	15	20	25	30	N/A
WRMP19	5	5	10	15	20	25	29

Note: Revised draft WRMP19 Risk is held at 29% from 2043/44

Baseline Target Headroom components

5.105 An example of the typical components of a Target Headroom profile is provided in Figure 5-13, illustrating the relative importance of each of the parameters.

5.106 Figure 5-13 shows baseline supply and demand Target Headroom components for the London WRZ. As described in Section C: Supply side uncertainty and Section D: Demand side uncertainty the following components are considered when calculating baseline Target Headroom

- S6 – Accuracy of supply side data
    - Additional supply side uncertainty in the London WRZ only around NLARS and bromates included as a separate component
- S8 – Uncertainty of impact of climate change on source yields
- D1 – Uncertainty in base year data
- D2 – Demand forecast variation
- D3 – Uncertainty of climate change on demand

5.107 Supply side climate change uncertainty (Supply component S8) and the demand forecast uncertainty (Sum of demand components D1-D3) are the most significant components of the

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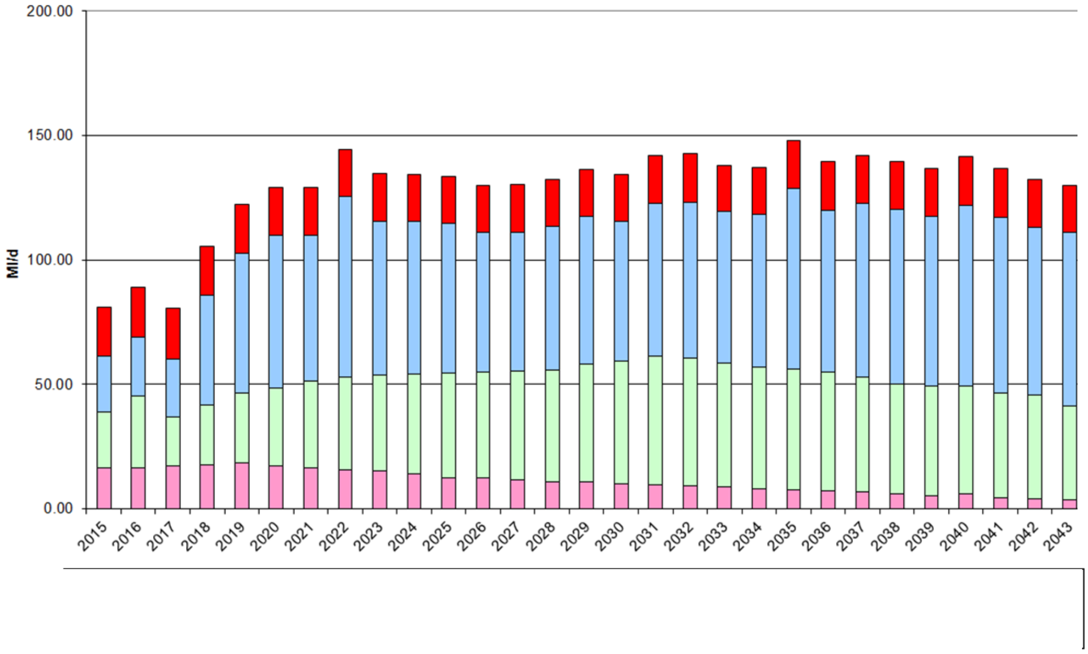
[27] Risk profile based on judgement (informed by the Environment Agency's 2018 WRPG to ensure an appropriate level of risk has been selected), the strength of customer research on reliability of supply, the future risks and their characteristics. We tested the plan in Section 10: Programme appraisal to changes in the supply demand balance which can also be used to test how the plan changes with different risk profiles.

headroom forecast for the London WRZ. Demand uncertainty (Sum of demand components D1-D3) is the largest uncertainty. Supply side climate change uncertainty (Supply component S8) is also a dominant component and continues to increase over the planning period; which is unsurprising given the relative importance of surface water supplies in this zone and the uncertainty around future river flows. The impact of supply side climate change uncertainty in other WRZs is less marked than in London with uncertainty around demand dominating. Further details of the component breakdown for each WRZ are given in Appendix V: Risk and uncertainty. The baseline DYAA Target Headroom is shown in Table 5-10 with the DYCP Target Headroom in Table 5-11. Note the Target Headroom is maintained at the same level in each WRZ from 2043/44 to 2100.

Figure 5-13: Baseline Target Headroom components for the London WRZ



5.108 It is noted that for final plan Target Headroom as described in Section C: Supply side uncertainty and Section D: Demand side uncertainty there are two additional components considered which are not considered in baseline Target Headroom or Figure 5-13:

- S9 Uncertain outputs from new resource developments
- D4 Uncertainty of demand management measures

5.109 The outcome from the final plan Target Headroom calculation, in terms of the magnitude of the uncertainty of these components compared to baseline components, is discussed in Section 10: Programme appraisal.

5.110 The correction made to climate change scaling factors within the Target Headroom model between the draft and revised draft WRMP19 resulting in a reduction in the climate change component of Target Headroom uncertainty is driving a reduction in overall headroom which is a key factor driving an overall reduction in Target Headroom from 86.70 Ml/d AR17 (88.81 Ml/d AR17+) to 79.24 Ml/d for AR18.

Table 5-10: Baseline Target Headroom by WRZ – DYAA

WRZ	Baseline Target Headroom – DYAA (Ml/d)						
	2016/17	**2019/20**	**2024/25**	**2029/30**	**2034/35**	**2039/40**	**2043/44**
Risk Profile →	5%	5%	10%	15%	20%	25%	29%
London	88.81	122.20	134.31	136.50	137.02	136.85	130.09
SWOX	9.00	11.82	13.89	14.12	12.52	12.26	11.77
Kennet Valley	4.02	4.41	5.17	5.35	5.63	4.36	4.06
Henley	0.33	0.59	0.73	0.63	0.51	0.52	0.46
SWA	3.13	5.42	5.16	4.64	4.55	4.20	3.92
Guildford	1.15	1.87	2.12	2.15	1.88	1.66	1.57

Table 5-11: Baseline Target Headroom by WRZ – DYCP

WRZ	Baseline Target Headroom – DYCP (Ml/d)						
	2016/17	**2019/20**	**2024/25**	**2029/30**	**2034/35**	**2039/40**	**2043/44**
Risk Profile →	5%	5%	10%	15%	20%	25%	29%
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	11.17	15.91	19.39	19.04	19.91	20.02	17.82
Kennet Valley	4.46	5.54	7.19	6.91	7.11	7.13	6.22
Henley	0.42	0.73	0.90	0.90	0.91	0.80	0.76
SWA	4.24	6.16	7.20	8.02	7.56	7.36	7.33
Guildford	1.55	2.57	3.27	3.45	3.31	3.17	2.74