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Final Water Resources Management Plan 2019

Technical Report - Target headroom

Final WRMP19 Technical Report - Target headroom

Contents

1. Introduction

This document covers the approach to, and assessment of, uncertainty within the supply and demand forecasts for derivation of an appropriate target headroom allowance in our final Water Resource Management Plan 2019 (WRMP19). This version of the report also includes appropriate changes following consultation on our draft Water Resources Management Plan, which took place in spring 2018.

Target headroom is the buffer which is incorporated into water resource planning to protect customers from the uncertainties associated with the supply and demand forecasting over the planning period. Specifically, it is defined in the UKWIR 2002 guidance[1] as "the minimum buffer that a prudent water company should allow between supply and demand to cater for specified uncertainties (except for those due to outages) in the overall supply-demand balance".

Potential uncertainties include political, social, environmental, climate change and technical factors, such as the error associated with a measurement that may significantly influence components of the supply-demand balance.

The need for target headroom was recognised by the Environment Agency and water companies during preparation of the 1999 WRMPs, and was endorsed by government ministers in *Maintaining Public Water Supplies* (DETR, 1999) stating that a precautionary approach is necessary "in view of the vital importance of maintaining supplies". Principle Guidance from ministers (Defra, 2004) required water companies "to plan to have sufficient headroom and use appropriate methodologies and guidance to achieve this".

There have been some significant changes in the treatment of uncertainty in water resources planning since the 1998 guidance[2]. In particular, there are new methodologies for assessing the effects of climate change and the preparation of a new target headroom assessment methodology in 2012 (Water Resources Planning Tools). All assessments have been completed in line with the *Water Resources Planning Guideline*[3] (or 'planning guidelines'), and the relevant supporting UKWIR methodologies.

Determining target headroom consists of the following basic steps:

- Collate data and information on each area of uncertainty in the supply and demand forecasts;
- Combine all of these data into a single distribution of uncertainty for each year in the planning period; and
- For each year, select an appropriate level of risk to incorporate into the supply demand balance.

These steps are described in detail in the following sections. Target headroom is not the only way that we deal with uncertainty in WRMP19. We also assess a number of supply-demand balance scenarios for stress-testing purposes. Some are linked to our target headroom assessment, for example our "high demand" scenario assumes that we would experience the maximum level of demand in our uncertainty window. Our scenario work is outlined in our *Final WRMP19 Technical Report - Options appraisal*.

[1] An Improved methodology for assessing headroom – Report Ref No. 02/WR/13/2

[2] UKWIR (1998) A Practical Method for Converting Uncertainty into Headroom

[3] Water Resources Planning Guideline (Environment Agency and Natural Resources Wales, 2018)

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1.1 Changes from draft to final WRMP19

Change	Reason	Update(s)	Relevant section(s)
Update of all final headroom values and graphs	Due to re-baselining demand	Planned base year update from 2015/16 to 2016/17[4]	Sections 4, 5, and 6
Explain distribution used for each component	Environment Agency request[5] for additional detail in report summarising target headroom distribution choice for each component and rationale	Updated text on approach and, where the distribution alters from triangular, this is detailed in the relevant section 2.1 and Appendix A	Section 2.1
Added values for distributions with descriptions of how the values were calculated	As above, Environment Agency request[5] for additional detail on the values used within the target headroom distribution (for all headroom components)	Added to Appendices	Appendix A, Appendix B
Gradual pollution of sources causing a reduction in abstraction	Environment Agency request[5] to explain/justify inclusion of physical structure of groundwater assets in target headroom component S5 (or remove)	Clarified the rationale for the approach used for groundwater assets	Appendix C and Section 3.1.5

2. Methodology and approach

There are several methodology guidance documents which can be used to define the target headroom allowance. The 2002 methodology was developed by Mott MacDonald for UKWIR to address the acknowledged shortcomings of the previous, "practical methodology" produced by UKWIR in 1998. It provides a more robust and explicit assessment of headroom issues than the previous method. A new method of assessing the WRMP evaluation process has been published[6], the 'problem characterisation decision process'[7] which was used for WRMP19 to decide how headroom was calculated. From the 'problem characterisation decision process' it was determined that the 2002 methodology was appropriate for this WRMP.

For each of our resource zones the components were assessed and the data input into a model to calculate the final target headroom. Monte-Carlo analysis is used to combine the risks from each component of uncertainty to give an overall distribution for headroom uncertainty. This is achieved by running thousands of trials in which values for each uncertainty component are randomly selected from within the component distributions and then combined to give an overall headroom distribution.

The analysis is repeated for each year of the planning period. To produce a distribution of uncertainty from these component distributions, percentiles are chosen to determine the level of uncertainty, balancing the risk and cost for the customer, company and environment. This involves consideration as to whether headroom alone is driving investment, or if it represents a significant proportion of a resulting deficit (Section 4). Another aspect is considering when in the time horizon the impacts are being driven, so that we aren't investing now for uncertainty that may reduce in time. The uncertainty (buffer) is added to the demand forecast.

2.1 Approach

The overall method and components remained the same as WRMP15 in line with the UKWIR (2002) methodology. The target headroom was calculated for each of the four resource zones (Strategic, Barepot, Carlisle and North Eden), over a 25 year planning period (2021-2045), and beyond to 2080.

The components suggested in the methodology to consider, and where appropriate, include in the calculation of target headroom are shown below:

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[4] See Section 1.1 of our *Final WRMP19 Technical Report - Demand for water*
[5] From EA 'minor comments' list, provided separately from the EA formal consultation response for consideration
[6] Water Resources Planning Tools 2012 – Report Ref. No. 12/WR/27/6
[7] WRMP 2019 Methods – Risk Based Planning – UKWIR Report Ref. No. 16/WR/02/11

Supply related:

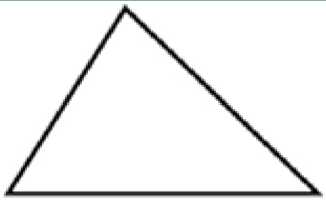
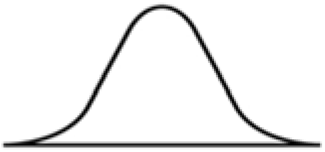
S1 Vulnerable surface water licences
S2 Vulnerable groundwater licences
S3 Time-limited licences
S4 Bulk imports
S5 Gradual pollution of sources causing a reduction in abstraction
S6 Accuracy of supply-side data
S7 Single source dominance and critical periods
S8 Uncertainty of impact of climate change on source yields
S9 Uncertain output from new resource development

Demand related:

D1 Accuracy of sub-component data
D2 Demand forecast variation
D3 Uncertainty of impact of climate change on demand
D4 Uncertain outcome from demand management measures

A probability distribution has been developed for each component to quantify the extent and likelihood associated with the uncertainty, depending on their characteristics. See Table 1 for common probability distribution functions. When determining the supply and demand forecasts the confidence in each element of the forecast dictates the parameters of uncertainty. The triangular distribution is the most frequently used, with the upper and lower bounds defined by the forecasting confidence; details of the distributions used for each component is detailed in Appendix 1. This link between all of the supply demand balance elements is an effective way of avoiding double counting uncertainty. Monte Carlo modelling was carried out (using @Risk Palisade software) for each resource zone on an annual basis over the planning period to determine the overall uncertainty distribution. For each resource zone, 10,000 trials were performed to derive the overall distribution for year.

Table 1 Common probability distribution functions (from UKWIR Water Resources Planning Tools (2012) Economics of Balancing Supply and Demand (EBSD) Report)

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 0	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

There have been relatively minor changes and refinements to the methods used to calculate the uncertainties associated with each of the headroom components, the details of which are outlined in the following sections.

The target headroom components can be seen in the Section 3. Aside from a general refresh of the supporting datasets, for WRMP19 the headline changes in approach are:

- 2080s UKCP09 projections selected for calculating the impact of climate change on deployable output in line with the latest regulatory guidance and using the latest water resources and hydrological model outputs (WRMP15 used projections for the 2030s). As a major headroom component, this has been a key driver of change in distributions and the size of target headroom. More information on the detail of climate change assessment can be found in the *Final WRMP19 Technical Report – Supply forecasting*;
- The accuracy of bathymetry data was added as an inherent supply-side uncertainty (albeit the impact of this addition is small);
- A refresh of the estimate of uncertainty based on the latest inflows[8] data, testing and appraisals. In particular, completing updates/revisions to inflow data and undertaking additional behavioural testing of the latest inflows methods. Better understanding of how hydrological data uncertainty differs between different inflow derivation types has been accounted for;
- As part of the latest demand forecasting, we explored whether other attributes of demand uncertainty should be included in item D2, for example, underground supply pipe leakage (USPL) and minor components; and
- As part of the change to water resource zones, consideration as to how the inclusion of West Cumbria supply area affects the Strategic Resource Zone.

[8] The calculation of unmeasured inflows into a reservoir from a water balance equation (change in storage plus compensation plus abstraction)

3. Components

A summary of the key supply and demand side uncertainty components included in the target headroom assessment is provided below.

3.1 Supply side components

This section outlines the uncertainty components for our supply forecasts (the baseline assessments are documented in the *Final WRMP19 Technical Report - Supply forecasting)*. For the Strategic and Carlisle Resource Zones, the components which have been included in this section relate directly to the uncertainty in the inputs into the supply side modelling software, Aquator^{TM} (this is a software package used to simulate our water resource systems in these more complex zones). Several aspects of the data input into the model are measured, the potential errors within these measurements are accounted for in this section of headroom. Not all of the components apply for North Eden and Barepot resource zones; where they do apply this has been stated and the uncertainty calculated.

3.1.1 S1: Vulnerable surface water licences

In accordance with the planning guidelines, no allowance has been made for uncertainties surrounding reviews of our abstraction licences. We are in continual dialogue with environmental regulators regarding the sustainability of our abstraction licences and any potential future need for changes. The Environment Agency provides sustainability changes to the water companies via the Water Industry National Environment Programme (WINEP). Any potential changes are identified well in advance of any implementation, which also allows for a process of determining the most appropriate changes, further investigations and potential mitigations. With regards the Water Framework Directive, our assessment in the plan shows that whilst there is some residual risk associated with the current abstraction licences, overall the operation of the licences, the reductions already noted by the Environment Agency and the schemes identified for the AMP6 investment period (2020-2025) should be enough to mitigate against any significant risks to the Water Framework Directive water bodies and they are therefore compliant with the requirements of the Water Framework Directive[9]. Therefore, on this basis there is no need to include this element in target headroom.

3.1.2 S2: Vulnerable groundwater licences

The planning guidelines, as detailed above in Section 3.1.1, also applies to this section. Therefore, there is no need to include this element in target headroom.

3.1.3 S3: Time-limited licences

The planning guidance states that '*time-limited licences which are due to expire during the period covered by the plan*' should be considered.

In dialogue with the Environment Agency we believe that renewal would occur if we were able to show:

- There is no damage to the environment;
- The need for the abstraction can still be justified; and
- Water is being used efficiently.

It is believed the only reason a licence would not be renewed would be due to a change in environmental conditions, such as climate change or where concerns are noted in relation to environmental objectives, e.g. Water Framework Directive (WFD). Engagement with the Environment Agency regarding renewing licences indicates there is not an issue at this time. The uncertainty in the impact of climate change is already accounted for in the headroom calculations in component S8. The only aspect which may potentially be incorporated into this component is the Water Framework Directive. In conjunction with the Environment Agency, a review of the potential licences which may be affected has been undertaken. This work feeds into the WRMP as a supply demand scenario rather than target headroom uncertainty, and as such is outlined in the *Final WRMP19 Technical Report - Supply forecasting*.

[9] Conclusion drawn from the *Draft Water Resources Management Plan 2019: Water Framework Directive Assessment* which is published alongside our *Draft Water Resources Management Plan 2019* and the accompanying technical reports.

As part of the consultation, the Environment Agency raised concerns regarding the Thirlmere time-limited licence. These concern primarily relate to the mitigation study, this study includes hydrological, geomorphological and ecological monitoring and aims to design a flow regime which would provide benefits to the ecology of St. Johns Beck downstream of Thirlmere Reservoir. We have requested confirmation that the Environment Agency does not plan any changes to other existing time limited licences, which our plan assumes will not be affected. From dialogue to date, we consider that our assumed renewal is appropriate to all abstraction licences and thus no additional allowance is needed.

Abstraction reform has not been included as part of the headroom calculation, to ensure there is no impact on deployable output. This is in line with the planning guidance, *'you should not plan for any changes to deployable output as a result of abstraction reform'*. It also states not to include uncertainty about sustainability changes within headroom (which are included in the WRMP as a supply demand balance scenario).

3.1.4 S4: Bulk imports

This is the uncertainty in the supply of an import into our network from another water company. All of our bulk imports are contractual agreements, and are therefore treated in the same way as our own abstraction licences, with no uncertainty included in headroom. No issues with the availability of our imports has been raised as part of our dialogue with the relevant companies.

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

This is the uncertainty in the deterioration of surface and groundwater sources due to pollution that will impact on the yield from that source[10]. For this assessment the surface and groundwater sources were assessed separately; where the yield is constrained by licence or water treatment work capacity it was not included.

As part of the review of surface water sources, 22 catchments were highlighted within safeguard zones where there is deteriorating water quality (e.g. colour or algae). As well the safeguard zone designation with the Environment Agency, risks are also mitigated through local algae management plans, catchment management interventions (for example, through our Sustainable Catchment Management Programme or "SCaMP") and treatment capabilities at our water treatment works. There are four sites which have been highlighted as increased risk in a supply-demand balance context. Rivington, Laneshaw, Mitchells and Castle Carrock are all at risk of reduced supply due to Geosmin and 2-Methylisobarneol (2-MIB). The solutions to these gradual pollution sources are due to be delivered by 2021/22 and 2022/23, as set out in the DWI reports. These four sites have not been included in headroom as the solutions are to be implemented at the beginning of the planning period. Due to these mitigations, we have identified that there is no need to include potential uncertainty around any permanent loss of yield for this component at this time, and any temporary loss of supply would be accounted for in the outage allowance.

The groundwater sources were reviewed to determine if there is uncertainty associated with the deterioration of:

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

The review resulted in applying uncertainty associated with future deployable output due to water quality risks. This was forecast for three specific periods in time: start of planning period (2020/21), middle of planning period (2029/30) and end of planning period (2044/45). For the supply-demand balance, linear interpolation was used between these periods to scale the risk accordingly. The risk assessments were supported by analysis of historical and current trends of raw water pollution monitoring. The review took into account any catchment measures/investigations into the water quality and the potential reduction these projects have on the rate and severity of the pollution on the groundwater sources. From the review it was determined that there was uncertainty associated with the deterioration of 23 boreholes in the Strategic Resource Zone and one borehole in the North Eden zone. The contribution to the uncertainty in headroom is outlined in Appendix C.

[10] This is location specific, and dependant on the catchment management section of the guidance

3.1.6 S6: Accuracy of supply-side data

We identified several components in the supply capability calculations where there was uncertainty in the data, these are detailed below:

- Hydrological data uncertainty (inflows/time series data);
- Modelling and operational uncertainty;
- Process and raw water losses;
- Groundwater data uncertainty;
- Compensation over-release;
- Demand saving uncertainty; and
- Bathymetry uncertainty.

Depending on the resource zone in question, the categories detailed above have been included.

3.1.6.1 Hydrological data uncertainty (inflows/flow time series data)

In our Aquator™ models the amount available for abstraction is determined from historic data which is based on inflows to reservoirs and flow time series for rivers and boreholes. There is an inherent uncertainty associated with inflow derivation methods and data used. The inflows and rainfall-runoff models have been refreshed, and where possible improved, with sensitivity testing also having been carried out on the data. 10% uncertainty has been applied to the Strategic, Barepot and Carlisle Resource Zones; this is due to the potential error in the measurement of the source data and the water balance calculations undertaken. There are no inflows for North Eden, which consists only of boreholes, and the constraints are related to licence limits or physical capacities rather than hydrological constraints; therefore there is no uncertainty in this respect.

3.1.6.2 Modelling and operational uncertainty

The Aquator™ model is a water resources simulation package. It includes control curves / operating policies for reservoirs which are derived as a guide to protect against minimum historic inflows. Operating to these in drought events of differing hydrological patterns could result in less than 'optimal' operation without taking into account other 'real-world' factors in reality. In a drought event, decisions will be made operationally based on the evidence available and the availability of water resources across the zone at the time. An allowance has been made for this uncertainty in deployable output estimate to represent that, in a large conjunctive system, real-life decisions could vary from the operation in the model setup.

Sensitivity tests have been completed during the testing of our Final Drought Plan 2018, which supported agreements and further definition on our use of strategic pumped sources. Our representation of water resources management in this plan is consistent with the Final Drought Plan 2018. This includes the outcomes of recent discussions with stakeholders on the operation of our strategic pumped sources.

For the Carlisle Resource Zone, in 2016 we undertook asset interventions to remove existing water quality constraints on River Eden to Castle Carrock pumping (to bolster the supply side of the balance). The project ensures that pumping the River Eden supply to Castle Carrock reservoir can be undertaken reliably at a higher storage level. Use of the pumps in line with the operation as specified in the Drought Plan 2018 has now become routine operation, and this removes an element of uncertainty around the support that the River Eden can provide to Castle Carrock included in WRMP15. Therefore, no operational uncertainty has been applied to this resource zone.

There is no model for the North Eden or Barepot Resource Zones therefore this component is not included in the headroom calculation for these zones.

3.1.6.3 Process and raw water losses

The uncertainty for process and raw water losses was broken down into two elements: the process loss uncertainty and the raw water loss uncertainty. For the raw water loss element, a Background and Burst Estimation (BABE) calculation was used, with an uncertainty of +/-25%. The process losses were calculated by breaking down where potential losses occur, through use of a questionnaire to the water treatment work (WTW) technical officers. Given the questionnaire style of data collection a 10% uncertainty was applied to the responses provided by the technical officers. The uncertainties calculated for the process loss and raw water loss for each WTW were then summed for the uncertainty of each water resource zone. For Barepot Resource Zone, no process losses were accounted for as it is non-potable water, with coarse screens being the only treatment.

3.1.6.4 Groundwater data uncertainty

For groundwater the uncertainty is in the hydrogeological data. It was found that for most sites the licence or physical asset capacities are the constraints. The uncertainty is based on the measurement of the groundwater data and pump efficiencies. A 10% uncertainty has been applied to the deployable output of the groundwater sources, this is supported by the groundwater assessments for climate change where most sources showed minimal sensitivity to groundwater levels.

3.1.6.5 Over-release (compensation and hands-off flow)

The uncertainty associated with the compensation over-releases consists of the:

- Accuracy of measurement of the river flows to identify an over-release to apply in supply modelling; and
- Variance around the over-release given operations to ensure that the statutory compensation amount is always released.

To calculate the compensation over-releases they were grouped into reservoir categories and an average of that category was then applied to all compensations within that grouping. The uncertainty was calculated as the minimum and maximum percentage over-release of the relevant category. We did not apply the statutory compensation as the minimum range, as it is expected that there would always be an over-release to ensure compliance with the licence.

For the hands-off flow buffer, a different method was used as it does not have a 1:1 ratio with the yield unlike the compensation releases. For the hands off flow, our Aquator^{TM} model was used to calculate the deployable output with and without the buffers in the model. This has been individually modelled for both the Strategic and Carlisle Resource Zones, the North Eden Resource Zone sources are boreholes only. For Barepot Resource Zone this has not been included, as the deployable output is based on the minimum amount that could be abstracted from the river.

3.1.6.6 Demand saving uncertainty

As part of the Aquator^{TM} model during periods of dry weather, customers are encouraged to become more water efficient and a saving is applied at drought trigger 4 as a demand saving reduction. Only the Strategic Resource Zone has demand saving applied; this is explained in the *Final WRMP19 Technical Report - Supply forecasting*. The expected saving due to demand saving restrictions is subject to uncertainty, yet can have an impact on the assessment of deployable output. In the baseline Aquator^{TM} model, a 5% saving at drought trigger 4 (mandatory temporary use ban) has been included throughout the year, in line with the Drought Plan 2018. Sensitivity testing determined the uncertainty, with a lower limit test of 3% saving at trigger 4 and an upper limit of 5% saving at trigger 3; this equates to a -31Ml/d and 12Ml/d range. Given historic data analysis there is no evidence that there are any significant demand savings from the implementation of temporary use bans in the Carlisle Resource Zone.

3.1.6.7 Bathymetry uncertainty

Bathymetry was added to the headroom calculation, as any uncertainty in this component can impact the overall reservoir storage, dead water storage and thus yield. We included this for completeness alongside the inflows uncertainty. As with any measurement undertaken there is an inherent uncertainty in the equipment's accuracy. For a bathymetry survey it is a combination of multiple equipment accuracy, weather influence and human error. These are usually reported as part of the bathymetric survey reports and a review of our current bathymetric survey reports provided an uncertainty of the measurements undertaken. Using the uncertainty quoted an uncertainty percentage was calculated (+/- 1.47%). It was assumed that there was a one to one relationship between the storage and yield of the reservoirs.

3.1.7 S7: Single source dominance and critical periods

This is not included in the methodology as detailed in the 2002 UKWIR methodology[11], because it is already accounted for in the supply-demand balance in the outage calculation.

3.1.8 S8: Uncertainty of impact of climate change on source yields

Since the last plan there has been a significant change in the planning guidelines as to how to calculate the impact of climate change and incorporate it into the plan. The main change as detailed in the *Final WRMP19 Technical Report - Supply forecasting*, is the calculation of the impact of climate change in 2080 and then scaling this back through the horizon to 1975. This results in a higher level of impact from climate change at the beginning of the planning period. Each of the water resource zones were analysed individually with varying levels of model complexity depending on the resource zone.

Due to the sheer number of projections, the complexity of the Strategic Resource Zone network and difficulties experienced during WRMP15, an emulator (simplified model) was created by Atkins using their Pywr software. This allowed 100 climate change scenarios to be modelled to help determine the shape of the headroom distribution (Figure 1). This is an enhancement over the WRMP15 method of modelling only 20 scenarios, which is a small number of values from which to create a distribution. Following this a representative 20 scenarios (see *Final WRMP19 Technical Report - Supply forecasting*) were modelled using the detailed Aquator™ model to improve the position of the distribution.

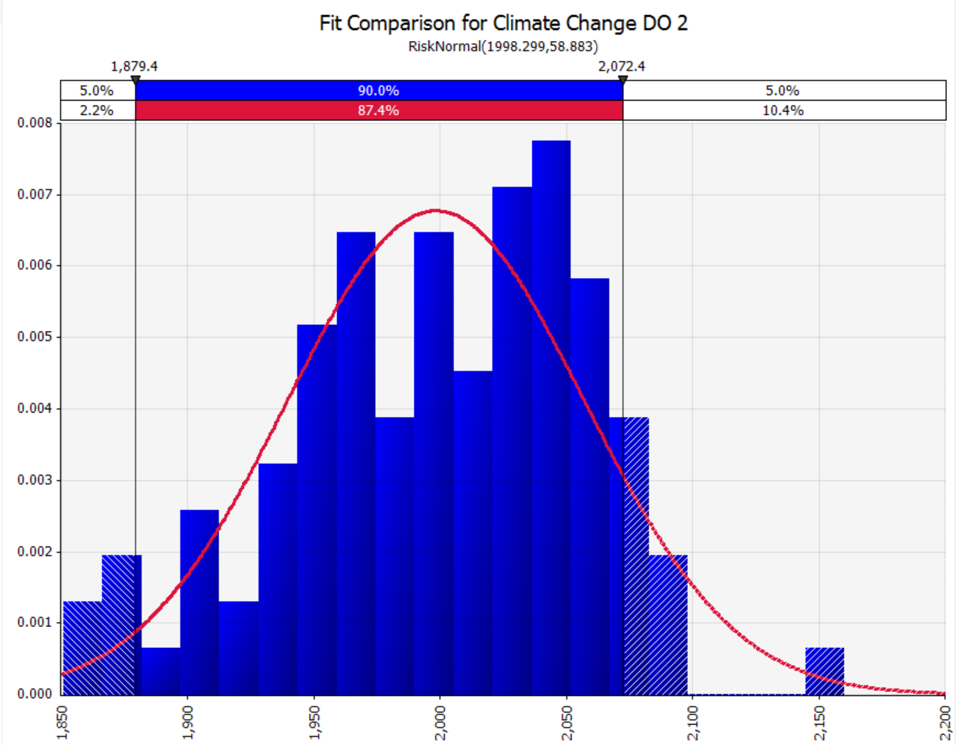
In summary, we used a combination of a large number of Pwyr model runs with lower accuracy and a small number of Aquator™ scenarios with higher accuracy to get the best overall result with the computing resources available. The headroom uncertainty was calculated using the difference between the deployable output impact of climate change and the potential distribution of that impact.

The climate change impact for the Carlisle Resource Zone was modelled using only an Aquator™ model and 20 scenarios. From this a discrete distribution was determined and applied to the headroom calculation. Building on our work in the Strategic Resource Zone, for future WRMPs we may look to increase the number of scenarios modelled to help define the shape of the distribution.

For the Barepot Resource Zone, the same approach as for the Carlisle Resource Zone was used. However, it found that there were negligible impacts of climate change on the resource zone and it was, therefore, not included in headroom.

For the North Eden Resource Zone, the climate change modelling showed that the constraints were the licences and physical asset capacities, and that any impact from climate change was not seen in the deployable output. Therefore, there is no climate change impact in the headroom calculations.

[11] An improved methodology for assessing headroom – Report Ref. No.02/WR/13/2



Statistics Grid

	Input	Normal
Minimum	1,850.79	−∞
Maximum	2,160.21	+∞
Mean	1,998.30	1,998.30
Mode	≈2,005.50	1,998.30
Median	2,005.50	1,998.30
Std Dev	58.88	58.88
Skewness	-0.4089	0.0000
Kurtosis	3.0214	3.0000
Left X	1,879.4	1,879.4
Left P	5.0%	2.2%
Right X	2,072.4	2,072.4
Right P	95.0%	89.6%
Dif. X	192.91	192.91
Dif. P	90.0%	87.4%
1%	1,850.79	1,861.32
5%	1,879.44	1,901.45
10%	1,911.91	1,922.84
15%	1,938.65	1,937.27
20%	1,953.93	1,948.74
25%	1,955.84	1,958.58
30%	1,967.30	1,967.42
35%	1,971.12	1,975.61
40%	1,984.49	1,983.38
45%	1,997.86	1,990.90
50%	2,005.50	1,998.30
55%	2,013.14	2,005.70
60%	2,024.60	2,013.22
65%	2,030.33	2,020.99
70%	2,037.97	2,029.18
75%	2,041.79	2,038.01
80%	2,049.43	2,047.86
85%	2,057.07	2,059.33
90%	2,066.62	2,073.76
95%	2,072.35	2,095.15
99%	2,085.72	2,135.28

Figure 1 The Strategic Resource Zone distribution from the 100 emulator results

3.1.9 S9: Uncertain output from new resource development

In the draft plan, we were forecasting a surplus in all resource zones, hence there being no driver for new resource development in the context of this component. However, since updating the base year for the final plan, there is a small deficit at the very end of the planning period in the Strategic Resource Zone. This small deficit will be more than countered by the leakage reductions included in the preferred plan (see Section 7.4 of the *Final WRMP19* main report), hence there is no driver for new resource development in this context. However, we do have a strategic choice to continue to explore water trading (see Section 6.5 of the *Final WRMP19* main report) and, if it were to happen, this would likely involve new resource development. Water trading is still subject to confirmed need in future, and therefore the precise nature and timing of any options to facilitate trading will alter over time. As a long-term strategic question, this position is expected to develop further following this planning cycle and be revisited in Water Resources Management Plan 2024. Therefore, we have not included an allowance for this uncertainty in target headroom for this plan. However, in any case, uncertainty in the Strategic Resource Zone for trading options is dealt with in part through direct simulation of key uncertainties (drought risk and climate change) in the extended methods process[12]. Furthermore, as we consider the main uncertainty / risk would be linked to the effects of climate change, we included a specific analysis step in option secondary screening[13] to remove any options which were deemed as being at high risk from climate change.

[12] *Final WRMP19 Technical Report - Options appraisal*
[13] *Final WRMP19 Technical Report - Options identification*

3.2 Demand side components

A summary of the key demand side uncertainty components included in the target headroom assessment is provided below. Further information on the base assessments and a detailed account of uncertainty derivation is also included in the *Final WRMP19 Technical Report - Demand for water*. The uncertainty has been informed through running scenarios and sensitivity testing when building the demand forecasting model.

For the final plan submission, target headroom has been updated to reflect revisions to the demand forecasts, derived from a 2016/17 base year[14] (see *Final WRMP19 Technical Report - Demand for water*).

3.2.1 D1: Accuracy of sub-component demand data

This reflects the fact that demand cannot be measured with total accuracy due to error in meters and measurement. To align with the uncertainty applied to our regulatory reporting data, an allowance of up to +/-1.02% of dry year demand (central forecast) has been applied to each of the resource zones using a triangular distribution to cover meter inaccuracies that may impact upon demand based data.

3.2.2 D2: Demand forecast variation

This section relates to a range of forecasting uncertainties in the household, non-household and minor components of demand. The *Final WRMP19 Technical Report - Demand for water* gives an overview of how the central forecast for each component is derived. Around this central forecast, upper and lower-bounds for uncertainty were calculated. This component was more heavily impacted by the base year update[15] discussed above. Whilst the end of the forecasting period remains static in 2045, the forecast is over a shorter period, given the later base year. In the draft plan, 2016/17 used 'forecast' data with its inherent uncertainties, whereas for the final plan it now uses observed data (e.g. free meter optants, properties). Uncertainty is thus applied from a later point in time, and over a shorter period. This is the primary reason for the reduction in the assessed target headroom between our draft and final plans, as shown in Section 7, which is particularly noticeable at the start of the planning period.

The upper target headroom forecast consists of the following factors:

- Unmeasured occupancy increases, associated with the Free Meter Option;
- Lower household consumption reduction, demand savings from the Free Meter Option and micro-component rates;
- Non-household consumption - 'Northern powerhouse' high economic growth scenario;
- Upper-bound 'dry year' uplift factor applied to household consumption/usage (+3%); and
- Five year maximum annual average value on minor components.

The lower forecast consists of the following factors:

- Use of "trend based" population and property forecast;
- Non-household consumption - Low economic growth scenario;
- Lower-bound 'dry year' uplift factor applied to household consumption/usage (-3%); and
- Five year minimum annual average value on minor components.

The variation between the upper, central and lower forecasts has been accounted for in the headroom assessments using triangular distribution.

This component was not relevant for the Barepot Resource Zone as it is a non-potable supply only.

3.2.3 D3: Uncertainty of climate change on demand

This uncertainty relates to the impact weather and climate change has on demand. For the upper forecast the 90th percentile impact and for the lower forecast the 10th percentile impact were used from the impact of Climate Change on Water Demand UKWIR project, accounting for the 'Northern Powerhouse' and 'lower' demand scenarios.

[14] We used 2015/16 as the base year for our draft plan submission. However, we stated in our *Draft Water Resources Management Plan 2019* that we would likely make this change to incorporate more recent demand data.

[15] Components D1 and D3 have also been impacted, however, the impacts were relatively small (a circa. 0.2 Ml/d increase related to D1 and a circa. 0.02 Ml/d related to D3) compared to the impact on component D2 (a circa. 10 Ml/d reduction).

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: Uncertainty in benefit of demand-side solutions

As per new resource development (Section 3.1.9) there are no supply-demand balance drivers for demand-side solutions. However, we have a strategic choice to enhance leakage reduction, and the balance between uncertainty and reliability has been a key factor in defining our leakage reduction programme (see *Final WRMP19* main report Section 7.4). There is considerable uncertainty in some of our leakage reduction options, particularly those related to innovative technologies or third party suppliers. These options have been selected within our leakage programme to occur slightly later within the planning period to allow a number of trials to be run to determine the uncertainty, and allow future planning rounds to make any adjustments, if appropriate. However, as stated in the main report, the precise combination of options or solutions to achieve the target leakage savings may change in future planning cycles based on the outcome of trials, practical experience, revised options costings etc. Any options with significant residual uncertainty have the potential to be replaced by other solutions in time.

3.3 Inter-dependency, correlation and mutual exclusion

3.3.1 Inter-dependency

As with WRMP15, no components are dependent on another component.

3.3.2 Correlation

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. This allows for climate change effects resulting in concurrent higher demand and lower deployable output. This is consistent with the approach taken for WRMP15.

3.3.3 Mutual exclusion

As with WRMP15, no components are mutually exclusive.

4. Percentile Choice

Once all the components as detailed above have been input into the headroom model a percentile choice is incorporated into the calculation to determine the confidence or level of risk that we will plan for. Depending on the amount of surplus available in the supply-demand balance the percentile choice can determine the amount of investment that goes into the plan over the planning period; it is therefore a carefully considered choice. Our percentile choice has been informed by interpretation of our data (position of central forecast and uncertainty), industry benchmarking and aligning with the planning guidelines (or supporting UKWIR methodologies).

These glide paths ensure an appropriate balance between taking adequate measures to safeguard the reliability of supply to customers and the avoidance of unnecessary costs. The factors which influence the choice of risk levels include:

- **Customer requirement for reliable, continuous supply of water:** This requirement has been consistently expressed by customers, for example, in customer surveys undertaken for the WRMP and business plan;
- **Consequences of failure to provide adequate supplies:** These are likely to include more frequent temporary use bans or drought permits/orders than the target level of service, and an elevated risk of needing extreme measures such as rota-cuts, standpipes or bowsers in severe droughts. Each of these would result in adverse or potentially hostile reaction from customers. Significant extra costs are also incurred when the possibility of drought emerges. These costs include additional publicity and promotion of water efficiency, short-term uneconomic demand management activity, contingency works to increase water availability in locations most severely affected etc.;
- **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):** A higher risk can be adopted in longer term planning, beyond the scheme planning and implementation horizon, as there is an

opportunity to wait and see how some of the uncertainties develop before needing to commence detailed planning;

- **The financial and/or environmental costs of providing supply-demand solutions:** The extent of financial and environmental costs may affect customers' willingness (or not) to accept a higher risk on the future achievement of the target level of service. For example, if major schemes with high costs are required to resolve potential future supply-demand uncertainties, customers may prefer that we delay expenditure until the issues are more certain, but if lower costs/impacts are involved customers are more likely to require that schemes be implemented to ensure adequate future levels of service; and
- **The scale of future uncertainties:** In accordance with regulatory guidance we have made no allowance for abstraction reform. Similarly, we have not sought to include uncertainty for unknown potential changes to environmental or other legislation.

We select a percentile for each year in the planning period. In the previous WRMP two separate "glide paths" of percentile choices were used in the final data, a constant 50th percentile for the climate change uncertainty component and 95-70th percentile (from 2020-2045 respectively) for all other components. This was due to the previous risk of undertaking significant future investment on the basis of very uncertain climate change analysis (carried over from WRMP09 to WRMP15). In WRMP19, however, we have a better understanding of climate change uncertainty, and a 50th percentile choice would be inappropriate. We have therefore used the same glide path for all components.

For this plan a variety of glide paths were considered and sensitivity testing was carried out across the risk profile to identify the target headroom risk values from the probability distributions of headroom uncertainty, see Figure 2[16]. The graph shows the impact in Ml/d on the Strategic Resource Zone supply-demand balance depending on the percentile chosen. The higher the percentile chosen the higher the confidence in the uncertainty calculated and in the supply and demand data. This is one reason why the percentile paths usually decrease over the planning period, as there is less confidence that the uncertainty calculated in 25 years' time is as accurate as in five years. Another reason for the percentile to decrease over the planning period is so that the headroom does not drive potentially unnecessary investment, as described above in relation to climate change.

[16] In line with the UKWIR WR27 methodology

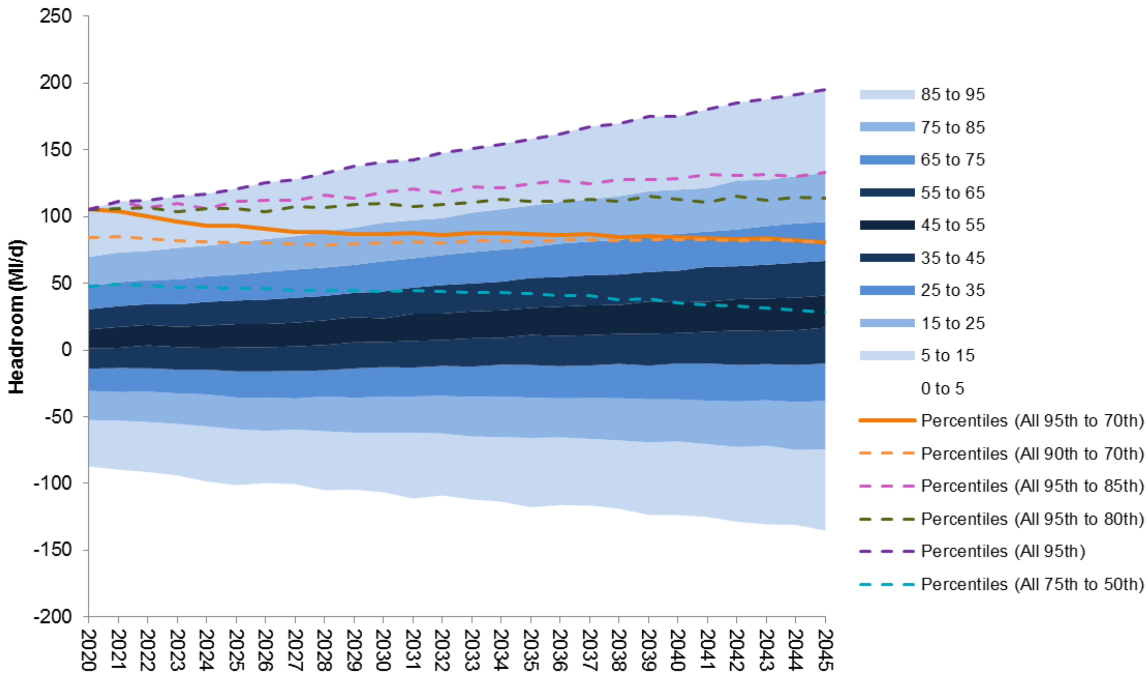


Figure 2 Illustrative results for headroom uncertainty for the Strategic Resource Zone with various risk profiles considered

A varying level of headroom risk over the planning period has been applied with a higher level of risk in future years than at present for the Strategic and Carlisle Resource Zones, 95th to 70th percentile (solid orange line in Figure 2). Therefore only 5% risk is applied at the beginning of the planning period (2019/20) and *via* an increasing profile, 30% at the end of the planning period (2044/45) as outlined in Table 2. This increase in profile is to account for the opportunity for our plans to be modified and adapted to changing circumstances, to prevent the risk of planning long-term investment on the basis of high uncertainty. This percentile choice does not trigger any deficit and hence investment in these resource zones.

A different approach of a continuous percentile choice of 5% uncertainty (95th percentile) was chosen for the North Eden and Barepot Resource Zones, see Table 3. Initially for the North Eden Resource Zone we applied the 95th to 70th percentile glide path, however, it resulted in a minuscule level of target headroom in 2045. Following engagement with the Environment Agency, a constant 95th percentile was applied throughout the planning period. This reflects that the uncertainty in the North Eden 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. The situation is the same in the Barepot Resource Zone, hence the same principles and glide path were applied.

Table 2 Summary of risk profile used to derive target headroom values for Strategic and Carlisle Resource Zones

	2019/20	2029/30	2039/40	2044/45
Risk of understating the supply-demand balance	5%	17%	26%	30%
Headroom uncertainty percentile	95th percentile	83rd percentile	74th percentile	70th percentile

Table 3 Summary of risk profile used to derive target headroom values for North Eden and Barepot Resource Zones

	2019/20	2029/30	2039/40	2044/45
Risk of understating the supply-demand balance	5%	5%	5%	5%
Headroom uncertainty percentile	95th percentile	95th percentile	95th percentile	95th percentile

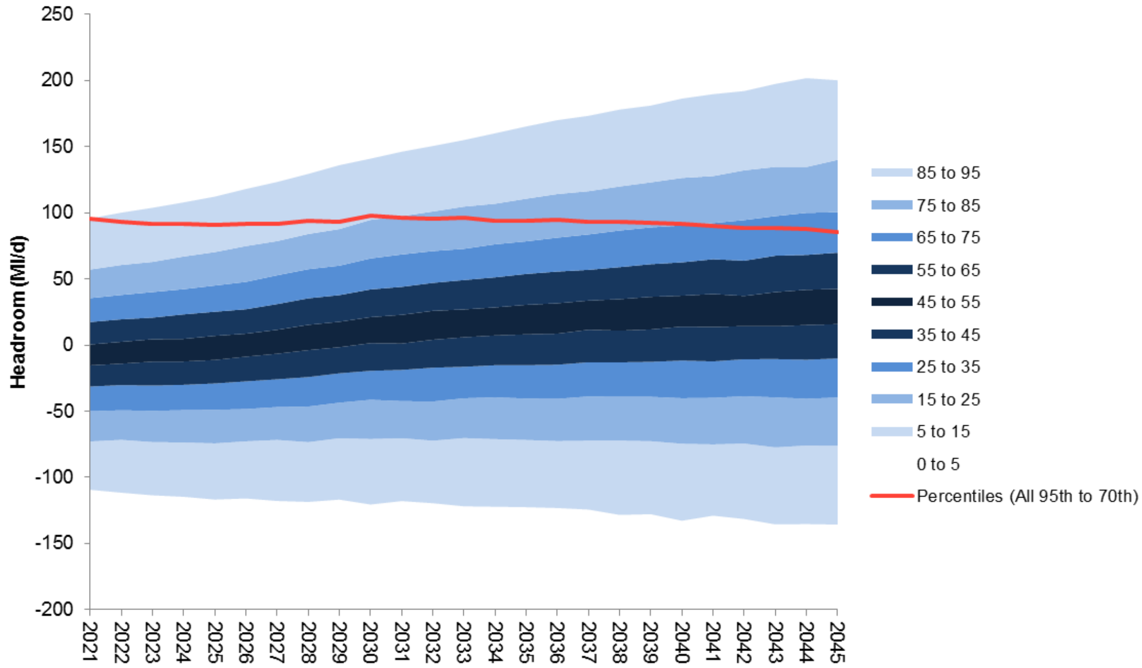


Figure 3 shows the illustrative results for headroom uncertainty for the Strategic Resource Zone as well as the results of the selected risk profile:

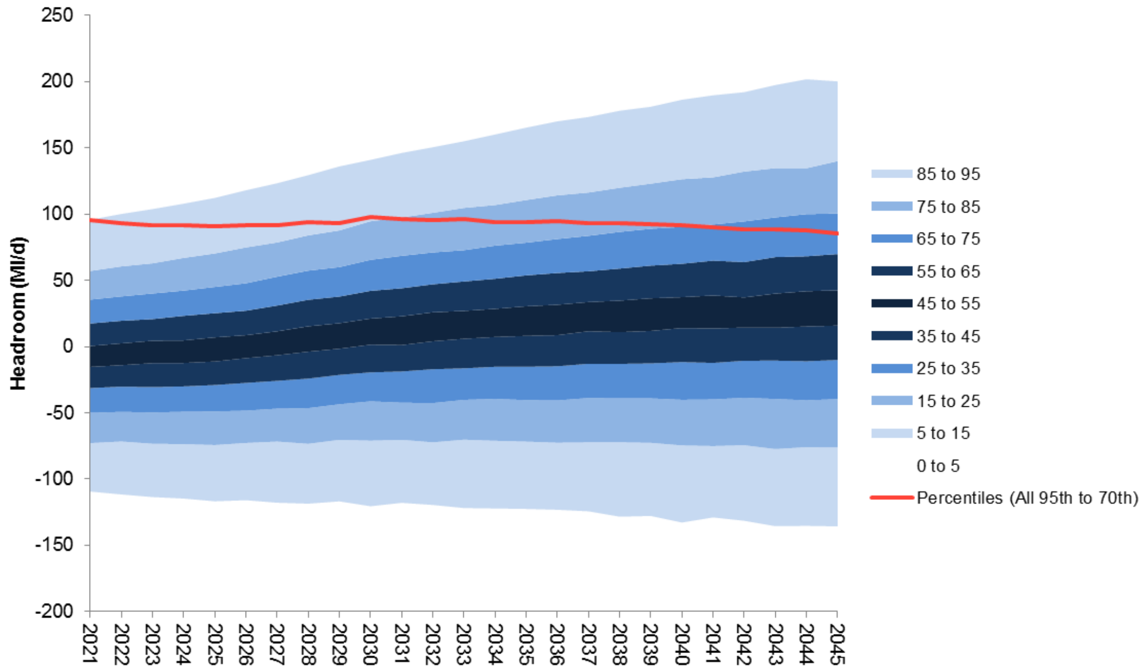


Figure 3 Illustrative results for headroom uncertainty with risk profile for the Strategic Resource Zone

4.1 Component breakdown across planning period

The breakdown of components that make up the target headroom across the planning period is shown for each of the resource zones in the figures below. For the Carlisle and Strategic Resource Zones there is a large influence from climate change; this is as expected due to the large proportion of water which comes from surface water. The other two major components are S6 and D2 the supply and demand forecast modelling uncertainty; a large proportion of this is due to the inherent uncertainty in modelling. Barepot Resource Zone is composed of only S6.

Table 4 Summary of components

Supply Side		Demand Side	
S1	Vulnerable surface water licences	**D1**	Accuracy of sub-component data
S2	Vulnerable groundwater licences	**D2**	Demand forecast variation
S3	Time-limited licences	**D3**	Uncertainty of impact of climate change on demand
S4	Bulk imports	**D4**	Uncertain outcome from demand management measures
S5	Gradual pollution of sources causing a reduction in abstraction[17]		
S6	Accuracy of supply-side data		
S7	Single source dominance and critical periods		
S8	Uncertainty of impact of climate change on source yields		

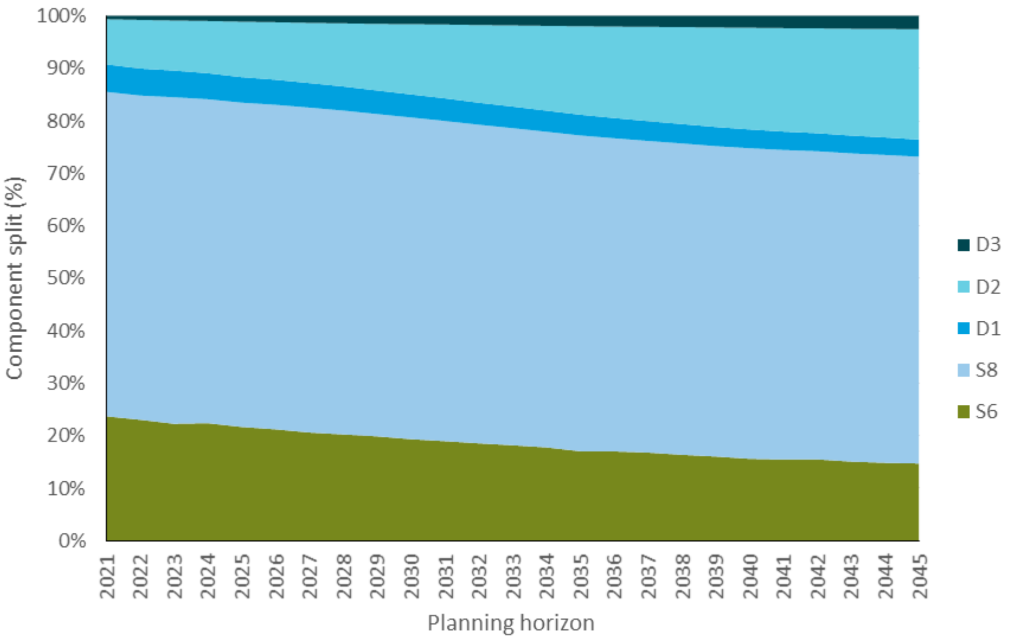


Figure 4 Proportion of each component that makes up the target headroom across the planning period for Carlisle Resource Zone

[17] This is location specific, and dependant on the catchment management section of the guidance.

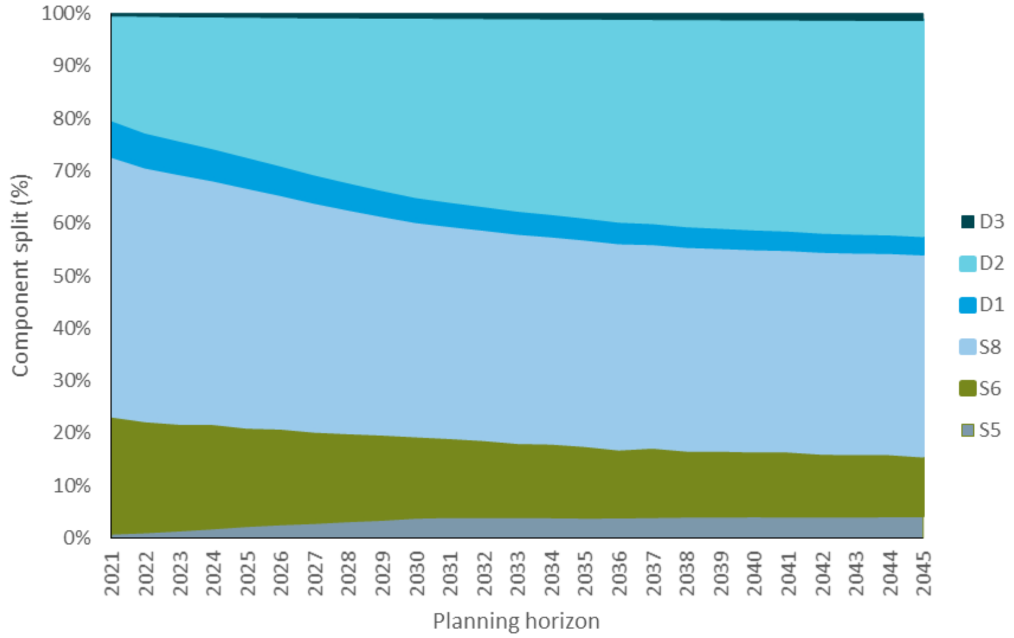


Figure 5 Proportion of each component that makes up the target headroom across the planning period for Strategic Resource Zone

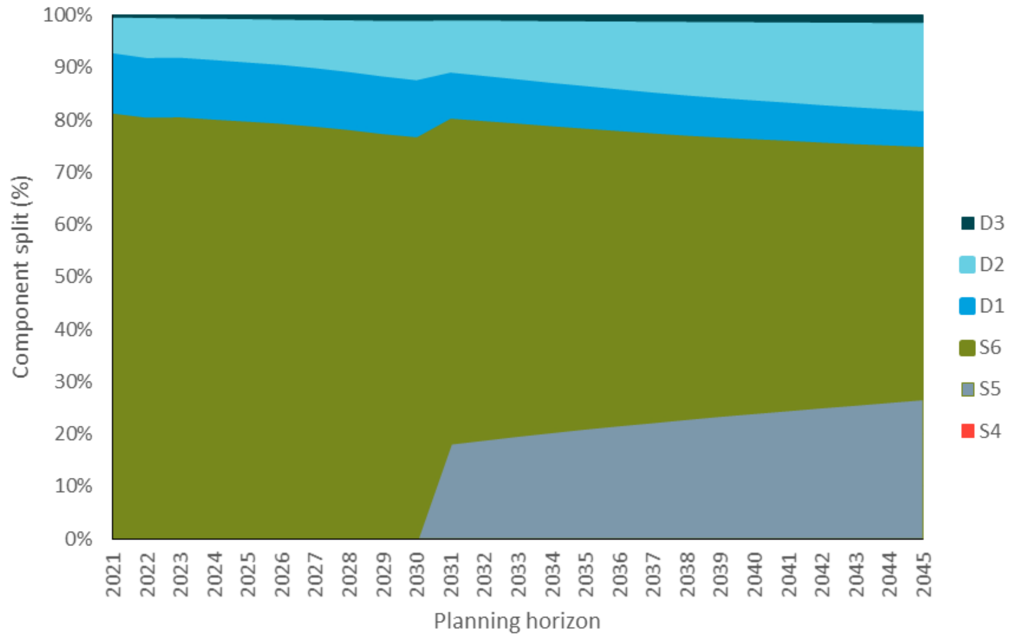


Figure 6 Proportion of each component that makes up the target headroom across the planning period for North Eden Resource Zone

5. Sensitivity analysis

As discussed previously, for the baseline supply demand balance the risk profile we used to derive our headroom values for the Strategic and Carlisle Resource Zones reduces from the 95th percentile at the beginning of the planning period to the 70th percentile by the end of the planning period, i.e. less confidence in our supply-demand balance in the longer term. For the North Eden and Barepot Resource Zones a continuous 95th percentile was used. These were defined in the draft plan when the percentiles chosen did not cause a deficit. Since the re-baselining of the plan there is now a small deficit at the end of the planning period[18], which is rectified by the leakage reductions in the final plan[19], therefore it was determined that the risk profile would not be altered.

Varying risk percentile profiles have been investigated on the impact of the baseline supply-demand balance. For the Strategic and Carlisle Resource Zones risk profiles of 95th to 80th percentile and 95th to 60th percentile were tested, Table 5 shows the resulting differences in supply-demand balance. The sensitivity testing showed that 95th to 70th percentile risk profile represented an appropriate level of confidence, with the leakage reductions that both zones remain in surplus whilst ensuring a relatively high confidence in meeting the supply-demand balance.

If the 95th to 80th percentile risk profile had been chosen in the final plan there would have been a deficit in the Strategic Resource Zone which would have driven investment, as shown in Figure 7. If we had chosen this percentile profile, it would have driven investment on the basis of future uncertainty, which we would better understand in future WRMPs (process repeated every five years). However, it should be noted that by implementing further leakage reductions as part of the plan there is no supply-demand balance deficit under the 95th to 80th percentile choice.

Table 5 The impact varying risk profiles have on the baseline supply-demand balance (Ml/d)

Water Resource Zone	Risk Percentile profiles	Target headroom values (Ml/d)	
		2020/21	2044/45
Strategic	95th to 80th	95.772	117.97
	95th to 70th	95.772	85.314
	95th to 60th	95.772	55.937
Carlisle (Critical Period)[20]	95th to 80th	2.352	1.803
	95th to 70th	2.352	0.766
	95th to 60th	2.352	-0.041

[18] Given the tighter supply-demand balance and small long-term baseline deficit in the final plan, it is worth noting this in the context of climate change as a major uncertainty. Our plan has adopted the recommended scaling of 2080s UKCP09 scenarios based on the latest EA guidance (Environment Agency (2017) Estimating impacts of climate change on water supply). This assesses climate change impact based on the 2080s, and scales climate change impacts back to 1975 (i.e. it is assumed that this is already taking place) and derives these impacts. The planning guidelines state "*By using the 2017 method, you may experience a bigger impact of climate change on your sources than in previous assessment in the first 0-5 years, due to the scaling factor. This is because the new approach quantifies the change that has already happened; previous methods put this change in the first few years of the planning period*". Whilst the guidelines allows for an older 2013 methodology to be used, we adopted the latest methods for both the draft and final plans. Some companies may have applied the old methodology and thus have a healthier relative position earlier in the planning period; care should therefore be taken when comparing between company plans and to our own 2015 Water Resources Management Plan.

[19] These were determined by considering leakage enhancements as a strategic choice (consulted upon for the draft plan), as opposed to being selected to specifically address a supply-demand deficit. See Section 6.2 of the *Final WRMP19* main report.

[20] The Critical period is the time taken in our flashy resource zones for sources to go from full to emergency storage levels. This period is used to define a two to three month "peak" type demand, which could potentially coincide with the "critical" time for the water resources systems. Further detail in *Final WRMP19 Technical Report – Demand for water.*

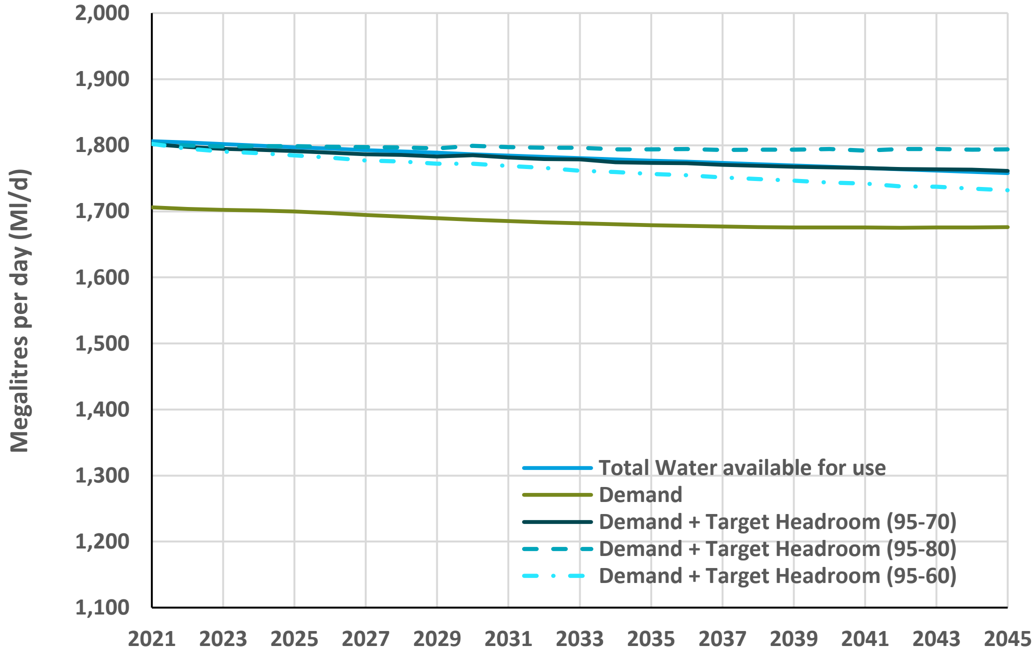


Figure 7 Strategic Resource Zone baseline supply-demand balance with different risk profiles for target headroom

For Carlisle the sensitivity testing shows that whichever risk profile was chosen the supply-demand balance would remain in surplus (as shown in Figure 8). On this basis the same risk profile was chosen as for the Strategic Resource Zone).

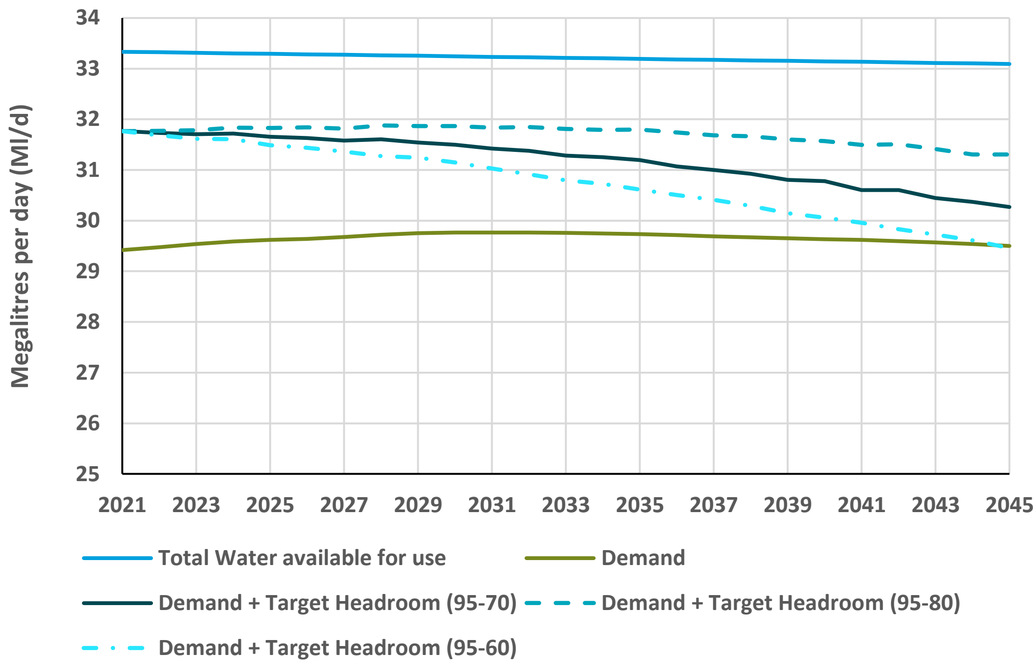


Figure 8 Carlisle Resource Zone baseline supply-demand balance with different risk profiles for target headroom

6. Target headroom values

The calculated target headroom values required in the supply demand balance for each resource zone are summarised in Table 6.

Table 6 Target headroom values

	2020/21		2030/31		2040/41		2044/45	
	Draft	Revised	Draft	Revised	Draft	Revised	Draft	Revised
Strategic Resource Zone (Dry Year)								
Target Headroom (Ml/d)	105.8	95.8	98.2	96.3	97.9	90.0	95.5	85.3
% of water for available use	5.8	5.3	5.5	5.4	5.5	5.1	5.4	4.9
Carlisle Resource Zone (Critical Period)								
Target Headroom (Ml/d)	2.55	2.4	1.93	1.7	1.25	1.0	1.07	0.8
% of water for available use	7.7	7.1	5.8	5.0	3.8	3.0	3.2	2.3
Barepot Resource Zone (Dry Year)								
Target Headroom (Ml/d)	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
% of water for available use	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
North Eden Resource Zone (Dry Year)								
Target Headroom (Ml/d)	0.28	0.2	0.28	0.2	0.31	0.3	0.33	0.3
% of water for available use	2.8	2.2	2.8	2.2	3.2	2.7	3.3	2.8

7. Comparison with previous plans

Table 7 summarises the target headroom values derived for our WRMP15. However, in Regulatory Reporting 2016, a revision was made to the supply-demand balance data, due to the Met Office updating their weather-demand model, the headroom values that resulted from this revision are shown in Table 7. This revision was reported through the Annual WRMP process. Table 8 summarises the target headroom values calculated for draft WRMP19, the years have been chosen for easy comparison with the WRMP15.

The main change between Table 7 and Table 8 in the target headroom calculation is due to climate change. There is minimal change in the North Eden Resource Zone figures which is mainly due to there being no impact from climate change applied. The other notable difference between the two tables is the resource zones. The West Cumbria and Integrated Resource Zones have been combined to make the Strategic Resource Zone for WRMP19, following the completion of the Thirlmere transfer.

Table 7 Target headroom values in Ml/d derived for WRMP15 RR16 update - dry year uplift method, with risk profiles of continuous 50th percentile for climate change and 95th to 70th percentile for all other components

	2015/16	2019/20	2024/25	2029/30	2039/40
Integrated Resource Zone	82.5	74.7	72.0	74.4	87.1
Carlisle Resource Zone	2.7	2.3	1.9	1.9	2.0
North Eden Resource Zone	0.3	0.2	0.2	0.2	0.3
West Cumbria resource zone	3.3	2.7	2.3	2.2	2.4

Table 8 Target headroom values in Ml/d derived for dWRMP19, with a risk profile for all components of 95th to 70th percentile for the Strategic and Carlisle Resource Zones and 95th percentile continuous risk profile for the North Eden and Barepot Resource Zones

	2015/16	2019/20	2024/25	2029/30	2039/40
Strategic Resource Zone	84.8	101.5	98.7	99.2	99.0
Carlisle Resource Zone	2.7	2.6	2.30	2.0	1.4
Barepot Resource Zone	1.4	1.4	1.4	1.4	1.4
North Eden Resource Zone	0.3	0.3	0.3	0.3	0.3

Table 9 summarises the target headroom values calculated for our final WRMP19 submission. As discussed in Section 3.2.2, the impact of the base year update on headroom component D2 is the primary reason for the reduction in the assessed target headroom between our draft and final plans.

Table 9 Target headroom values in Ml/d derived for WRMP19, with a risk profile for all components of 95th to 70th percentile for the Strategic and Carlisle Resource Zones and 95th percentile continuous risk profile for the North Eden and Barepot Resource Zone

	2015/16	2019/20	2024/25	2029/30	2039/40
Strategic Resource Zone	85.5	89.8	91.1	97.5	91.3
Carlisle Resource Zone	2.4	2.3	2.0	1.7	1.1
Barepot Resource Zone	1.4	1.4	1.4	1.4	1.4
North Eden Resource Zone	0.3	0.2	0.2	0.2	0.3

Appendix A – Breakdown of components

A triangular distribution was used for the majority of our components, as outlined in Table 1, due to a continuous distribution being the best fit for the data. The majority of our data falls within a range which defines the least likely and maximum likely, with the most likely being defined by the data. This approach is defined by the nature of the data available on these components. Where a more complex distribution applies to the data, this is detailed and justified in the table below. Where Triangular distribution is not used it is detailed in the table below.

Headroom component	Uncertainty assessed	Distribution chosen	Data
S1	Vulnerable surface water licences	None	Due to the Environment Agency guidance this was not included, as uncertainty about changes to licences would be know several years in advance of implementation.
S2	Vulnerable groundwater licences	None	Due to the Environment Agency guidance this was not included, as uncertainty about changes to licences would be know several years in advance of implementation.
S3	Time-limited licences	None	In line with the Final WRPG (2016), have assessed whether it is appropriate to include uncertainty on time limited licence renewal terms in WRMP19. This will be linked to wider WFD appraisals.
S4	Bulk imports	Triangular distribution	Used contractual rate for maximum, used modelled / dry year allowance figure for most likely, and used five lowest values over five years for minimum.
S5	Gradual pollution of sources causing a reduction in abstraction	Discrete/custom distribution	These sources were all groundwater sources, based on a review of water quality risks and data. A likelihood profile was estimated over time, along with an estimated DO impact, which meant a discrete/ custom distribution was applied.
S6	Hydrological data uncertainty (inflows / flow time series data)	Triangular distribution	Uncertainty informed by the latest inflows testing, data and appraisals. A 10% range was applied across inflows on an expert judgement basis to reflect instrumental error etc. This was informed by rainfall-runoff model testing and comparison to base inflows completed as part of climate change appraisals.
S6	Modelling and operational uncertainty	Triangular distribution	Based on sensitivity testing of strategic operational resource state curves and the impacts on DO.
S6	Process and Raw water losses	Triangular distribution	Uncertainty in calculations for water losses, across WTW and upstream raw water assets.
S6	Groundwater data uncertainty	Triangular distribution	Hydrogeological data and pump capacity.
S6	Compensation over-releases	Triangular distribution	Degree of compensation control around statutory amounts and baseline assumptions, supported by observed data analysis, particularly during drier periods.
S6	Demand saving uncertainty	Triangular distribution	Demand saving restrictions, informed by historic event analysis.
S6	Bathymetry data uncertainty	Triangular distribution	Reflect the accuracy of bathymetry data and operability when operating close to dead water levels (e.g. water quality). Determined from actual survey data.
S7	Single source dominance and critical periods	None	As following the 2002 UKWIR guidance, will not use this component.

Headroom component	Uncertainty assessed	Distribution chosen	Data
S8	Uncertainty of impact of climate change on source yields	Normal distribution (Strategic); Custom / discrete distribution (Carlisle); No distribution (North Eden and Barepot)	Using the latest climate change assessment techniques a relatively high number of scenarios were available in the Strategic Resource Zone (noting this is a high vulnerability zone) to inform the uncertainty distribution (i.e. supported by the Pywr emulator modelling). This allowed an overall estimate of uncertainty compared to the estimate of DO impact using the weighted average of all scenarios. As the impact of climate change varies over time, this was applied for each year of the planning period. Due to the number of data points this allowed a specific distribution to be assessed for the Strategic Zone – this resulted in a normal distribution being the best fit. Given the smaller number of modelled scenarios in the medium vulnerability Carlisle Resource Zone, a custom / discrete distribution was used. There are no impacts on supply in the North Eden and Barepot Resource Zones, thus no distribution is required.
S9	Uncertain output from new resource development	None	Not assessed.
D1	"Base year" data and meter inaccuracy	Triangular distribution	An allowance of up to ±1.02% of normal year demand (central forecast) was made to cover meter inaccuracies that may impact upon demand base data.
D2	Population, property and occupancy forecast (impacts household consumption/usage)	Triangular distribution	Informed by latest outputs from surveys, in line with Final WRPG and UKWIR methodology on population, property and occupancy.
D2	Non-household consumption/usage	Triangular distribution	Economic scenarios for the North West of England and associated uncertainty in econometric model.
D2	"Minor components"	Triangular distribution	Based on historic data, and determined by the minimum and maximum average value for the last 5 years.
D2	"Dry year" uplift	Triangular distribution	Upper and lower bound "dry year" uplift factor applied to household demand. Full review of weather-demand model and associated uncertainty.
D3	Uncertainty of impact of climate change on demand –climate change uplift	Triangular distribution	The uncertainty in potential impacts on water demand, as represented by the lower and upper impacts derived from the Impact of Climate Change on Water Demand UKWIR project, was included.
D4	Uncertain outcome from demand management measures	None	Not assessed.

Appendix B – Headroom statistics by resource zone

As indicated in Appendix A, a number of components were not assessed. The assessment of component S5, the gradual pollution of groundwater sources, is specifically detailed in Appendix C. The table below presents data for the other components that were assessed.

Resource zone	Headroom component	Uncertainty assessed	Lower bound (Ml/d)[21]	Baseline[22] (description)	Upper bound (Ml/d)[21]
North Eden	**S4**	Bulk Imports/ Exports	0	This uses the contractual amount	0
	S6	Process and raw water losses	0	Based on calculated losses across the Water Treatment Works and upstream losses, detailed in *Final WRMP19 Technical Report - Supply forecasting*	0.01
	S6	Groundwater data uncertainty	-0.44	Deployable output assessed against data and pump efficiencies	0.44
	D1	"Base year" data and meter inaccuracy	-0.07	Central dry year demand forecast	0.07
	D2	Demand forecasts	-0.77	Central dry year demand forecast	0.20
	D3	Climate Change uplift	-0.01	Central dry year demand forecast with climate change	0.01
Carlisle	**S6**	Hydrological data uncertainty	-0.61	Baseline inflows as detailed in the *Final WRMP19 Technical Report - Supply forecasting*	0.61
	S6	Modelling and operational uncertainty	-1.2	Operating policies consistent with the Final Drought Plan 2018	1.2
	S6	Process and raw water losses	-0.12	Based on calculated losses across the Water Treatment Works and upstream losses, detailed in *Final WRMP19 Technical Report - Supply forecasting*	0.12
	S6	Over-releases	-0.1	Estimated average dry year over-release volume derived using historic data, detailed in *Final WRMP19 Technical Report - Supply forecasting*	0.1
	S6	Bathymetry data uncertainty	-0.09	Defined reservoir storage using the latest bathymetry data	0.09
	S8	Uncertainty of impact of climate change on source yields	-2.96	Median impact of climate change from scenarios modelled	3.67
	D1	"Base year" data and meter inaccuracy	-0.30	Central dry year demand forecast	0.30
	D2	Demand forecasts	-3.94	Central dry year demand forecast	2.12
	D3	Climate Change uplift	-0.15	Central dry year demand forecast with climate change	0.22
Strategic	**S4**	Bulk Imports/ Exports	0	This uses the contractual amount	0
	S6	Hydrological data uncertainty	-113.57	Baseline inflows as detailed in the *Final WRMP19 Technical Report - Supply forecasting*	113.57

[21] Where there is variation in the uncertainty across the planning period the largest variations are presented here
[22] Baseline refers to the value used in the supply and demand forecasts, around which target headroom uncertainty is defined

	S6	Modelling and operational uncertainty	-6.00	Resource state in line with the operating policies (consistent with Appendix 8 of the Final Drought Plan 2018)	19.00
	S6	Process and raw water losses	-6.23	Based on calculated losses across the Water Treatment Works and upstream losses, detailed in *Final WRMP19 Technical Report - Supply forecasting*	6.23
	S6	Groundwater data uncertainty	-14.50	Deployable output assessed against data and pump efficiencies	14.50
	S6	Over-releases	-13.53	Estimated average dry year over-release volume derived using historic data, detailed in *Final WRMP19 Technical Report - Supply forecasting*	11.91
	S6	Demand saving	-31.00	5% Temporary Use Ban saving at Trigger 4 in line with the Final Drought Plan 2018, detailed in *Final WRMP19 Technical Report - Supply forecasting*	12.00
	S6	Bathymetry data uncertainty	-17.04	Defined reservoir storage using the latest bathymetry data	17.04
	S8	Uncertainty of impact of climate change on source yields	-441.00	Median impact of climate change from scenarios modelled	137.45
	D1	"Base year" data and meter inaccuracy	-17.67	Central dry year demand forecast	17.67
	D2	Demand forecasts	-118.55	Central dry year demand forecast	190.36
	D3	Climate Change uplift	-3.89	Central dry year demand forecast with climate change	6.12

Appendix C – Gradual pollution of groundwater sources

Nitrate – Permo-Triassic Sandstone (Cheshire/Warrington)

Delamere group boreholes, Manley Common and Five Crosses, Bearstone, Winwick/ Houghton Green, and Rushton Spencer

0% chance of treatment process losses over the next five years, rising to 5% by 2029/30 and if any trends rise, or continue to rise and other water is not available for blending, 10% chance by 2044/45. These figures are consistent with those used for the previous Water Resources Management Plan as there is no further evidence to change the figures.

Nitrate – Permo-Triassic Sandstone (Penrith)

Bowscar

Based on the data observed, there is negligible (reflected as 0%) chance that water quality within the deep aquifer system will deteriorate within the next five years (0% reduction in deployable output), rising to a 5% chance by 2029/30 (5% reduction in deployable output) and increasing to a 10% chance by 2044/45 (10% reduction in deployable output). These figures assumes that the water quality in the shallow aquifer system continues to deteriorate, with an increased net abstraction from the deep boreholes. The figures are different to those reported in the previous Water Resources management Plan and have been reduced for the middle of the planning period (from 25% chance, 10% reduction in deployable output) due to the stable water quality observed in boreholes 3 and 4 to enable successful blending.

Solvents and saline intrusion – Permo-Triassic Sandstone (Cheshire/Warrington)

Pocket Nook

10% chance of partial loss of output over the next five years (assumed 10% reduction in total deployable output), rising to 50% by 2029/30 (assumed 50% reduction in deployable output) and remaining at 50% loss of deployable output by 2044/45 (assumed 50% reduction in deployable output). This is consistent with the figures from the previous Water Resources Management Plan, which was lowered from the WRMP09 figure due to better management of annual abstraction rates from the boreholes that exhibit these deterioration characteristics.

Newton and Grange Boreholes

Grange – 25% chance of partial loss of output from the source over the next five years (assumed 10% reduction in deployable output), rising to 50% chance of partial loss of output from the source by 2029/30 (assumed 15% reduction in deployable output) and 75% chance of partial loss of output by 2044/45 (assumed 20% reduction in deployable output). Total loss of the source considered unlikely given the current mode of operation of the source for high demand support.

Newton – 5% chance of partial loss of output from the source over the next five years (assumed 5% reduction in deployable output), rising to 10% by 2029/30 (assumed 10% reduction in deployable output) and 15% by 2044/45 (assumed 15% reduction in deployable output). Total loss of supply from the source considered unlikely.

Solvents, nitrate and cryptosporidium – Permo-Triassic Sandstone (Cheshire)

Prenton

Solvents: Based on the current evidence but assuming some uncertainty in the rate of increase in solvent contamination at the source, there is a 5% chance of partial loss of output of the deployable output over the next five years (assume 5% reduction in deployable output), rising to 10% by 2029/30 (assumed 10% reduction in deployable output) and 15% by 2044/45 (assumed 50% reduction in combined deployable output).

Nitrate: 0% chance of treatment process losses over the next five years, rising to 10% by 2029/30 based on the current data and if trends continue to rise and other water not available for blending, 25% chance by 2044/45.

Figures not considered for previous WRMP and if sources of nitrate not established, there is a risk of a treatment requirement throughout the planning cycle which is reflected in the proposals.

Cryptosporidium: Intermittent and not expected to alter deployable output values.

Saline intrusion – Furness aquifer (Cumbria)

Schneider Road

At the current rates of abstraction, no water quality deterioration is observed as the conductivity values are stable. Therefore, there is a small 5% chance (assumed 10% reduction in deployable output) that partial loss of the deployable output of the group would be observed over the next five years, rising to 10% chance by 2029/30 (assumed 10% reduction in deployable output) and a 20% chance by 2044/45 (assumed 10% reduction in deployable output).

Asset Condition – Collapse or partial collapse and potential for water quality deterioration

Unlike other source assets, due to the nature of the structures, the collapse of adits and mine workings would make it incredibly difficult or impractical to reinstate the asset. Therefore, there is an accepted risk that deterioration of these structures may have resulting impacts on water quality that impact future availability without other interventions. Deterioration may cause turbidity or discolouration as well as the loss of structure.

Butterworth Hall – adit collapse associated with abandoned mine workings

There is a 25% chance that partial loss could occur by 2029/30 and 50% by 2044/45.

Bickerstaffe and Springfield, Prenton, Wirral, Houghton Green and Winwick and Warrington – adit collapse

There is a 10% chance of partial loss (25%) of the deployable output from each source by 2029/30 and a 25% chance by 2044/45.

Levers Water mine workings – adit collapse associated with abandoned mine workings

Risk of loss of the source could be 25% by 2029/30 and 50% by 2044/45.

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