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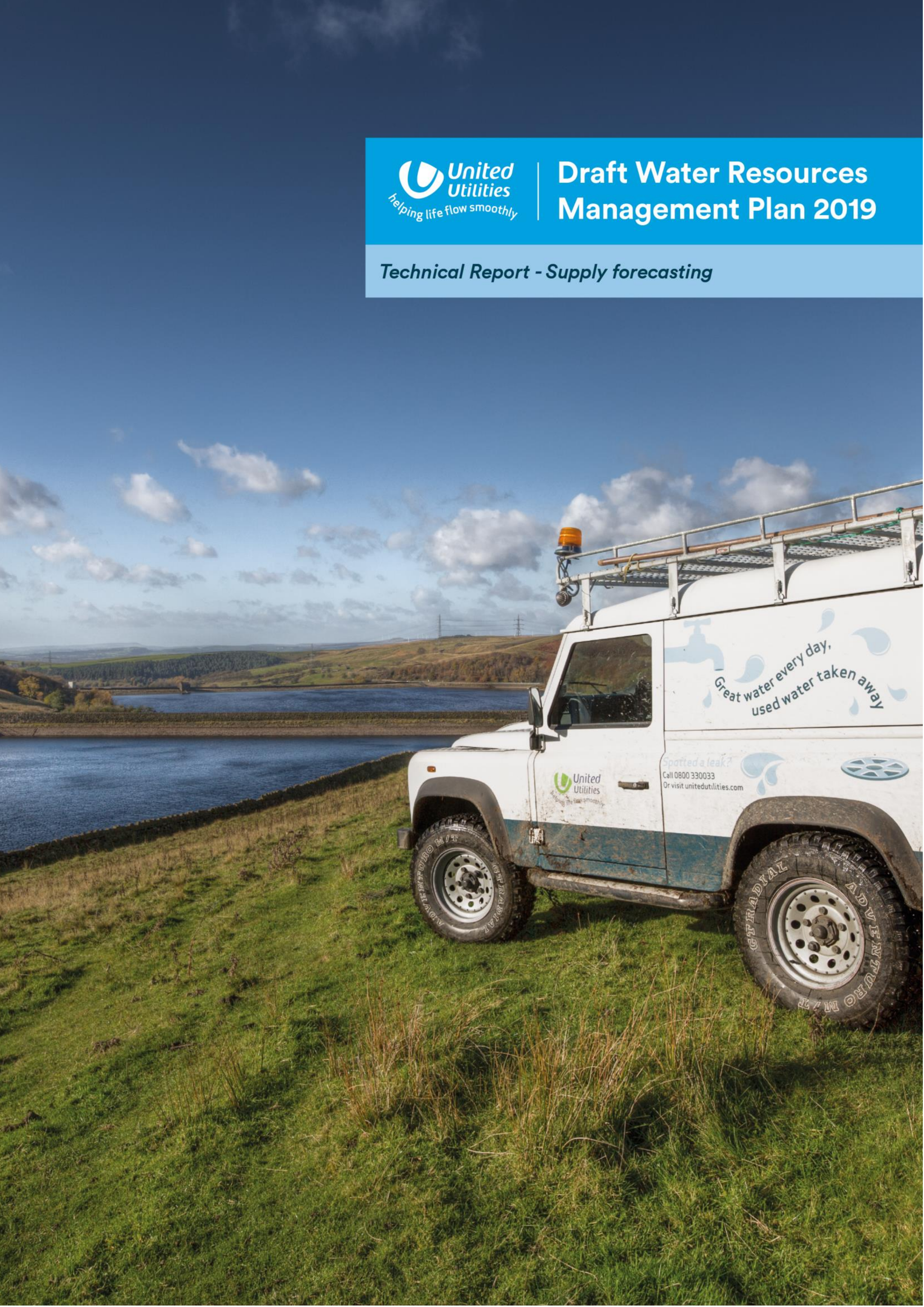
Draft Water Resources Management Plan 2019

Technical Report - Supply forecasting



Draft WRMP19 Technical Report – Supply forecasting

Contents

1. Introduction

This technical report sets out our approach to deriving robust resource zone level supply forecasts in our draft Water Resource Management Plan 2019 (WRMP19). Our approach to forecasting future supply has been informed by our engagement with customers, stakeholders and regulators, including during our pre-consultation activities.

Historically this was named the Yield Review, however the name revision to Supply Forecasting represents the importance of zonal level supply capability now and across the planning horizon rather than individual source yields. Our supply forecasts adhere to the guiding principles as set out in the Water Resources Planning Guideline (Environment Agency, 2017) and this report aims to demonstrate the way in which we have consistently applied national best practice. Contained within this technical report are details of the assessment of source deployable outputs, outage allowances and water available for use (WAFU) for each resource zone. We expect the final Plan to be completed in 2018 following a period of consultation, and will support our 2019 Periodic Review for the AMP7[1] period.

We have followed national best practice methods and guidelines to assess supplies. Since the original Surface Water Yield Assessment (National Rivers Authority, 1995), guidance has been reviewed and updated on a number of occasions. Key documents for this Water Resources Management Plan (WRMP) include:

- The latest Water Resources Planning Guideline (Environment Agency, 2017);
- WR27a Handbook of Source Yield Methodologies (UKWIR, 2014);
- Estimating the impacts of climate change on water supply (Environment Agency, 2017);
- Climate Change Approaches in Water Resources Planning – overview of new methods (Environment Agency, 2013); and
- WRMP19 Methods – Risk Based Planning (UKWIR, 2016)

We engaged with regulators early in the planning process, sharing a detailed internal methodology with the Environment Agency during spring-summer 2016. We ensured that feedback from this process was taken into account when developing our supply forecast. For the Environment Agency, this has also been supported by holding bi-monthly WRMP liaison meetings, and we have also engaged with Natural Resources Wales and Natural England periodically. We held “special interest” sessions on specific technical topics such as climate change and water supply modelling. Ofwat have also been updated through the process of developing the WRMP to inform them of our progress and chosen approach.

As per the Water Resources Planning Guideline (Environment Agency, 2017) this technical note provides a breakdown of our supply forecast setting out:

1. The deployable output of a commissioned source or group of sources for the design drought, as constrained by; hydrological yield, licensed quantities, environment, asset constraints (pumps, mains, treatment), and water quality. This assessment forms the baseline deployable output per resource zone.
2. An assessment and quantification of the impacts on our resource zone deployable output and WAFU due to:
    a. Future changes to deployable output from sustainability changes, climate change, and any other changes
    b. Transfers and any future inputs from third parties
    c. Short term losses of supply known as outage
    d. Any operational use of water or loss of water through the abstraction to treatment process
3. We also test the supply forecast to extreme droughts or worse than historic scenarios via the Drought Links table in accordance with the new guidelines (EA, 2017).

This technical appendix to the draft WRMP19 documents our approach to, and the outcome of, assessing future supply availability. If you wish to contact us about this report, or any other part of the draft WRMP, please email water.resources@uuplc.co.uk.

[1] An Asset Management Plan (AMP) is a business planning period that is five years in duration. AMP7 covers the period April 2020 to March 2025

2. Defining our water resource zones

We supply water to some 7.1 million people and 200,000 businesses in Cumbria, Lancashire, Greater Manchester, Merseyside, most of Cheshire and a small portion of Derbyshire. We own and operate over 100 water supply reservoirs, various river and stream intakes, as well as lake abstractions and numerous groundwater sources. More than 90% of our water supply comes from rivers and reservoirs, with the remainder from groundwater, although this balance may vary slightly in a dry year. This contrasts with the rest of England, where significantly less is supplied from rivers and reservoirs. Abstracted water is treated at water treatment works before being supplied to customers through an extensive network of aqueducts and water mains.

2.1 Approach

We have defined our Water Resource Zones (WRZs) using the Environment Agency's WRZ assessment methods (Water Resource Zone Integrity, 2016). This exercise, which was completed and shared with the Environment Agency in June 2016, demonstrates that within each resource zone the abstraction and distribution of supply is largely self-contained and the majority of customers experience broadly the same risk of supply failure due to resources shortfall and same level of service for demand restrictions. In appraising our WRZs we reviewed the previous Water Resource Zone Integrity report from our 2015 plan, and followed the Environment Agency guidance. We liaised with the Environment Agency to discuss the process followed and the conclusions drawn from this activity.

2.2 Change in assumptions from our 2015 Plan

The main change from WRMP15 relates to our resource zones, as detailed below and shown in Figure *1*. We have appraised four resource zones (Strategic[2], Barepot, Carlisle and North Eden) in WRMP19. As a long-term 25 year strategic view, our WRMP19 reflects the merging of the previous West Cumbria and Integrated Resource Zones. We are now calling this the Strategic Resource Zone to draw distinction with the previous zones. As well as the change in resource zone boundary, the name also reflects the functionality of the zone, where key strategic sources are balanced to manage supply to customers. This has been discussed previously with the Environment Agency and acknowledges the dependency on Thirlmere transfer delivery. The project is progressing well and, having gained planning approval in November 2016, we have now commenced construction of the scheme and remain on track to meet the project delivery date of 31 March 2022 (as included in WRMP15).

Through our engagement activities with the EA on the plan, we also decided to include a new resource zone for Barepot. This is geographically within the Strategic Resource Zone, but has been delineated as a separate zone as it comprises a non-potable supply to industrial customers at Barepot in West Cumbria. It is a small resource zone supplied by a surface water abstraction from the River Derwent at Barepot, Workington.

Our resource zones have been reviewed and concluded to either fully or partially meet the definition of a resource zone. The resource zones are listed by category and with a brief description below;

- **Strategic Resource Zone – partially meets the definition (retain on principle of proportionality)**
  The largest of our water resource zones comprising more than 98% of the total population served. Supply is managed in a fully conjunctive manner across South and West Cumbria, Lancashire, Greater Manchester, Merseyside, most of Cheshire, and a small part of Derbyshire.

  The resource zone is centred upon major aqueducts, which deliver water from the Lake District to Keswick, Penrith, South and West Cumbria, Lancashire and Greater Manchester, and from Lake Vyrnwy reservoir and the River Dee regulating reservoirs, to Cheshire and Merseyside. Two bi-directional pipelines connecting the River Dee and Vyrnwy aqueducts to the Thirlmere and Haweswater Aqueducts allow strategic sources in the north and south to be balanced across the zone. There are connections from the aqueducts to all towns and centres of population in these areas, so that; local sources (impounding reservoirs and boreholes) operate in a conjunctive manner with the major regional sources; and risk can be balanced in their use relative to

[2] Note that references to the Strategic Resource Zone in this document refer to the former Integrated Resource Zone, which will be larger on completion of the Thirlmere Transfer scheme and include the customers currently supplied by the existing West Cumbria Resource Zone. The new name allows distinction from the previous supply area and configuration of the Integrated Resource Zone.

strategic sources. The resource zone has a critical period of between 6-18 months depending on the scenario in question.

- **Barepot Resource Zone – fully meets definition**
  The smallest of our resource zones in terms of number of customer, this is a non-potable supply from the River Derwent to industrial customers in Barepot, Workington. There are no other connections and it is therefore the largest area within which resources may be effectively shared. The zone has a low supply risk because of the abstraction licence volume relative to the lowest recorded river flow.

- **Carlisle Resource Zone – fully meets definition**
  Serves a population of around 109,000 in the Carlisle local authority area and a small part of Allerdale District. It is served by two sources – the River Gelt via Castle Carrock Reservoir and the River Eden at Cumwhinton. In our previous Water Resources Management and Drought Plans, we included water quality constraints on an existing pumped transfer from the River Eden to support storage in Castle Carrock reservoir. Since the development of these plans, in April 2016 we completed modifications to the assets to mitigate these raw water quality constraints. The increased reliability means that we are now able to pump at an earlier stage than previously assumed, so that increased use of this transfer is possible. This aligns with our Drought Plan 2017. The resource zone has a critical period[3] of around three months.

- **North Eden Resource Zone – partially meets definition (retain on principle of proportionality)**
  Serves a population of around 14,000 people in the rural, northern part of the Eden District of Cumbria. Most of the zone is supplied from boreholes in the Sherwood Sandstone aquifer, whilst the Alston area is supplied from a bulk water supply from Northumbrian Water. The zone is loosely connected, however, is uniformly of very low risk.

[3] Critical period definition: The length of time between a reservoir being full and the reservoir reaching minimum storage during the worst drought on record.

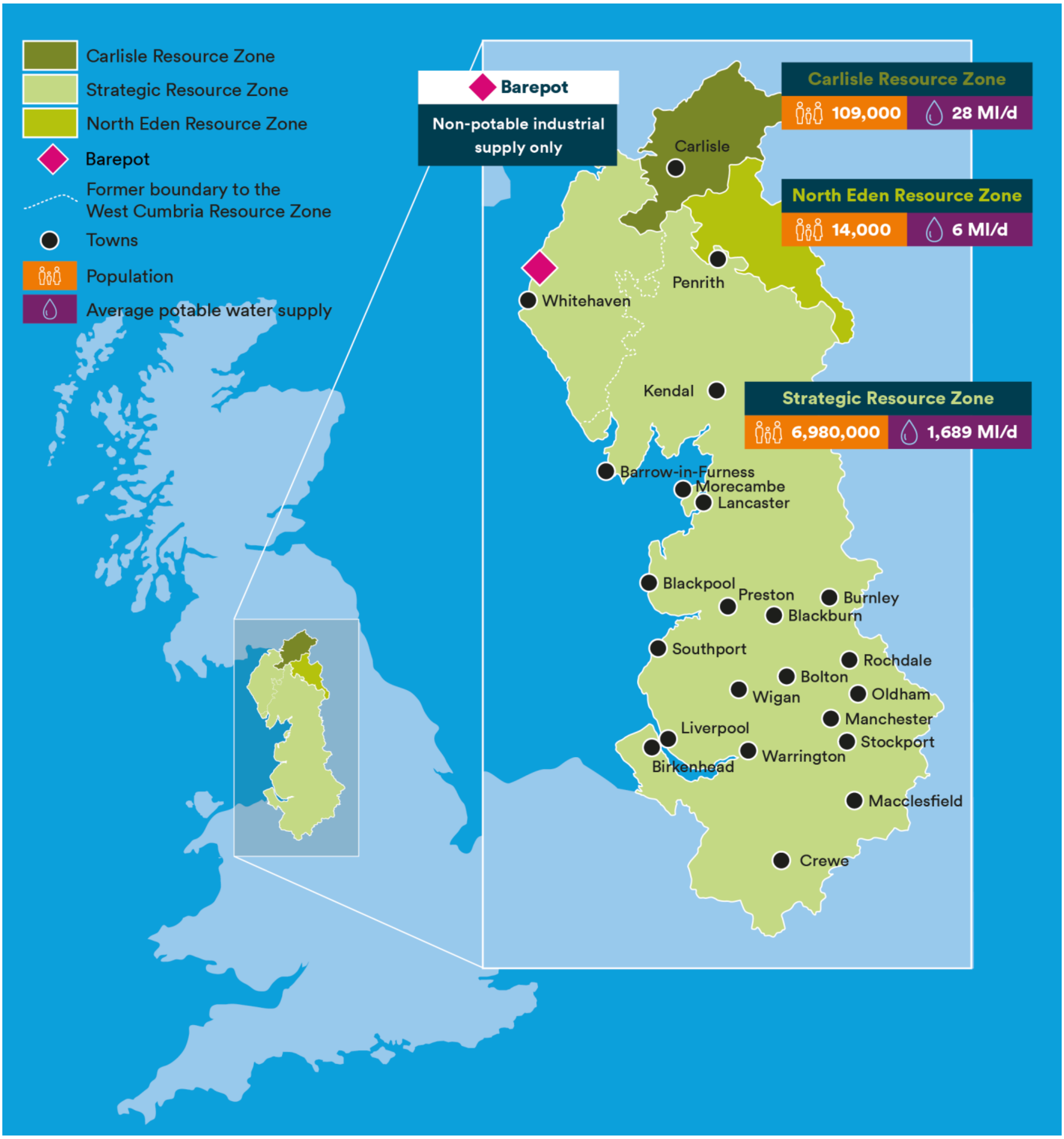


Figure 1 Resource zones in the North West from 2022, including the former boundary to the West Cumbria Resource Zone

2.3 Previous developments in our water resources capability

The most notable recent drought event in our region was in 1995/96. This two season drought affected the whole of our region, and to safeguard supplies the following actions were implemented;

- 14 month temporary use ban;
- 6 month drought order to restrict non-essential water use; and
- A total of 19 drought orders and 9 drought permits to abstract additional water from reservoirs, lakes and groundwater sources.

Following the 1995/96 drought we committed, through Water Resource Planning and Drought Planning, to improving the resilience of water supplies in the North West. The following section describes the improvements that have been achieved since 1995. Following these enhancements to our network and service (coupled with significant reductions in demand since that time), we are confident that should we experience a dry weather event, as seen during 1995/96, the impact on water resources, customers and the environment would be much less severe.

2.3.1 Leakage and demand management

Since 1995, we have actively reduced demand for water, through leakage reduction and other demand management activities, thereby reducing the amount that needs to be abstracted from the environment. Demand for water has decreased by more than 25%, from around 2,400 Ml/d in 1995 to 1,730 Ml/d in 2016. A large proportion of this reduction is due to the fact that leakage has been almost halved during this period. A wide range of activities to promote water efficiency have occurred and the number of households that are metered has also increased significantly.

2.3.2 Changes within our resource zones

We have also constructed two bi-directional pipelines between Merseyside and Manchester in our Strategic Resource Zone; the latest was completed in 2012. This has greatly enhanced our ability to transfer water within the zone and in particular to improve the security of supply to Greater Manchester and Merseyside. During the 1995/96 event we invested in a series of local connectivity enhancements (including new pipelines, pumping stations, and treatment capability) as well as intensive demand management actions to increase water supply availability.

Over the last 15 years, our focus has been on securing the resilience of our supply network, this includes enhancing the security of raw water supplies to the Wirral by duplicating a sole supply raw water main, and growing our distribution network to support local growth initiatives such as the Omega development in Warrington.

We have also been working to reduce the risk of water quality impacts resulting from system operation. Largely this has been delivered through the cleaning of our large diameter trunk main network and the associated cleaning or refurbishment of the downstream trunk main network, allowing us to operate the distribution system to its design capacity without risk of mobilising material from within the main which could compromise quality.

As described in Section 2.2 the Thirlmere Transfer scheme is now in progress for completion in 2022. This will connect customers in the existing West Cumbria Resource Zone to Thirlmere reservoir via a new pipeline and a new water treatment works near Redmain. As described above we have chosen to rename the resource zone on this basis. This marks a big step forward in terms of supply and sustainability to the West Cumbria area.

In our Carlisle Resource Zone we increased the supply from the River Eden to provide an additional 5 Ml/d in 2004. This source enhancement was required to overcome future predicted water shortages due in part to new development in the Carlisle area (United Utilities' Water Resources Plan 1999). In operational practice, however, there were constraints due to water quality which meant this couldn't be realised. The issue was subsequently addressed in April 2016 by changing the discharge point of River Eden water into Castle Carrock reservoir. This has improved reliability and enables increased use of the River Eden to Castle Carrock transfer. This has increased the WAFU in the zone, which is discussed further in Section 15. The additional WAFU has already been declared in both our Annual Water Resources Review (for 2016 and 2017) and our Drought Plan 2017.

Additionally to the WAFU increase in the resource zone we are currently in the process of renewing the trunk main system that supplies the City of Carlisle and surrounding areas. This will not only enhance the resilience of the supply system, but also deliver an improved water quality compliance from the removal of historical deposits of metals in the distribution system.

In the North Eden Resource Zone we identified water shortages during prolonged dry weather for the Alston part of the Eden local authority area in 1999. As a result, a new bulk supply of drinking water from Northumbrian Water was constructed in 2004 to serve the Alston area. There have been no further developments to the resource zone since this time.

In 2009, the Environment Agency informed us that because of their review of abstraction licences to comply with the European Union Habitats Directive, they would be modifying the abstraction licences in our West Cumbria Resource Zone (for Ennerdale Water and Dash Beck). We outlined interim measures in our WRMP15 to alleviate the pressures on Ennerdale Water until the Thirlmere Transfer scheme is completed, including:

- Leakage reduction and enhanced water efficiency promotion;
- Increased connection between the Crummock and Quarry Hill areas of West Cumbria; and
- Development of South Egremont boreholes to reduce Ennerdale Lake abstraction.

We recognise from pre-consultation feedback that whilst we have plans to maintain the supply-demand balance from WRMP15 that future plans for the environment and assets in this zone are of key interest to stakeholders. Therefore we have included further detail on this matter in the *Draft WRMP19 Technical Report - West Cumbria Legacy* document that is published on our website alongside this plan.

Until the Thirlmere Transfer scheme is implemented we will continue to report on progress and assess the West Cumbria supply-demand balance position through the Annual Water Resources Review process.

2.4 Levels of service

Following customer experience of the drought event in 1995/6, we introduced an improved level of service for water supply, with implementation of statutory water use restrictions and drought permits/orders not more than once in every 20 years on average (5% annual average risk). This improved level of service was effective from the year 2000 onwards. Since then, there has been one hosepipe ban in 2010, but no drought permits/orders have been implemented. Our minimum level of service for water supply reliability standards is shown in Figure 2 below. This aligns to our WRMP15.

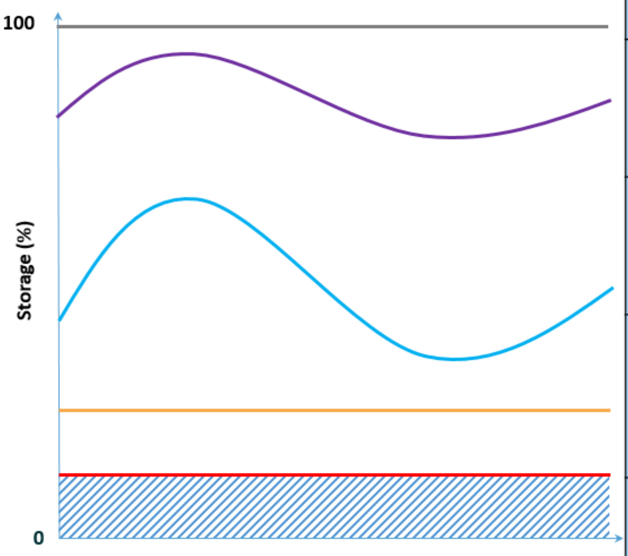
Water use restrictions and drought permits to augment supply on average
once in 20 years
(5% annual average risk)

Drought orders to ban non-essential water use
once in 35 years on average
(2.9% annual average risk)

United Utilities considers that it is
unacceptable to plan for rota cuts or standpipes
even during extreme drought conditions

Figure 2 Our minimum level of service for water supply reliability standards

A guide to key reservoir terminology and the points at which different levels of service actions are implemented are shown in Figure 3. Note that this does not apply to our Barepot and North Eden Resource Zones as they do not have any surface water storage.



	Description	Level of service	Current stated level of service
Top water level	Maximum reservoir capacity	N/A	N/A
Resource state	Used to determine resource relative 'health'. Above the curve is healthy, below is unhealthy	N/A	N/A
Drought trigger 4	Aligns to our Drought Plan	Implementation of Temporary Use Bans (TUBS) and Drought Permits/Orders	1 in 20 years on average (5% annual average risk)
Emergency storage	A reserve water storage capacity for use in a worse than historic drought. Does not contribute to deployable output	Implementation of non-essential use bans	1 in 35 years on average (2.9% annual average risk)
Dead water	Storage volume that is not usable for water supply	Implementation of emergency drought orders	Unacceptable even during extreme drought conditions

Figure 3 Reservoir terminology and current levels of service (note that resource state is a modelling concept)

In our last plan we committed to explore further the potential to reduce the frequency of drought permits/orders to augment supplies (powers to take more water from the environment during drought). Alongside this we have explored different levels of service to understand the resilience of our supply system. Within this note we refer to levels of service in a number of different aspects, as indicated below:

- Level of service and its representation in our baseline supply assessment is discussed in Section 6.1.7;
- How we have tested different levels of service (relative to our baseline position) is detailed in Section 16.1, and supports our consideration of improved level of service as a strategic choice in the main report;
- Our forecast level of service across the planning horizon is detailed in Section 16.2; and
- How we have explored our resilience and the benefits of supply and demand drought options including those linked to level of service is detailed in Section 17.

3. Risk based planning for our supply forecast

The review of our source yields and supply capability has followed industry standard methodologies. One of the main tasks, as set out in the UKWIR Risk Based Planning guidance, is to select one of three 'risk compositions' to reflect the extent to which risk is incorporated into the WRMP. Supply-side considerations were identified as a key area of risk in our problem characterisation[4], the outcomes and choices from which have been shared with the Environment Agency, Natural Resources Wales and Ofwat. The meaning of the risk compositions can be explained as follows:

- Risk composition 1 corresponds to the traditional approach which involves planning for the worst historical drought on record, taking a single deterministic view of the future.
- Risk composition 2 incorporates different futures by including synthesised droughts which are more severe than those on record, but still considered to be plausible.
- Risk composition 3 builds on risk composition 2 by creating a full suite of synthesised hydrological conditions, thereby allowing a probability of occurrence to be assigned to drought events.

The approach to calculating our supply forecast for each resource zone is described below.

1. **Strategic Resource Zone**: is consistent with risk composition 3. The main driver for this choice is our desire to understand the key risks in this complex non-linear supply system (combined with a potential future water trading scenario) as fully as possible, including how likely they are to occur. To achieve this we have successfully completed a number of challenging steps including generating stochastic hydrology and developing a new emulator model of the Strategic Resource Zone. For our baseline supply-demand balance assessment we've used the worst historic drought on record to define deployable output, but the resource zone has then been tested for risk and resilience response using our extended methods process. We have taken a probabilistic approach, for example in assessing the return periods for differing levels of service, or using frequency based performance metrics to inform options selection[4] (rather than the traditional supply-demand balance need method of previous plans).
2. **Other resource zones**: are consistent with risk composition 2. Problem characterisation identified that the strategic needs and complexity factors were low. However, we have used stochastic hydrology for Carlisle and Barepot, and extreme value analysis for North Eden to inform the testing of plausible droughts. This supports our understanding around more extreme events to help populate the Drought Links table (see Section 17).

[4] Our *Draft WRMP19 Technical Report – Options appraisal* includes details of our problem characterisation assessment and options selection process

4. What is included in our supply forecast

There are two key closely linked supply-side definitions referred to in this report: deployable output and water available for use (WAFU). Both of these figures are calculated at resource zone level and are representative of a dry year annual average supply scenario. We have used a critical period demand forecast for our Carlisle Resource Zone, further detail is included in the *Draft WRMP19 Technical Report – Demand for water*.

As defined in the UKWIR 'Handbook of source yields methodologies' deployable output is:

> *the output of a commissioned source or group of sources or of bulk supply as constrained by;*
> - *Licence, if applicable;*
> - *Pumping plant and/or well/aquifer properties;*
> - *Raw water mains and/or aqueducts;*
> - *Transfer and/or output main*
> - *Treatment; and*
> - *Water quality*
>
> *for specified conditions and appropriate demand profiles to capture variations in demand over the year.*

The Environment Agency's guidance requires companies to determine the deployable output for the design drought chosen to test the supply system. Our design drought for this draft WRMP is based on the worst event on historic record. However to test our system and resilience further we have also used stochastic hydrology (risk composition 3) to derive a fully risk based plan (based on probability analysis of drought events not seen in the historic record). This has been described in Section 3 above, and further detail on how we have completed the Drought Links table is included in Section 17.

From the Environment Agency guidelines, to calculate WAFU a supply forecast takes into account the following elements:

- The deployable output;
- Future changes to deployable output from sustainability changes, climate change, and any other changes you may be aware of;
- Transfers and any future inputs from third parties;
- Short term losses of supply and source vulnerability known as outage; and
- Any operational use of water or loss of water through the abstraction-treatment process.

WAFU (own sources) is defined[5] as:

> *WAFU (own sources) = (deployable output) – (reductions to deployable output + outage allowance + process losses)*

To calculate Total WAFU:

> *Total WAFU = WAFU (own sources) + (raw water imported + potable water imported) – (raw water exported + potable water exported) – non-potable supplies*

The following supply forecast components can be found in the sections listed below;

Deployable output (Section 5); sustainability changes (Section 7); climate change (Section 10); transfers and exports (Section 11); outage (Section 13); and operational losses (Section 14). The resulting total WAFU is presented in Section 15.

Throughout this plan, the concept of a baseline deployable output is referred to, and is defined as described above. This baseline has then been used for comparison against different scenarios (for instance different potential sustainability changes as shown in Section 7), and considered in combination with potential climate change impacts (Section 10).

[5] Definitions from Water Resources Planning Tools, UKWIR 2012

5. Baseline deployable output

Table 1 shows the summary of deployable output resulting from detailed assessment, and draws on the assumptions set out in Section 6. More detail on the changes between our 2015 and 2019 plans (reflecting changes in base deployable output assessment prior to sustainability reductions), and for sustainability reductions may be found in Section 5.1 and Section 7 respectively.

The Environment Agency 2017 planning guidance states that we should clearly explain which factor(s) constrain deployable output, this is summarised in Table 1. Note that any contributions from supply drought measures are not included in the baseline deployable output assessment.

The knowledge of the deployable output constraints is useful when considering model sensitivity and options development. In order to inform options identification and appraisal, sensitivity and options runs were completed to help understand the benefits of resource options with regards these constraints, as well as the extent of any option utilisation (excludes North Eden and Barepot).

Table 1 Summary of baseline deployable output results

		Strategic Resource Zone	Barepot Resource Zone	Carlisle Resource Zone	North Eden Resource Zone
1	Baseline deployable output at 2020/21 (Ml/d)	2,112.6	34.1	35.9	8.7
2	Sustainability reductions (Ml/d)	No change – as WRMP15	No change	No change – as WRMP15	No change – as WRMP15
3	Baseline deployable output with sustainability reductions (Ml/d)	2,112.6	34.1	35.9	8.7
4	Constraint on deployable output	Haweswater storage (reaches emergency storage), which occurs in the model run during 1984. 1995/96 is more severe for the Pennines, but also is very close in terms of minimum Haweswater drawdown	Annual abstraction licence limits.	Castle Carrock storage (reaches emergency storage) which occurs in 1976.	Borehole annual abstraction licence limits.

As indicated in Table 1 there are no sustainability reductions impacting deployable output for our baseline position. However, potential future sustainability reductions have been identified that are likely to require further investigations with the Environment Agency in the 2020-2025 period to confirm if they will go ahead. The impact of these potential future changes has been assessed in scenario and sensitivity testing. This is discussed further in Section 7.

5.1 Deployable output comparison between our 2015 and 2019 plans

Our WRMP19 deployable output assessment marks a major review of resource zone supply capability. Both the Strategic and Carlisle Resource Zone models and their system representation have been improved for the plan. This section aims to quantify the change in baseline deployable output on a like for like basis, and summarise the nature of the changes made.

It should be recognised that whilst we have tracked and audited model changes at each stage of the process, it is not practical to precisely quantify the impacts of individual changes. The conjunctive nature of the models means that the impacts are dependent on the order of implementation (some changes can be mutually beneficial). This section thus aims to keep quantification to a high-level and explain the legitimacy of changes towards improved deployable output appraisal.

There are a number of factors that constrain the Carlisle Resource Zone deployable output. For the baseline deployable output this is the hydrological yield of the River Gelt/Castle Carrock reservoir system. Under some other scenarios tested during plan development the River Eden annual abstraction licence was found to be the constraint.

Note that Barepot Resource Zone is not included in this section as it has been assessed for the first time in our WRMP19 hence there is no deployable output history.

Table 2 High level breakdown of changes in deployable output from the 2015 plan to the baseline for our 2019 plan

	Item	Strategic Resource Zone	Carlisle Resource Zone	North Eden Resource Zone
1	WRMP15 Aquator™ modelled or resource zone deployable output at 2020/21[6]	2,144	34.7	8.7
2	Model development activities	+6	+1.9	N/A
3	WRMP19 data refresh	-26	-0.2	0
4	Improved approach[7]	-8	-0.5	0
5	WRMP19 Aquator™ modelled or resource zone deployable output at 2020/21	2,116	35.9	8.7
6	Change from our 2015 Plan	-28	+1.2	0

The remainder of this section summarises the key changes made to impact the deployable output assessment between our 2015 and 2019 plans. There is no detail included for the North Eden Resource Zone as it has not changed.

Strategic Resource Zone

- Update to the Aquator™ water resources modelling package, with improved resource allocation algorithm ensuring improved behavioural simulation
- Updated dry year base demands (with losses), and the distribution of the total resource zone demand between demand centres has been reviewed.
- Asset capacities and costs have been reviewed and updated to 2016/17 values, as well as reoptimisation of Burnley reservoir group and Lake Vyrnwy control curves
- Disaggregation of groundwater supply areas in the south of the region
- Update of inflows to end-2015 and updated flow factors for ungauged sites
- Updates to the Vyrnwy system including new bathymetry data, and reviews of the regulation release representation
- Revision of groundwater source and group deployable output calculations and inclusion of peak deployable output representation in the model
- Revision to drought triggers using updated target spacing, adopted as per Drought Plan 2017 assumptions. Review and adoption of demand saving levels with an assumption of a 5% saving from Trigger 4
- Representation of the Thirlmere Transfer scheme to represent the system post-2022, including an amendment to the flood drawdown release volume. Discussions around the future release volume are ongoing, and the revised draft WRMP will be updated to account for any more updated view.
- Inclusion of compensation over-releases and hands off flow buffers within the Aquator™ model

Carlisle Resource Zone

- Improvements to operational rules controlling both the pumped and gravity transfer of water between the River Eden and Castle Carrock. This is to reflect the need to keep Castle Carrock as full as possible during the summer months in line with actual operational practice, and ensures that assessments follow the guidance set in the UKWIR (2014) Handbook of source yield methodologies
- Earlier pumping support available from the River Eden to Castle Carrock (in line with the Drought Plan 2017 and Annual Water Resources Review 2016 and 2017 updates). Previously this would occur when storage in

[6] Note that for the WRMP15 values the final plan deployable outputs are used. This is to allow for a like for like comparison with the Strategic Resource Zone that assumes completion of the Thirlmere Transfer scheme.

7 Improved approach accounts for our climate change assessment. Whilst this data has been refreshed for WRMP19 we have followed the latest guidelines which calculate climate change impact for the 2080s and uses a different scaling factor to distribute this impact across the planning horizon. Particularly for the Strategic Resource Zone, our modelling approach for WRMP19 surpasses that for WRMP15, and therefore we have classified our climate change assessment as an 'improved approach'. Further detail on our climate change assessment is included in Section 10.

Castle Carrock reaches drought trigger 3, however constraints have been removed that now enables this earlier support at drought trigger 1. The pumping station capacity has been amended to reflect operational limits

- Inflows have been updated to 2015 using improved rainfall runoff models. Ullswater has been included in the Carlisle Resource Zone modelling as this influences flow in the River Eden upstream of the Cumwhinton abstraction point
- Inclusion of a hands off flow buffer to Hynam Bridge gauging station and the River Gelt. This is consistent with the approach used in the Strategic Resource Zone
- Asset capacities and costs have been reviewed and updated to 2016/17 values. Note that relative cost is the most important factor in Aquator™ rather than absolute costs, and these are only used to balance resources realistically when sources are healthy.
- Updated dry year base demands (with losses), and the distribution of the total resource zone demand between demand centres has been reviewed. All demand centres vary in deployable output analysis in line with assessment principles
- Castle Carrock reservoir emergency storage has been revised to reflect the updated demands.

6. What is covered in our deployable output forecast

6.1 Deployable output approach

As outlined in Section 1 we have completed assessments of deployable output in line with the good practice principles and methodologies available. For this draft WRMP, we assess deployable output for all four of our resource zones. We adopt different approaches, on a risk basis, depending on the complexity of resource zone. The UKWIR guidance (2012) was used to assess the complexity of each resource zone, and they have been categorised for the assessment into three categories based on UKWIR (2012, Ref: Figure 4) Step 1. Source details are contained in Section 6.1.3 and a summary of the groundwater sources is in Section 6.1.4. The resource zone categorisations are documented in Table 3, the outcome is unchanged from our WRMP15.

The North Eden Resource Zone has low complexity, and therefore the yields of the different sources in the resource zone are simply summed together. Barepot Resource Zone, which is new for WRMP19 is similar to our North Eden Resource Zone in that it is of low complexity and constrained by abstraction licence limits The two more complex zones are dominated by surface water sources that are used conjunctively, supply from each source is balanced to reflect that they might be in different states at different times. The supply network means that water from these different sources can be moved around the resource zone. Due to a combination of the non-linear response of sources along with potential supply side risks (namely climate change) and system constraints, it is not appropriate to simply sum together source yields and we used the water resources model, Aquator™ (developed by Oxford Scientific Software), to determine deployable output.

Table 3 Resource zone categorisations and approach for WRMP19

	Strategic Resource Zone	Barepot Resource Zone	Carlisle Resource Zone	North Eden Resource Zone
Complexity	High	Low	Medium	Low
Deployable output assessment framework	Conjunctive use assessment required	Source deployable output assessment only	Conjunctive use assessment required	Source deployable output assessment only
Deployable output constraints	Drought magnitude	Abstraction licence limits	Drought magnitude	Abstraction licence limits
Tools to use in assessment	Aquator™ software	Output from source yield assessment	Aquator™ software	Output from source yield assessment

The remainder of this section aims to provide an overview of the deployable output approach, and cover Steps 3 and 4 of the UKWIR (2012) requirements. Datasets and constraints are covered within the sections for each resource zone. Step 2, Climate Change vulnerability is addressed in Section 10.

In many areas, guidance and methodologies necessarily leave room for choice by the practitioner to make informed choices, based on risk and system characteristics, and these have been clearly stated in this document. As a starting position we have built on the approaches we used in previous planning cycles and indicated where and why our approach for WRMP19 has differed during liaison with the regulators. We acknowledge their support in developing this assessment of future supply.

6.1.1 Aquator™ modelling software

Aquator™ is a state of the art water resources model that is widely used across the UK for behavioural modelling. This approach is more sophisticated than examining reliable yield alone, and is appropriate for time variant systems that have a storage element. The use is suitable for complex river abstractions with hands off flow constraints, as well as for reservoirs, conjunctive use and system wide scale analysis.

The model represents the key components of a supply network (e.g. reservoirs, rivers, boreholes, pipes, water treatment works and demand areas) and connects them together to simulate the resource zone as a whole (an example Aquator™ schematic is shown in Figure 4). Crucially it contains key constraints including hydrological conditions, abstraction licences and physical constraints such as pipe or water treatment work capacities and reservoir dead water storage levels. As an input to the model historical time series such as river flows are included (see Section 6.1.3 for information). The package is highly customisable (using Visual Basic for Applications, VBA) to help define the system rules and logic for representation in the model. As these models are used for water resource zone scale assessments there is a balance to strike in terms of the detail represented and the need to capture operational capability and principles. It should be recognised that there is a degree of system simplification applied and that it can be difficult to represent the human element of how the system operates, that can vary on a day to day basis (for example, operational decisions based on short-term weather forecasts).

In accordance with the Handbook of Source Yields reservoir emergency storage is also included in the Aquator™ models, further detail on our emergency storage is included in Section 6.1.8.

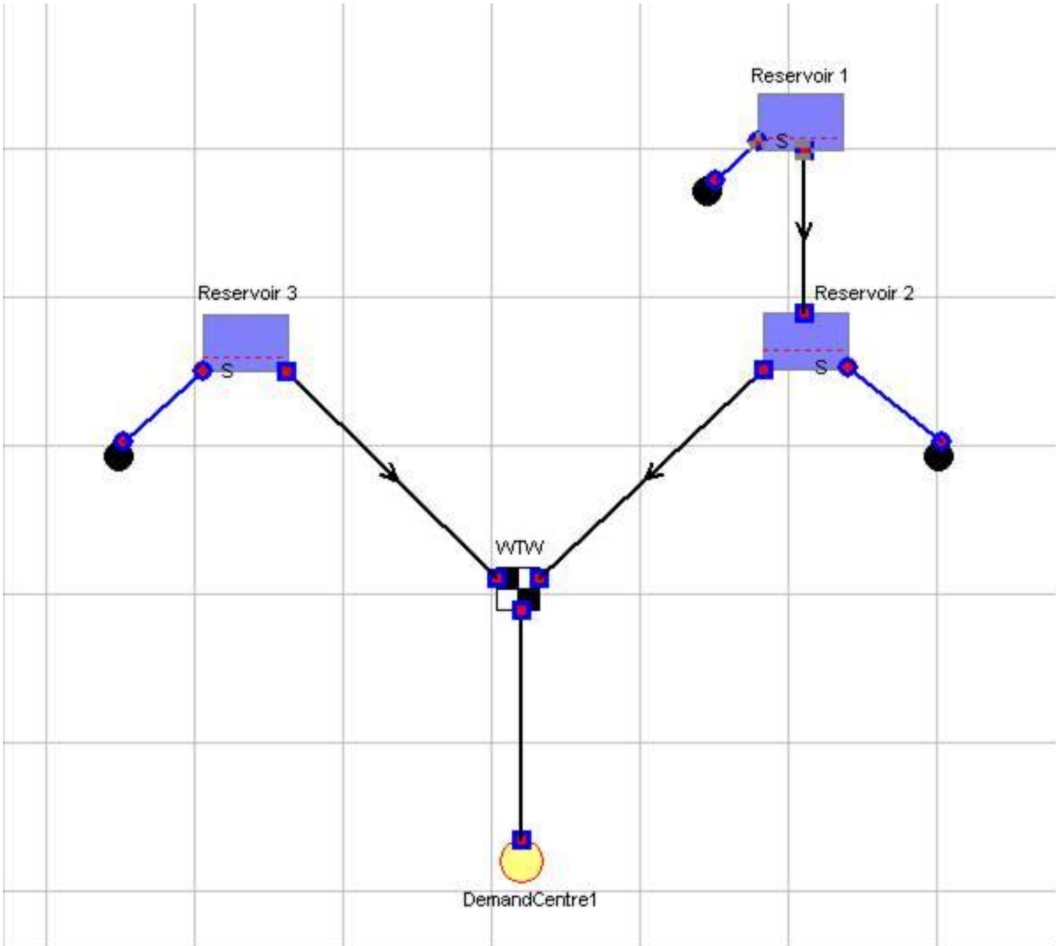


Figure 4 Example Aquator™ schematic demonstrating a simple resource zone model with three reservoirs, a water treatment works, and a demand centre

Once running, the model aims to utilise available supplies to meet daily demands across the resource zone, subject to the various constraints and rules. This daily allocation of water is completed using a linear programming algorithm; however, the basic order of calculation is as follows:

- “Satisfy minimum flow” constraints - ensure supply to any single demand via a treatment works that has a minimum rate)
- “Meet minimum demand” (discrete areas) – If any demands have to be supplied via a given route regardless of resource health or cost, this is completed at this stage.
- “Use Healthy Resources” – Where resources are defined as healthy, these sources are used to meet demand preferentially (over ‘unhealthy’ ones). Where there is sufficient flexibility to choose between healthy resources, this is done by maximising lower cost supplies.
- Use “Resource Scarce” or “Less Healthy” sources – If a resource is below a defined threshold to denote it is to some degree ‘less healthy’, Aquator™ will preferentially take from these remaining resources if required depending on the degree of resource health (best first)

A critical concept for Aquator™ is therefore 'Resource State', which determines respective resource health[8]. Essentially this is a factor to allow sources to be viewed relative to each other and balance resources. Anything above a value of 1 is deemed healthy, and anything at or below 1 is deemed unhealthy, down to a value of zero being totally unavailable. The variance against a value of 1 therefore denotes the extent of resource health accordingly. All resources can have a resource state, although in some cases this may be 'infinite' subject to other constraints (for example, unlike a reservoir, a river may be defined simply be 'available' subject to licence constraints); the reflection of resource state may be chosen by the user. A source may also have two resource states, for example, one for level of a reservoir and another to reflect the annual licence usage, and in such cases Aquator™ uses the lowest.

Typical resource states are as follows, although actual setup is very specific to the case in question:

- Source Licences: An annual licence, for example, has a resource state based on its pro-rata usage over the year to ensure an appropriate, sustainable use over its duration
- River abstractions: Resource state may be defined as 'healthy' above a defined river flow, e.g. hands-off level
- Reservoirs: Resource state is usually defined by the position of a control line or trigger, thus below the selected line the resource is considered increasingly scarce. In addition the control curves are used to assess the sustainability of water abstractions during times of drought, and they aid decisions to reduce or increase abstraction rates.
- Boreholes: Boreholes may have a supply rate set as a resource state (e.g. to reflect a sustainable rate or baseload take), or as all sources, with a licence constraint

For our WRMP15 we developed a control curve optimisation tool with Oxford Scientific Software and Exeter University. The tool used a 'genetic algorithm' approach. The curves generated for the last plan have been retained for this WRMP19 and have been reviewed and updated by exception where there is a known change to reservoir; capacity, operation, inflows (that has an impact on deployable output), or compensation requirements. The updated control curves are discussed further in Section 6.2.

In addition to these we have standalone single reservoir models for those sources with control curves and yield cut-back rates applied (i.e. Pennines sources) that we use to assess the yield of individual sources and separate sub-systems.

Further detail on the specifics of Aquator™ modelling within each resource zone is covered in the sections 6.2 (Strategic Resource Zone) and 6.3 (Carlisle Resource Zone).

6.1.2 Testing deployable output

In order to determine deployable output, the models are set up to simulate how the current supply system would be expected to react to historical (or other future) hydrological conditions. Demand across the resource zone is initially set in line with the annual average dry year demand with a seasonal profile (see Section 6.1.6) and is then proportionally increased by iterating demand (up and down within a defined range) to derive the maximum supply possible over the full hydrological record.

The result corresponds to the maximum overall level of demand that is met before the system fails. A failure could be a shortage of water at a demand centre, a reservoir emptying, or potentially a drought trigger being breached more often than the level of service stated to our customers. The deployable output is typically defined during the driest period in the record, when the system is under the most stress.

There is good correlation between model outputs and actual historic droughts. In the Strategic Resource Zone, deployable output is defined by the 1984 drought, with simulated storage levels in 1995-1996 also becoming very low. In the Carlisle Resource Zone deployable output is defined by the 1976 drought event. As explained in Section 6.1 the deployable output of the Barepot and North Eden Resource Zones is not determined by Aquator™ as they are defined by annual licence constraints as opposed to a dry period.

[8] Whilst this term has been used operationally in the context of strategic pumping, it is originally, and continues to be, a modelling concept for producing plausible model behaviour (i.e. the model tries to balance across all known sources rather than rely too heavily on a particular source for it to then face a higher risk of failure).

Stochastic inflow records allowed us to provide more certainty around the return periods (or probabilities of events occurring in each year) for our historic events than we were able to in previous planning rounds. We used 17,400 years of inflow records for the Strategic and Carlisle Resource Zones to assess the return period of the deployable output defining droughts.

The deployable output defining events in the historical sequences are estimated to have a return period of 1:94 years in the Strategic Resource Zone for 1984 (1.06% annual average risk), and around 1:90 years (1.1% annual average risk) for the Carlisle Resource Zone. We have further explored how our resource zones behave perform during more extreme droughts using the Drought Links table in Section 17. More detail on how these return periods have been derived is included in Appendix B.

6.1.3 Hydrological data

The majority of our supply is from surface water sources (approximately 90% across the region). The development and improvement of hydrological inflow sequences for our main surface water sources is shared between us and the Environment Agency, and Natural Resources Wales where appropriate, drawing on combined datasets and expertise. We have a long experience of working with the Environment Agency in this manner.

Most of the flow sequences used are either naturalised river flow sequences or derived using mass-balance techniques with observed data (water balance methods), rather than rainfall-runoff models. The mass-balance inflow sequences cover all of our major resources (sometimes referred to as parent inflows). In cases where data are not available for a source, or missing for part of the record, we typically use a flow factoring approach (using proportional Average Annual Flow (AAF) against the parent record), for example, for smaller Pennines sources in the Strategic Resource Zone. Behavioural testing of system models and inflows using the 2010 drought period as a case study found that patterns of key reservoir drawdown assessed were closely comparable with that of observed records, thus supporting the robustness of this approach for this WRMP.

As part of the climate change assessment (see Section 10), Catchmod rainfall-runoff models for parent inflows sites were reviewed and where possible improved. These models were used to produce monthly flow change factors in order to perturb the baseline inflow sequences. We have not used these sequences explicitly in deployable output assessments, in agreement with the Environment Agency due to the shorter record length of rainfall-runoff models in many cases. Our approach is always to include the best available source of data in our inflow sequences, so in a handful of cases, the rainfall-runoff models have been adopted as improved sequences by exception. For the River Eden this replaced a previous rainfall-runoff model, for the River Gelt this replaced a combined rainfall-runoff model and observed flow record and for Swindale Beck and the Haweswater minor intakes which were previously factored from Haweswater, the rainfall-runoff model better represented the individual, flashy catchments.

A summary of the derivation of hydrological inflows data are provided in Table 4.

Table 4 Summary of hydrological inflow data[9]

Source	Length of inflow record	Method of inflow derivation
Strategic Resource Zone		
Haweswater, Ullswater and Windermere	1927-2015	Observed data where available, otherwise regression with Thirlmere inflows
Thirlmere, Stocks, Rivington and Vyrnwy	1927-2015	Observed data
Heltondale and Wet Sleddale	1927-2015	Regression with Haweswater inflows
Swindale and minor intakes	1927-2015	Rainfall-runoff models where data available, otherwise regression with Haweswater inflows
Barnacre, Longridge (Whitebull), North Pennine reservoirs	1927-2015	Regression with Stocks inflows
South Cumbria reservoirs	1927-2015	Regression from Thirlmere inflows
South Pennine reservoirs	1927-2015	Regression from Longdendale inflows
Cownwy	1927-2015	Observed data where available, otherwise Severn Trent data
Marchnant	1927-2015	Observed data where available, otherwise regression from Vyrnwy inflows
River Lune and Wyre	1927-2015	Naturalised observed flows
Lancaster Fells	1927-2015	Observed data where available, otherwise 'dry year'/average year average
Seathwaite Tarn/River Duddon and River Dane	1927-2015	Deployable output estimated in standalone Aquator™ model using available observed data
River Dee system	1927-2015	Derived from Vyrnwy inflows by Natural Resources Wales
Carlisle Resource Zone		
River Eden	1961-2015	Catchmod rainfall-runoff model
Gelt intakes	1961-2015	Catchmod rainfall-runoff models
Barepot Resource Zone		
River Derwent	1976-2017	Observed data

There are no UU surface water sources in the North Eden Resource Zone at present.

For the Strategic Resource Zone there are no known events of relevance in the 1920-1927 period[10] for the North West (this was a severe event in other areas of the UK). Extension of datasets prior to 1920 would be extremely difficult for the Strategic Resource Zone due to the limited availability of datasets in the North West covering the whole zone (as all inflows would need to be updated in conjunction). The current deployable output is also drought magnitude driven (rather than restricted by Levels of Service). We have engaged with the Environment Agency on this matter previously, and have not extended this sequence prior to 1927. Note however that for this WRMP19 we have developed 17,400 years of stochastic hydrology with which we are able to test our system response to a range of drought events of different severities. Further detail is included below and in Appendix B.

During consultation on our WRMP15 the Environment Agency noted that the length of record the company used to assess the deployable output was very short for two sources in our Strategic Resource Zone, the River Duddon and the River Dane, which together contribute around 1% to resource zone deployable output. For these sources we calculated yield separately over a shorter period and then applied the yield value as an available abstraction in the full 1927-2015 modelling run. For WRMP19 we have reviewed these inflow series and consider that the current representation for the River Duddon is appropriate. For the River Dane the review is ongoing with the aim of improving the representation in Aquator™ for our revised draft WRMP19 (which we expect to publish in summer 2018). The likely impact on regional deployable output is minimal.

[9] Note that additionally we have 17,000 years of stochastic hydrology data for the Strategic and Carlisle Resource Zones

[10] The UKWIR handbook of source yields methodology recognises that it may be acceptable to use records commencing post-1920, and may be justified by the nature of the system in question and the availability of data. Extending inflow series beyond the records already available to us would be both extremely time consuming, and due to the lack of robust input data potentially unreliable for deployable output assessment, thus should be considered on a risk basis.

Our Carlisle Resource Zone is drought magnitude driven with regards to deployable output (rather than level of service) and research by Environment Agency (2006) and UU (internal research) has not indicated any greater severity events within the 1920-1961 period. Outputs from the Environment Agency document was referenced in the UKWIR (2012) WR27 project, stating that three of the four most severe events occurred in the last two decades (no higher magnitude events were found in reconstructed data to the 1800s), although cautioned if a level of service 'frequency approach' was used. These issues have been discussed with the Environment Agency and we conclude that our inflow period is suitable for this WRMP supply forecast assessment.

Stochastic weather generation uses relationships between rainfall, potential-evapotranspiration (PET) and climatic drivers, such as the North Atlantic Oscillation (NAO) and sea surface temperature (SST) to create "what if" sets of weather, that are equally as likely to have occurred as the historically observed weather. This technique has been used to create 17,400 years of inflows data for our Strategic and Carlisle Resource Zones, containing more severe events than those in the historic record. We used these long records to assess how severe the events that defined our baseline deployable output are, and to place more accurate return periods on them, as well as to test our systems' resilience to more severe events. More detail on how we have derived stochastic hydrology is included in Appendix B.

6.1.4 Groundwater sources

Groundwater sources provide around 10% of the total amount of water we supply to customers, although this varies from year to year. Most groundwater sources are operated in conjunction with surface water sources within integrated supply systems and are therefore used intermittently. However, some provide constant supplies to particular local areas and are always in use. Our North Eden Resource Zone is supplied only from groundwater.

The major aquifers in North West England are the Permo-Triassic sandstones which have significantly different properties and characteristics from the limestone and Chalk aquifers of Southern and Eastern England. We also have a small number of sources which abstract water from minor aquifers, e.g. the Namurian (Millstone Grit) and Westphalian (Coal Measures).

The review of groundwater source yields has been completed in accordance with the standard UKWIR methodology (UKWIR, 1995) and subsequent guidance provided by the Environment Agency. The yields of the groundwater sources are reported separately and have been completed as a sub-assessment for input to this wider yield review. The review identified average and peak deployable output, as well as the potential yield (which based on the greater of the daily or annual licenced capacities). Aquator™ simulations include all surface water and groundwater sources within the modelled resource zones[11]. The deployable output derived for groundwater sources within the Strategic Resource Zone have been grouped on an area basis for inclusion in the model.

The outputs from our groundwater sources are almost always constrained by either the abstraction licences or water treatment/pump capacities. The exceptions are where the supply system constrains the output from the source or where groundwater levels approach the borehole pumps, i.e. hydrogeological constraints. Water levels only influence the outputs of a small number of sources, mainly those which draw water from the minor aquifers where groundwater storage is limited and drawdown effects are generally larger.

6.1.5 Asset constraints and licences

We completed a full review of asset constraints and licences with regards constraints on source output and system deployable output. In some cases these have been assessed as part of sub-assessments such as the Groundwater Review, whereas in other cases are explicitly included within Aquator™ modelling (where relevant) to ensure robust simulation.

In deriving asset capability for this draft WRMP we reflect:

- **Asset capability in AMP7.** For our previous plan we reflected the anticipated end of AMP6 position (2019/20), and therefore assumed completion of numerous AMP6 capital projects. From previous experience we know that the programme shifts during Business Plan development, combined with normal

[11] Aquator™ models are used for our Strategic and Carlisle Resource Zones, see sections 6.2 and 6.4 for further information on model specifics

business planning prioritisation (i.e. if a new need arises or an issue is identified as higher priority). With this in mind our approach for our 2019 plan is that the assets should reflect available capability at the beginning of the planning horizon (2020/21, start of AMP7). There is little change identified between the asset capabilities used for WRMP15 and WRMP19.

- **Water quality.** In deriving the values for each asset we have engaged across the business to arrive at the minimum and maximum flow values that can be sustained in a dry event (noting that this is different from short-term peaks in supply to meet peaks in demand).

Data were collated along with justification for the choice made where there may be multiple sources of data. This is particularly important for assets such as water treatment works where historic design capacities may not be representative of real-world current and future operating capability. The asset assumptions have been reviewed with both operational and planning teams. The process followed to assess asset capability for our WRMP19 is shown in Figure 5. We have also completed sensitivity tests to better understand the impacts of key constraints on deployable output, both informing options appraisal and to target further improvements of data where required.

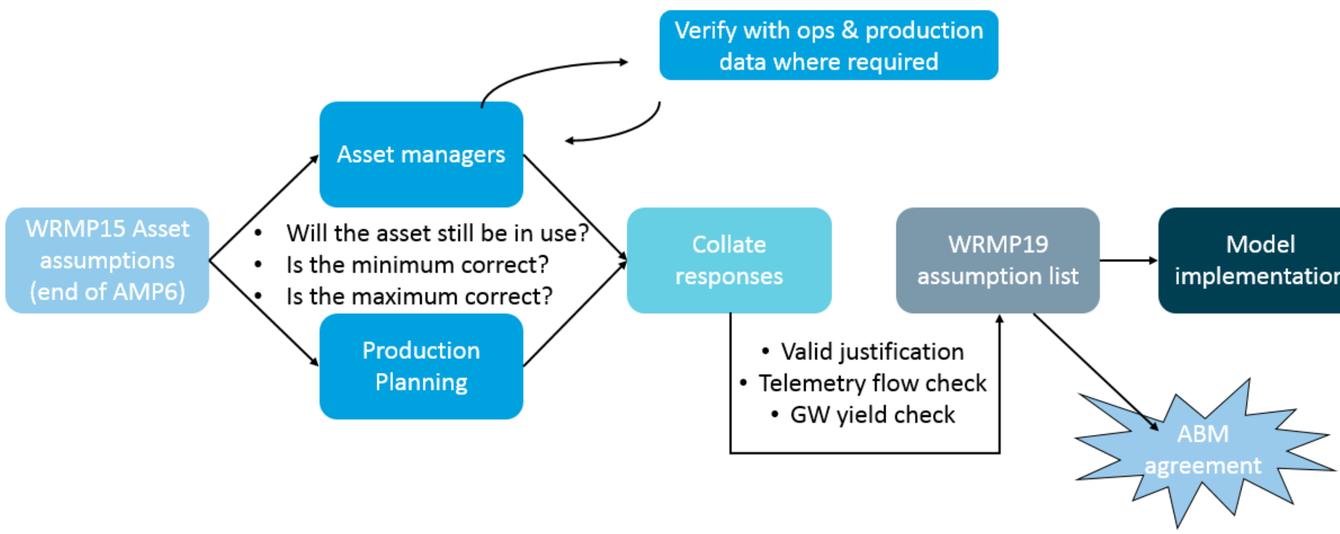


Figure 5 Process followed to determine WRMP19 asset capability

For this plan we have ensured that licenced volumes are represented in determining deployable output (either in the Aquator™ models or supply assessment). Other licence conditions such as "hands off flows" are also reflected, and it is assumed that provided the conditions of the licences are represented (and met in models) they are sustainable and that their use will not cause deterioration.

We have 36 time limited licences across the region with expiry dates ranging between 2018 and 2037, the majority of these are located in the Strategic Resource Zone. All newly granted licences are time limited. The main change since our WRMP15 has been the granting of the Haweswater and Thirlmere licences. Originally these were contained within one licence, but now have individual licences for each intake (or group of intakes).

We work with the Environment Agency on licence renewals, and evaluate the risk of non-renewal for these licences as low as the Environment Agency have a presumption of renewal for time limited licences, unless environmental evidence indicates there is a risk of deterioration in future. Where there are concerns around the sustainability of licences in future these have been included in the Water Industry National Environment Programme for investigation (often referred to as WINEP). We have had no indication from the Environment Agency that any of our time limited licences are environmentally damaging and have assumed that they will be renewed on a like-for-like basis. Of our time limited licences the River Eden licence in Carlisle contributes significantly to the resource deployable output. As a sensitivity test, the impact of reducing the annual licence from 8,000 Ml to 7,546.4 Ml reduced resource zone deployable output by 3.8 Ml/d (10.6% of baseline deployable output).

6.1.6 Demands

For the Strategic and Carlisle Resource Zones, dry year demands and profiles (where relevant) are included within the Aquator™ models. These demands are scaled proportionally to search for the deployable output level. In this regard, the demand profile and the baseline apportionment of demands can have a strong influence on deployable output[12]. The forecasting of dry year demand is covered within a separate technical report, however, there are specific aspects that are relevant to the deployable output methodology.

In our 2015 plan we used 2012/13 base year demands (upon which forecasts were based) as the baseline demands in Aquator™, based on actual demand proportions between demand centres. For WRMP19 we have used 2015/16 demands for the base year for this draft WRMP. Demand values include the addition of raw water and process losses, apportioned to each demand centre (see Section 14 for details), which ensures a better representation of the spatial variation of 'demand' across the zone. It should be noted that in calculation of WAFU, losses are removed from the deployable output calculation; their inclusion within the Aquator™ models is to promote realistic model behaviour.

Dry year demands are calculated for each year through the whole planning horizon, although inherently only one set of baseline demands (using a single year) may be included in modelling. The UKWIR Handbook of Source Yield Methodologies (2014) states that it is good practice to apply demand profiles to give a realistic pattern of variation throughout the year where seasonal trends occur, and also that:

Appropriate demand profiles should be determined based on demand data from previous representative years, for example using years with dry summers if dry weather scenarios are being modelled.

Taking this into account, a dry year monthly profile has been included for the Strategic Resource Zone, representing observed trends in the 1995 drought event, and the same profile is used throughout each year of the model run.

The Carlisle Resource Zone model does not utilise a demand profile. This is because analysis of historic demands has demonstrated that there is a weak seasonal trend in the zone, and that monthly profiles in any given year are extremely variable. As the timing of a peak may under-estimate or over-estimate deployable output (depending on whether or not it coincides with hydrological drawdowns), it is therefore considered more robust not to include any profile for this flashy, short critical period system. This approach is consistent with the assumptions used for our WRMP15.

It should also be noted that for the Strategic Resource Zone, non-UU demands and non-potable demands do not ramp up/down in a deployable output analysis against the base levels. These demands are subsequently added to the Aquator™ result to produce a total deployable output (as they are UU supplied demands included in deployable output). The Dee non-UU demands represent the abstraction licence maximums, but these vary slightly depending on the storage of the Dee system in line Natural Resources Wales operating rules and assumptions (e.g. reflecting adherence to cut-backs enforced by Natural Resources Wales, this is included for realistic model simulation).

6.1.7 Level of service representation

Our current minimum level of service for water supply is outlined in Section 2.4. This section describes how level of service is represented in our supply assessment, and how it affects our baseline deployable output. The impact and treatment of level of service in the context of deployable output differs across resource zones. The Environment Agency Water 2017 Resources Planning Guideline requires that companies are clear on the treatment of level of service in their plans.

Level of service applies throughout the region and covers both statutory water use restrictions (known as temporary use bans, and formerly known as hosepipe bans), drought permits and drought orders. The assumptions surrounding levels of service, and how they are accounted for in assessing our baseline deployable output, are included in Table 5.

[12] For instance if a more stressed area has higher demands relative to its neighbours it will be more likely to constrain overall deployable output

Table 5 Assumptions and rationale surrounding levels of service in assessing baseline deployable output

Resource zone	Assumption	Rationale	Outcome
Strategic Resource Zone	Drought triggers	In line with the Drought Plan 2017	Levels of service for TUBS and drought permits does not constrain deployable output, which instead is constrained by Haweswater reaching emergency storage.
	Benefits of drought permits and orders not included[13]	In line with the planning guidelines they are not accounted for in defining baseline deployable output	
	Temporary use ban saving of 5%, implemented at drought trigger 4	5% demand saving based on historic data analysis	
	Emergency storage	Use of emergency storage is not permitted in the baseline deployable output run	
	Post-processing of level of service events	This is a manual exercise following an Aquator™ model run, whereby events are excluded from contributing to level of service, for instance if: • There are multiple crossings of trigger 4 during a drought event • Time spent below trigger 4 is 6 days or less • Trigger 4 is crossed whilst the River Dee is being regulated	
Barepot Resource Zone	N/A – non-potable resource zone, constrained by licence rather than drought		
Carlisle Resource Zone	Drought triggers	In line with the Drought Plan 2017	Levels of service for TUBS does not constrain deployable output, which instead is constrained by Castle Carrock reaching emergency storage.
	There are no drought permits or orders within the zone	In line with the Drought Plan 2017	
	Temporary use ban saving of 0%	It is not considered likely that these restrictions will have a significant impact given historic data analysis and the demographics of the area[14]	
	Emergency storage	Use of emergency storage is not permitted in the baseline deployable output run	
North Eden Resource Zone	Drought triggers	In line with the Drought Plan 2017. Determined by licence when 100% for the whole resource zone group has been abstracted.	The North Eden Resource Zone does not reach drought trigger 4 in the historic record. Deployable output is constrained by annual licence limits, and not by levels of service.
	Benefits of drought permits and orders not included[13]	In line with the planning guidelines they are not accounted for in defining baseline deployable output	

As part of the supply assessment, in line with water resources planning guidance where appropriate, we have assessed different levels of service to understand the impact on deployable output. These are detailed in Section 17.

[13] The benefits of drought supply measures and demand restrictions have been explored to populate Table 10: Drought plan links and deployable output overview (see Section 17)

[14] A 3% decrease in demand was tested when Castle Carrock reservoir reaches drought trigger 4, giving a 0.1 Ml/d increase in resource zone deployable output. Further detail is included in Section 6.4.2

We consider it unacceptable to plan for rota cuts and standpipes even in an extreme drought[15]. We look at how our system behaves in more extreme droughts in Section 17, and explore the potential use of these measures in extreme drought events.

6.1.8 Dead water and emergency storage

In both AMP3 and AMP4, a review of all dead water values was carried out in parallel with the review of yields. Where appropriate changes were made to the dead water values to take account of water quality or technical problems experienced during the 1995/96 drought and other known constraints. For our WRMP19 all dead water values have been checked for consistency and updated where appropriate, for example where new bathymetry data has been produced[16].

The UKWIR Handbook of Yield Methodologies (2014) defines emergency storage as:

> *A reserve water storage capacity aimed at accommodating the operational uncertainty for the duration of a particular drought. The value of the reserve store should be agreed with the regulators and should be reflected in the level of risk a water company is taking across the planning period.*

From the UKWIR WR27 Deployable Output Report (2012):

> *For Water Resource Zones with large surface water reservoirs, there are issues with using a fixed volume of storage based on 15 or 30 or 45 days of assumed demands. If the assumed demand is too high, over-provision of emergency storage would result, with an unrealistically low DO.*

Companies have a choice on the emergency storage allowance, which should factor in the nature of the system in question as well as a level of risk. The Handbook of Source Yield Methodologies also outlines the aim of 30 days emergency storage, although it does acknowledge that this can vary in agreement with the Environment Agency and that a smaller emergency storage may be appropriate in a large conjunctive resource zone where drought conditions are unlikely to occur with the same severity across the whole area.

For WRMP19 our approach to emergency storage is similar to our 2015 plan. As groundwater resources in the region are generally constrained by licence or asset capability rather than hydro-geology, emergency provision has only been applied as emergency storage on reservoir sources. It is therefore assumed that borehole sources will make up a proportion of overall demand. For us this results in either 20 or 30 days[17] of supplies reserved in reservoirs to meet supply in a drought of specified duration that is worse than any drought in the historic record. Therefore emergency storage does not contribute towards deployable output.

No emergency provision is included in North Eden, as it is entirely borehole fed and constrained by abstraction licences.

In the Strategic Resource Zone the emergency storage volume has been recalculated using the same methodology applied in our 2015 plan. The sources with control curves and yield cut-back rates applied (i.e. Pennines sources) have had emergency storage calculated iteratively within Aquator™ single reservoir models such that the allocation is 20 days of the yield calculated plus 20 days compensation flow. Haweswater and Thirlmere reservoirs have their 20 days allocation calculated based on a sample base deployable output run in the resource zone model, which estimates the expected demand on these resources accounting for the contributions from the other local and groundwater resources at the time of drought. The River Dee emergency storage allocation is consistent with that determined by Natural Resources Wales in the Dee General Directions and included in their standalone Aquator™

[15] For context, in the Strategic Resource Zone the worst historic drought, 1984, has an estimated return period of 1 in 94 years on average (or 1.06% annual average risk).

[16] For this draft WRMP we have incorporated new bathymetry data for Lake Vyrnwy. In addition to this we have amended the storage volumes at two reservoirs in the Pennines (Whiteholme and Lower Castleshaw) where the top water level has been permanently reduced, however the dead water values remain the same.

[17] The Handbook of Source Yields Methodology states that most companies aim for 30 days emergency storage, but recognises that in a large integrated resource zone drought conditions are unlikely to occur with the same severity across the whole area, a smaller emergency storage volume may be appropriate as some support would be available from other parts of the system. The water resource planner must balance the need to plan for a severe drought whilst avoiding unreasonable constraints on yield. Alternative values (to the 30 day allowance) can be used if agreed with the Environment Agency. In our calculations we assume there would be zero inflow into the reservoir at such a time, therefore in reality we would expect the emergency storage volume to potentially last for more than the specified allowance period.

model. This method is a significant improvement as it more closely apportions emergency storage to the expected source demands in a dry year.

The emergency storage allowance of 20 days adopted for the Strategic Resource Zone is less than the 30 days noted in the Handbook of Source Yields Methodology. This is due to the resource zone size (so it is very unlikely all sources will be at emergency storage at the same time across the entire region), and the diverse nature and geographical spread of the sources from North Wales, the Pennines, and the Lake District. The benefits of this diversity were witnessed during 2003, 1995/96 and previous droughts. Since then we have also improved network connectivity (Section 2.3.2) allowing to balance these areas very effectively. In effect our allowance is based on 20 days storage across the whole resource zone, however in an emergency we would expect supplies to outlast this, because we could move water from areas unaffected / less affected by the emergency. Finally it should be pointed out that our emergency storage allocation is calculated on the assumption that there would be zero inflow; in reality there would be at least some inflow to most sources and we would have a few days of additional supply in this respect.

The Carlisle Resource Zone is much smaller and has fewer alternative sources of supply. This results in reduced resilience and flexibility compared to the Strategic Resource Zone, and therefore a greater requirement for emergency storage. However, the resource zone has a flashy catchment response with a short critical period. Emergency storage for the resource zone is based on 30 days yield of the River Gelt/Castle Carrock system, taking into account the hands off flow conditions in the Gelt system.

6.1.9 Reservoir compensation over-releases

The release of compensation flows from impounding reservoirs can be subject to some inaccuracy irrespective of infrastructure. Therefore, operationally an additional amount over the compensation flow requirement is released. This acts as a buffer and ensures that statutory releases comply with licence conditions, however, there is also uncertainty around the exact over-release amount. Where appropriate, as with our 2015 plan, we have accounted for compensation over-releases into our deployable output assessments to reflect this additional 'lost' water, however the application of these losses has been improved for this plan (see below). We have included improved compensation release control options as potential options for our future plans, further details are included in our *Draft WRMP19 Technical Report – Options appraisal.*

In our WRMP15 an assumption of 10% over-release for Haweswater and 5% for all other reservoirs was used. For the Strategic Resource Zone 16.10 Ml/d was deducted from the supply-demand balance[18].

For our 2019 plan a new approach has been employed. Reservoir level and compensation data (from 2010 to 2017) for each reservoir has been analysed for summer and winter periods to show any seasonal variation in release. The reservoir controllers were consulted on the over-release volume relative to the statutory requirement. If the over release is due to lack of control then this was used as the compensation over release. However, if the over release is due to caution then the controllers advised the lowest release they would be able to reduce to in a dry period and this value was used as the compensation over release. The reservoirs were split into categories based on the compensation requirement and the average percentage over release calculated for each category. Where there were no available data for a reservoir, the average percentage over release for that category was used as the over release. The total volume of over release calculated in this assessment is 22.0 Ml/d. This is marginally higher than the 16.1 Ml/d used in our last plan which used an assessment based on a smaller number of sites.

Uncertainty around the over-release amounts is captured within our target headroom assessment, further detail is included in the *Draft WRMP19 Technical Report – Target headroom*. In addition to this, the over-release sites were linked to the options identification (*Draft WRMP19 Technical Report – Options identification)* and were filtered through the screening process to determine if improving compensation release control was feasible as a resource management option.

The over-release amounts have been included in the Aquator™ models directly. This is an improvement from the 2015 plan approach as the impact is accounted for in the areas of the system where the reservoirs are located, rather than the assumption being aggregated across the whole resource zone. Implementation of the compensation

[18] In our 2015 Plan in the West Cumbria Resource Zone the 5% over-release at Ennerdale and Crummock was included in the Aquator™ model, and a range around that figure was included in headroom to reflect uncertainties.

over-releases in the Strategic Resource Zone model had a 19 Ml/d reduction to deployable output, demonstrating that application within the model is not a 1:1 ratio impact.

6.1.10 Hands off flow buffers

Many of the rivers and lakes from which we abstract have a hands off flow condition below which we are not permitted to abstract. In order to remain compliant with these conditions, abstraction is started or ceased at a river flow greater than the hands off flow. There is also uncertainty around the measurement of the river flow due to the instruments used to measure river level.

Inclusion of hands off flow buffers is an improvement for our 2019 plan. For pumped sources, available river flow and abstraction data from 2010 to 2016 has been analysed to identify periods of pump starting and stopping at river flows near the hands off flow requirement. The difference between river flow and hands off flow at this point has been calculated. Some sources respond very quickly to rainfall which makes it difficult to use the data to determine an appropriate buffer so the results from a less flashy source have been applied across all pumped intakes. For gravity abstractions, the over-release amounts from the compensation over-release assessment have been applied.

Uncertainty around the buffer amount is captured within our target headroom assessment. Further detail is included in the *Draft WRMP19 Technical Report – Target headroom.*

The buffer amounts have been included in the Aquator™ models directly. Implementation of the hands off flow buffers in the Strategic Resource Zone model had a 4 Ml/d reduction to deployable output, with a 0.1 Ml/d reduction to deployable output in the Carlisle Resource Zone model. These reductions demonstrate that application within the models has significantly less than a 1:1 ratio impact.

6.2 Strategic Resource Zone

An Aquator™ resource zone model is used to calculate deployable output for the Strategic Resource Zone. Detailed information on surface water sources and inflows within this resource zone is included in Section 6.1.3.

6.2.1 Deployable output

- Model deployable output is 2,115.6 Ml/d, defined by Haweswater reservoir reaching emergency storage in 1984;
- The deployable output has been tested for Levels of Service accounting for triggers on the Haweswater and the Dee, trigger 4 is crossed during four events in the 89 year model run; and
- The critical period for the deployable output model run is between 6-18 months depending on the drought event in question.

Changes in deployable output between our 2015 plan and the baseline for our WRMP19 are described in Section 5 and can be categorised as such:

- model development activities – e.g. increased level of detail in some system areas;
- WRMP19 data refresh – asset capability, costs, source yields, and emergency storage; and
- improved approach – e.g. compensation over-releases within the model, accounting for groundwater peak deployable output, and improved climate change impact assessment

The Strategic Resource Zone Aquator™ model build is largely the same as our 2015 plan. Several areas of the model have been disaggregated[19] to balance the level of detail represented in the models with computational run time and the source contribution to the resource zone.

The key assumptions and approach for the Strategic Zone are summarised below:

- Demand centre representation: The model allocates demand to 33 demand centres as well as allowing for the demands on the River Dee of from non-UU abstractors based on Environment Agency Dee General Directions maximum allocations. The majority of these demand centres are based on Demand Monitoring Zone (DMZ) areas, which are the fundamental building block for UU's Water Resource Zones. However since

[19] Areas of disaggregation include; Southern Command Zone (SCZ); Fishmoor; and Longdendale and Audenshaw reservoirs

our 2015 Plan we have reviewed this level of detail and disaggregated further where applicable when there is a constraint to supply within the DMZ scale. This is particularly apparent around the southern area (to the west of pumped strategic links) which is now represented at a higher level of detail than our last plan, and in some instances has more than one demand centre per DMZ to account for the potential supply from either the Dee or Vyrnwy aqueducts. As mentioned in Section 6.1.6 above, non-UU demands and non-potable demands do not ramp up/down in a deployable output analysis against the base levels.

- Dee-Only Demands: The modelling of the River Dee includes abstractions from the river by Canals and Rivers Trust, Dwr Cymru/Welsh Water and Dee Valley Water, and UU's non-potable supplies to Dwr Cymru and the Wirral. In the model we have assumed non-potable supplies of 80.3 Ml/d based on historic average takes (demands are non-seasonal). Non-UU demand values were agreed with Natural Resources Wales during our WRMP15.

- 'Local Reservoir Sources' and Reservoir Operating Rules: Aquator™ allocates supply to demand based using the standard software procedure outlined in Section 6.1.1, subject to constraints and defined control rules. Model setup aims to mimic real-world operation, whereby local sources (Pennines and South Cumbrian reservoirs) are operated at sustainable rates (yield cut-backs) when below control curve, putting demand onto the regional system (e.g. Haweswater, Dee and Thirlmere), upon which the latest Aquator™ algorithms are used to balance the risk of failure based on resource status. The control rules are derived in order to maximise water supplied in the critical period of a reservoir source. The VBA controls allow Aquator™ to determine the supply rate above curve, and in any case minimum flows are defined by asset minimums (e.g. WTW min). When below curve, any boreholes directly associated with a reservoir are permitted for use at deployable output rates to support storage, reflecting typical operational practice. Source groups are typically at a combined DMZ level, which serves a balance between system detail and computational requirements.

- Groundwater Source Representation: In previous planning rounds only average groundwater deployable output was accounted for, and this was applied as a daily maximum on the borehole components. For our 2019 plan we have improved on this approach by including the peak deployable output as the maximum supply from the boreholes. This links in part with the disaggregation of the southern area of the resource zone described above. The average deployable output is accounted for as an annual yield on each groundwater component, derived by multiplying the average deployable output by 365 days. This total volume for the annual yield acts as a resource state to determine the relative 'health' of the source and ensures that the abstraction licence conditions are not breached. The setup and inclusion of boreholes and/or borehole groups is dependent upon their location in the system and relationship to surface-water sources. Minimum rates are defined where a baseload take is required (e.g. due to water quality reasons).

- Drought Triggers and Demand Saving: There are two 'Demand Saving Groups' based on the Dee and Haweswater drought triggers. When the relevant trigger is crossed, Aquator™ imposes a resource zone wide demand saving on UU demand centres (except non-potables) if at least one group trigger is crossed. When Trigger 4 is crossed (classed as Demand Saving Level 2 in Aquator™, where Trigger 3 is Level 1), a minimum 30 day 'hold' is applied once triggers are re-crossed as storage recovers; this represents that restrictions would not be immediately lifted. The River Dee triggers also control maximum UU abstraction from the River Dee in line with Natural Resources Wales operating rules. Drought triggers are also used to control asset use in some cases, explained elsewhere.

- Strategic pumped resources[20]: Haweswater Reservoir is one of two sources in the Strategic Resource Zone that has drought triggers. Ullswater and Windermere provide support by offsetting abstraction from Haweswater to retain storage to reduce the risk of needing to implement drought powers. Storage in Haweswater can also be protected directly by reducing abstraction. Additionally the West East Link Main, commissioned in 2012, enables us to transfer more water from the south of the Strategic Resource Zone towards Manchester. These actions, and others, reduce demand on Haweswater, and risk is balanced across the resource zone as a whole as part of operational management. The operation of these resources are in line with that defined within our Drought Plan 2017.

[20] Following the dry spell in early 2017, we reviewed our operation of strategic pumping and included detail of this in our Drought Plan 2017. These changes have been accounted for in the supply forecast for WRMP19.

- Waterbanks: Environmental 'waterbanks' are included in the model for Vyrnwy, Thirlmere, Heltondale (Haweswater) and Windermere, which are operated by the Environment Agency.
- Model Costs: The latest unit costs available for the 2016/17 financial year were included in Aquator™. Relative cost is the most important factor in Aquator™ rather than absolute costs, and costs are used to balance resources when sources are healthy.

6.2.2 Strategic Resource Zone emulator model

The Strategic Resource Zone emulator is a rapid assessment model built using the Pywr modelling platform[21]. In the emulator model some aspects of the resource zone are aggregated (for instance some of the Pennines reservoirs), but it has sufficient detail to capture the key supply-demand components and to give a similar response to the Aquator™ Strategic Resource Zone model. As the emulator does not include the level of detail of the full model, it is more computationally efficient and can be used to simulate many more scenarios. The emulator model has been used alongside our more detailed Aquator™ as part of the advanced techniques employed for our WRMP19, including as an enhancement to the climate change assessment (see Section 10) for scenario sampling purposes and in testing our plans (see Appendix B for how we have used stochastic hydrology to test our plans).

6.2.3 Demand side drought restrictions

The Strategic Resource Zone model includes demand side drought restrictions in determining the deployable output, in line with the assumptions stated in Section 6.1.7 and Table 5. There are two 'Demand Saving Groups' based on our Dee and Haweswater drought triggers. When trigger 4 is crossed, Aquator™ imposes a resource zone wide demand saving on UU demand centres (non-UU demands and non-potable demands) if at least one group trigger is crossed.

Natural Resources Wales determine the Dee General Directions which includes regulation rules, drought triggers, and cut back rates. Our representation of the Dee system aligns to the Dee General Directions principles. The River Dee triggers also control our maximum abstraction from the River Dee in line with Natural Resources Wales Dee operating rules.

The resource zone is susceptible to prolonged dry weather or multi-season drought events. In the baseline model, when simulated at deployable output level of demand, the level of service is for a temporary use ban to occur at a 1 in 22 year average frequency (4.5% annual average risk). This is a slight improvement to the level of service from our WRMP15 of 1 in 20 years on average (5% annual average risk)[22]. The deployable output results are determined by the availability of supplies during the driest period (1984) and are not impacted by aiming to meet level of service.

The deployable output benefit of demand side restrictions was tested during plan development. Our previous plan accounted for a 3% demand saving on crossing drought trigger 3 when voluntary water use restrictions would be applied. However analysis of available evidence suggests that the instantaneous[23] demand saving from a temporary use ban would likely be higher than the 3% in the Strategic Resource Zone Aquator™ model. The 3% demand saving aligns to the demand saving over the full period of the hosepipe ban applied in 2010. However, analysis of rainfall data indicates there was heavy rainfall shortly after the implementation of the hosepipe ban in July 2010, so it is difficult to determine whether the demand, as well as the resulting demand saving, was suppressed.

Reviewing the demand saving from the hosepipe ban[24] in 1995/96, the demand saving in the weeks ending 20 August 1995 and 27 August 1995, was 6% and 12% respectively. Therefore, it is appropriate to use a higher demand saving than the 3% in our 2015 plan, but look to apply it at drought trigger 4 in line with the evidence that statutory water use restrictions (i.e. hosepipe bans, now temporary use bans) will deliver a demand saving. A 5% demand saving was considered as this represents the instantaneous[23] demand saving at the start of the hosepipe ban in 2010 (from the week ending on 18 July 2010) and an average over the initial period of the hosepipe ban in 1995/96 (August to September).

[21] Pywr is a generalised network resource allocation model written in the programming language Python
[22] This shows a marginal improvement however is only based on a handful of events in the historic record over a slightly longer record this time.
[23] In this context, this term refers to the demand saving over a week, as this is the highest temporal resolution of the data
[24] Statutory use bans were formerly known as hosepipe bans but are now recognised as temporary use bans.

Sensitivity testing around the demand saving amount assumptions has been completed for the Strategic Resource Zone and this helped to inform the target headroom component S6 Accuracy of supply-side data. Further detail on the assessment of target headroom can be found in the *Draft WRMP19 Technical Report – Target Headroom*.

6.3 Barepot Resource Zone

The sole water source in the Barepot Resource Zone is an abstraction from the River Derwent, and the assessment is relatively straightforward. Deployable output is calculated by examining the constraints around this source for the resource zone. Aspects considered include the abstraction licence limits, historical river flow, and any infrastructure constraints. Resource zone deployable output is defined by the abstraction licence with conditions in place.

6.4 Carlisle Resource Zone

The Aquator™ Carlisle Resource Zone model is used to calculate deployable output for the Carlisle Resource Zone. Detailed information on surface water sources and groups in this resource zone is included in Section 6.1.3.

The Carlisle Aquator™ model build is largely the same as our 2015 plan. The model parameters have been updated to reflect current operation and constraints and there have been improvements to the flow modelling with the addition of Ullswater to the River Eden representation. All demand centres are scaled proportionally in a deployable output analysis. During the preparation for this 2019 plan we applied for renewal of the time limited element of the River Eden at Cumwhinton abstraction licence, which was subsequently granted. We tested the sensitivity of resource zone deployable output to the time limited aspect of the licence (as detailed in Section 6.1.5).

The key changes to resource zone deployable output between WRMP15 and WRMP19 are detailed in Section 5.

The modelling approach is consistent with guidance set out in the UKWIR (2014) Handbook of source yield methodologies and UKWIR (2016) WRMP19 methods – risk based planning methods and with the approach used in this plan for the Strategic Resource Zone.

- Model deployable output is 35.9 Ml/d, defined by Castle Carrock reservoir reaching emergency storage in 1976;
- The deployable output has been tested for Levels of Service and Castle Carrock crosses drought trigger 4 once (1976) in the 54 year model run; and
- The critical period for the deployable output model run is 13 weeks and 4 days (approximately 3 months).

6.4.1 Abstraction Licence Constraints

The River Eden abstraction licence is time limited (this has recently been renewed and has an end date of 31 March 2030). In the plan we assume that future renewals will be granted, however as a sensitivity the impact of reducing the licence was tested during plan development. The impact of reducing the time limited annual licence from 8,000 Ml to 7,546.4 Ml reduced resource zone deployable output by 3.8 Ml/d to 32.1 Ml/d.

Sustainability and environmental impacts of the River Eden and Gelt abstractions have been subject to detailed investigations, most recently under the Habitats Directive and Water Framework Directive. Following this work sustainability reductions to the River Gelt abstractions were assessed and applied in our WRMP15. The increased hands off flows are also included in the base model assumptions for this 2019 plan (potential future sustainability reductions are identified and tested in Section 7).

6.4.2 Demand Side Drought Restrictions

As discussed in Section 6.1.7 there are no demand side drought restrictions assumed for the Carlisle Resource Zone. On the rare occasion that drought triggers are crossed as it is not considered likely that any restrictions will have a significant impact on demand given the demographics of the area. The deployable output benefit of demand side restrictions was tested during plan development. A 3% decrease in demand was tested when Castle Carrock reservoir reaches drought trigger 4, giving a 0.1 Ml/d increase in resource zone deployable output. The benefit is limited as trigger 4 is only slightly higher than emergency storage. The assumptions for drought triggers and demand saving align with our Drought Plan 2017.

The baseline level of service for temporary use bans (at 1 in 50 years, or 2% annual average risk) is much better than our agreed level of service (1 in 20 years, or 5% annual average risk). The deployable output results are determined by the availability of supplies during the driest periods and are not impacted by aiming to meet level of service.

6.5 North Eden Resource Zone

Our water sources in the North Eden Resource Zone consist entirely of boreholes. Deployable output for these sites is calculated individually and combined to produce the deployable output for the resource zone.

7. Our role in achieving sustainable abstraction

A **sustainability change** is any change to a water company abstraction licence to protect (prevent deterioration) or improve the environment. The Environment Agency provides sustainability changes to the water companies via the Water Industry National Environment Programme (WINEP).

A **sustainability reduction** is the reduction in water company deployable output due to a sustainability change (licence change). A sustainability reduction is calculated by the water company and included in its WRMP. Note that a sustainability change may not lead to a sustainability reduction if the source deployable output is limited by another constraint, such as hydrological yield or pump capacity

7.1 Baseline position

In determining WAFU any reductions associated with achieving sustainable abstraction must be accounted for. In line with the guidance we have liaised with Environment Agency and Natural Resources Wales to determine if we have any abstractions from water bodies that are at risk from deterioration, and include the requirements set out in the WINEP[25], which sets out measures needed to protect and improve the environment.

In our WRMP15 we included a number of sustainability changes and in the 2015-2020 period we are investing to implement them[26]. We are on track to have completed all investigations and options appraisals AMP6 (covering April 2015 to March 2020) by the agreed dates. The sustainability changes from our 2015 plan have therefore been accounted for in assessing our baseline supply forecast for WRMP19.

The assessments of our data and that provided by the Environment Agency regarding the current abstraction licences indicate that although there is some residual risk, overall the operation of the licences, the reductions noted by the Environment Agency and the schemes identified for AMP6 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.[27]

There are multiple drivers for sustainability reductions as shown in Table 6, along with a summary on how we have approached each item.

[25] Our assessments for WRMP19 are based on WINEPv1. When WINEPv2 was released in September 2017 we checked that the relevant impacts have been assessed. Some items have changed and the items included in scenario B (see Table 7) may need to be included in our baseline deployable output review. We will ensure that for our revised draft WRMP19 the baseline deployable output assessment will include the most up to date WINEP information.

[26] Two sustainability changes at Ennerdale Water and Over Water in our West Cumbria Resource Zone will come into effect on completion of the Thirlmere Transfer scheme in March 2022. Further information on the future legacy of sources and assets in West Cumbria is detailed in the *West Cumbria Legacy* report published alongside our plan.

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

Table 6 Breakdown of sustainability change sources and how we have addressed them in WRMP19

Source of sustainability change	Information on our approach
Water Industry National Environment Programme (WINEP)	Inclusion of certain (green) and indicative (amber) sustainability changes in baseline deployable output. Unconfirmed (red) and 'direction of travel' (purple) changes to be included in scenario testing. These include Water Framework Directive (WFD) no deterioration drivers which were accounted for in our WRMP15, and are therefore already within the baseline assessment for our 2019 plan. Any issues identified through the Heavily Modified Water Bodies (HMWB) driver are also included in WINEP.
Abstraction reform	Some licences are potentially at risk of being revoked by the Environment Agency due to non-use. Our assessment has not identified any licences that we believe are at risk of revocation. Therefore potential sustainability changes from this issue are not included in WRMP19.
Time limited licences due for renewal during the planning period (or before)	Our assessment has not identified any licences that we believe are at risk of non-renewal on like for like terms. Therefore potential sustainability changes from this issue are not included in WRMP19.

In discussion with the Environment Agency and Natural Resources Wales there are a number of potential sustainability reductions in future AMPs, these include:

- Those which have been identified by the Environment Agency and included in WINEP; and
- The Environment Agency's assessment of existing sources which could cause deterioration under the Water Framework Directive (WFD).

Note that there are no potential sustainability changes for the Carlisle or North Eden Resource Zones. Scenarios for the Strategic and Barepot Resource Zones are discussed in more detail Sections 7.2 and 7.3.

7.2 Future changes – Strategic Resource Zone

There are no new sustainability changes to include in our baseline supply forecast. However we have identified potential future sustainability changes that require further investigation in the 2020-2025 period to confirm if they will go ahead. Due to the uncertainty, these sustainability changes have been grouped into scenarios and tested to determine the potential changes they could have on our future supply. Further detail of the potential changes in each scenario is included in Appendix A.

Sensitivity testing indicates that there is a potential impact of -14 Ml/d to Strategic Resource Zone future deployable output. This is relatively small in the context of the Strategic Resource Zone deployable output, and is approximately 0.7% of the total deployable output. The results from the sustainability changes sensitivity testing are shown in Table 7.

Table 7 Scenarios used to test potential future sustainability changes and relative impact on Strategic Resource Zone deployable output

Scenario	Variance from baseline (Ml/d)
Baseline	
Scenario A: baseline + WINEP red sustainability changes	0
Scenario B: scenario A + adaptive management schemes	-7
Scenario C: scenario B + WFD impacts on surface water bodies	-7
Scenario D: scenario C + WFD impacts on groundwater bodies	-14

The Environment Agency have classified our abstractions and structures which could cause a barrier to eel passage into high, medium and low priority categories. For high priority sites the majority have either investigations or projects to address the requirements that are ongoing in AMP6 (April 2015 to March 2020) with any outstanding high priority sites due for completion in AMP7 (April 2020 to March 2025). Any medium or low priority sites will be addressed as part of standard 'business as usual' asset management activities. We have assumed there is no impact on the availability of supply. We have several sites where there might be an impact on supply, and we are working with the Environment Agency through the WINEP process to define which schemes will progress and what the impact on supply could be. For fish passage projects in AMP6 and AMP7, we have not identified any impacts on the availability of supply.

7.3 Future changes – Barepot Resource Zone

With the Environment Agency we are reviewing the abstraction licence used to supply the Barepot Resource Zone under the Habitats Directive driver. We are examining the potential to reduce the daily licence volume from 34.1 Ml/d to 30 Ml/d, with an assumed implementation date of 1 January 2018. This has been modelled as a scenario, and reduces total WAFU from 34.07 Ml/d to 30 Ml/d, and reduces the surplus at 2044/45 from 5.75 Ml/d to 1.69 Ml/d. The requirement for this change is not yet confirmed, and for our draft WRMP19 we have included it as a scenario. If there are any revisions to the abstraction licence over the coming months they will be accounted for in our revised draft WRMP19 (expected summer 2018).

8. Invasive non-native species

Invasive non-native species (INNS) are broadly defined as species whose introduction and/or spread threaten biological diversity or have other unforeseen impacts[28]. INNS can also result in operational problems, for example, the fouling of intake screens or pipes by zebra mussels. Risk of INNS transfer associated with our existing operations which involve transfer of raw water between catchments will be the subject of an investigation in AMP7 (April 2020 to March 2025) which will be included on the Water Industry National Environment Programme (WINEP). We have already been working with the Environment Agency to develop a prioritised list of inter-catchment transfers for investigation. The output from the investigation will be a risk assessment, and if necessary mitigation measure development and an options appraisal will be undertaken to determine the required measures for those sites identified as high risk. Therefore there may be potential implications for supply from AMP8 (April 2025 to March 2030) onwards, but at present there insufficient definition to include these within the supply forecast. Options that have been considered for this plan have been assessed and through this process the risk of potential inter-catchment transfers is identified. Mitigation measures have been included within the scope of the options to prevent INNS transfer in line with Environment Agency guidance.

Further information of the INNS risk assessment completed for this plan is included in our *Draft WRMP19 Technical Report – Options appraisal*.

[28] Definition from The Great Britain Invasive Non-native Species Strategy, August 2015 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/455526/gb-non-native-species-strategy-pb14324.pdf

9. Abstraction reform – evidence needs

With the exception of the River Dee and Lake Vyrnwy, which are licensed by Natural resources Wales, all other sources within our region have abstraction licences granted by the Environment Agency. In line with the Water Resources Planning Guideline we have not included any changes to deployable output from abstraction reform. We have recently responded to the Welsh Government consultation on 'Taking forward Wales' sustainable management of natural resources'. Under abstraction reform, catchments are either classed as enhanced or standard. In our area only the Lune and Wyre are classed as enhanced[29]. At the time of developing our WRMP19 we are still awaiting firm proposals for abstraction reform in both England and Wales. All of our licences are used in a conjunctive system so, particularly in a drought event, it is difficult to predict how our abstraction from sources other than the Lune and Wyre would be adapted given the variable nature and characteristics of each specific drought event.

We have a number of sources that are used as 'drought sources' that feature in our Drought Plan 2017. These are non-commissioned sources, and for our Drought Plan 2017 a range of engineering specialists including mechanical, electrical and civil disciplines completed a thorough review and identified the requirements needed to bring each source back into operation. Alongside this work, we also sought to better understand the specific benefits of bringing each source back into use by examining our water resource models alongside risks, for example associated with water quality compliance to customers. This included considering the benefits under extreme drought scenarios.

The results of this work led to a refinement of the supply side options presented in this plan, resulting in 12 options being identified. Some of the previous options in the Final Drought Plan 2014 are now in operational use and so are no longer included as non-commissioned drought options. For the remainder, we concluded that they offer no additional benefit of any significance during a severe drought, alongside our other drought options. Therefore, we removed them from the Drought Plan 2017, but have considered their future potential use in this WRMP where they have been filtered through the options identification and appraisal process. Further information can be found in the *Draft WRMP19 Technical Report – Options identification* and *Draft WRMP19 Technical Report – Options appraisal* documents that are published alongside our plan.

[29] Note that the Severn catchment is also classed as enhanced but only on its lower reaches outside our area of influence e.g. Severn Middle Shropshire and Severn Middle Worcestershire.

10. Climate change

An assessment of climate change impacts has been completed to meet the requirements of the new guidance contained within the Environment Agency (2017) supplementary information and supporting methodologies contained within the EA-UKWIR (2012) Climate Change Approaches in Water Resources Planning.

Climate Change has been treated in a risk-based manner with a choice of approach based on the outcomes of a required resource zone vulnerability exercise. In line with the requirements of the water resources planning guidelines, during the pre-consultation phase we discussed the climate change approach with the Environment Agency and Natural Resources Wales.

The stages of the climate change assessment, as detailed in the guidance, are described in the sections that follow. An overview of the assessment process followed is shown in Figure 6.

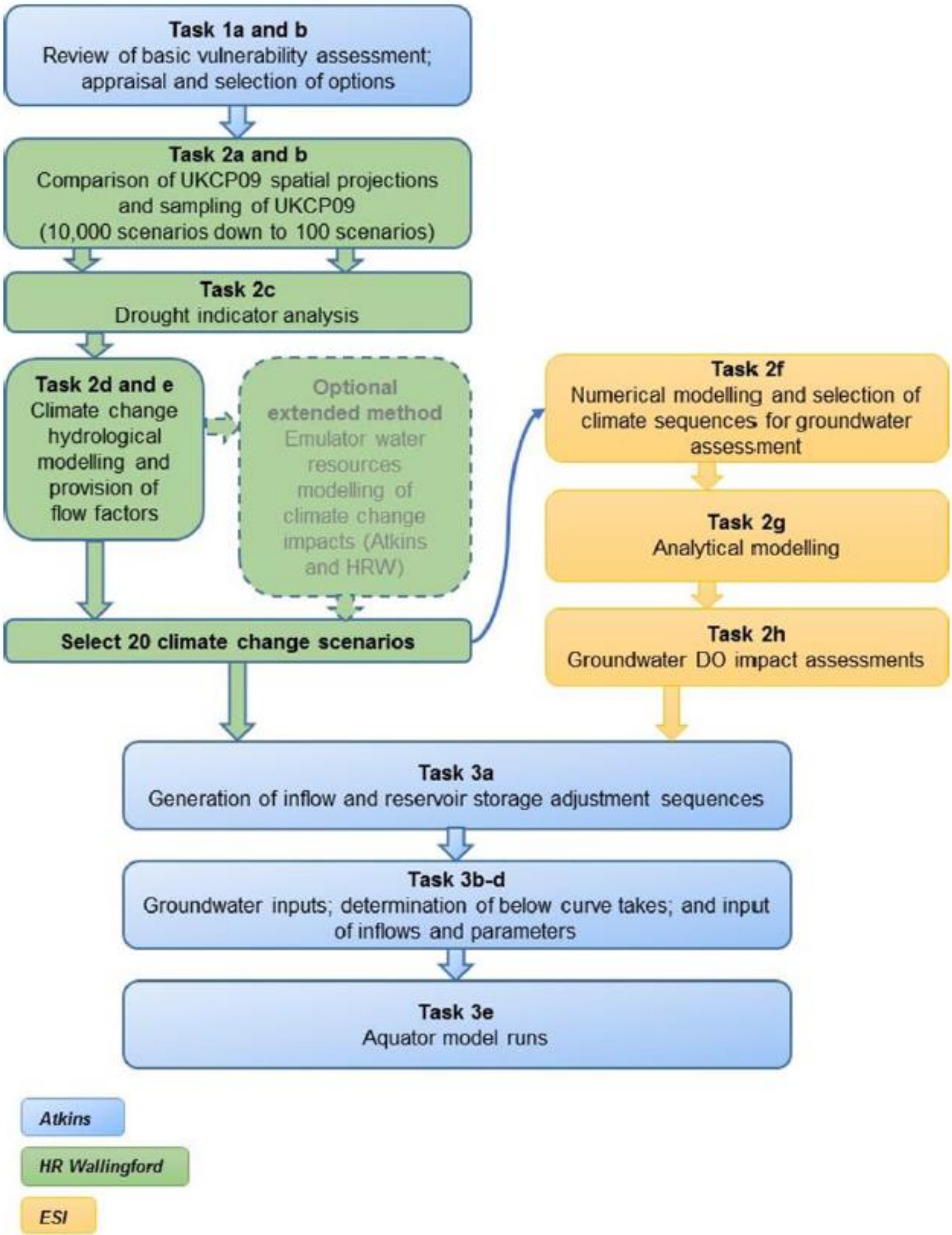


Figure 6 Overview of approach for the WRMP19 climate change assessment

10.1 Basic vulnerability assessment

For the basic vulnerability assessment we used the deployable output impacts of the 20 climate change scenarios up to 2035 that were assessed as part of WRMP15. The uncertainty range and mid scenario deployable output percentage change were plotted to determine the vulnerability classification of each resource zone. From the basic vulnerability assessment the resource zones were classified according to Table 8, noting where there are changes from the basic vulnerability assessment we completed for WRMP15. Note that the full climate change assessment of the 2080s for the West Cumbria Resource Zone was not within scope for WRMP19 at this time.

For Barepot Resource Zone, which is assessed for the first time for this WRMP, there are no previous climate change impact results that can be used to determine the uncertainty range or deployable output change. Therefore an assessment of the available data were completed using basic vulnerability assessment tables (consistent with the other resource zones). Whilst the information available could be taken to suggest that the vulnerability of the Barepot Resource Zone is low, it has been classified as being of medium vulnerability because the available data to inform the assessment is limited and, therefore, suggests some degree of uncertainty around the assessment of potential climate impacts on the zone.

Table 8 Climate change initial vulnerability assessment outcomes

Resource Zone	Uncertainty range	Deployable output impact	Classification	Change from WRMP15
Strategic	No change from WRMP15 assessment	No change from WRMP15 assessment	High vulnerability	No change from WRMP15 classification
Barepot	Not previously assessed	Not yet understood for Barepot Resource Zone	Medium vulnerability	N/A
Carlisle	Increased from WRMP15 assessment	No change from WRMP15 assessment	High vulnerability	Assessment at WRMP15 gave a medium vulnerability, however the high vulnerability approach adopted for the Strategic and West Cumbria Resource Zones was also applied to Carlisle for consistency.
North Eden	No change from WRMP15 assessment	No change from WRMP15 assessment	Low vulnerability	No change from WRMP15 classification

10.2 Calculating river flows

The updated methodology includes a tiered approach to estimate the impact of climate change on river flows based on the basic vulnerability classification of each water resource zone (EA, 2017). Based on the vulnerability classification of high for the Strategic and Carlisle Resource Zones, Tier 3 is required to be undertaken. Tier 3 in the guidance is defined as 'UKCP09/Water Company own approach' (EA, 2017), and is the highest of the three available tiers of analysis. Despite being classed as a medium vulnerability, this approach was also adopted for the Barepot Resource Zone.

The assessment for WRMP19 builds on the approach developed for WRMP15 and uses the UKCP09 medium emissions[30] scenario. This follows a review conducted by one of our water resources consultancy providers HR Wallingford. The emissions scenarios represent plausible pathways of the type of world we are planning for. Whilst our current trajectory of emissions is closer to the high emissions scenario, this is not necessarily a good indicator of the validity (or not) of the long term emission scenario. To consider the climate change impacts for the 2080s using the high emissions scenario, and potentially plan investment on this basis, is something that we would not be

[30] The Environment Agency supplementary guidance recommends that water companies use a minimum of the Medium emissions scenario for the spatially coherent projections or UKCP09 probabilistic projections. Also, in an alternative approach it recommends the use of future flows, which is based on medium emissions.

comfortable with, particularly in the context of a repeating five year planning cycle. Therefore, we have retained the use of the medium emissions scenario as per our WRMP15 climate change assessment.

A drought indicator was developed to select a sub-sample from the 10,000 UKCP09 scenarios for the 2080s. Latin Hypercube Sampling (LHS) was completed to select a sub-sample of 100 scenarios from 10,000. The 100 climate scenarios were then ranked using the best regression equation found from the drought indicator analysis based on minimum estimated reservoir storage, and a sub-sample of 20 representative scenarios was chosen.

At WRMP15 we found that the ranking of drought severity estimated by the drought indicators did not correlate well with the ranking of the scenarios when based on deployable output of the zone calculated with the Aquator™ model. In addition, with the extended time horizon (2080s), scenarios have more extreme rainfall and temperature changes which are known to make the drought indicators more sensitive. Therefore in parallel to the above activity, for the Strategic Resource Zone, the Pywr emulator model (see section 6.2 for details) was used to run 100 scenarios and generate deployable output impacts. These runs were also used to help inform the target headroom assessment (uncertainty distribution shape) as outlined in the *Draft WRMP19 Technical Report – Target headroom*.

From the 100 ranked deployable output results, 20 representative scenarios were selected rather than on drought indicators alone. The scenarios selected for the Strategic Resource Zone using Pywr were also used to assess the impact of climate change on the Carlisle Resource Zone as the zones are close geographically and allowed consistency. Similarly, in contrast to WRMP15 the same scenarios were used for sources in North Wales. Following detailed analysis the benefits of consistency within the same resource zone were seen to outweigh the differences between climate change projections for each region (which were found to be relatively limited).

For the 100 scenarios, each climate change scenario was represented by monthly flow factors which were applied to the historic inflow sequences in the models, along with any groundwater deployable output impacts, which are discussed in the next section (in WRMP15 this was completed for the 20 UKCP09 scenarios). Flow factors were calculated based on the outputs of rainfall-runoff models. For this assessment a number of more reliable rainfall-runoff models available, and these provided the majority of flow sequences into the Strategic Resource Zone Aquator™ model in the WRMP19 assessment. Where applicable flow factoring was applied in a consistent way with our baseline (Section 6.1.3). There were only five sequences in the Strategic Resource Zone for which there was no rainfall-runoff model, or spreadsheet model. These were small catchments that made minor contributions to the total input of the model and therefore no transposition tool was created, instead factors from geographically close catchments were used.

For the Barepot Resource Zone, factors derived from the River Eden were used as the Eden catchment showed the best correlation based on hydrological response.

For the Carlisle Resource Zone factors were provided for all inflow sequences other than the River Gelt (Old Water), which was calculated using an empirical relationship from the other flows.

The specificity of the factors for each catchment in this assessment allows a more precise assessment of system response to the climate change scenarios.

10.3 Calculating deployable output impacts

As mentioned above, in the Pywr model 100 scenarios were run for the Strategic Resource Zone, from which 20 representative scenarios for the 2080s were selected. The 20 scenarios were modelled in the Strategic Resource Zone and Carlisle Resource Zone Aquator™ models. For the North Eden Resource Zone the groundwater source yields were reassessed for each of the 20 climate change scenarios.

The range of deployable output impacts around the baseline deployable output can be seen in Figure 7 and Figure 8 below.

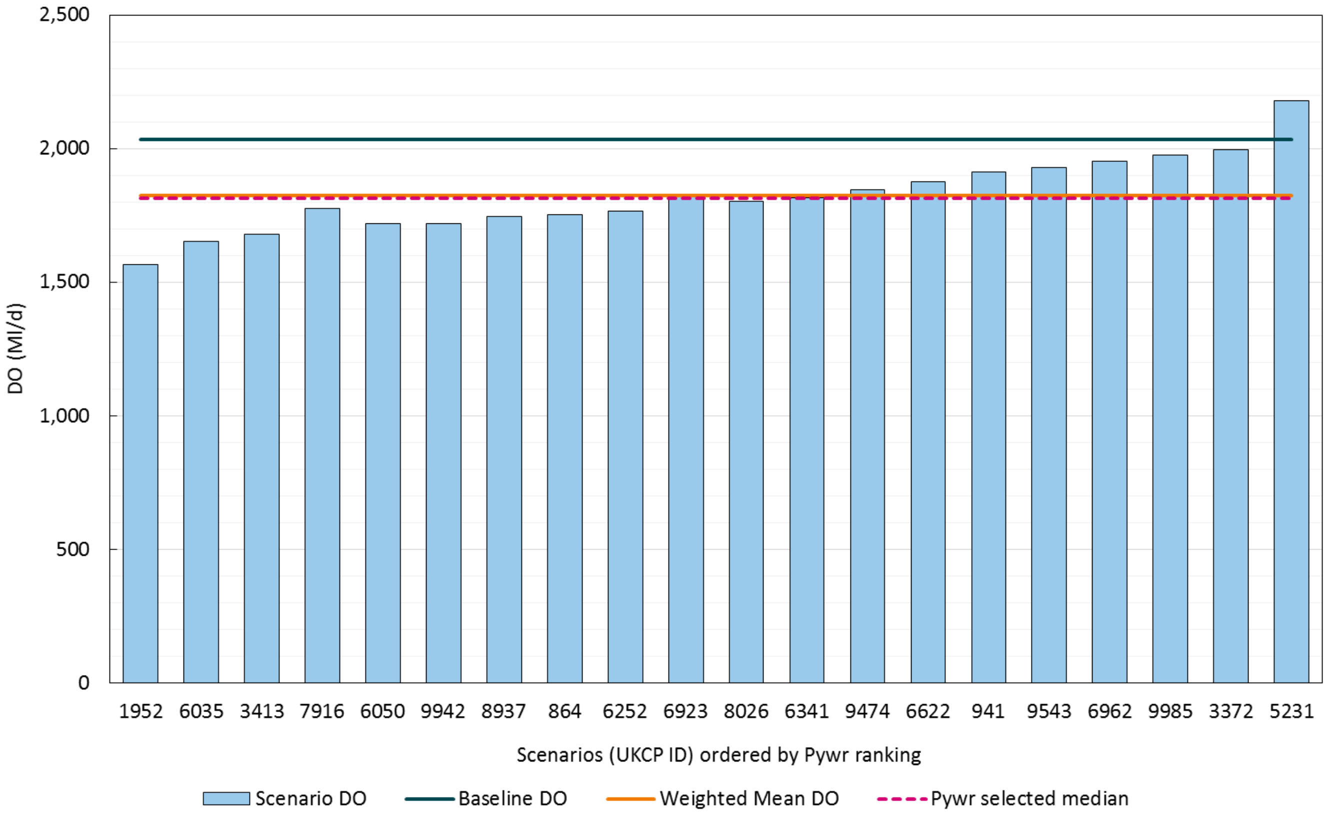


Figure 7 Graph of Strategic Resource Zone UKCP09 Aquator™ deployable output results for the 2080s, ordered by the Pywr ranking

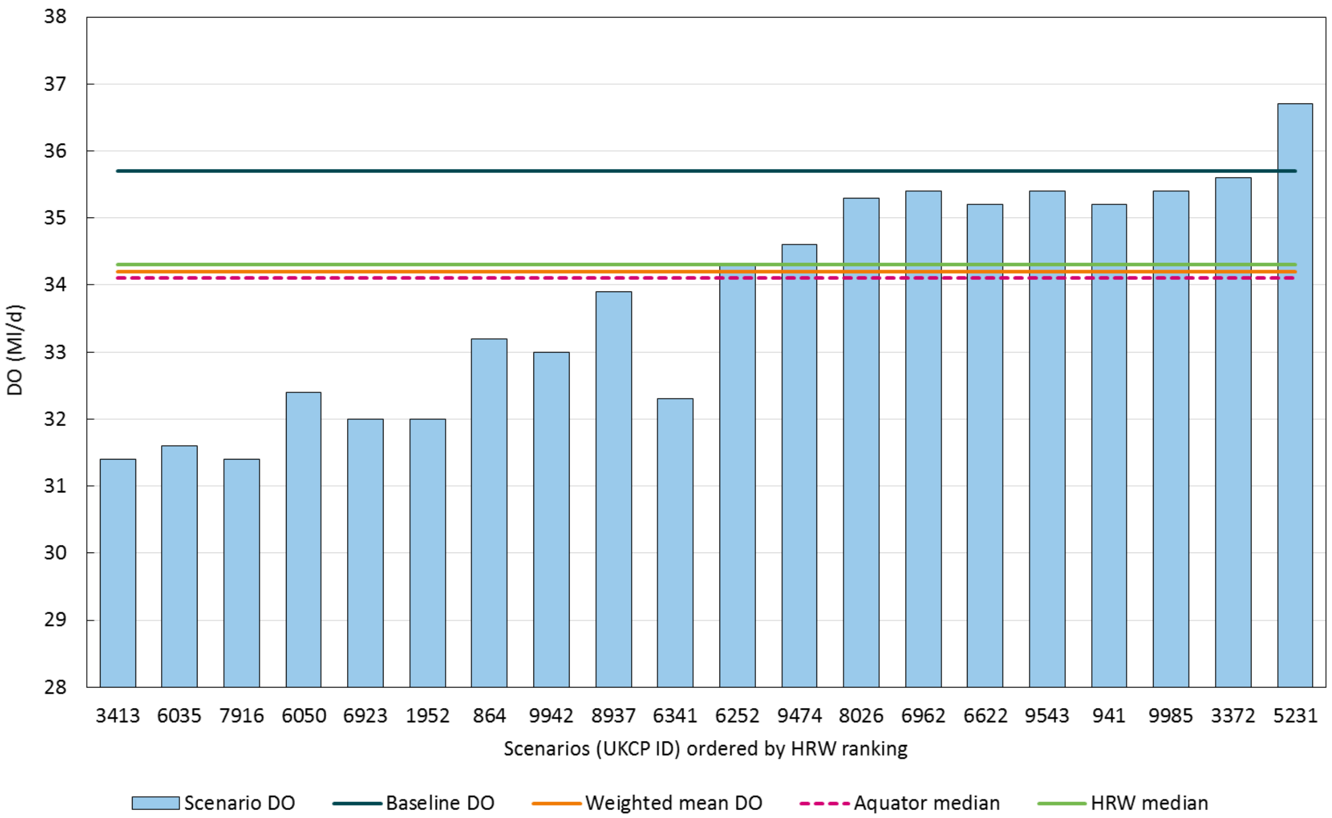


Figure 8 Graph of Carlisle Resource Zone UKCP09 Aquator™ deployable output results for the 2080s, ordered by the drought index ranking

For the Strategic Resource Zone the 100 emulator results were analysed and found to have a normal distribution. For the 20 Aquator™ results with weightings a normal distribution was applied in line with the emulator. The median impact was taken forward for application in the supply-demand balance.

For the Barepot Resource Zone the minimum flows from each climate scenario were found to be above the deployable output, ranging between 40 Ml/d and 128 Ml/d, with a median of 60 Ml/d. It should be noted that the minimum of this range represents an extremely severe drought. Therefore the climate change impacts are not a constraining factor on the resource zone deployable output of 34.1 Ml/d.

For the Carlisle Resource Zone the 20 Aquator™ results were found to have a discrete distribution. We decided not to transpose the normal distribution from the Strategic Resource Zone emulator results to reflect the different system response to climate change. The median impact was taken forward for application in the supply-demand balance.

As the North Eden Resource Zone comprises groundwater sources only, the climate change assessment was based around assessing the groundwater yields under the 20 UKCP09 scenarios. Two of the five sources in the resource zone were identified as being susceptible to climate change related changes in water level, however this could be addressed either by other boreholes, or alternatively by lowering the existing pump levels. With these assumptions in place, overall the resource zone was not found to be vulnerable to climate change, and therefore no climate change impact was assumed (this result is consistent with WRMP15).

10.4 Scaling and uncertainty

The scaling factor used in the supply demand balance aligns to the Environment Agency supplementary information:

$$Scale\ factor = \frac{Year - 1975}{2085 - 1975}$$

The climate change impacts included in the supply-demand balance for each resource zone are shown in Table 9. The 2085 impacts are based directly on the results of the assessment and the 2035 impacts were derived using the scaling equation above. The impacts are included as change to deployable output to derive WAFU. A comparison with the climate change impacts calculated for our 2015 plan is in Table 10, along with a commentary on any observed differences.

To account for uncertainty a 95th-70th percentile[31] glidepath has been adopted for target headroom, further detail can be found in the *Draft WRMP19 Technical Report – Target headroom*.

Table 9 WRMP19 Summary of climate change impacts included in the WRMP19 supply-demand balance

Resource Zone	Baseline deployable output (Ml/d)	Climate change deployable output (Ml/d)	Climate change impact (Ml/d)
Strategic	2,118	1,913 50th percentile from normal distribution	-113 Ml/d at the year 2035 -205 Ml/d at the year 2085
Barepot	34.1	N/A	N/A
Carlisle	35.7	34.6 50th percentile from input results	-0.6 Ml/d at the year 2035 -1.1 Ml/d at the year 2085
North Eden	8.7	N/A	N/A

[31] Percentile choice reflects both the degree of confidence in data and potential risk

Table 10 Comparison of climate change impacts from WRMP15 and WRMP19

Resource Zone	WRMP15 climate change impact at the year 2035 (Ml/d)	WRMP19 climate change impact at the year 2035 (Ml/d)	Difference (Ml/d)	Comment
Strategic	-122	-113	-9 Ml/d	WRMP19 impact is within the same region of the WRMP15 impact
Barepot	N/A	N/A	N/A	N/A not assessed at WRMP15
Carlisle	-2.0	-0.6	-1.5 Ml/d	Lower impact for WRMP19 is linked with transfer improvements made in the zone and associated increased resilience
North Eden	N/A	N/A	N/A	No change

11. Water transfers

11.1 Existing transfers

We do not have any inter-resource zone transfers[32], although there are some very small inter-connections for emergency use only. Following changes to the water market from 1 April 2017, holders of new water supply licences can provide supplies of water to eligible non-household premises. There are currently eight licensed water suppliers[33], with retail authorisation, operating within our area. We share water resources with other water undertakers, and include more detail on these in Table 11 and the bullet points below.

These quantities and transfer amounts are used to determine deployable output and WAFU. They are not anticipated to change significantly during the course of the WRMP planning period. In some cases the actual transfer capacity is higher; this is normally governed by either the inter-company agreement or by network constraints. Any variation in transfer quantities within this capacity could potentially impact the resource zone WAFU, however most of the transfers are so small that they are virtually insignificant. A notable exception is the export to Welsh Water and, to a lesser extent, the import from Northumbrian Water.

- The River Dee, managed by Natural Resources Wales through a regulation scheme. Other abstractors from the River Dee include Dŵr Cymru Welsh Water, Dee Valley Water PLC (now owned by Severn Trent Water Ltd) and the Canal and River Trust. A raw water export from the River Dee to Welsh Water and non-potable supplies (total based on average demands in the region of 80 Ml/d, of which 28 Ml/d corresponds to the export to Welsh Water), are included in the Aquator™ model for the determination of deployable output for the Strategic Resource Zone (Section 6.2). This means that we can be sure that this quantity of water can be reliably supplied at this point in the network throughout all of the dry periods in our records.
- We also have a few very small bulk supplies with Dee Valley Water PLC and Severn Trent Water Ltd, including imports and exports from both companies;
- Lake Vyrnwy is owned by Severn Trent Water Ltd, regulated by the Environment Agency with Severn Trent Water to manage the River Severn regulation system. Other abstractors from the River Severn include; Severn Trent Water, South Staffordshire Water and Bristol Water;
- Burnhope reservoir supplies Northumbrian Water Ltd, who also provide a small import of water from this source into our supply area around Alston; and
- Leep Water Networks Ltd (formerly Peel Water Networks Ltd) also operates as a water and sewerage undertaker to the MediaCityUK development in Greater Manchester.

[32] Work is currently ongoing to develop a link from Thirlmere reservoir to supply customers in our existing West Cumbria Resource Zone. As detailed earlier in this report (Section 2) on completion customer in West Cumbria will be supplied from Thirlmere reservoir. As a long-term 25 year strategic view, our WRMP19 reflects the merging of the previous West Cumbria and Integrated Resource Zones. For WRMP19 we have renamed this the Strategic Resource Zone to draw distinction with the previous zones. As well as the change in resource zone boundary, the name also reflects the functionality of the zone, where key strategic sources are balanced to manage supply to customers

[33] Details of all licensed water suppliers can be found at http://www.ofwat.gov.uk/regulated-companies/ofwat-industry-overview/licences/

Table 11 Summary of existing import and export arrangements with other companies

Water undertaker	Resource Zone	Amount	Information
Imports			
Dee Valley Water PLC	Strategic	<0.1 Ml/d	Crewe by Farndon (based on average transfer amounts over the last five years)
Northumbrian Water Ltd	North Eden	1.3 Ml/d	Potable supply from Burnhope reservoir. Based on contractual amount. We contacted Northumbrian Water to confirm the assumption is mirrored in the WRMP for each company
Severn Trent Water Ltd	Strategic	<0.1 Ml/d	Mow Cop
Exports			
Dee Valley Water PLC	Strategic	1.2 Ml/d	Gredington (based on a combination of normal/average transfer amounts over the last five years and contractual maximums)
Dŵr Cymru Welsh Water	Strategic	28 Ml/d	Raw water (Heronbridge), based on contractual maximum
Leep Water Networks Ltd (formerly Peel Water Networks Ltd)	Strategic	0.3-1.0 Ml/d	The agreement is for us to supply up to 1.6 Ml/d, however current supply is around 0.3 Ml/d, and we forecast this to increase to around 1 Ml/d across our planning horizon (MediaCityUK)
Northumbrian Water Ltd	Carlisle	<0.1 Ml/d	Reaygarth
Severn Trent Water Ltd	Strategic	<0.1 Ml/d	Biddulph, Congleton and Kidsgrove (based on a combination of normal/average transfer amounts over the last five years and contractual maximums)
Severn Trent Water Ltd	Strategic	Contingency	Llanforda (used by exception for contingency purposes) (based on a combination of normal/average transfer amounts over the last five years and contractual maximums)

11.2 Future transfers

We have explored the potential to make the best use of markets for water resources, specifically with a proposed water export from Lake Vyrnwy. Whilst our Draft WRMP19 shows that we have a supply-demand surplus, our strategy for water trading has looked beyond this, and started to develop a plan that will ensure no deterioration in levels of service, water quality, resilience or the environment. This approach is in line with the planning guidelines and the Water UK long term water resources planning study. Our 2015 plan we identified technically feasible export options in conjunction with other water companies, and explored the potential impacts as a scenario in the plan. There was a 'high' impact on our supply-demand balance of significant new exports up to 180 Ml/d from our Strategic Resource Zone. This means that options would need to be implemented to maintain resilient supplies to customers. There would be a national benefit to such an arrangement if it allowed resilient supplies to other areas at lower cost and there would be a benefit to the North West due to the revenues paid by the importing company. In this plan, we have a strategic choice to consult on the potential for pursuing such exports in our draft WRMP19, and this is presented in Section 6.5 (complemented by Section 7) of the draft WRMP19 document.

At this stage, our preferred plan recommends that we continue to explore water trading, which in effect would be a new arrangement to transfer water as an export from our system to another water company. We expect that any movement of water under a trade would only be realised relatively infrequently from the mid-2030s onwards[34], and subject to further investigation and study.

During the development of this part of our plan we liaised closely with Thames Water to ensure that the assessment in our respective WRMPs aligned as far as practical. We worked jointly with Thames Water to develop a stochastic sequence of 17,400 years that was regionally coherent (we discuss this further in Appendix B). The stochastics

[34] Our assessment is based on 2035, however, it may be considered as representative of a trade occurring at any point in the 2030s. It is unlikely that any trade will be required before this date based on discussions with Thames Water. If the trade is at a later date, defined by Thames Water's own draft Water Resources Management Plan and/or subsequent work, we will reassess our plans accordingly in future. This is relevant because, as we were finalising this draft plan, Thames Water advised us that in the current Water Resources South East regional strategy the water would instead be needed from the late 2040s onwards.

sequence was used in our extended methods assessment, which is detailed in our *Draft WRMP19 Technical Report – Options appraisal*. We also ensured that common assumptions were adopted between companies, for instance the utilisation sequence for a trade.

To assess the impacts of a future trade on WAFU the following steps were taken:

- The preferred enabling works and a new demand centre supplied from Lake Vyrnwy was built into the Aquator™ model of the Strategic Resource Zone, along with shared assumptions for utilisation;
- A deployable output assessment with the trade in place was used to determine a reduction in deployable output from the baseline position. This was a -81 Ml/d adjustment based on trading 180 Ml/d from Lake Vyrnwy; and
- The adjustment in deployable output is used as a reduction to deployable output (and subsequently WAFU) in the preferred plan supply-demand balance.

12. Drinking water quality

We carry out monitoring of our water supplies 365 days of the year to ensure they meet the standards defined in the Water Supply (Water Quality) Regulations 2016 (as amended). Water quality samples are taken from water treatment works, supply points, service reservoirs and water supply zones at frequencies defined by regulations.

As part of the our Regulatory Reporting requirements, water quality performance is measured by mean zonal compliance, water treatment work coliform non-compliance, service reservoir integrity index, number of WTW turbidity failures greater than 1 NTU and distribution maintenance index. The results from our regulatory samples across all our asset types contribute to these measures. The methodologies for gathering this data and the performance and compliance of these measures are set out in our Regulatory reporting. The data are published in the Drinking Water Inspectorates Chief Inspectors Report.

In determining asset capability assumptions for WRMP19 (see Section 6.1.5) we have looked at the plausible capacity for each asset, taking into account drinking water quality constraints and the need to meet these water quality obligations. Future water quality risks to source yield are defined in target headroom, and detailed in our *Draft WRMP19 Technical Report – Target headroom*.

13. Outage allowance

An outage allowance is applied to recognise that some sources will temporarily become unavailable during the 2020-2045 planning period due to planned and unplanned events such as:

- Short-term water quality problems and pollution incidents;
- Seasonal effects on surface water sources, e.g. algae problems and geosmin, turbidity;
- Asset failure or temporary constraints at water sources and treatment works; and
- Reservoir safety works requiring a drawdown of reservoir level.

The outage allowance therefore takes account of any asset failures that could reduce the available deployable output in a drought period.

13.1 Planned and unplanned outage events

Outage allowance aims to account for the effects of the following factors associated with impounding reservoirs:

- Probability of failure assessment for each reservoir due to a number of causes, e.g. flood, earthquake etc.
- Planned reservoir remedial works, as there will always be a programme of work at our reservoirs.
- Unplanned reservoir remedial works based on experience of unplanned outages during AMP5 (April 2010 to March 2015) that are incidental to or a result of changes to the planned works.

However we have made no allowance for other planned works programmes, because:

- The scale and type of future works over the full 25 year planning horizon is unpredictable, and is dependent on future legislation and the outcome of price review determinations.
- In delivering planned programmes of work we seek to minimise the impacts on supply by managing the duration and timing of work, and by mitigation measures.

We will continue to keep the Environment Agency informed of significant aspects of each year's outage programme where these have potential to affect water resources and supply reliability. We will also comment on forthcoming planned outage expectations in the annual Water Resource Plan Review.

13.2 Methodology and assessment

In line with the Environment Agency (2016) supporting guidance we have used the UKWIR (1995) methodology to determine the outage allowance for our resource zones. The UKWIR methodology is detailed in the report *Outage Allowance for Water Resource Planning* (1995). In our assessments we have drawn upon data that we have for observed outage events, both planned and unplanned, as well as legitimate outage events.

The general method is as follows:

- Identify asset failures that will have an impact on deployable output. These are termed "Legitimate Outage Scenarios";
- Assign frequencies and durations to the asset failures;
- Carry out Monte-Carlo simulations of all the legitimate outage scenarios;
- Each simulation will generate an overall deployable output impact for the resource zone, which allows the creation of a probability distribution of deployable output impacts; and
- Choice of percentile to represent outage allowance in WRMP19. Percentile choice reflects both the degree of confidence in data and potential risk

Further guidance is given in "Uncertainty and Risk in Supply & Demand Forecasting" (UKWIR, 2002) and "WRMP 2019 Methods – Risk Based Planning" (2016), which indicate that a planning allowance for outage in the region of 70^{th}–90^{th} percentile should be used. We have used this guidance and experience of actual outages since the publication of our WRMP15, to identify several areas of improvement to the outage allowance methodology.

Updates to the methodology approach applied for this plan can be categorised in two ways:

Data updates:

- Several data sets used for the supply forecast are also used as inputs to the outage allowance calculations. As described above in this report, the asset capability (see Section 6.1.5) and source yields (see Section 6.1) have been reviewed for this WRMP19. These updated values are used to determine the potential deployable output impact of a given outage event, taking into account the yield of the source and the asset capability.

Method changes:

- **Intermittent use assets deployable output impact calculation**
  We have a number of assets that are used intermittently (e.g. several boreholes and strategic potable water pumps and aqueducts that enable transfers of water between parts of the Strategic Resource Zone, which help to maintain resilient supplies). Previously, an annual average deployable output impact was calculated for these assets. We have improved the method by taking account of how they are operated in reality (this includes peak deployable output for groundwater sources as discussed in Section 6.1.4). Deployable output impact is now calculated using asset maximum design capacity and Aquator™ modelled percentage utilisation. This approach is based on joint probability theory (i.e. the likelihood of how often an asset is needed to run and the likelihood of that asset failing).
- **Normal probability distribution for water treatment work outages**
  The last two years of historical outage data for water treatment works, reported annually to the Environment Agency (i.e. includes only legitimate outages), was used to derive a single, normal distribution for annual average water treatment work outage, because it is the most representative of all outages experienced for these assets. This supersedes the previous approach, which identified water treatment outages with the potential to have the biggest impact on outage, requiring individual failure probabilities.
- **Wider consideration of potable water assets**
  We added representation of this type of asset was included in the outage allowance for the Strategic Resource Zone for consideration for those potable water assets key to maintaining resilient water supplies.

13.3 Our percentile choice

In WRMP15, the 95th percentile was used in deriving the outage allowance. A pan-industry review of outage allowance showed that percentiles selected were typically lower, and that we had adopted a more risk-averse view than most other water companies. Therefore, for WRMP19, we have reconsidered the choice of percentile and level of outage risk, in combination with the 75th-90th percentile range specified in the UKWIR 2016 guidance. This was also necessary because of several additional factors, including experience of actual outages and greater consideration of key potable water assets since the last planning round and to ensure adherence to best practice industry guidelines (UKWIR, 2016). The 80th percentile has been chosen to determine the outage allowance volume for each water resource zone for WRMP19. This is an appropriate outage allowance for our plan, as it reflects the full extent of outages experienced since WRMP15, whilst accounting for the practicalities of managing resources and drought risk (e.g. long term works shutdowns not included in outage allowance, that occur prior to recognition of an emerging drought).

13.4 Our outage allowance

The calculated outage allowance for each resource zone are shown in Table 12. Note that for Barepot Resource Zone there is no history of outage or perceived risk. As the resource zone has been assessed for the first time for WRMP19 there is no comparative data from previous plans to include in Table 12.

Table 12 Outage allowance calculated for our WRMP19 compared to our previous allowance

Resource Zone	WRMP15 outage allowance (Ml/d)	WRMP19 outage allowance (Ml/d)	Difference (Ml/d)	Reason for difference
Strategic	74.3	101.3	+27.0	• Inclusion of additional events following review of actual outage: flooding events, poor raw water quality and unplanned maintenance at WTWs. • Wider consideration of asset types (i.e. potable aqueducts)
Barepot	N/A	0.00	N/A	N/A not assessed at WRMP15
Carlisle	1.98	1.55	-0.43	Lower probability of exceedance chosen – i.e. 80th percentile for WRMP19 compared to 95th percentile for WRMP15
North Eden	0.06	0.05	-0.01	Lower probability of exceedance chosen – i.e. 80th percentile for WRMP19 compared to 95th percentile for WRMP15

In volumetric terms the most significant change in outage allowance from WRMP15 is for the Strategic Resource Zone, where the 101.3 Ml/d allowance has increased by 27 Ml/d. This is largely due to the inclusion of additional events (e.g. pollution events) and wider consideration of asset types (failure of raw water and potable water aqueducts).

The impacts of pollution events are based on experience during AMP5 period (April 2010 to March 2015) such as a diesel spillage in the River Wyre that would have severely limited the use of both the Lune and Wyre sources for drought recovery. The possibility of similar incidents on the River Dee has also been considered. The effect of poor water quality in the River Dee on water treatment capacity at Huntington has also been included because of the high significance of this source both during and after a drought.

The failure of raw water assets and potable aqueducts was not included for WRMP15, but has been included in the current review. This was also based on recent events and is supported by information available from improved corporate data systems and expert knowledge. The types of events included are failure of raw water pumping stations; pipelines from key sources; and also failure of potable aqueducts.

14. Raw water and process losses

This section outlines our approach in assessing the operational use of water or losses through the abstraction to treatment process. In calculating WAFU, raw water and process/operational losses are subtracted from deployable output to represent the water lost between source and demand. Losses are included on demands in the Aquator™ models to represent the 'actual' demand on a source during a dry year, although are then subtracted in order to calculate WAFU (this is discussed in Section 6.1.6). For WRMP19 we revised these figures using updated data and a refined methodology, although the resulting values produced are comparable with the previous plan. The detail of the method applied is available in supporting audit documentation; however, this section provides an overview of the approach taken.

In calculating the raw water and process losses several potential methods were investigated, however the two methods were employed for WRMP19 are:

- Questionnaire data for the process losses; and
- Burst and Background Estimates (BABE) analysis for the raw water losses. This requires a number of different data sets[35] which is collated per water treatment works and the associated raw water mains upstream.

Compared to the assessment of raw water and process losses at WRMP15, for this WRMP19 assessment there are several differences as detailed below:

- A reduced pressure value for the Strategic Resource Zone raw water loss value (resulted in only a small change);
- An increase to raw water losses in the Carlisle Resource Zone due to an increase in mains length[36];
- A decrease to raw water losses in the North Eden Resource Zone due to a decrease in mains length;
- For process losses the questionnaire used is more detailed and allows a breakdown of the loss per process, capturing the complexity at some of our water treatment works; and
- Raw water losses for the Strategic Resource Zone includes completion of the Thirlmere Transfer scheme, with gravity supply along the ~32km length and associated losses.

The resulting losses by resource zone are shown in Table 13, and the overall change between WRMP15 and WRMP19 can be seen in Table 14. The total raw water and process loss for the West Cumbria Resource Zone at WRMP15 was 1.26 Ml/d. As this zone is not being assessed in isolation for WRMP19 it has not been included in the comparison table below. Overall the total raw water and process losses calculated for WRMP19 are around 22 Ml/d less than those we used in WRMP15. The majority of this change is driven by the revised value for the Strategic Resource Zone, however, in relative terms the allowance for losses in our Carlisle Resource Zone has increased, and this is associated with a revision to the length of mains in the resource zone.

Note that for the Barepot Resource Zone there are no process losses as the water supply is non-potable and the only treatment is coarse screens, for which there is no metered data available. Barepot Resource Zone is not included in Table 14 as the resource zone was not assessed at WRMP15 and there is no comparative data.

Table 13 Summary of calculated process and raw water losses

Resource Zone	Raw water losses (Ml/d)	Process losses (Ml/d)	Total raw water and process losses (Ml/d)
Strategic	13.53	28.44	41.96
Barepot	0.03	0.00	0.03
Carlisle	0.43	0.12	0.55
North Eden	0.00	0.04	0.04
Total	**13.98**	**28.60**	**42.58**

Numbers may not sum due to rounding

[35] Length of raw water main, age of assets, pressure, number of bursts
[36] Castle Carrock WTW used a ~5km assumption in WRMP15 compared to ~16km for WRMP19

Table 14 Comparison of total raw water and process losses from WRMP15 to WRMP19

Resource Zone	WRMP15 total raw water and process losses (Ml/d)	WRMP19 total raw water and process losses (Ml/d)	Change (Ml/d)
Strategic	64.55	41.96	-22.59
Carlisle	0.26	0.55	+0.29
North Eden	0.03	0.04	+0.01
Total	**64.83**	**42.55**	**-22.28**

Within the Environment Agency engagement activities we proposed to investigate how the loss values might be better incorporated into the water resources models. However, technicalities with the software prevented this from being achieved. We therefore retained the WRMP15 approach of including raw water and process loss values on the demand centres in the Aquator™ model.

15. Water available for use

The tables below bring together each element of the supply assessment to form WAFU, for values to be taken through to the supply demand balance for each resource zone. The tables show the WAFU both at the start and end of the planning period. Included are deployable output adjustments for sustainability reductions and climate change impacts to demonstrate how these change across the planning horizon. Imports and exports are outlined in Section 11.

For the Strategic Resource Zone an additional column is included in Table 15 to demonstrate the impact of the Thirlmere Transfer scheme when it becomes operational in March 2022.

Table 15 Results of supply assessment - Strategic Resource Zone WAFU

Component of supply forecast (Ml/d)	Strategic Resource Zone		
	2020/21	2022/23	2044/45
Baseline deployable output	2,112.6	2,115.6	2,115.6
Sustainability changes (from 2020/21)	0.0	0	0.0
Climate change deployable output impacts	-85.5	-89.2	-130.1
Forecast deployable output	**2,027.0**	**2,026.4**	**1,985.4**
Non-potable/raw water supplies	-71.6	-72.2	-75.0
Raw water and process losses	-42.0	-42.0	-42.0
Outage	-101.3	-101.3	-101.3
Imports	0.03	0.03	0.03
Exports	-1.6	-1.7	-2.1
WAFU	**1,810.6**	**1,809.2**	**1,765.0**

Numbers may not sum due to rounding

Table 16 Results of supply assessment - Barepot Resource Zone WAFU

WAFU (Ml/d)	2020/2021	2044/2045
Baseline deployable output	34.10	34.10
Sustainability reductions impact	0.00	0.00
Climate change deployable output impacts	0.00	0.00
Forecast deployable output	**34.10**	**34.10**
Average non-potable and raw water supplies	-26.9	-26.9
Raw water and process losses	-0.03	-0.03
Outage allowance	0.00	0.00
Imports	0.00	0.00
Exports	0.00	0.00
WAFU	**34.07**	**34.07**

Numbers may not sum due to rounding

Table 17 Results of supply assessment - Carlisle Resource Zone WAFU

WAFU (Ml/d)	2020/2021	2044/2045
Baseline deployable output	35.90	35.90
Sustainability reductions impact	0	0
Climate change deployable output impacts	-0.46	-0.70
Forecast deployable output	**35.44**	**35.20**
Average non-potable and raw water supplies	0	0
Raw water and process losses	-0.55	-0.55
Outage allowance	-1.55	-1.55
Imports	0	0
Exports	0.00	0.00
WAFU	**33.33**	**33.09**

Numbers may not sum due to rounding

Table 18 Results of supply assessment - North Eden Resource Zone WAFU

WAFU (Ml/d)	2020/2021	2044/2045
Baseline deployable output	8.74	8.74
Sustainability reductions impact	0	0
Climate change deployable output impacts	0	0
Forecast deployable output	**8.74**	**8.74**
Average non-potable and raw water supplies	0	0
Raw water and process losses	-0.04	-0.04
Outage allowance	-0.05	-0.05
Imports	1.30	1.30
Exports	0	0
WAFU	**9.96**	**9.96**

Numbers may not sum due to rounding

16. Level of service

From this supply forecast assessment our baseline level of service for water use restrictions is summarised below, along with a brief summary of the approach taken.

All companies have stated levels of service which stipulate the frequency at which they expect to apply supply restrictions or apply for drought permits and orders during dry weather. Our current level of service is detailed in Section 2.4 and Figure 2. As part of the planning process we have explored the possibility of changing these levels of service based on the following considerations:

- Customer, regulator and other stakeholder views;
- The impact of the change on the supply-demand balance; and
- Any associated costs.

The detailed responses to customer research in this area are contained within our *Draft WRMP19 Technical Report - Customer and stakeholder engagement.* In general customers valued avoiding a deterioration in levels of service, and also placed value on improvements to existing levels of service, particularly for drought permits / orders to augment supplies. To provide a higher level of service, i.e. less frequent restrictions or drought permits/orders, would require a greater investment in water supplies, or more extensive demand management. The supply requirement amounts have been identified through this supply forecasting process, and link into the *Draft WRMP19 Technical Report – Options appraisal*.

The alternative scenarios that have been completed examine the relationship between deployable output and level of service for Demand Saving restrictions, and are presented below.

16.1 Testing different levels of service

Alternative levels of service have been assessed as described in the following sections. Note that in general all assessments follow the approach set out in Table 5 (Section 6.1.7); any exceptions are noted below. The testing from the assessments provides a supply requirement (Ml/d) to meet the improved levels of service. This feeds into the options appraisal process that assigns a cost to meet the requirements and compares the cost to customer research. Further information can be found within the *Draft WRMP19 Technical Report – Options appraisal*.

Note that different levels of service have been tested for the Strategic Resource Zone only; our assessment of the baseline position for the Barepot, Carlisle and North Eden Resource Zones shows that we do not anticipate restrictions being implemented in these resource zones. Our final planning level of service for all resource zones is included in Section 16.2, and resource zone responses to different severities of drought events is discussed Section 17.

16.1.1 Strategic Resource Zone

Demand use restrictions (temporary use bans)

- Deterioration to a 1 in 10 year reference level/10% annual average risk: This was tested for our WRMP15 by increasing the drought trigger ordinates systematically to bring on demand restrictions earlier and more frequently. We have not tested this further for WRMP19 because our customer research indicates that there is no support in favour of a deterioration to the existing levels of service (which is 1 in 20 years on average, or 5% annual average risk)
- Improvements to 1 in 40 year and 1 in 80 year levels, or 2.5%/1.25% annual average risk respectively: using Aquator™ the number of demand saving events within a model run was restricted effectively keeping more storage 'reserve' in place (less severe drawdowns). From this assessment the difference in resource zone deployable output (i.e. a lower value than the baseline) was used to identify the supply requirements and amounts needed to maintain our baseline supply-demand balance surplus. The total supply required ranges from 129 Ml/d to 166 Ml/d.

Drought permits and drought orders

- The benefits of drought permits and orders are not included in our baseline assessment of deployable output in line with the Water Resources Planning Guideline. For this assessment a spreadsheet model was used, and assumed that drought permits and orders would be implemented after a temporary use ban (which occurs at drought trigger 4). This involved creating a new hypothetical 'trigger 5' at which point the benefits from drought permits and orders to augment supplies would be realised. This aligns to specific feedback from the Environment Agency that all possible measures would be taken (for example a temporary use ban at trigger 4) before applying for and implementing drought permits / orders. The position of trigger 5 was iterated to meet the desired level of service based on simulated reservoir storage from an Aquator run. The supply requirement was determined by calculating the loss of deployable output from later implementation of the drought permits and orders. In doing this it was assumed that the replacement supply capacity would be available from the start of the reservoir down period (hence limiting the capacity of new options that would be required to realise the change).

- For this assessment we used the results from populating the Drought Links table (see Section 17), based on 17,400 years of model runs using our stochastic hydrology sets. The assumed benefit (Ml/d) of drought permits and orders aligns to our Drought Plan 2017. If the level of service for drought permits and orders is less frequent than at present, the supply requirement (Ml/d) is defined by the benefit that is effectively lost through to the improvement. Given the volume of data used (17,400 years) it was not possible to apply all of the post-processing assumptions that we outlined in Table 5, specifically with regards to Dee regulation. However, the assessment is still deemed to be appropriate and gives sufficient confidence in the results due to the length of the stochastic hydrologic record used.
- The total supply required to meet the improved levels of service is 10 Ml/d (for a 1 in 40 year, or 2.5% annual average risk) or 18 Ml/d (for a 1 in 80 year, or 1.25% annual average risk).

Non-essential use bans

- This has not been assessed for WRMP19; changes to resilience to extreme droughts were explored through the use of emergency drought permits and orders only.

Alternative levels of service for drought permits and orders are included within our preferred plan (as detailed in Section 7.7 of our draft Water Resources Management Plan 2019). The position of trigger 5 has not been formally defined or adopted, and via the consultation process we will gather customer and stakeholder feedback on our proposals. The adoption of an improved level of service for drought permits and orders is planned for 2025, and is dependent on the outcome from consultation. If this shows support for an improvement, the trigger would be defined through a future Drought Plan around the point of implementation of the change in level of service.

16.2 Final planning level of service

This section outlines our future levels of service throughout the planning horizon (2020-2045) with the preferred plan in place. Our preferred plan incorporates four strategic choices (shown below). Further information on our preferred plan can be found within the main document for the Water Resources Management Plan 2019.

- Enhance leakage reduction by a total of 80 Ml/d over the planning period;
- Improve levels of service for drought permits and orders from 1 in 20 years to 1 in 40 years (moving from 5% to 2.5% annual average risk);
- Increase resilience to others hazards, specifically for our regional aqueduct system; and
- Continue to explore national water trading.

The proposed change from our current stated levels of service is shown in Figure 9 and is explained in Section 6.3 of the Draft Water Resources Management Plan document.

	Current stated	Future stated
Trigger 4	**Temporary Use Bans (TUBS)** 1 in 20 years on average (5% AR)	**Temporary Use Bans (TUBS)** 1 in 20 years on average (5% AR)
Trigger 4/5	**Drought permits and orders** 1 in 20 years on average (5% AR)	**Drought permits and orders** 1 in 40 years on average (2.5% AR) from 2025
Emergency storage	**Non-essential use bans** 1 in 35 years on average (2.9% AR)	**Non-essential use bans** 1 in 80 years on average (1.25% AR) from 2025
Dead water storage	**Emergency drought orders** Unacceptable even during extreme drought conditions	**Emergency drought orders** Unacceptable even during extreme drought conditions

Figure 9 Future levels of service from our preferred plan (which is open to consultation)

For WRMP19 Defra provided a direction[37], Section 3 of which contained the below subsections requiring water supply companies to:

(b) for the first 25 years of the planning period, its estimate of the average annual risk, expressed as a percentage, that it may need to impose prohibitions or restrictions on its customers in relation to the use of water under each of the following—

> *(i) section 76;*
>
> *(ii) section 74(2)(b) of the Water Resources Act 1991(**b**); and*
>
> *(iii) section 75 of the Water Resources Act 1991,*
> *and how it expects the annual risk that it may need to impose prohibitions or restrictions on its customers under each of those provisions to change over the course of the planning period as a result of the measures which it has identified in accordance with section 37A(3)(b);*

(c) the assumptions it has made to determine the estimates of risks under sub-paragraph (b), including but not limited to drought severity;

The quoted sections of the Water Resources Act 1991 refer to the measures given in Table 19, and the circumstances under which they would be imposed. The measures are referred to by resource zone in the following sections. Results have been generated using our extended methods tools to quantify the risk of any of these being imposed over the planning period[38]. As far as possible the same principles outlined in Table 5 have been applied, however there are some exceptions which are detailed below. Note that the stated level of service return period has been capped at a 1 in 1000 year event (this is equivalent to 0.1% average annual risk), beyond this events are displayed as 1:>1000 years, or better than 0.1%.

[37] The Water Resources Management Plan (England) Direction 2017 (Defra, 2017)
[38] Further information can be found in our *Draft WRMP19 Technical Report – Options Appraisal*

Table 19 Restrictions for which annual risk must be assessed

Section of the Water Resources Act 1991	Description	When expected to be imposed by UU
Section 76	Temporary use bans (2010 amendment to Section 76)	Drought trigger 4 in Haweswater or Dee
Section 74(2)(b)	Non-essential use bans	Emergency storage in Haweswater or the Dee
Section 75	Emergency drought order	Imposed upon reaching dead water

16.2.1 Strategic Resource Zone

To assess the risk of the imposition of the various restrictions the extended methods process was used to test the response of the system under the various conditions that could be faced over the planning period. To do this we used a drought library containing 66 droughts ranging in severity from 1:10 year events, to 1:1000 year events, interspersed with randomly selected years, including non-drought years. The droughts were selected from 17,400 years of stochastic inflows and perturbed with appropriate climate change factors. The selection process involved running these 17,400 years of stochastic flows through the Pywr simplified model at stepped demands and assessing the number of “events” at each demand. In this case reaching emergency storage was the “event” used to give the frequency and therefore return periods. Due to the volume of data used in the assessment it was not possible to impose the post-processing assumption that a trigger crossing would not class as a level of service contributing event if the River Dee was in regulation.

Because the impact of climate change would vary across the planning period the demand in each scenario was adjusted to reflect this variation. At the beginning of the planning period demand was reduced, and from 2035 onwards demand was increased. The leakage reduction that forms part of the preferred plan (as detailed in Section 7.7 of our draft Water Resources Management Plan 2019) was used to adjust demand in the model to emulate geographically dispersed leakage control.

Prior to 2035, it was assumed that there was no trading to Thames Water and no options in place. From 2035 onwards it was assumed that water from Vyrnwy was being traded to Thames and that the options required (as set out in our preferred plan) to offset the reduced supply would all have been in place.

Table 20 Strategic Resource Zone level of service across the planning horizon (% annual risk shown in brackets)

Strategic Resource Zone level of service	Stated level of service (annual average risk)	2020/21	2025/26	2030/31	2035/36	2040/41	2044/45
Water use restrictions (Section 76)	1:20 years (5%)	1:22 years (4.6%)	1:22 years (4.5%)	1:26 years (3.9%)	1:34 years (2.9%)	1:34 years (2.9%)	1:34 years (2.9%)
Drought permits and orders	1:20 years (5%) (strategic choice to move to 1:40 from 2025 – for consultation)	As above	Trigger not yet defined				
Non-essential use bans (Section 74(2)(b)	1:35 years (2.9%) (1:80 from 2025)	1:131 years (0.8%)	1:152 years (0.7%)	1:163 years (0.6%)	1:157 years (0.6%)	1:157 years (0.6%)	1:157 years (0.6%)
Rota cuts/standpipes (Section 75)	Not acceptable even in extreme drought	1:1000 (0.1%)	1:1000 (0.1%)	1:1000 (0.1%)	1:964 (0.1%)	1:855 years (0.1%)	1:1000 years (0.1%)

Note that for rota cuts and standpipes the level of service appears to deteriorate slightly between 2030/31 and 2040/41 before recovering to 1 in 1000 years in 2044/45. This is caused by slightly different demands driving differences in behaviour in the model, and reaching emergency storage at slightly earlier points. This can cause resource states to change across the model (as discussed earlier in Section 6.1.1) and triggers the use of emergency storage at a slightly earlier point in time. As can be seen from Table 20 however, there is little difference to level of service for rota cuts and standpipes which remains at 0.1% annual average risk throughout the planning horizon.

16.2.2 Barepot Resource Zone

Barepot Resource Zone is supplied via river abstraction and does not have drought triggers. For WRMP19 the availability of water and forecast WRMP19 demands have been used to assess the likelihood of customer restrictions during the plan period.

Deployable output for the resource zone is determined by the abstraction licence. Investigations of extreme droughts and climate change have found that under future climate scenarios including extreme droughts there is unlikely to be any reduction in the deployable output.

Demand in the resource zone is currently 80% of the deployable output and this is not forecast to change during the plan period. Note that climate change and outage impacts have been assessed as zero (as detailed in Sections 10 and 13 respectively).

As a result we do not anticipate any customer restrictions in Barepot Resource Zone during the plan period.

16.2.3 Carlisle Resource Zone

The frequency of Castle Carrock modelled storage reaching drought trigger 4, emergency storage and deadwater, were tested with the 17,000 years of stochastic modelling used to inform the Drought Links table (Section 17). This assessment used a range of demands in line with the demand forecast prepared for WRMP19, and the model was used to assess how frequently the system was unable to meet the specific demand. Note that there are no drought permits or orders to augment supplies for the Carlisle Resource Zone. Our Drought Plan 2017 includes an option to use Castle Carrock deadwater and a demand reduction option.

Using the specified demand with the historic hydrological sequence alone does not generate any 'failures' to meet demand, therefore the use of stochastic hydrology was imperative in assessing level of service across the planning horizon (see Table 21).

Table 21 Carlisle Resource Zone level of service across the planning horizon (% annual risk shown in brackets)

Carlisle Resource Zone level of service	Stated level of service (annual average risk)	2020/21	2025/26	2030/31	2035/36	2040/41	2044/45
Water use restrictions (Section 76)	1:20 years (5%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)
Drought permits and orders	1:20 years (5%) (strategic choice to move to 1:40 from 2025 – for consultation)	N/A There are no drought permits or orders for the Carlisle Resource Zone					
Non-essential use bans (Section 74(2)(b))	1:35 years (2.9%) (1:80 from 2025)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)
Rota cuts/standpipes (Section 75)	Not acceptable even in extreme drought	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)	1:>1000 years (better than 0.1%)

16.2.4 North Eden Resource Zone

The North Eden Resource Zone does not reach drought trigger 4 in the historic record. Climate change testing of potential future scenarios and extreme drought analysis (as detailed in Sections 10 and 17 respectively) has found that the water level in the resource zone is relatively insensitive to climate. Trigger 4 is set at the cumulative borehole annual licence (3,192 Ml) and overall output from the boreholes in the resource zone in WRMP19 would not reach trigger 4 in any year during the plan period. The resource zone is in surplus and we do not expect any change in the level of service during the first 25 years of the plan.

In line with the planning guidelines we have tested the system response and level of service experienced in a 1 in 200 year event (0.5% annual average risk). As specified earlier in this document resource zone deployable output is constrained by annual licence limits. These are not reached in the 1 in 200 year event, so level of service is greater than 1 in 200 (0.5% annual risk).

17. Drought Links (Table 10)

Links between the WRMP and Drought Plan are described in a new table released by the Environment Agency, referred to as the Drought Links table[39], and this is populated for each resource zone. This table summarises the deployable output for key historic and design droughts (droughts with 0.5%. 0.2% and 0.1% annual average risk[40]) and describes the deployable output benefit associated with measures proposed in the Drought Plan 2017. The Drought Links table helps the Environment Agency to meet their aspiration for better alignment of Water Resources Management Plans and Drought Plans. It shows which drought measures are included in the WRMP deployable output assessment, and demonstrates how the existing drought options add resilience to the system. The table also can act as a potential appraisal route for drought options.

Our assessment uses historic flow for all resource zones and, for the Strategic and Carlisle Resource Zones, uses stochastic flow datasets to provide a broader set of potential more severe drought scenarios. This allows the drier end of the distribution to be more acutely sampled. Development of the stochastic flow datasets is described in Appendix B. We have investigated severe / extreme droughts for our 'no trading' scenario, section 11.2 describes how this might change in the future with additional trading of water from Lake Vyrnwy. We have developed a demand sequence that is consistent with the stochastic flow data to test our future trading scenario (Appendix B).

We have taken a slightly different approach to identifying and testing droughts in each resource zone to ensure that we make best use of the available information and that our methods are proportionate to the supply risks in each resource zone. WRMP19 methods – risk based planning[41] describe three ways of measuring supply drought severity (called metrics). This can be done by measuring climate (e.g. rainfall), hydrology (e.g. river flow or groundwater levels) or system stress (e.g. failure to deliver supply). In complex resource zones, such as our Strategic and Carlisle Resource Zones there are many factors that contribute to a supply drought, these include climate, hydrology and infrastructure (e.g. sources and links between them). A system stress metric is the best way to take account of all of these factors in combination and we have used our Strategic and Carlisle Resource Zone models to investigate supply failure under drought scenarios.

Our Barepot and North Eden Resource Zones are less complex and a supply drought would be triggered by hydrological factors. So in these resource zones we have used hydrological metrics to investigate severe droughts, frequency of low river flows at Barepot and low groundwater levels in North Eden. This is appropriate given the lower complexity in these resource zones (see section 6.1).

17.1 Strategic Resource Zone

1984 and 1995/6 are key historic droughts in the Strategic Resource Zone. Deployable output is derived in the Aquator™ resource zone model and is constrained by Haweswater reaching emergency storage. Severe and extreme droughts (with 0.5%. 0.2% and 0.1% annual average risk[40]) were identified using stochastic data in the Pywr Strategic Resource Zone simulator model. For severe and extreme droughts the system is allowed to use its emergency storage, as this would be the case during droughts that are worse than those in the historic record. The stochastic data were also used to estimate the probability of the historic droughts. Allowing the use of emergency storage increases the deployable output for the extreme droughts and these cannot be compared consistently with the historic droughts.

In line with guidelines, the WRMP models for the Strategic Resource Zone do not include any drought supply measures. Demand reductions are applied in the model on crossing the appropriate drought trigger and these determine the level of service. The benefit of drought demand measures in the historic droughts was assessed in the Aquator™ resource zone model and assumed for the stochastic droughts. The deployable output benefit of demand reductions across the resource zone is +39 Ml/d to +41 Ml/d. The stochastic droughts are based on frequency of reaching deadwater and do not relate to specific historic drought events.

[39] This is the Table 10 Drought plan links as included in the Environment Agency Planning tables.

[40] These are equivalent to return periods of 1 in 200 (0.5% annual average risk), 1 in 500 (0.2% annual average risk) and 1 in 1000 (0.1% annual average risk)

[41] UKWIR (2016), WRMP19 – Risk Based Planning Methods, Report Reference 16/WR/02/11

Figure 10 shows the Strategic Resource Zone deployable output periods including the benefit of WRMP demand management measures for a range of drought return periods.

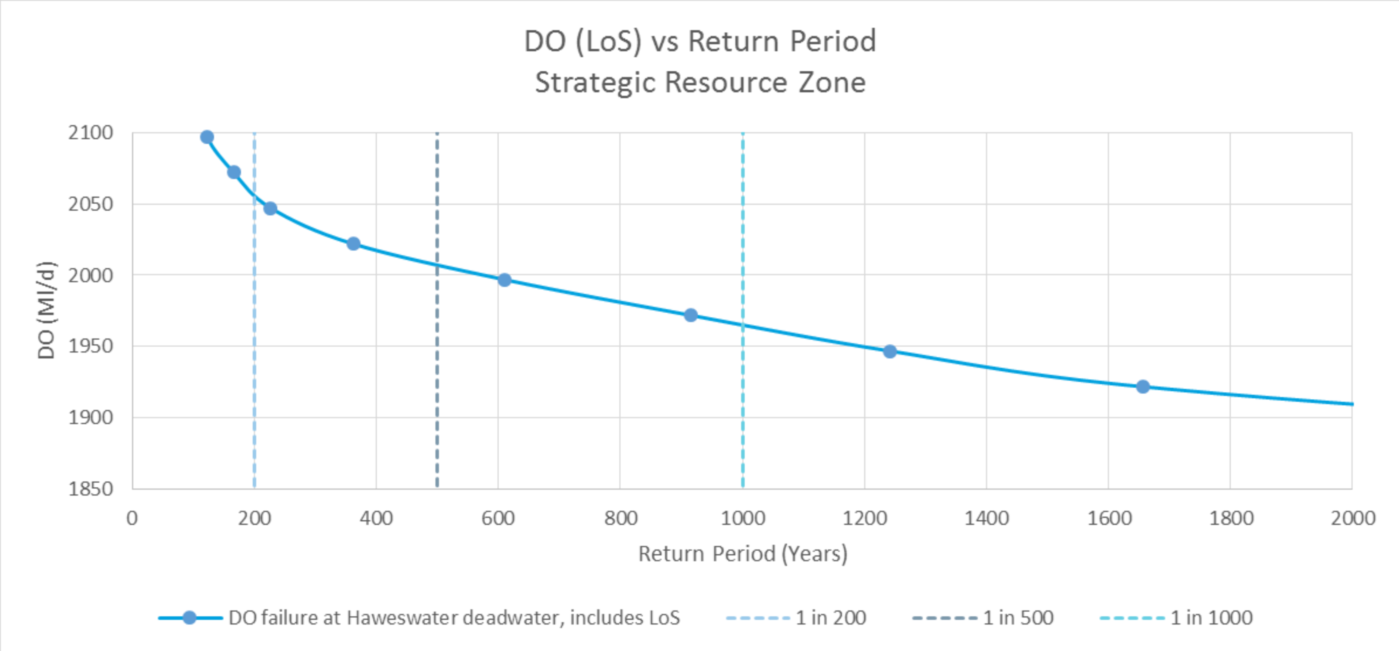


Figure 10 Strategic Resource Zone deployable output (with level of service) and return period

Drought supply measures are described in the Drought Plan 2017, and a drought tool has been developed to model these measures in Aquator™. The drought tool was used to assess the benefit of drought supply measures for the 1984 and the 1995/96 drought events and assumes an average benefit for other droughts. The deployable output benefit of drought supply measures across the resource zone is 81 to 83 Ml/d. These drought measures, combined with the use of emergency storage allowance that we include in our planning model are more than the reduction in deployable output that we forecast for the severe and extreme droughts. This indicates that our Strategic Resource Zone would be resilient to severe and extreme droughts. Individual drought measures were assessed for historic drought events as part of the options appraisal for this WRMP19[42]. Additional work is planned between draft and final plan to refine this estimate for the range of severe/ extreme droughts and the Drought Links table will be updated if required.

17.2 Carlisle Resource Zone

The Carlisle Resource Zone deployable output is constrained by either the emergency storage in Castle Carrock reservoir or the River Eden annual licence which can be exceeded following an extended dry summer. The historic droughts chosen to populate the Carlisle Drought Links table are 1976 (Castle Carrock emergency storage constraint) and 2003/4 (Eden annual licence constraint) as these demonstrate the performance of drought measures for each type of supply drought. There are no drought supply or demand reduction measures in the WRMP for the Carlisle Resource Zone. The Drought Plan 2017 includes an option to use Castle Carrock deadwater and a demand reduction option. The benefits of these were assessed using the Aquator™ Carlisle Resource Zone model.

Stochastic flow data are available for the Carlisle Resource Zone (17,200 years of data) and this was used to identify appropriate severe and extreme droughts with system stress measured by failure to meet demand. The Aquator™ Carlisle model was run for a range of demands and the number of years that the system supply fails for each demand was identified (using the Aquator™ 'Scottish deployable output' tool). The return period of these demand failures was calculated and example droughts with the required return periods (0.5%. 0.2% and 0.1% annual average risk) were identified from the modelled system failures. These represent events where operating the resource zone at the relevant demand would lead to a supply failure 1 year in *X*. The sample droughts were used to test the impact on deployable output of Drought Plan 2017 measures for the Drought Links table.

[42] See *Draft WRMP19 Technical Report – Options appraisal*

As with the Strategic Resource Zone, the model was allowed to use emergency storage in Castle Carrock reservoir, as this would happen in extreme drought situations. This increases the deployable output in drought events which are constrained by the available storage in Castle Carrock reservoir and leads to deployable output failures due to the River Eden annual abstraction licence. Figure 11 shows the return period associated with supply failure for the modelled demands. Return periods for the historic droughts were estimated using a similar graph constructed from model runs with emergency storage enabled to be consistent with the rest of the WRMP.

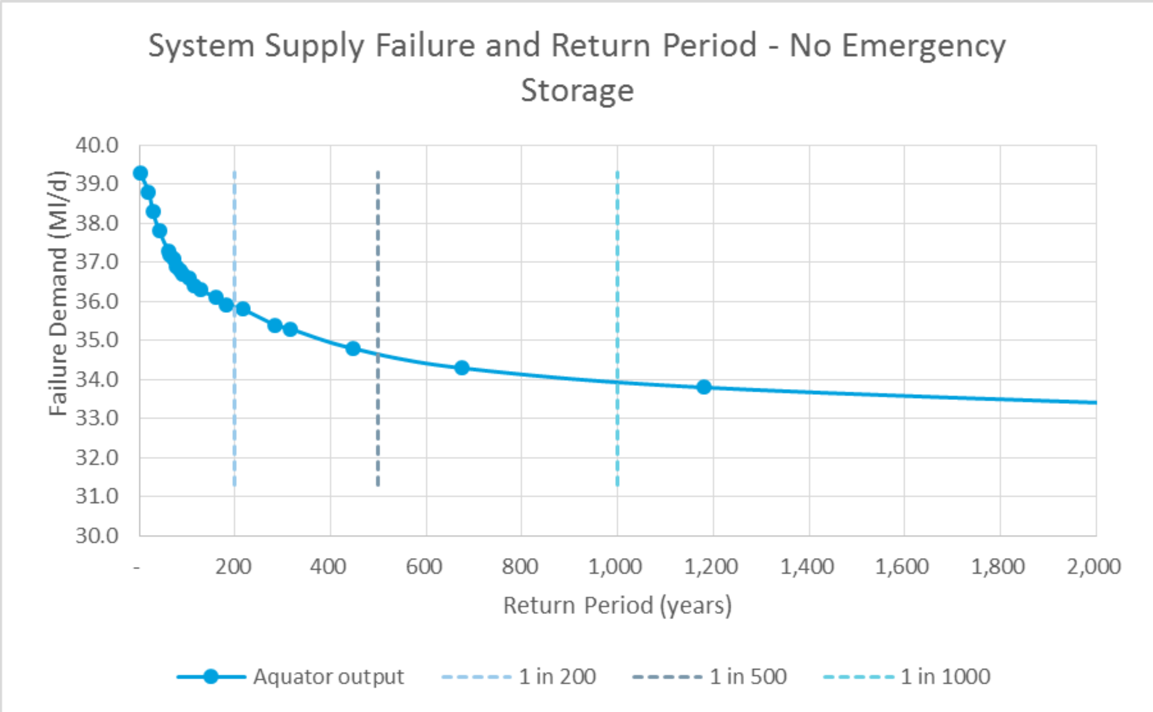


Figure 11 System supply failure and return period in the Carlisle Resource Zone

The Drought Plan 2017 supply option of using Castle Carrock deadwater had a deployable output benefit in the historic drought but does not show a benefit in the extreme droughts as with emergency storage in use deployable output is not constrained by storage in Castle Carrock.

The demand reduction option did not show a deployable output benefit as drought trigger 4 is very close to the emergency storage in the historic events. In extreme events system failure is not caused by low storage in Castle Carrock and there is no modelled deployable output benefit as demand saving is not triggered.

17.3 North Eden Resource Zone

Deployable output in the North Eden Resource Zone is constrained by the annual abstraction licence of the groundwater sources and the size of the surface water import from Northumbrian Water Ltd (NWL). The groundwater sources reached drought trigger 1 in 1995 and 2003 and these have been chosen as the historic droughts to populate the Drought Links table for this resource zone. There is a single North Eden drought measure in the Drought Plan 2017, this is to relax the annual licence limit and gives a benefit of 1.67 Ml/d. There are no demand measures proposed for the resource zone. Since 2003 there has been a decrease in demand on the groundwater sources, our Drought Plan 2017 indicates that 2015 demand was 59% of the annual licence. CEH published drought reviews of 1995/6[43] and 2003[44], these include rainfall return periods for UK regions and these give the probability of the 1995/6 and 2003 drought conditions in North Eden Resource Zone.

The NWL import has been assessed as resilient to drought, it is a small part of a larger NWL system, and for populating the Drought Links table it is assumed that this water would be available in extreme droughts. The North Eden groundwater sources are relatively insensitive to weather condition. Modelling for the WRMP19 climate

[43] Marsh T.J. (1995) *The 1995 Drought – A water resources review in the context of recent hydrological instability*. Institute of Hydrology. (http://nrfa.ceh.ac.uk/sites/default/files/The_1995_Drought.pdf accessed 19/09/17)
[44] Marsh T.J. (2004) *The UK Drought of 2003 – an overview*. British Geological Survey and Institute of Hydrology. (http://nora.nerc.ac.uk/510184/1/N510184CR.pdf accessed 19/09/2017)

change assessment found that even under the most extreme climate change scenario tested the minimum water level decreased by just over 1m. Water level measurements in Staffield borehole were used to develop an extreme value plot and this indicated that even for the most extreme event (1 in 1000, 0.1% annual average risk) the change in ground water level would be similar to that seen in the climate change scenarios. Water levels are shown in Figure 12, the blue points represent the minimum observed groundwater level in each year and the orange points show where 1 in 500 and 1 in 1000 water levels would be based on the available observed data.

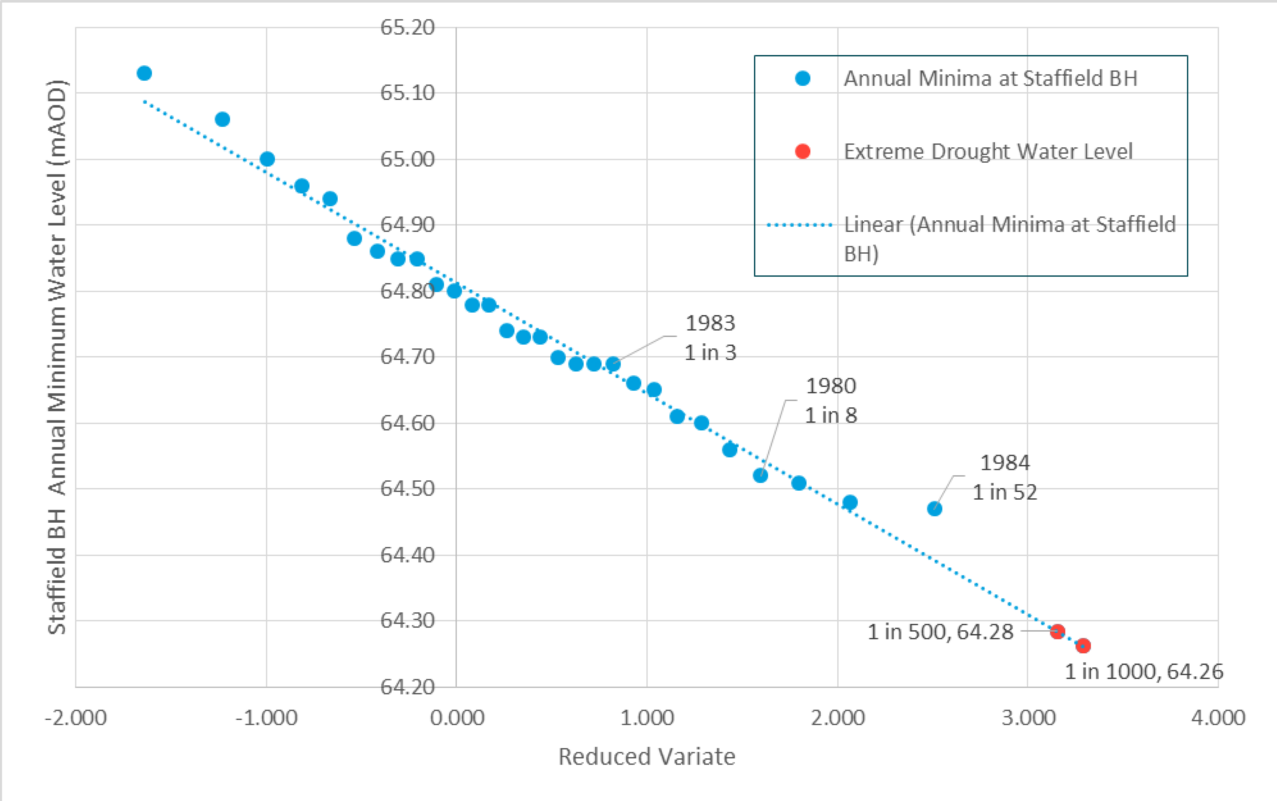


Figure 12 Extreme value plot for groundwater level in North Eden Resource Zone

The climate change modelling concluded that the annual licence would continue to be the constraint on deployable output under the climate change scenarios. As extreme drought water levels are similar to these scenarios, we have assumed that annual licence would also be the deployable output constraint for the drought scenarios. Confidence is increased by noting from the WRMP19 groundwater yield assessment (Section 6.1.4) that in most cases individual boreholes in each group can deliver the group yield indicating there is flexibility in the supply. In addition available source diagrams for individual boreholes show that there is generally significantly more than 1m between the current pump levels and the deepest advisable pump level indicting that pumps could be lowered should the drought impact on water levels be more severe.

17.4 Barepot Resource Zone

Barepot Resource Zone contains a single river abstraction and deployable output is constrained by the abstraction licence. Observed and stochastic flow data has been used to assess the availability of the abstraction for historic droughts in 1984 and 1995/6 and a range of severe droughts. The drought years and design scenarios chosen (0.5%, 0.2% and 0.1% annual average risk) are consistent with the Strategic Resource Zone. The relationship with the stochastic flow in the River Eden was used to investigate low flow events that are more severe than those in the historic record. Analysis of river flow for these drought scenarios found that even in a 1 in 1000 low flow event flows were still greater than the abstraction limit, and the annual licence remains as the deployable output constraint for all drought scenarios. This is shown in Figure 13 below, note that the y axis is truncated just above mean annual minimum flow (252 Ml/d).

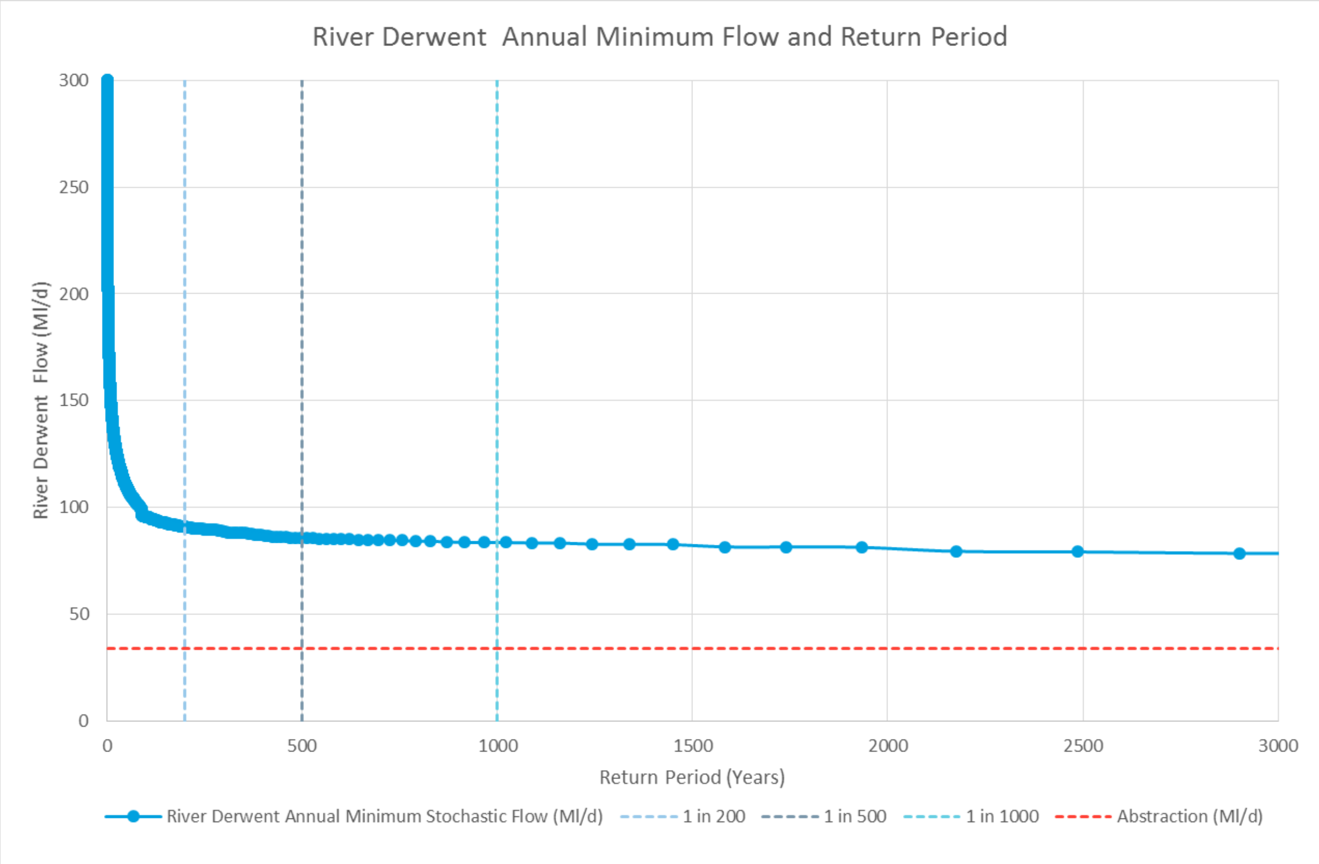


Figure 13 Return Period for Annual Minimum Flow in the River Derwent (Barepot Resource Zone)

There are no drought supply measures or demand restrictions in this resource zone.

17.5 Outcomes from populating the Drought Links table

We have tested a range of historic, severe and extreme droughts (1 in 200, 1 in 500 and 1 in 1000) for each of our resource zones. The North Eden and Barepot Resource Zones are resilient to extreme droughts as their deployable output is determined by their abstraction licence limits and our investigations indicate that this volume of water would still be available during extreme droughts. The benefit of Drought Plan 2017 actions is summarised in Table 22.

The emergency storage allowance we include in our assessment of deployable output in the Strategic and Carlisle Resource Zones means these are already resilient to a 1 in 200 drought event. The water available from these resource zones would be reduced in a 1 in 500 or 1 in 1000 drought event, however, in the Strategic Resource zone existing Drought Plan 2017 measures would compensate for this decrease.

Table 22 Summary of deployable output impact of Drought Plan 2017 measures

Drought Scenario (Indicative return period)	Strategic Resource Zone[a, b]			Barepot resource Zone		Carlisle Resource Zone[b]		North Eden Resource Zone	
	Change in Available Supply (Ml/d)	Benefit of Drought Plan Actions (Ml/d)		Change in Available Supply (Ml/d)	Benefit of Drought Plan Actions (Ml/d)	Change in Available Supply (Ml/d)	Benefit of Drought Plan Actions (Ml/d)[c]	Change in Available Supply (Ml/d)	Benefit of Drought Plan Actions[d] (Ml/d)
		Supply	Demand						
1 in 200	+26	+82	+40	0	No drought measures proposed in Drought Plan	-0.2	0	0	+1.67
1 in 500	-24	+82	+40	0		-1.2	0	0	+1.67
1 in 1000	-74	+82	+40	0		-2.2	0	0	+1.67

Notes

a. Demand restrictions are included in the WRMP base deployable output for the Strategic Resource Zone.
b. Carlisle and Strategic Resource Zones do not have an emergency storage allowance for these severe droughts reflecting how the resource zones would be operated in practice under these conditions.
c. Includes both supply and demand actions for Carlisle Resource Zone (as Table 5 Assumptions and rationale surrounding levels of service in assessing baseline deployable output).
d. North Eden Drought Plan 2017 actions are supply only.

18. References

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Appendix A – Potential future sustainability changes

Source	Driver	Sustainability change	Testing approach
Scenario A			
Naddle Beck	WINEP	0.95 Ml/d prescribed flow	Implement prescribed flow + over release in Aquator™ model
Scenario B			
Dean Clough Reservoir	Potential adaptive management scheme	0.11 Ml/d compensation flow	Implement compensation flow + over release in standalone Fishmoor model then incorporate into Aquator™ model
Pickup Bank Reservoir	Potential adaptive management scheme	0.43 Ml/d compensation flow	Implement compensation flow + over release in standalone Fishmoor model then incorporate into Aquator™ model
Pennington Reservoir	Potential adaptive management scheme	1.12 Ml/d compensation flow	Amend compensation flow + over release directly in Aquator™ model
Rake Brook Reservoir	Potential adaptive management scheme	1.90 Ml/d compensation flow	Amend compensation flow + over release directly in Aquator™ model
Walverden Reservoir	Potential adaptive management scheme	2.33 Ml/d compensation flow	This is an increase from current 1.8 Ml/d compensation flow. Assume additional requirement needs to be released from Coldwell Reservoir. Amend compensation flow + over release directly in Aquator™ model
Lee Green Reservoir	Potential adaptive management scheme	1.47 Ml/d compensation flow	This is an increase from current 1.0 Ml/d compensation flow. Amend compensation flow + over release directly in Aquator™ model
Grizedale Reservoir	Potential adaptive management scheme	1.38 Ml/d compensation flow	Implement compensation flow + over release in standalone Barnacre model then incorporate into Aquator™ model
Chew Reservoir	Potential adaptive management scheme	0.95 Ml/d compensation flow	Chew Brook feeds into Dovestone Reservoir so no impact on releases from system
Blackstone Edge Reservoir	Potential adaptive management scheme	0.17 Ml/d compensation flow	Amend compensation flow + over release directly in Aquator™ model
Scenario C			
Langden and Hareden system	WFD impacts on surface water bodies	3.38 Ml/d prescribed flows: 0.17 Ml/d at Smelt Mill Clough 1.30 Ml/d at Losterdale Brook 0.35 Ml/d at Penny Brook 0.69 Ml/d at Lanefoot Brook 0.35 Ml/d at Cowley Brook 0.52 Ml/d at Dean Brook	Apply prescribed flows in inflows derivation spreadsheet then import revised time series into Aquator™ model

Source	Driver	Sustainability change	Testing approach
Newton Hollow BH	WFD impacts on surface water bodies	5 year rolling abstraction limit of 205 Ml	None – disused source not included in Yield Review
Mouldsworth BH	WFD impacts on surface water bodies	5 year rolling abstraction limit of 11,023 Ml	Separate GW26 into BHs with annual licence of 7,387.6 Ml and Mouldsworth with 5 year rolling licence limit of 11,023 Ml
Bearstone BH	WFD impacts on surface water bodies	5 year rolling abstraction limit of 2,130 Ml	None – source not included in Yield Review
Scenario D			
Sandiford BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 765 Ml	Amend annual licence of GW24 to 5 year rolling licence of 12,890 Ml
Cotebrook No 1 BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 475 Ml	
Delamere BHs	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 5,875 Ml	
Eddisbury BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 4,085 Ml	
Organsdale BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 435 Ml	
Cotebrook No 2 BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 1,255 Ml	
Foxhill BHs	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 4,675 Ml	Amend annual licence of GW26 to 5 year rolling licence of 25,195 Ml
Manley Quarry BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 5,675 Ml	
Mouldsworth BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 5,805 Ml	
Manley Common BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 3,215 Ml	
Five Crosses BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 5,825 Ml	
Schneider Road BHs	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 6,870 Ml	Separate GW4 into Ulpha with annual licence and Schneider Road and Thorncliffe Road with 5 year rolling licence limit
Thorncliffe Road BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 4,330 Ml	
Helsby BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 0 Ml	None – disused source not included in Yield Review
Hooton BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 0 Ml	None – disused source not included in Yield Review
Eaton BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 0 Ml	None – disused source not included in Yield Review

Source	Driver	Sustainability change	Testing approach
Ashton BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 0 Ml	None – disused source not included in Yield Review
Newton Hollow BH	WFD impacts on groundwater bodies	5 year rolling abstraction limit of 205 Ml	None – disused source not included in Yield Review

Appendix B – Use of stochastic hydrology

In the past water resources planning has largely been based upon using historic hydrological data sets[45] to test the response of water resource system to extreme weather events. High quality hydrological data only became available in the 20th century, meaning that only around 100 years of data were used when testing systems. This period contained around five droughts, which is a small population in statistical terms, and was unable to provide return periods for events of differing severity with any certainty.

To mitigate these data limitations a technique for developing long time series of stochastic weather, which could be converted into flow sequences, was developed. Our framework partners, Atkins, worked in conjunction with Newcastle University to create a 17,400 year dataset of weather, and subsequently inflows, for our Strategic and Carlisle Resource Zones.

The stochastic weather generator used reflected the latest research in this field, and was very similar in nature to the generator used recently by Thames Water, Anglian Water and Water UK for their ongoing water resources studies. The approach we adopted represents the best and most reliable method that was available for water resources planning. Using this approach generated spatially coherent rainfall and potential evapotranspiration (PET) across each of the study resource zones (see Figure 14).

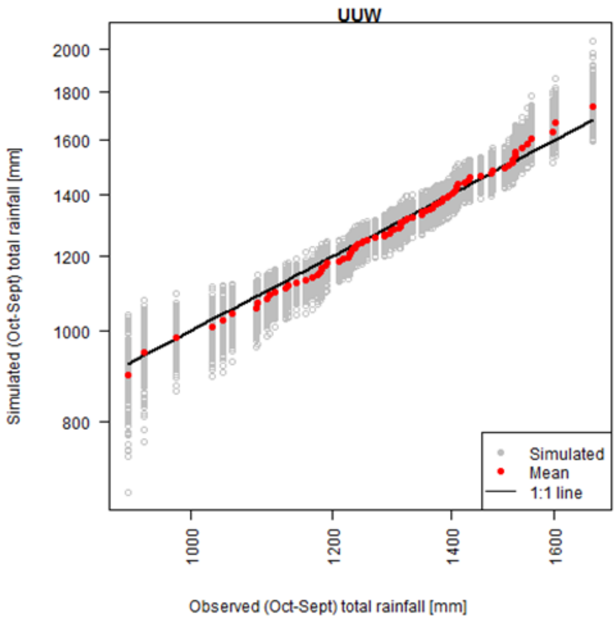

Figure 14 Maintaining spatial coherence in rainfall evidenced by matches that are achieved at both the catchment and regional level

The weather generator (a computer model) was trained on historical rainfall and PET data, and was able to find good relationships between these variables and the North Atlantic Oscillation (NAO) and sea surface temperature (SST), showing that these were the climatic drivers of weather in the North West region. Using this correlation, 200 sets of “what if” NAO and SST records were created, and these were in turn used to create 200 sets, each 87 years long, of rainfall and PET data sets, all of which were equally as likely to have happened as the historically observed weather. Although there was an equal probability of these weather events occurring they contain some more severe droughts than those in the historical record.

The rainfall and PET data generated were processed with our existing rainfall-runoff models to create 17,400 year inflow data sets for the zonal water resource models. These stochastic flows were used in a number of innovative ways for this plan, and these are discussed in turn below.

[45] The historic hydrological data used in developing this supply forecast is detailed in Section 6.1.3.

Assessing historic event severity

The stochastic flows were run through our water resource models to assess system response under more numerous events of a similar severity to the historic droughts observed and also more severe droughts. This allowed us to identify how often in 17,400 years we would expect to see a drought of a similar severity to the deployable output defining event[46]. The uncertainty regarding the return period was therefore reduced.

Options appraisal

We used these inflows in our options appraisal to test portfolios of options under 66 different droughts, rather than the five historical droughts, with some as severe as 1:1000 years (0.1% annual average risk). The options selected represent the best value portfolio, as they would provide the benefits sought under a wide variety of conditions. This was a step change in options appraisal.

Drought resilience

We assessed the ability of our systems to maintain supplies in droughts more severe than those in the historic record. We were able to provide deployable output values for droughts with a specific return period (in the Drought Links table, see Section 17), and there was increased certainty over these return periods.

Spatially coherent Thames drought sequence

Atkins carried out a spatial coherence study to match the stochastic sequences for the Thames region, and for the North West. This was used to create a Thames demand sequence that matched our stochastic record, allowing us to thoroughly test our system in a trading scenario.

[46] As mentioned in Section 5 the deployable output defining events are 1984 for the Strategic Resource Zone and 1976 for the Carlisle Resource Zone.