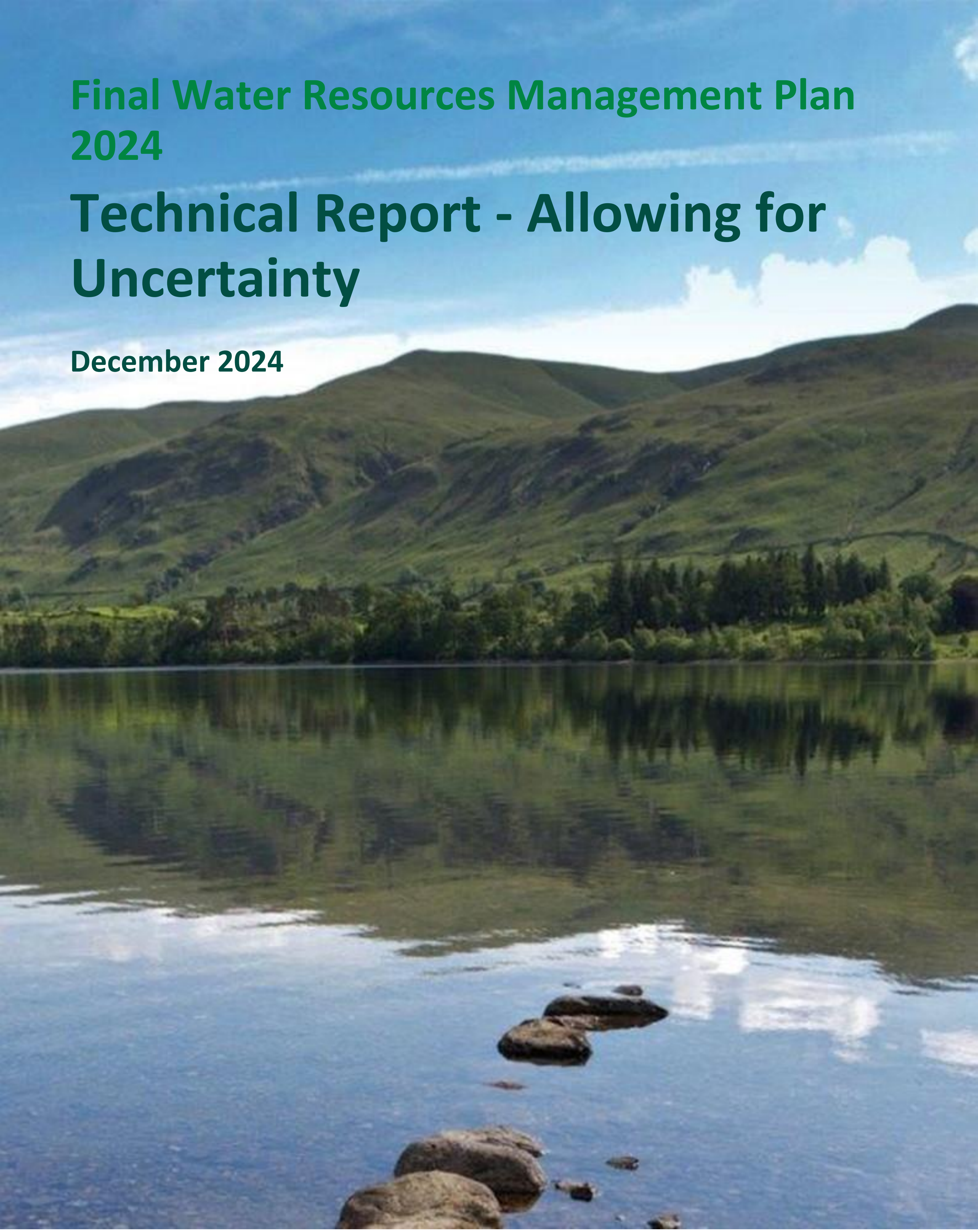
Final Water Resources Management Plan 2024

Technical Report - Allowing for Uncertainty

December 2024



Water for the North West

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1. Introduction

In preparing our future projections of the supply-demand balance, there are inevitably uncertainties inherent within the supply and demand forecasts, which we need to consider. Our supply-demand balance, therefore, includes a margin between supply and demand to allow for these uncertainties. This margin is known as 'target headroom', and we calculate appropriate values of target headroom for each planning scenario considered in our plan for each resource zone. The target headroom value determined for each year across the planning horizon is termed the target headroom allowance. Our assessment of target headroom complies with statutory guidelines and is in line with industry standard practice.

There are a range of factors leading to uncertainty in our forecasts of supply and demand over the planning horizon. These include: accuracy of meters measuring abstractions and distribution input; uncertainty in hydrological and hydrogeological data; modelling and operational uncertainty; variation in future demand forecasts due to uncertainty in factors such as population forecasts, consumption trends and economic growth; uncertainty in the future impacts of climate change; risks of future pollution/water quality impacts on supply availability; and risks of changes to the company's abstraction licences for sustainability or other reasons. The aim of calculating a target headroom allowance is to provide a reasonable margin to cover the statistically combined impact of all of these factors on the supply-demand balance, at a defined level of risk.

This technical report provides an overview of the methodology used to calculate the target headroom allowances for each resource zone, and a summary of the key uncertainty factors incorporated within the assessment. All guidance and reference documents referred to in the text are listed in Appendix A.

In parallel with our target headroom assessment, we have given further consideration to four key areas of uncertainty, which are of most significance to our plan. These are: climate change, demand management reductions, our environmental destination and the magnitude and timing of national water trading. We have created an adaptive plan to ensure that our preferred (most likely) plan can adapt to future variations in these key factors, beyond the range of variations included in target headroom allowances. This approach is in line with regulatory expectations for our Water Resources Management Plan 2024.

Further details of our adaptive planning approach are provided in our *Technical Report – Deciding on future options*.

1.1 Changes from draft to revised draft WRMP

Our draft Water Resources Management Plan 2024 was published in December 2022 for a period of public consultation, following which we updated the plan to address the feedback received and any other changes identified. A summary of the changes to our target headroom assessment, and to this report, is provided below.

Table 1 Summary of changes for revised draft WRMP

Change	Reason	Relevant section(s)
Updated supply and demand uncertainty components with revised draft input data	To align with supply-demand balance data in revised draft plan	Section 3
Provided further details on the methodology used to assess the gradual pollution uncertainty component	To address consultation feedback from the Environment Agency	Section 3.1.1
Reviewed and updated the headroom risk profile for North Eden Resource Zone	To address consultation feedback from the Environment Agency and to reflect benchmarking of UK water companies' risk profiles	Section 4.4
Added sections summarising our target headroom assessments for the adaptive planning scenarios in our plan	To address consultation feedback from the Environment Agency	Sections 5 and 6.2

1.2 Changes from revised draft to final WRMP

There were no further changes to our target headroom assessment following the completion of our revised draft Water Resources Management Plan.

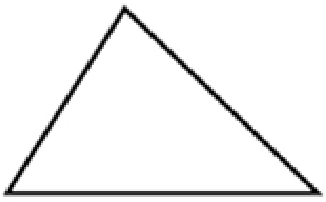
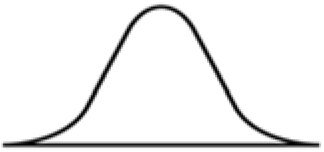
2. Methodology

As for our previous (2019) Water Resources Management Plan, we have adopted the industry standard method for the calculation of target headroom allowance in each of our resource zones (RZs). The method is outlined in An Improved Methodology for Assessing Headroom (UKWIR, 2002) and referred to by the Environment Agency (EA) in their Water Resources Planning Guideline (December 2021).

In this approach, a probability distribution is assigned to each individual risk or uncertainty factor within the supply-demand balance, based on known data and other relevant information. These probability distributions are then combined using a statistical technique called Monte Carlo simulation, which iteratively takes random samples from each distribution and sums them according to specified rules. The summed result of each iteration then forms a point on the curve of the combined distribution; by sampling the distributions over a large number of iterations it is then possible to build up a probability distribution to correctly represent the overall risk or uncertainty of all factors taken together.

Examples of typical probability distribution types are shown in Table 2. The triangular distribution is the most frequently used, with the upper and lower bounds representing the range of uncertainty around the most likely (baseline) value of a particular component.

Table 2 Common types of probability distribution recommended in UKWIR's target headroom methodology

Type	Basic Shape	Description	Application
Triangular		Most easily defined continuous distribution. Defined by a least likely, most likely and maximum likely value. Can be skewed either way.	Forecasting situations where the supply or demand value can be any value within a range and the most likely value can be estimated. May not be appropriate if highly skewed.
Normal		Symmetrical continuous distribution defined by a mean and standard deviation.	Most commonly applied to random uncertainties (known unknowns).
Log-Normal		Skewed continuous distribution defined by a mean and standard deviation.	Forecasting situations where there is a large difference between the maximum and the most likely values such that a triangular distribution is considered unsuitable.
Exponential		Continuous distribution defined by rate. Minimum value always equals zero.	Forecasting situations where the most likely and minimum values are zero, but there is a possibility of a large positive value.
Discrete/Custom		Non-continuous distribution defined by values and probabilities.	Forecasting situations where specific values apply and values between do not. For example, chance events where the outcome is a particular value or zero.

The Monte Carlo simulation software @RISK was used for the analysis, which operates in conjunction with the Microsoft Excel spreadsheet package.

Due to the random nature of the Monte Carlo simulation technique, it is not possible to guarantee that identical results will be generated each time the same simulation is run. However, by selecting a suitably large number of iterations for the simulation, to give an acceptable mean standard error for the simulation results, it is possible to obtain repeatable results to an acceptable level of accuracy. The 2002 UKWIR methodology suggests using 5,000 as a typical number of iterations. However, in practice, it has been found that more consistent results can be obtained using 100,000 iterations. All Monte Carlo simulations undertaken for our 2024 Water Resources Management Plan target headroom assessment have, therefore, been run for 100,000 iterations.

The target headroom allowances for each resource zone are in megalitres per day, or Ml/d, and are read off the selected probability point on each combined headroom distribution produced from the Monte Carlo simulation as outlined above. In order to determine a single profile of target headroom allowance across the planning period, for each planning scenario, it is necessary to select the appropriate level of risk on which to base the target headroom allowance for each year. This defines the probability point on the headroom distribution at which to take the target headroom value. For example, if a percentile of 95 per cent is selected, this corresponds to a 95 per cent probability that the selected target headroom allowance will be adequate to cover the range of simulated uncertainties, or a five per cent risk that it will not.

The resulting profile of target headroom allowances for each resource zone is then incorporated within the supply-demand balance analysis for each year across the planning period.

3. Review of uncertainty factors

Key areas of future risk and uncertainty in our future supply-demand balance were identified through discussion and correspondence with the relevant water resources planning technical experts and operational staff at United Utilities Water. These were categorised with reference to the uncertainty factors specified in the 2002 UKWIR methodology.

A summary of the key uncertainty factors which should be considered in the target headroom assessment, as set out in the UKWIR 2002 methodology, is provided in Table 3, along with an overview of the key assumptions and probability distribution types used to represent these factors in the Monte Carlo simulation.

Table 3 also includes factors that are excluded from our target headroom assessment, with a brief explanation for their exclusion. The Environment Agency Water Resources Planning Guideline (2021) specifies the approach towards uncertainty and abstraction licences; details of how this has influenced our approach are given below.

Table 3 Summary of uncertainty factors and key assumptions adopted for target headroom assessment

Factor	Name	Description	Key assumptions and probability distribution adopted
S1	Vulnerable Surface water licences	Risk of future loss of deployable output due to sustainability changes to surface water abstraction licences for environmental reasons.	Excluded from assessments, as EA guidance states that target headroom 'should not include any allowance for uncertainty related to sustainability changes to permanent licences'.
S2	Vulnerable Groundwater licences	Risk of future loss of deployable output due to sustainability changes to groundwater abstraction licences for environmental reasons.	Excluded from assessments, as EA guidance states that target headroom 'should not include any allowance for uncertainty related to sustainability changes to permanent licences'.
S3	Time Limited Licences	Risk of future loss of deployable output due to non-renewal of time limited abstraction licences.	Excluded from assessments, as EA guidance states that target headroom 'should not include uncertainty related to non-replacement of time-limited licences on current terms'.
S4	Bulk Imports	Risk of future loss of deployable output due to changes in bulk supply agreements (imports only).	Excluded from assessments, as United Utilities Water's bulk imports are contractual agreements.
S5	Gradual Pollution	Risk of future loss of deployable output due to pollution and/or water quality issues which cannot be mitigated or recovered.	Discrete distributions are defined for each individual source at risk of loss of supply due to diffuse or point source pollution. The magnitude of the loss in Ml/d and the associated likelihood of loss are specified for each source depending on the particular risk (e.g. nitrates, salinity, solvents, colour, algae).
S6	Accuracy of Supply-Side Data	Uncertainty surrounding the accuracy of supply-side data e.g. percentage accuracy of abstraction meters, uncertainty in hydrological inflow data and bathymetric data used in supply modelling.	Triangular distributions are defined to represent the range of uncertainty for each subcomponent, applied to individual sources where appropriate.
S7	Single Source Dominance	(This factor was included in a previous headroom methodology, but is excluded from the current UKWIR methodology as it was considered to be an outage issue and would, therefore, be accounted for elsewhere in the supply-demand balance).	N/A

Factor	Name	Description	Key assumptions and probability distribution adopted
S8	Impact of Climate Change on Deployable Output	Uncertainty surrounding the future impact of climate change on deployable output (varying estimates of loss depending on scenario).	The potential impact on deployable output has been assessed using Pywr and Aquator™ modelling techniques for a large number of different UKCP18 climate change scenarios. The uncertainty between these scenarios is then represented as a normal distribution, with the parameters determined from climate change scaling of model output.
S9	New Sources	Uncertainty surrounding the available yield of new resource developments included in the final planning supply-demand balance.	Our final planning supply forecasts include future delivery of new sources. As this is a key area of uncertainty for our plan, we have covered this through our adaptive planning approach and, therefore, this factor is excluded from our target headroom.
D1	Accuracy of Subcomponent Demand Data	Uncertainty surrounding the accuracy of demand-side data i.e. percentage accuracy of distribution input meters (generally located at service reservoirs).	Triangular distribution to represent meter accuracy uncertainty of demand-side data.
D2	Demand Forecast Variation	Uncertainty surrounding future demand forecasts, which may be higher or lower than assumed in the baseline supply-demand balance.	Central, lower and upper sets of demand forecasts are developed, with the lower and upper forecasts incorporating the uncertainty in key subcomponents within the forecasts (e.g. population growth, economic uncertainty, dry year uplift factor etc.). The overall uncertainty is then defined as triangular distributions with the minimum and maximum parameters taken from the lower and upper forecast ranges, relative to the central forecasts, for the appropriate resource zone and planning year.
D3	Impact of Climate Change on Demand	Risk of future increases in demand due to climate change impacts (varying estimates of demand effects depending on scenario).	The central demand forecasts include an assumed percentage increase due to climate change effects, based on the median impacts from a study undertaken by UKWIR in 2013[1]. The 10th and 90th percentile impacts from the UKWIR study were taken as the range of uncertainty around this central estimate.
D4	Demand Management Measures	Uncertainty surrounding the impact on future demand of demand management measures including leakage reduction, metering strategy and water efficiency activities.	Our final planning demand forecasts include future demand savings from leakage reduction and water efficiency activities, however there is a degree of uncertainty around the savings which will be achieved from this work. As this is a key area of uncertainty for our plan, we have covered this through our adaptive planning approach and therefore this factor is excluded from our target headroom assessment.

For some of the specified factors, details of uncertainty ranges at subcomponent level were considered in order to improve the level of detail and accuracy within the assessment. For example, for factor S6 (Accuracy of supply-side data), the Monte Carlo simulation was broken down into the following uncertainty subcomponents:

[1] Impact of climate change on water demand (UKWIR 2013).

- Hydrological data;
- Stochastic data sampling;
- Modelling and operational;
- Process and raw water losses;
- Groundwater data;
- Compensation over-releases;
- Demand saving impacts on supply; and
- Bathymetric data.

For factor S5 (gradual pollution of sources), each individual source which has been identified as being at risk of deployable output reduction due to water quality issues is represented as a separate subcomponent within the Monte Carlo simulation. These subcomponents include both groundwater and surface water sources, and a range of potential water quality risks (see Section 3.1.1).

Within the simulation, separate probability distributions were defined for each subcomponent, and these were combined statistically with all other uncertainty factors through the Monte Carlo simulation process as outlined above.

The parameters required to specify the probability distribution for each uncertainty factor were calculated from a combination of historic data relating to the particular area of risk or uncertainty, and the expert judgement and knowledge of our water resources and operational staff. In addition, information from research studies was used where appropriate (for example studies carried out by UKWIR[2] to assess the impact of climate change on demand). All assumptions relating to uncertainty factors included in the target headroom assessment for the 2019 Water Resources Management were reviewed and updated where appropriate using the latest data and research.

3.1 Overview of supply-side uncertainty factors

As outlined in Table 3, we have excluded the supply-side uncertainty factors S1, S2, S3, S4, S7 and S9 as these are not applicable to our assessment of uncertainty for the Water Resources Management Plan 2024. Our plan includes a review of vulnerable groundwater and surface water licences as part of our assessment of sustainability changes and our future environmental destination; further details are provided in our *Technical Report – Supply forecast* and *Technical Report – Environmental destination*.

3.1.1 S5: Gradual pollution of sources causing a reduction in abstraction

This factor reflects the risk of losing part or all of the yields of individual sources in the future, due to pollution and other water quality issues. Reductions in groundwater source yields may be due to the deterioration of:

- Native groundwater quality due to natural processes or anthropogenic activities; and
- The physical structure of groundwater assets (boreholes, wells, adit systems), beyond design standards, which would impact on water quality and turbidity.

Examples of groundwater risk factors for which we have made an allowance in our target headroom assessment include solvents, salinity, nitrates and asset collapse. Our assessment includes more than 50 headroom subcomponents representing specific risks at individual sites (at some sites there are multiple risks included).

The potential risks relating to gradual pollution impacts on source yield were assessed according to two key parameters:

[2] Impact of climate change on water demand (UKWIR 2013).

- The **magnitude** of deployable output or source yield which is at risk of loss, in Ml/d; this may be 100% of the source yield or a lesser percentage if there is a risk of reduction in abstraction but not full loss of a particular source; and
- The **likelihood** of loss in a stated year, for example if there is a 1 in 4 chance that the loss will occur then this is expressed as a 25% chance of loss.

The magnitude and likelihood of source yield for each identified site and associated risk were assessed for different points within the WRMP planning period, taking into account mitigation measures including blending and treatment options, which may be feasible to limit the magnitude of potential yield loss in some cases. The uncertainties have generally been represented as discrete probability distributions in the simulation model, with a small probability of losing some or all of the source yield and a larger probability of no loss (although in some cases the probability and magnitude of yield loss is assumed to increase over time).

With respect to our surface water sources, we have identified potential water quality risks to our treatment works based on data for the last five years. The data has enabled us to estimate the frequency and magnitude of reductions in asset capacity due to water quality issues such as colour, geosmin, manganese, iron and algae (water quality issues require more time to treat and therefore can impact on total capacity). We have excluded any events which are accounted for in our outage allowance, and the remaining events have been used to determine probability distributions representing the risk and magnitude of potential deployable output impacts due to asset capacity reductions at key sites.

3.1.2 S6: Accuracy of supply-side data

The range of uncertainty surrounding our supply-side data is divided into several subcomponents, reflecting some of the key inputs to our modelled estimates of system deployable output and Water Available for Use (WAFU). These subcomponents are as follows:

- **Hydrological data uncertainty**: Our water resources models are used to determine system deployable output from stochastic data sets on catchment and river inflows; however, inflow data may be subject to variation due to meter accuracy and calculation/simulation methods. We have therefore used the models to calculate the deployable output values which would result from +/- 10 per cent variation in inflow data sets; this gives a range of between -115.34 Ml/d and +94.96 Ml/d around our baseline Strategic RZ deployable output estimate representing the uncertainty in stochastic inflow data. This range is entered as a triangular distribution in the target headroom simulation for the Strategic RZ. For the Carlisle RZ, a similar approach provides a range of -0.84 Ml/d to +0.09 Ml/d around the baseline modelled deployable output for the zone. Our North Eden RZ does not contain any surface water sources and therefore this factor does not apply. For our Barepot RZ, as this is supplied by a single surface water abstraction, we applied an uncertainty range of +/- 10 per cent variation in the deployable output value.
- **Stochastic weather generator and data sampling uncertainty**: Our historic data record of around 100 years is not long enough to derive supply forecasts for a drought of 0.2 per cent annual risk (occurring in 1 in 500 years on average), so these are derived from long-term data sets (19,200 years of data) produced by a stochastic weather generator. Within the weather generator process these data sets are sampled randomly from 1,000 to 400 realisations, however, the nature of the sampling process gives rise to a degree of uncertainty in our modelled supply values. The standard error of sampling 400 realisations of the data sets from 1,000 realisations translates to a small range of uncertainty around the baseline deployable output, represented as a normal distribution with a mean of zero and standard deviation of +/- 0.5 per cent of deployable output.

  There is also some bias correction applied to rainfall data to ensure that the observed data sits within the 50 per cent prediction interval of the full stochastic data set. This process marginally reduces deployable output compared to using non-bias corrected data, by an average reduction of 1.1 per cent and a standard deviation of +/- 1 per cent (based on the variation in bias correction across different catchments and assuming that the changes in rainfall metrics translate to similar changes in deployable output). This is applied as a normal distribution to represent the range of uncertainty in deployable output for this sub-component.

- **Modelling and operational uncertainty**: Our water resources simulation models have been developed and refined over the years to represent operational reality as closely as possible; this includes regular reviews and updates of operational rules and system constraints such as water treatment works and pumping station capacities and seasonal demand profiles. A model validation exercise using 2018 data to compare observed and simulated reservoir storage, water treatment works output and pumped volumes at key locations, produced good results and has improved confidence in our modelled supply estimates.

  However, it is impossible to fully represent every aspect of day-to-day operation of a large and complex water supply system in a simulation model, and, therefore, a degree of uncertainty applies to the supply forecasts. We estimated the range of uncertainty by inspecting the difference in observed and simulated storage at key reservoirs from the 2018 validation exercise referred to above. By comparing the volumetric difference across the overall drawdown period, it was possible to estimate the daily demand difference which equated to the difference in minimum reservoir storage at the lowest point on the drawdown curve. This difference was found to be 14 Ml/d and so a triangular distribution with a minimum of zero and a maximum of 14 Ml/d was applied as the uncertainty range to represent this factor in the target headroom assessment (for the Strategic Resource Zone). This is an improvement to the methodology adopted for our previous (2019) assessment, as it is based on a comparison with observed data. For the Carlisle Resource Zone, the water supply system is operationally more straightforward to represent in our water resources model, and therefore no modelling uncertainty has been applied for this resource zone. Supply forecasts for the North Eden and Barepot Resource Zones are too simplistic to be assessed in water resources models, therefore this component is not included in the target headroom calculation for these resource zones.

- **Process and raw water losses**: The impact on our system deployable output (DO) of the small percentages of losses, which occur both at our raw water abstraction sites and within the processes of our water treatment works, have also been assessed using our water resources models. The data used for the analysis were the average losses in Ml/d at each individual water treatment works over a six-year period (2015–2020), along with the highest and lowest values calculated on a yearly basis. The average, lowest and highest loss values were assessed in the water resource models as three separate scenarios to provide three values for the impact on DO. The average DO impact was taken forward as the baseline impact into the supply-demand balance, while the relative differences of the low and high DO impact were taken as the minimum and maximum of a triangular uncertainty distribution in the target headroom assessment. This results in an uncertainty range of -17 Ml/d to +62 Ml/d for the Strategic Resource Zone, and -0.2 Ml/d to +0.55 Ml/d for the Carlisle Resource Zone. For the North Eden Resource Zone, the uncertainty range was determined directly from the average, lowest and highest loss values in the dataset (as this resource zone is not modelled in Aquator™), giving a range of -0.15 Ml/d to +0.18 Ml/d around the baseline (average loss) of 0.15 Ml/d.

- **Groundwater data uncertainty**: The uncertainty around groundwater data relates to the measurement of groundwater abstractions and pump efficiencies. We reviewed these factors for our draft Water Resources Management Plan 2024 and applied a range of +/- 5 per cent to the groundwater deployable output in both our Strategic and North Eden Resource Zones, based on a comparison between manual and telemetry data from groundwater abstraction meters. For the Strategic Resource Zone, the groundwater deployable output is 348.7 Ml/d, with an uncertainty range of +/- 17.43 Ml/d in the headroom model, while for North Eden Resource Zones the groundwater deployable output is 9.63 Ml/d with an uncertainty range of +/- 0.48 Ml/d included in the headroom component. There are no groundwater sources in the Carlisle or Barepot Resource Zones.

- **Compensation over-releases**: The uncertainty associated with reservoir compensation releases relates to the accuracy of streamflow measurement and the operational requirement to ensure that no less than the statutory compensation amount is released, meaning that there is always an over-release to ensure compliance with the licence. The lower and upper bounds of the over-releases were based on the minimum, average and maximum percentage over-release, calculated from recent available data. The average over-release percentages are applied to all compensation sites within the water resources model. The headroom uncertainty range was calculated as the minimum and maximum percentage over-release of each relevant category, relative to the average values applied in the water resources model. Further details are provided in our *Technical Report – Supply forecast*. In addition, uncertainty associated with hands-off flow buffers was included based on the modelled deployable output impact (7 Ml/d) of including these buffers in the water resources model.

- **Demand saving deployable output uncertainty**: We have updated this component based on research by Atkins about the benefits of demand saving measures conducted for our Final Drought Plan 2022. This research involved carrying out multiple runs of our water resources models using different assumptions about the percentage savings in demand, which can be achieved from different measures (campaigns for voluntary restraint, temporary use bans and non-essential use bans). The percentage savings applied in the different scenarios were within the range applied by UK water companies, based on UKWIR studies and/or their own experience and data from recent droughts. The modelling indicated that the deployable output impact of these scenarios ranged from -38 Ml/d to +45.7 Ml/d, compared to the scenario adopted in our central supply estimates for the Strategic Resource Zone, and from -0.1 Ml/d to +0.4 Ml/d compared to the Carlisle Resource Zone central estimates. These values were adopted as the minimum and maximum values of triangular distributions to represent the demand saving uncertainty for each of these two resource zones. Our supply forecasts for Barepot and North Eden Resource Zones do not assume any impact on deployable output from demand savings, as the deployable output is defined by licence constraints rather than target levels of service, therefore, we have not included any allowance for demand saving uncertainty in the target headroom assessments for these resource zones.
- **Bathymetric data uncertainty**: Uncertainty surrounding bathymetric survey data of our raw water storage reservoirs can affect the assumed parameters for storage capacity, dead water and yield, which can ultimately impact on our estimates of system deployable output. A review of recent bathymetric surveys of our reservoirs has shown that only one survey – that of Ennerdale Water in 2000 – quoted an uncertainty range for the measurements; all other surveys stated that the error of the terrestrial measurements was within the acceptable error bounds. Using the measurement range quoted and the maximum depth of Ennerdale, a representative uncertainty percentage of 1.47 per cent was calculated and applied to latest reservoir yield estimates (assuming a linear relationship between the storage and yield of the reservoirs) for all reservoirs in the Carlisle and Strategic RZs. This resulted in an uncertainty range for this factor of +/- 17.04 Ml/d for the Strategic RZ and +/- 0.09 Ml/d for the Carlisle RZ. There are no raw water storage reservoirs in our Barepot or North Eden Resource Zones.

3.1.3 S8: Impact of climate change on supply

The potential future impacts of climate change on our supply forecasts have been assessed using our water resources models, Pywr and Aquator™. We initially tested a large number of scenarios from the UKCP18 climate projections for RCP (Representative Concentration Pathway) 8.5, including:

- 12 Regional Climate Models;
- 28 Global Climate Models; and
- 3,100 probabilistic projections (3,000 for the North-West River Basin and 100 for England and Wales).

RCP 8.5 was selected for the model simulations as there were insufficient UKCP18 products available for the alternative RCPs (e.g. 2.6 and 6.0). However, the outputs were then scaled to RCP 6.0, using scaling relationships based on temperature derived by Atkins[3] for water companies in England and Wales, as on the balance of scientific evidence we believe this to be the most likely trajectory. We have assessed the potential supply-demand balance impacts of the more extreme projections (RCP 2.6 and RCP 8.5) through our adaptive planning approach (see our *Technical Report – Deciding on future options*).

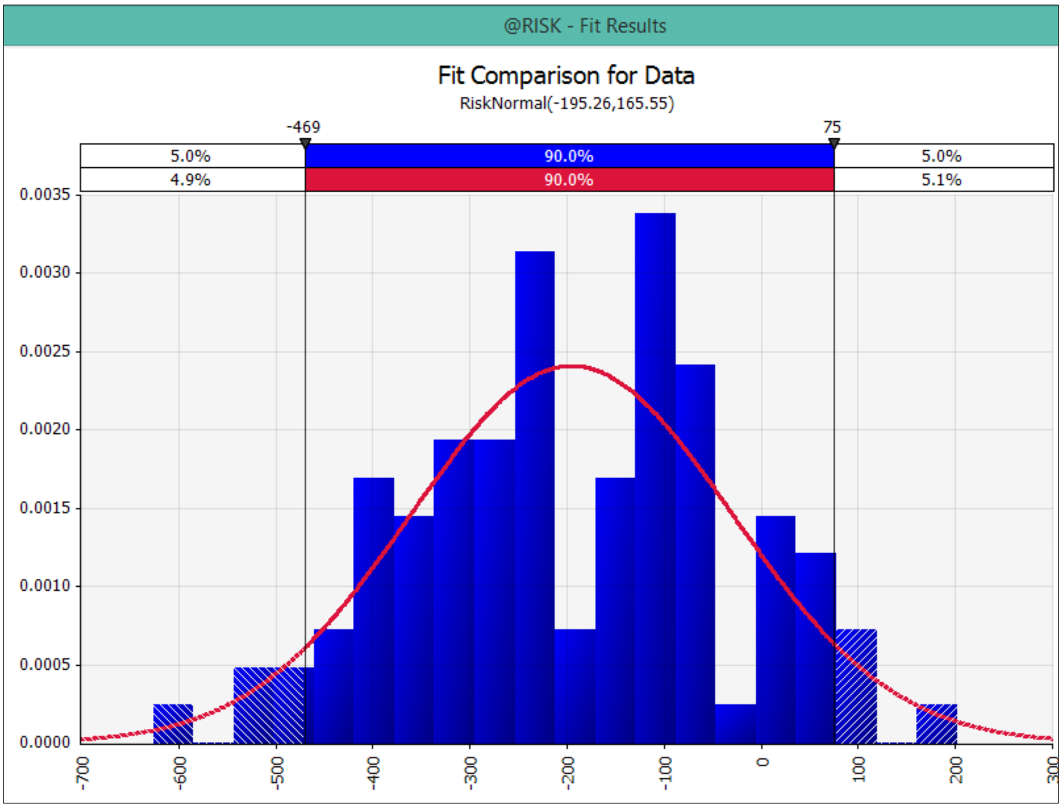
For the Strategic Resource Zone, the Pywr model was initially used to assess the system response of all 3,140 climate change scenarios; the results were then used to sample a set of 100 representative probabilistic scenarios for more detailed analysis using both Pywr and Aquator™. The simulated impacts of these scenarios on the system deployable output were then scaled to RCP 6.0 and used to define a normal distribution (as shown in

[3] Regional Water Resources Planning Climate Data Tools – Operational Framework for Implementing the Supplementary Guidance on Climate Change, Atkins, 2021.

Figure 1). We used the 12 Regional Climate Models, modelled in Aquator™, to define the median impact, which was applied to the system deployable output for the Strategic Resource Zone in our baseline supply forecasts. The variation around the median was represented as a normal distribution (defined by the 100 probabilistic scenarios modelled in Pywr) in the Monte Carlo headroom uncertainty analysis (for each year in the planning period). The standard deviation parameters of the normal distributions in the target headroom assessment were taken from the distributions fitted to the sets of simulated impacts.

More detail on our approach to assessing the impact of climate change on supply is provided in our *Technical Report – Supply forecast*.

Figure 1 Normal distribution fitted to simulated impacts of 100 probabilistic projections (Strategic Resource Zone)



The same approach was used to determine the median climate change impact, and a normal distribution representing the headroom uncertainty range for Carlisle Resource Zone (dry year annual average planning scenario only).

Our dry year critical period for Carlisle Resource Zone is the dry year peak week, and the supply forecasts for this scenario are determined from licence constraints and physical system capacity. Therefore, the deployable output for this scenario is not affected by the impacts of climate change, and no uncertainty for supply impacts of climate change was included within the headroom component for Carlisle Resource Zone (dry year critical period scenario).

Similarly, previous climate change modelling for North Eden Resource Zone indicated that the constraints were the licences and physical asset capacities, and that any impact from climate change did not affect the deployable output. Therefore, no uncertainty for climate change impact on supply was included in the target headroom calculations.

For Barepot Resource Zone, previous modelling has indicated that there were negligible impacts of climate change on the resource zone (as the supply forecasts are defined by licence conditions) and it was therefore not included in target headroom.

3.2 Overview of demand-side uncertainty factors

All of the demand-side headroom components have been included in our target headroom assessment, although the component D4 is only applicable to our final planning scenario as this relates to uncertainty in the projected demand savings to be achieved from our selected demand-side resource options, in particular leakage reduction and water efficiency activities. For our draft plan, uncertainty in demand saving measures is addressed through an adaptive planning approach, in line with regulatory guidance.

3.2.1 D1: Accuracy of sub-component demand data

This component reflects the fact that demand cannot be measured with total accuracy due to error in distribution input meters. To align with the uncertainty applied to our regulatory reporting data, an allowance of up to +/-1.02 per cent of our baseline dry year demand forecast has been applied to each of the resource zones; this is the overall confidence range around distribution input determined from a review of the confidence ranges around individual components of the water balance, consistent with the confidence ranges used in the Maximum Likelihood Estimation (MLE) method of reconciling the water balance. The uncertainty of +/- 1.02 per cent is applied within the headroom model using a triangular distribution, to represent the overall range of uncertainty in demand due to meter accuracy ranges of individual demand subcomponents. This is consistent with the assumptions applied for this factor in our previous water resources management plan uncertainty assessments.

3.2.2 D2: Demand forecast variation

We recognise that there is uncertainty inherent within our future demand forecasts, and we have assessed a range of scenarios, in particular relating to varying assumptions around population and property growth, patterns of household water use and economic factors. The range of uncertainty surrounding future demand forecasts is captured within the range between the upper and lower forecast, with the adopted forecast scenario being the 'most likely' as defined for the probability distributions. The differences between the upper and most likely forecasts, and between the most likely and the lower forecasts, form the parameters of triangular distributions, which are input to the Monte Carlo simulation model to represent uncertainty in future demand forecasts.

Details of the assumptions and methodologies adopted to prepare our lower, baseline and upper forecasts are provided in the *Technical report – Demand for water*. However, a brief summary of the key features of the upper and lower forecasts respectively is included here for information.

The upper demand forecast is a housing-led scenario and consists of the following factors:

- Population and property forecasts based on Local Plan housing growth trajectory with a high migration rate assumption from 2050 to 2100;
- 'Economy First' economic growth scenario for the non-household forecast;
- Upper-bound 'dry year' uplift factor (derived from the Met Office weather demand model) applied to household consumption/usage;
- Annual metering rate of unmeasured properties (baseline without enhanced promotion) of one per cent; and
- Five-year maximum annual average value assumed for minor demand components.

The lower demand forecast is an ONS 2018 trend-based scenario and consists of the following factors:

- Population and property forecasts based on ONS 2018 trends with a low migration rate assumption from 2050 to 2100;
- 'Constrained growth' economic growth scenario for the non-household forecast;
- Lower-bound 'dry year' uplift factor (derived from the Met Office weather demand model) applied to household consumption/usage;
- Annual metering rate of unmeasured properties (baseline without enhanced promotion) of 1.5 per cent; and
- Five-year minimum annual average value assumed for minor demand components.

The variations between the upper, baseline (most likely) and lower forecasts for the Carlisle, Strategic and North Eden Resource Zones are shown in Figure 2, Figure 3 and Figure 4 respectively. The graphs illustrate the demand forecast uncertainty ranges included within the target headroom assessments.

Figure 2 Demand forecast variation – Carlisle Resource Zone

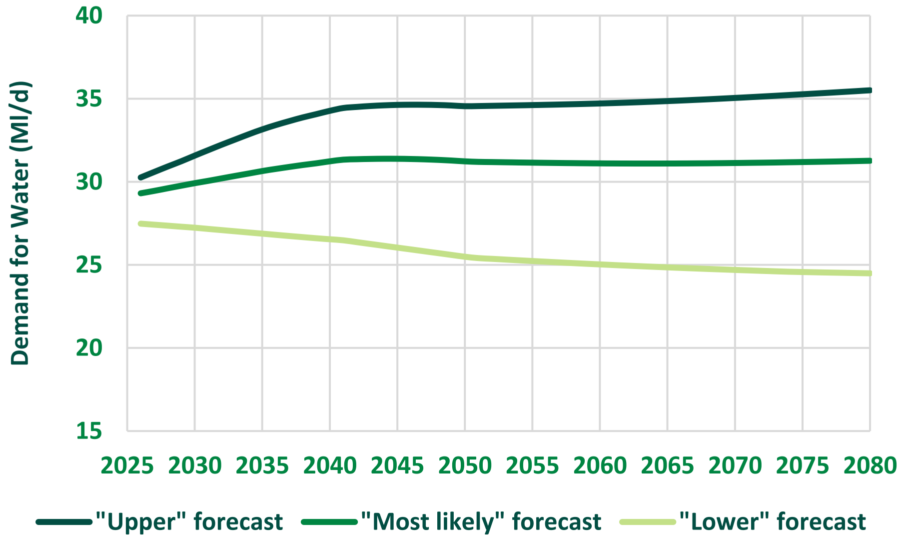


Figure 3 Demand forecast variation – Strategic Resource Zone

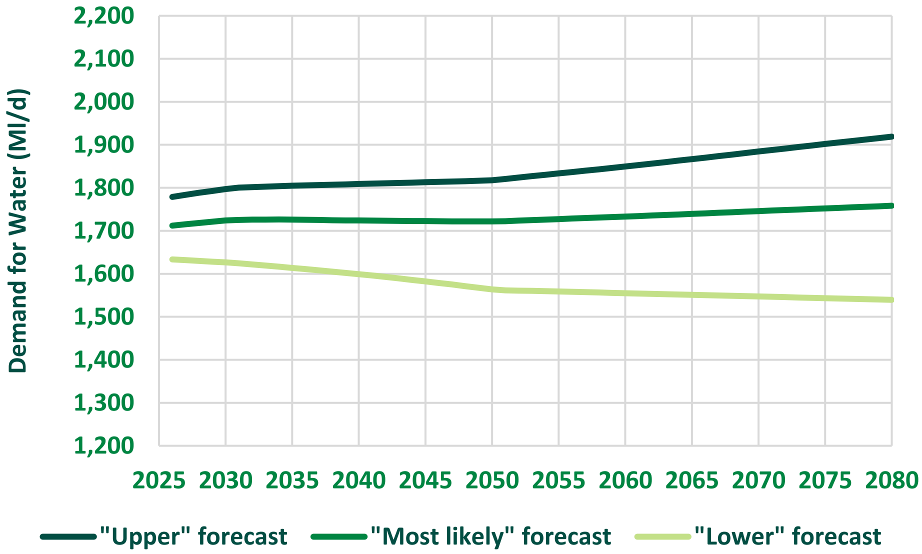
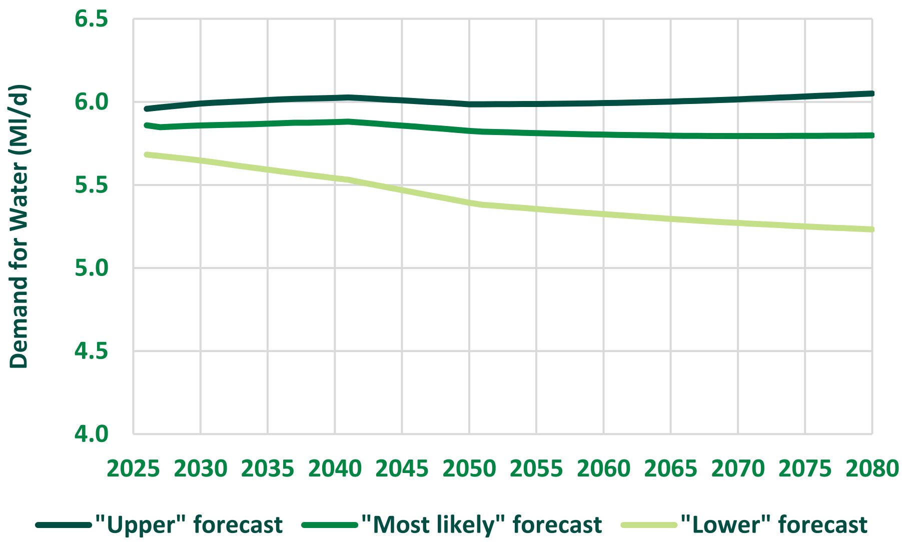


Figure 4 Demand forecast variation – North Eden Resource Zone



For Barepot Resource Zone, the variation in demand forecast was based on the range between our high growth, low growth and central forecasts from our previous (2019) assessment, as a review of uncertainty factors for this resource zone concluded that the previous target headroom assessment did not need to be updated (Section 4.2).

3.2.3 D3: Impact of climate change on demand

This component relates to the uncertainty in the future impacts of climate change on demand. These impacts are based on a study carried out by UKWIR[4], which applied regression techniques to household consumption and weather parameters to develop weather-demand relationships for several case study datasets from UK water companies. The weather-demand models were then applied to perturbed weather data from a number of UKCP climate scenarios to estimate the range of percentage impacts of climate change on demand. As an output from the study, UKWIR provided look-up tables from which the percentage impacts of climate change on demand for the 10th, 25th, 50th, 75th and 90th can be selected for each year across the planning horizon.

Our demand forecasts include the median or 50th percentile impacts of climate change applied to the external use component of household consumption. We have applied the lowest and highest percentile impacts from the look-up tables to household consumption to give a range of uncertainty around the baseline in Ml/d; these form the minimum and maximum parameters for triangular distributions adopted in our target headroom assessments for the Carlisle, Strategic and North Eden Resource Zones.

For the Barepot Resource Zone, based on historic trends in use, there is no clear weather/climatic response on the industrial consumption/usage and climate change impacts are assumed to be negligible.

3.2.4 D4: Demand management measures

Our final planning supply-demand balance includes a suite of demand management measures, which are targeted at reducing demand over the planning horizon of our water resources management plan in line with government aspirations as set out in the National Framework for Water Resources. The key areas of demand management are as follows:

- Water efficiency activities: investment in water efficiency promotion targeted to achieve a reduction in per capita consumption (PCC) from 144 l/h/d in our base year 2019/20, to 110 l/h/d by the year 2050. (Our plan starts from 2025, however, 2019/20 is used as the base year from which to project our observed demand forwards to create our demand forecast); and
- Leakage reduction: increased investment to accelerate the pace of our leakage reduction activities targeted to achieve a 50 per cent reduction in leakage by the year 2050 (from a baseline of 2017 to 2018).

[4] Impact of climate change on water demand (UKWIR 2013).

Accounting for the delivery of PCC reductions, there is forecast to be a significant reduction in demand. However, there is uncertainty over the magnitude of demand savings, which will be achieved in practice by the range of measures we are planning to implement. As this is a key area of uncertainty for our plan, we have assessed the impacts of any variation in the forecast delivery of demand savings through our adaptive planning approach (see our *Technical Report – Deciding on future options*, for more details). This factor has, therefore, been excluded from our target headroom allowances.

3.3 Component dependency and correlation

As with previous water resources management plan assessments, no headroom components are dependent on another component, or mutually exclusive.

In view of the positive correlation between climate change effects on demand and supply, a correlation coefficient of 0.75 has been applied in the Monte Carlo modelling for the S8 and D3 components. The coefficient has been chosen in line with guidance on the selection of correlation coefficients provided in the UKWIR 2002 methodology and allows for climate change effects resulting in concurrent higher demand and lower deployable output. This is consistent with the approach taken for previous water resources management plan assessments.

4. Risk profile

The Monte-Carlo simulation process produces a probability distribution of combined headroom uncertainty for each year across our planning period. From this, a target headroom allowance is selected at the required level of risk in each year.

The selection of percentile or risk profiles across the planning period is a carefully considered choice, as it determines the zonal target headroom allowances and ultimately the supply-demand balance and potential investment needs for each resource zone. Factors to be considered in the selection of risk profiles include the following (although this is not an exhaustive list):

- The resilience of the resource zone to future uncertainty, for example some resource zones are relatively resilient to the future impacts of climate change due to the nature of their supply systems;
- The degree of flexibility and/or interconnectivity of the supply system, for example when considering a large zone with multiple interconnected sources and alternative modes of operation to meet demand, it may be appropriate to accept a higher level of headroom risk than for a small, isolated zone with limited supply options;
- Industry benchmarking of typical risk profiles adopted for water resources planning, particularly for resource zones with similar characteristics;
- The need to avoid disproportionate and/or unnecessary investment, particularly where the baseline supply-demand balance is forecast to improve, for example due to demand management activities;
- Accepting an increased level of risk further into the future, when there is more time to plan and adapt to the uncertainty factors included in the target headroom allowance, in line with Environment Agency guidelines;
- Period of time required to plan and implement the optimal supply-demand solution (e.g. new water supply schemes, leakage reduction or other demand management programmes); and
- The financial and/or environmental costs of providing supply-demand solutions.

Our selected profiles of headroom percentile and corresponding risk for each resource zone are presented in Sections 4.1 to 4.4 below.

4.1 Strategic Resource Zone

Our selected risk profile for the Strategic Resource Zone is based on a probability of 80 per cent at the start of the period (representing a risk of 20 per cent that the target headroom allowance is exceeded), tapering down to a probability of 70 per cent in 2049/50 (30 per cent risk).

This is lower than the profile of 95 to 70 per cent adopted for our 2019 Water Resources Management Plan; the increased risk level at the start of the planning period is mainly due to the following:

- For this plan, we are accounting for some of the key areas of uncertainty (e.g. demand growth, climate change impacts, demand savings from our leakage and PCC reduction activities) through our adaptive pathways and, therefore, our target headroom allowances are not the sole method by which we allow for the risks of future variations to our supply-demand balance. Reducing our target headroom allowance due to the use of adaptive planning is a clear requirement from Ofwat and we have received similar feedback in pre-consultation.
- There is more inherent uncertainty in a 1 in 500-year supply-demand balance, particularly where available supply is constrained by raw water availability. We have incorporated uncertainty factors relating to our stochastic weather generator and inflows, which have increased the supply-side element of our target headroom assessment, therefore, to avoid disproportionate investment in the early years solely due to this factor, it is appropriate to select a higher risk as a starting point for the tapered profile.

- The medium to long-term supply-demand balance position is dominated by significant benefits from our leakage reduction and demand management policies. A higher risk level is appropriate in the early years of the plan to avoid unnecessary investment in supply options for the shorter term, which won't then be required in the medium to long term. This is in line with our approach to prioritise 'no regrets' investment.

Our Strategic Resource Zone is a large, interconnected supply system with some limited operational flexibility to transfer water around parts of the system to meet variations in demand patterns. Therefore, a relatively higher risk is acceptable and is broadly in line with the target headroom profiles selected for notable other resource zones in the UK with similar characteristics.

Table 4 shows the selected profiles of target headroom percentile and corresponding risk for the Strategic Resource Zone.

Table 4 Strategic Resource Zone – Selected target headroom profile

	2025	2030	2035	2040	2045	2050
Risk of understating the supply-demand balance	20%	22%	24%	26%	28%	30%
Headroom uncertainty percentile	80th Percentile	78th Percentile	76th Percentile	74th Percentile	72nd Percentile	70th Percentile

4.2 Barepot Resource Zone

A review of uncertainty factors relevant to the Barepot Resource Zone concluded that there have been no significant changes to any of the assumptions, and as this is a simple supply system constrained by licence conditions and not by raw water availability there is no requirement to update the target headroom assessment for this resource zone. The profile of headroom percentiles calculated for the 2019 Water Resources Management Plan will therefore be adopted for the this plan also.

The risk profile selected for the Barepot target headroom allowance across the planning period was a fixed 95th percentile glidepath across the planning period of our 2019 plan (i.e. the risk fixed at five per cent). The target headroom allowance previously calculated for Barepot Resource Zone was shifted forward by five years to align with the required planning period for this plan.

Table 5 shows the selected profiles of target headroom percentile and corresponding risk for Barepot Resource Zone.

Table 5 Barepot Resource Zone - Selected target headroom profile

	2025	2030	2035	2040	2045	2050
Risk of understating the supply-demand balance	5%	5%	5%	5%	5%	5%
Headroom uncertainty percentile	95th Percentile	95th Percentile	95th Percentile	95th Percentile	95th Percentile	95th Percentile

4.3 Carlisle Resource Zone

As for the Strategic Resource Zone, our selected risk profile for the Carlisle Resource Zone is based on a probability of 80 per cent at the start of the period (representing a risk of 20 per cent that the target headroom allowance is exceeded), tapering down to a probability of 70 per cent in 2049/50 (30 per cent risk). The glide path of reducing percentiles across the planning period is in line with Environment Agency guidance and reflects that the later years allow increased time to plan and adapt to the uncertainty factors within the supply-demand balance.

The reasons for the selection of the 80 to 70 per cent profile are the same as those outlined for Strategic Resource Zone in section 4.3 above.

Table 6 shows the selected profiles of target headroom percentile and corresponding risk for the Carlisle Resource Zone (note that the same profile is adopted for both the dry year annual average and dry year peak week planning scenarios).

Table 6 Carlisle Resource Zone – Selected target headroom profile

	2025	2030	2035	2040	2045	2050
Risk of understating the supply-demand balance	20%	22%	24%	26%	28%	30%
Headroom uncertainty percentile	80th Percentile	78th Percentile	76th Percentile	74th Percentile	72nd Percentile	70th Percentile

4.4 North Eden Resource Zone

A relatively low risk (ten per cent) profile is appropriate for this resource zone as it is a relatively isolated supply system with limited interconnectivity and no surface water storage. The constant 90 per cent percentile profile reflects the fact that the modelled headroom uncertainty in this resource zone does not increase into the future to the same extent as the Strategic and Carlisle Resource Zones, as supplies are limited by abstraction licences and physical capacities rather than climate change.

Table 7 shows the selected profiles of target headroom percentile and corresponding risk for the North Eden Resource Zone.

Table 7 North Eden Resource Zone – Selected target headroom profile

	2025	2030	2035	2040	2045	2050
Risk of understating the supply-demand balance	10%	10%	10%	10%	10%	10%
Headroom uncertainty percentile	90th Percentile	90th Percentile	90th Percentile	90th Percentile	90th Percentile	90th Percentile

5. Adaptive planning approach

As outlined previously, we have also addressed key areas of future uncertainty through an adaptive planning approach. These key areas are climate change, demand forecast variation, our environmental destination and the magnitude and timing of national water trading. We have assessed a range of different scenarios, as set out in our *Technical Report – Deciding on future options*. In order to avoid any double counting of uncertainty within each alternative scenario, we created a number of customised target headroom profiles in which the probability distributions for certain components have been adjusted to represent the range of uncertainty applicable to one or more of the adaptive plan scenarios.

Table 8 presents a summary of the customised target headroom profiles, showing what adjustments were made to the baseline headroom assumptions in each case. These have been created for our Strategic and Carlisle resource zones only, as adaptive planning has not been undertaken for our Barepot and North Eden resource zones.

Note that uncertainty regarding our environmental destination (timing and magnitude of abstraction reductions) and the magnitude and timing of water trading are both excluded from our baseline headroom assessment, so there is no requirement to customise the headroom profiles for these factors. All other components, not shown in the table, have been retained with the existing assumptions as for the baseline headroom assessment.

Table 8 Summary of customised target headroom profiles for adaptive plan scenarios

	Changes to headroom uncertainty components	
Customised profile	S8 (Climate change impacts on supply)	D2 (Demand forecast variation)
Low climate (RCP2.6) and low demand	Uncertainty range defined by RCP2.6 probabilistic climate scenarios	Uncertainty range defined by variation around ONS 2018 main forecast
High climate (RCP8.5)	Uncertainty range defined by RCP8.5 RCM climate scenarios	No change from baseline headroom
Low climate (RCP2.6)	Uncertainty range defined by RCP2.6 probabilistic climate scenarios	No change from baseline headroom
Low demand	No change from baseline headroom	Uncertainty range defined by variation around ONS 2018 main forecast
High climate (4°C world) and high demand (no reduction in per capita consumption from 2025)	Uncertainty range defined by RCP8.5 RCM climate scenarios	Uncertainty range defined by variation around high demand forecast assuming no reduction in per capita consumption

6. Results

The combined headroom distributions generated by the Monte Carlo simulations are shown in Figure 5 to Figure 8 for each of our resource zones. The graphs show the variation in headroom for probability bands from five to 95 per cent for each planning scenario as applicable (the dry year peak week scenario is only applicable to the Carlisle Resource Zone).

Figure 5 Carlisle Resource Zone headroom distribution (dry year annual average)

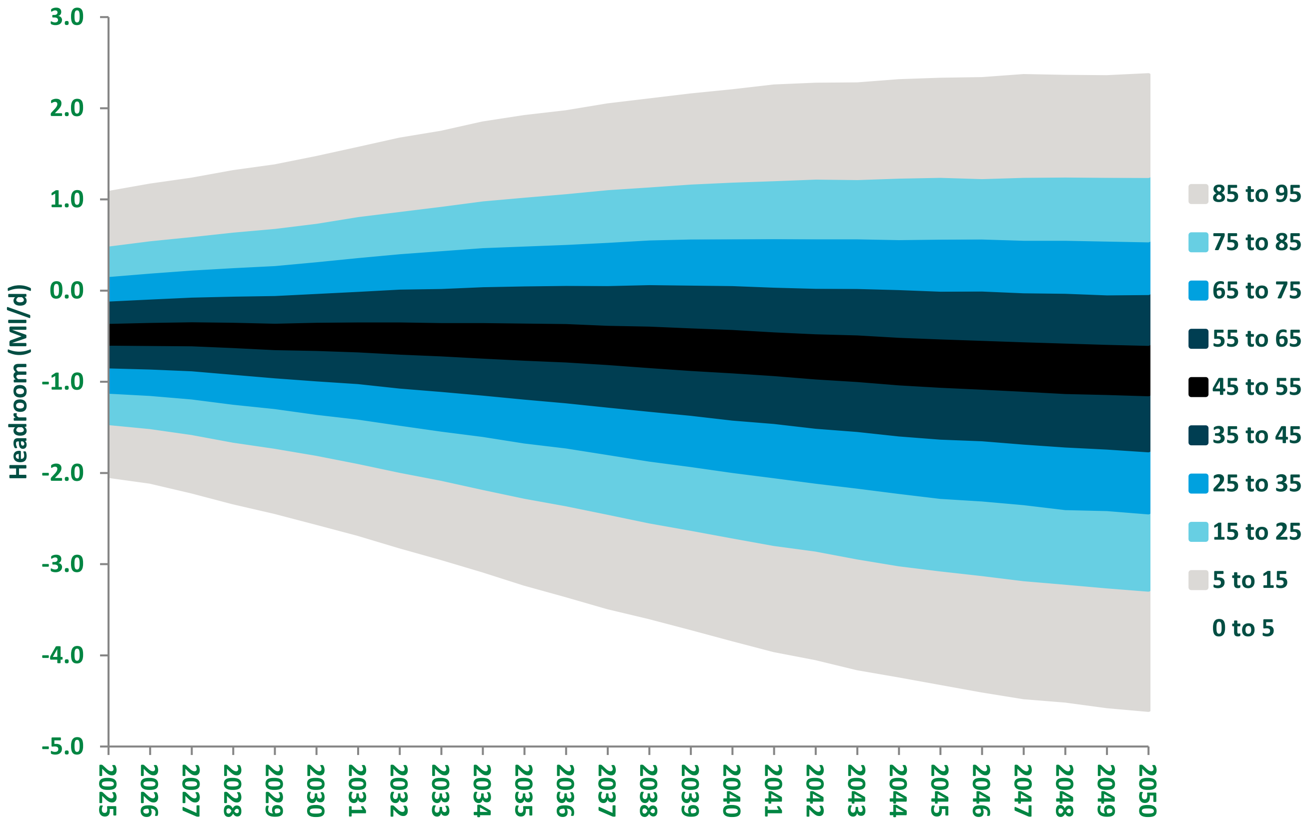


Figure 6 Carlisle Resource Zone headroom distribution (dry year peak week)

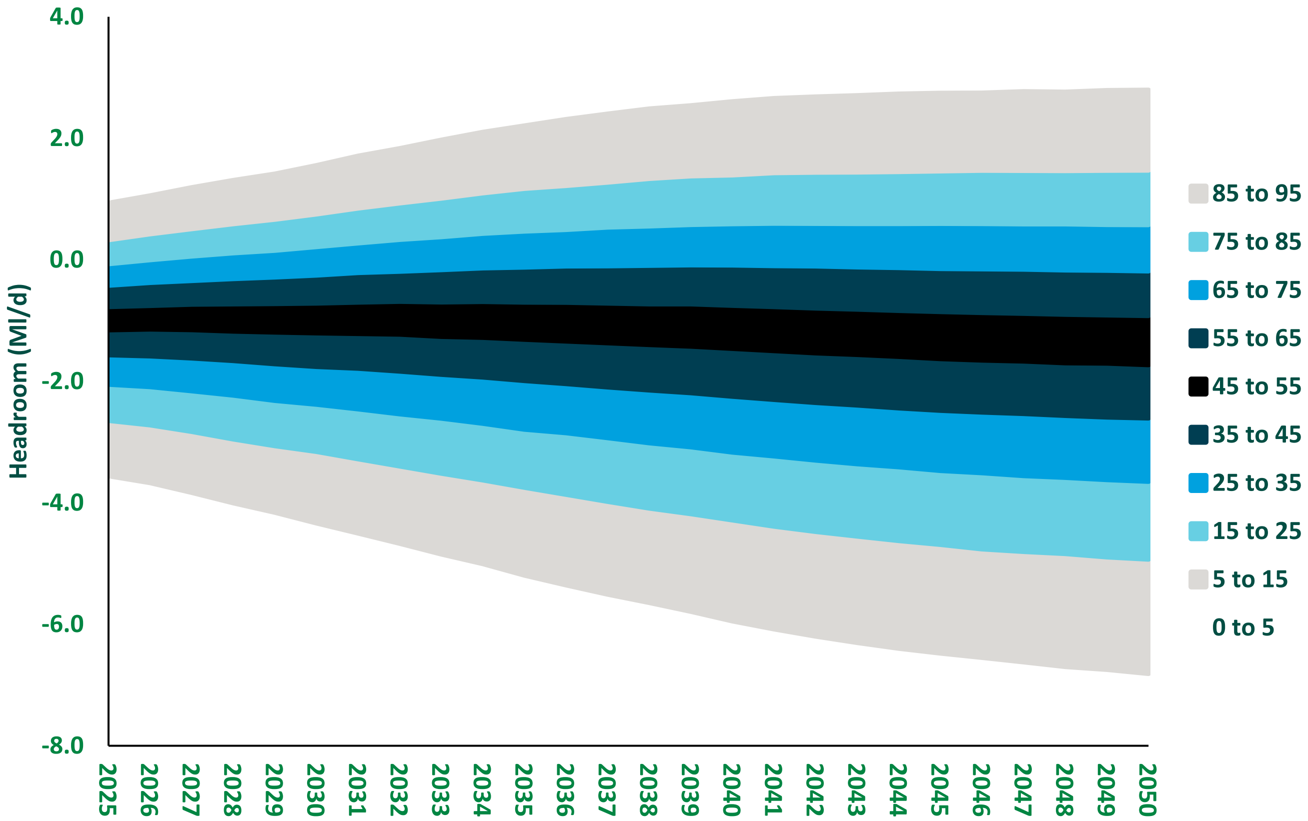


Figure 7 North Eden Resource Zone headroom distribution (dry year annual average)

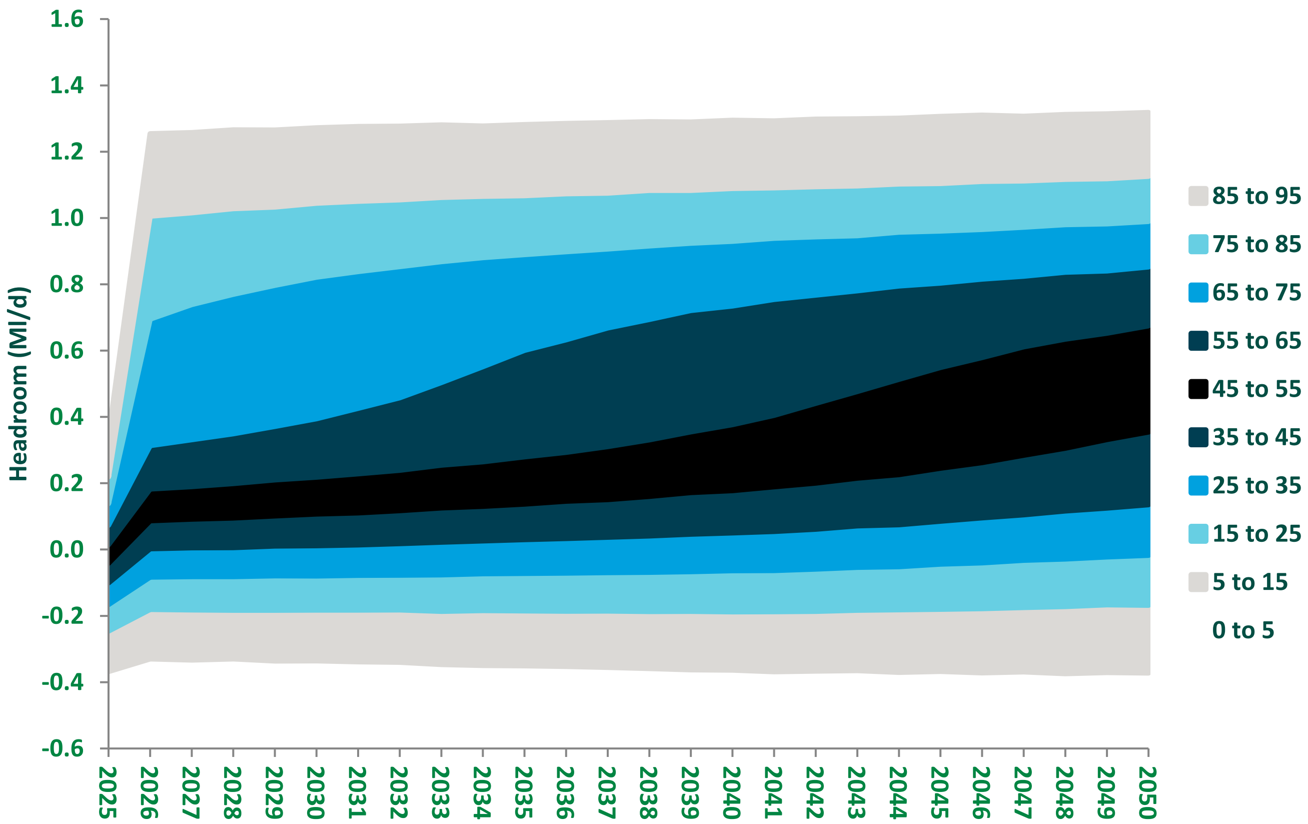
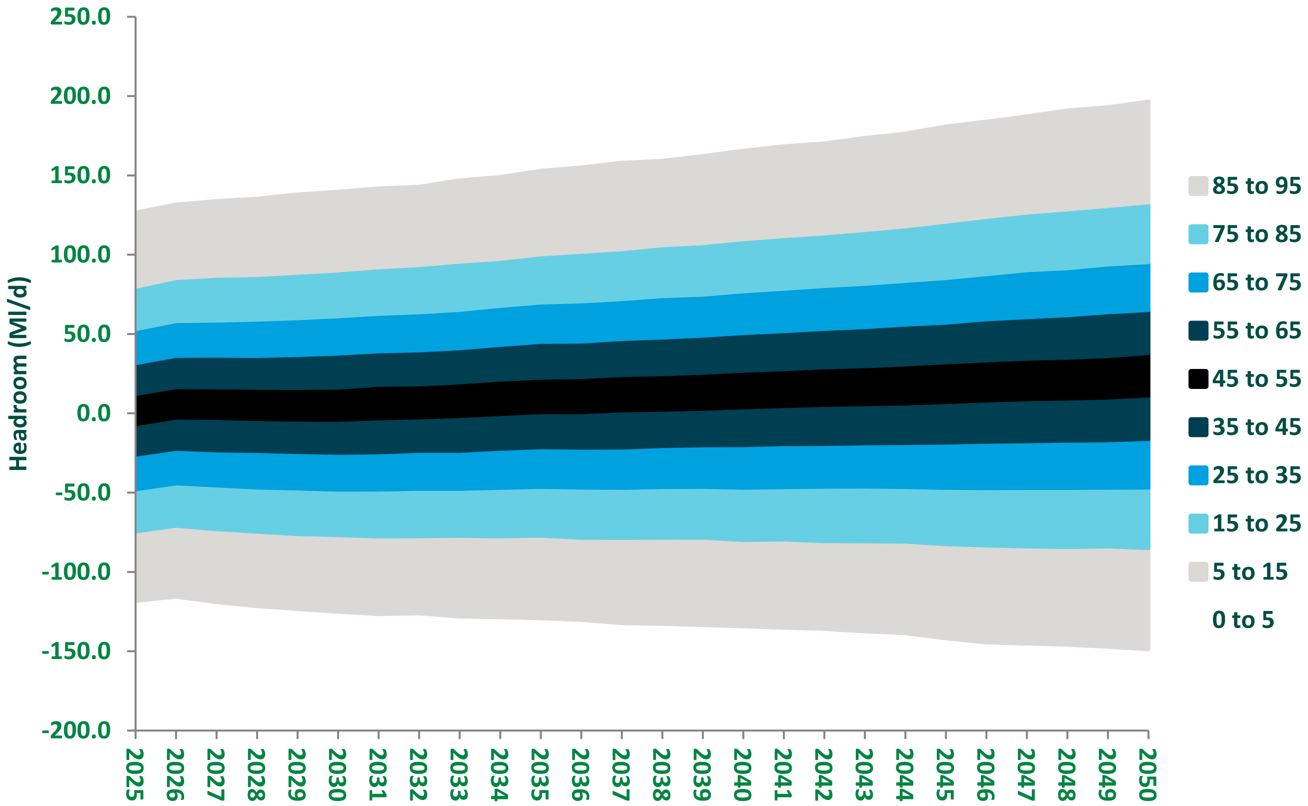


Figure 8 Strategic Resource Zone headroom distribution (dry year annual average)



The selected profiles of target headroom allowances for each of our water resource zones are shown in Table 9 and Table 10. Note that the dry year critical period planning scenario only applies to the Carlisle Resource Zone, hence this is the only resource zone shown in Table 10.

Table 9 Summary of target headroom allowance by Water Resource Zone (Dry Year Annual Average Planning Scenario)

	Dry Year Annual Average Target Headroom Allowance (Ml/d) for year:					
Water Resource Zone	2025/26	2030/31	2035/36	2040/41	2045/46	2049/50
Strategic	68.52	68.47	70.97	73.39	76.07	80.04
Carlisle	0.34	0.47	0.53	0.48	0.35	0.26
North Eden	1.12	1.15	1.17	1.18	1.19	1.20
Barepot	1.41	1.41	1.41	1.41	1.41	1.41

Table 10 Summary of target headroom allowance by Water Resource Zone (Dry Year Critical Period Planning Scenario)

	Dry Year Critical Period Target Headroom Allowance (Ml/d) for year:					
Water Resource Zone	2025/26	2030/31	2035/36	2040/41	2045/46	2049/50
Carlisle	0.16	0.38	0.50	0.46	0.29	0.19

6.1 Relative contribution of uncertainty components

It is not possible to provide a breakdown by component of the overall target headroom allowance values in Ml/d, due to the nature of the Monte Carlo simulation method, which combines statistical distributions by random sampling rather than by linear summation of individual component values. However, by analysing the output from individual distributions representing each component (or combined distributions for components which comprise a number of subcomponents, such as S5 and S6), it is possible to estimate the proportional contribution of each component to the combined target headroom distribution at the selected risk level for each year.

Figure 9, Figure 10 and Figure 11 below show the percentage breakdown of the target headroom allowance by component across the planning period for the Carlisle, North Eden and Strategic Resource Zones respectively.

The graphs indicate that in the early years of the planning period, target headroom is dominated by supply-side uncertainty (components S5 and S6, although S5 does not apply to the Carlisle Resource Zone). The impact of S5 in our North Eden and Strategic Resource Zones is initially relatively low; however, it does grow over time as the potential impacts of water quality issues become more significant in future years.

The relative impact of demand forecast variation is relatively static in the North Eden Resource Zone, whilst in the Carlisle Resource Zone dry year peak week scenario it increases significantly until around 2040, and then reduces somewhat to 2050. By contrast in the Strategic Resource Zone dry year annual average scenario, the relative contribution of demand forecast variation starts at less than 20 per cent and then declines steadily across the planning horizon as other factors such as climate change and water quality impacts become more significant over time.

Figure 9 Carlisle Resource Zone target headroom by component (dry year peak week)

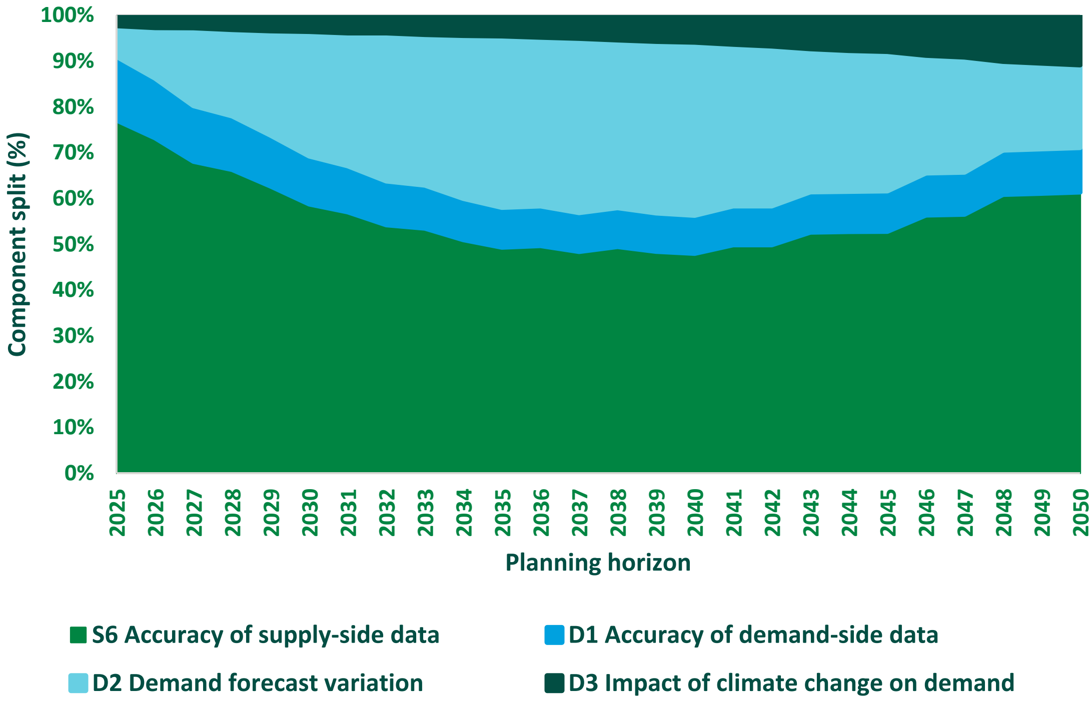


Figure 10 North Eden Resource Zone target headroom by component (dry year annual average)

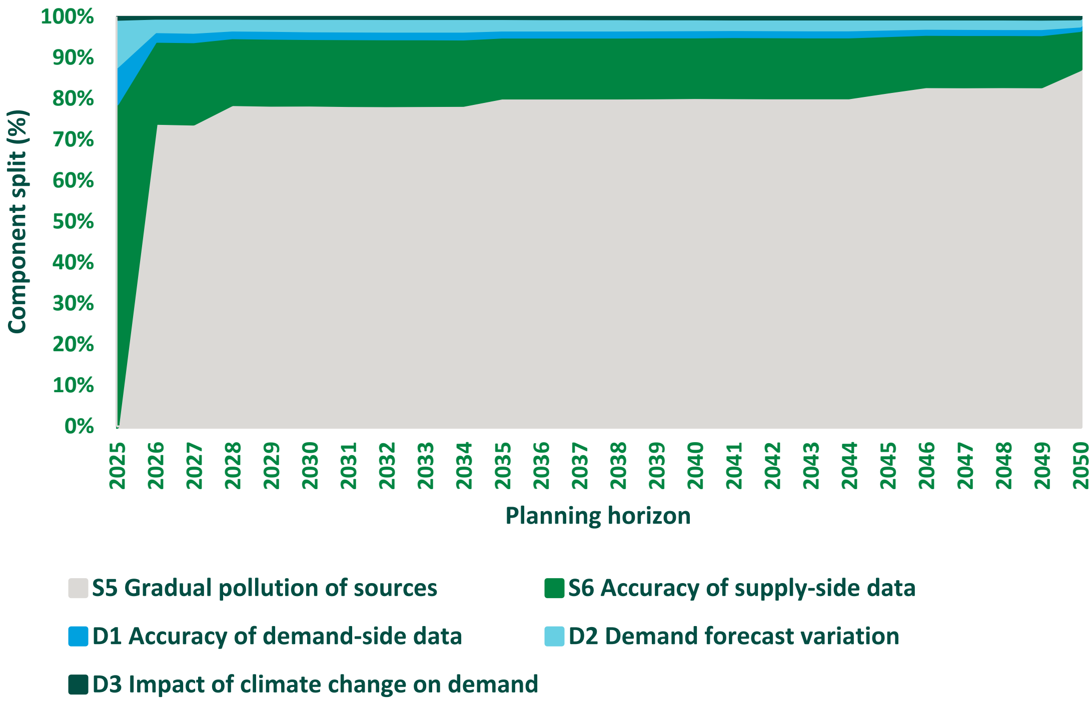
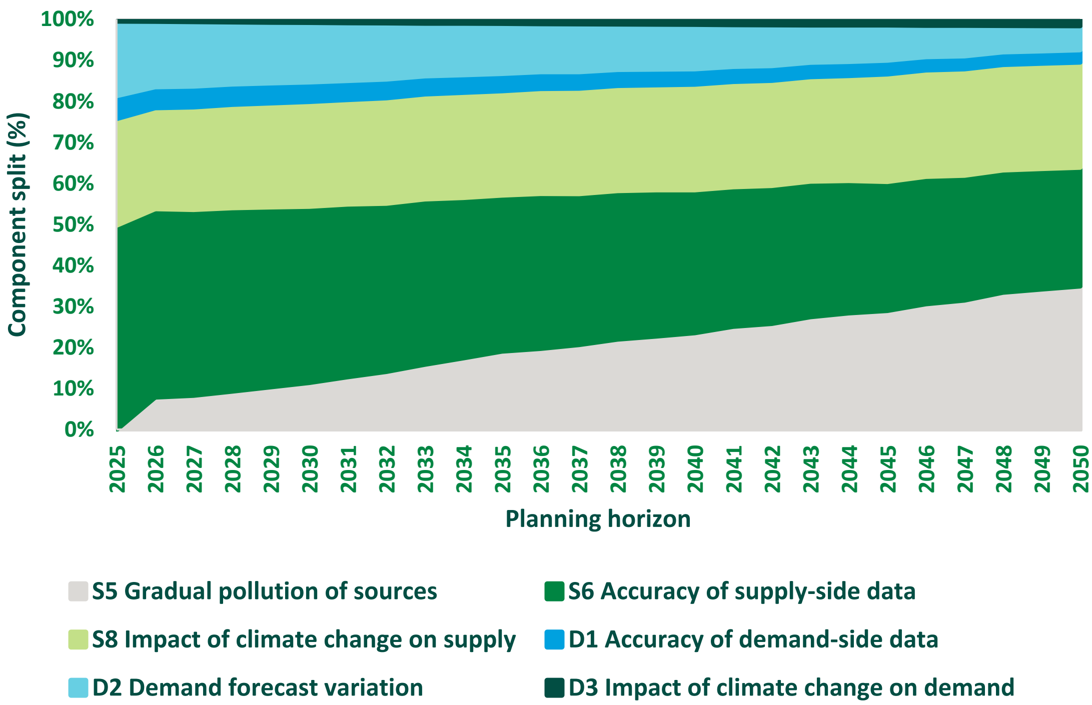
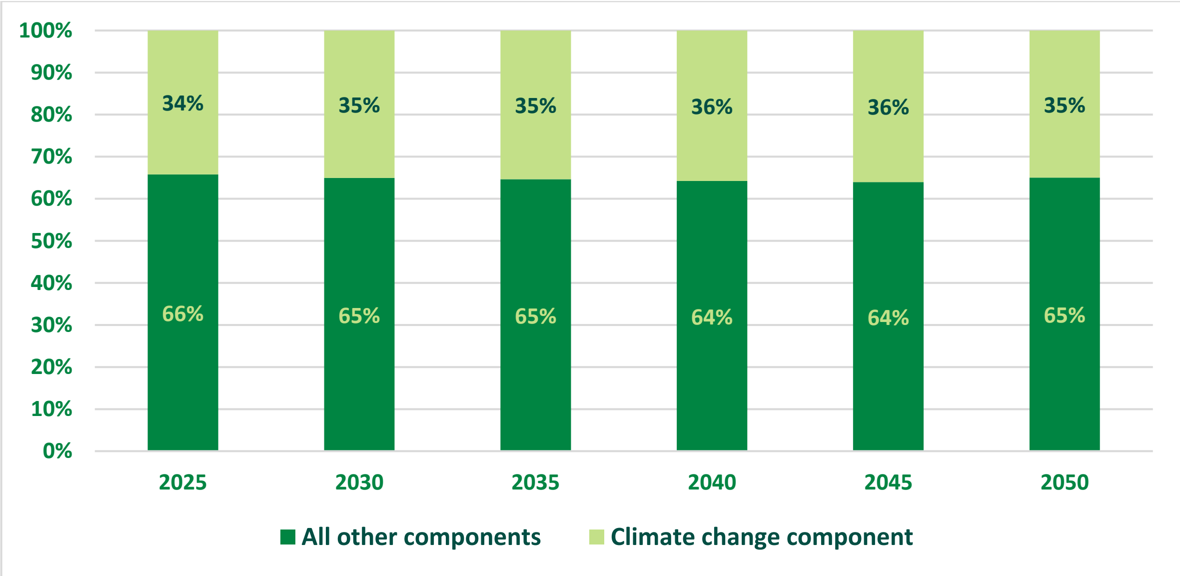


Figure 11 Strategic Resource Zone target headroom by component (dry year annual average)



The uncertainty in future climate change impacts on both supply and demand (factors S8 and D3 in the diagrams above) makes up approximately a third of the Strategic Resource Zone target headroom allowance (Dry Year Annual Average), as shown in Figure 12 below. The impacts of climate change on supply (factor S8) are the third largest contributor to the target headroom allowance for this resource zone, after the gradual pollution of sources (factor S5) and the accuracy of supply-side data (factor S6).

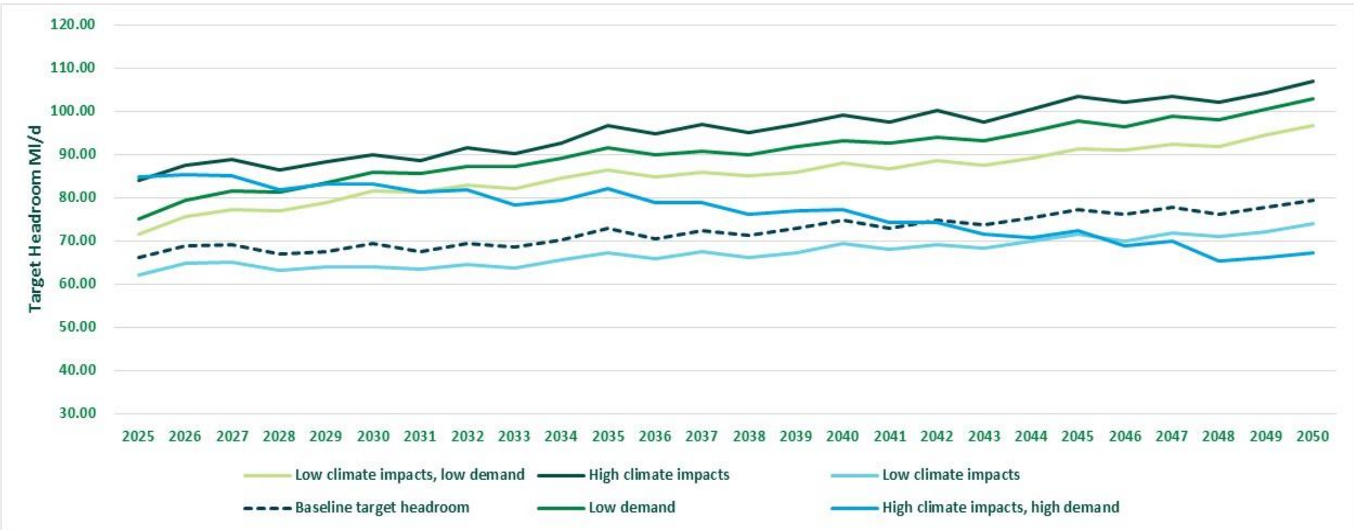
Figure 12 Contribution of climate change components to target headroom – Strategic Resource Zone



6.2 Target headroom for adaptive plan scenarios

As outlined in Section 5, we prepared a number of customised target headroom profiles with different uncertainty assumptions corresponding to the range of adaptive plan scenarios we have tested. The level of uncertainty varies in each assessment, depending on the adjustments made to the baseline headroom components, therefore the magnitude of the resulting target headroom profiles varies relative to the baseline target headroom profile. Figure 13 shows the adaptive planning target headroom profiles calculated for our Strategic Resource Zone.

Figure 13 Target headroom profiles for adaptive planning - Strategic Resource Zone



7. Conclusion

The target headroom assessment undertaken for the Water Resources Management Plan 2024 has included a full review of all relevant uncertainty factors in the supply-demand balance analysis for our water resource zones. Updates to the data and assumptions underpinning our target headroom Monte Carlo simulation have been implemented as and where appropriate, and this has included the addition of a number of new subcomponents compared to our previous (2019) assessment. For example, as our supply forecasts are now based on the use of stochastically generated hydrological data to determine supply estimates for a 1 in 500 return period, we have added a new headroom subcomponent to allow for uncertainty in our stochastic data sampling approach.

The profiles of target headroom allowances generated for each resource zone, using a carefully selected glide path of probability or risk across the applicable planning period, are added to our demand forecasts as a margin of uncertainty prior to determining the zonal supply-demand balance. This minimises the potential impact of future variations in our baseline forecast supply surpluses and/or deficits due to the range of uncertainty factors that have been assessed.

We have also addressed some of the key areas of uncertainty for our future supply-demand balance through our adaptive planning approach. Further details are provided in our *Technical Report – Deciding on future options*.

Appendix A Guidance and methodology references

Meeting our future water needs: a national framework for water resources (Environment Agency, March 2020).

Water Resources Planning Guideline Version 10 (Environment Agency, Ofwat and Natural Resources Wales, December 2021).

An Improved Methodology for Assessing Headroom (UKWIR, 2002).

Demand forecasting methodology WR-01/A and Forecasting Water Demand Components: Best Practice Manual 97/WR/07/1.

Impact of climate change on water demand (UKWIR, 2013).

Risk based planning methods (UKWIR, 2016).

Pathways to long-term PCC reduction (Artesia/Water UK, 2019).

Uncertainty and Risk in Supply & Demand Forecasting (UKWIR, 2002).

Regional Water Resources Planning Climate Data Tools – Operational Framework for Implementing the Supplementary Guidance on Climate Change (Atkins, 2021).

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