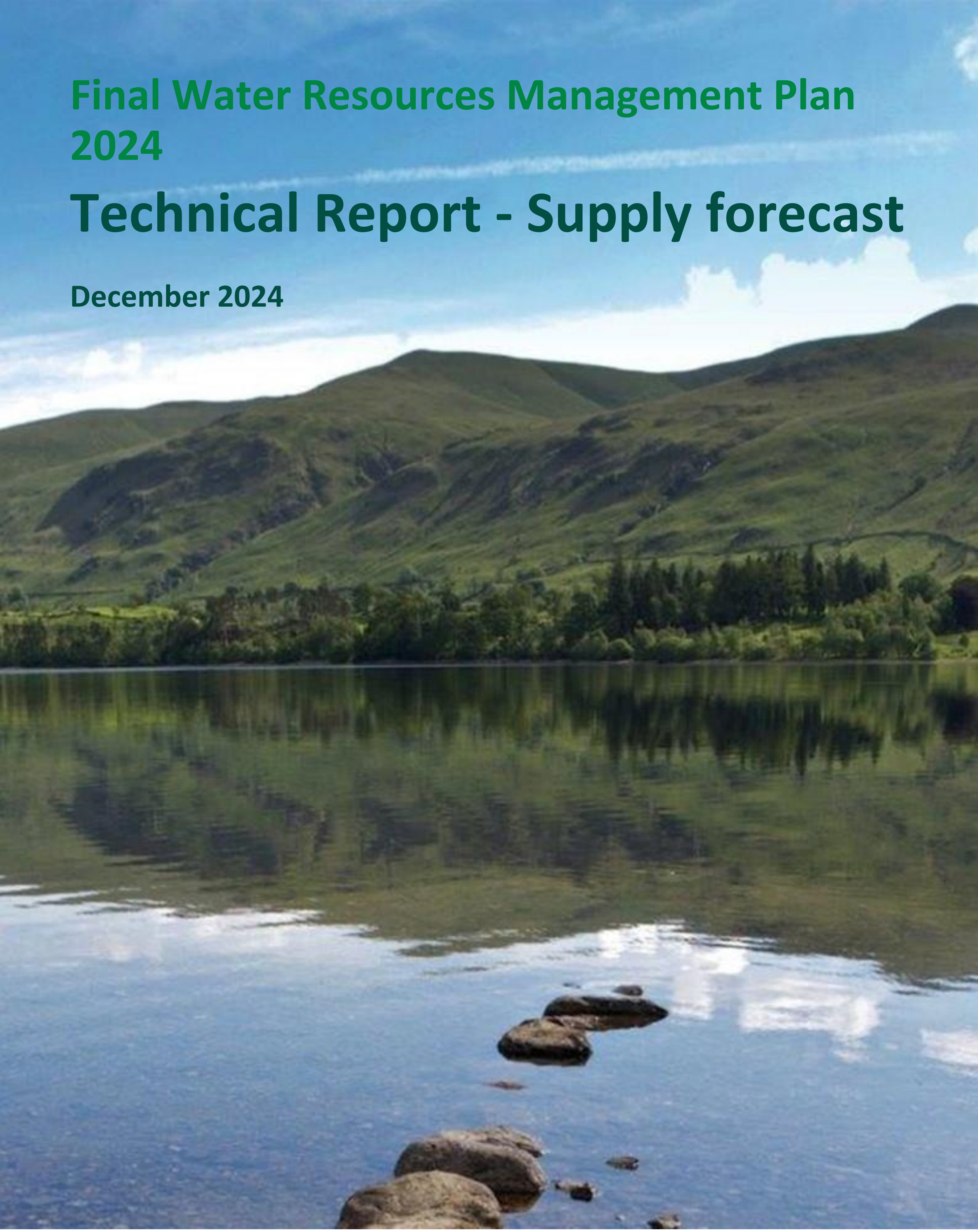
Final Water Resources Management Plan 2024

Technical Report - Supply forecast

December 2024



United Utilities

Water for the North West

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1. Introduction

This technical report sets out our approach to deriving robust resource zone level supply forecasts in our Water Resources Management Plan 2024 (WRMP24). Our approach to forecasting future supply has been informed by the latest regulatory guidelines, best practice and regional planning group methodologies, and our engagement with customers, stakeholders, regulators, and members of Water Resources West (WRW) regional planning group.

Our supply forecasts adhere to the guiding principles as set out in the Water Resources Planning Guideline (Environment Agency, 2021). This report aims to demonstrate the ways in which we have applied national best practice, how we have introduced new innovative methods, and how we have been consistent with the WRW supply forecasting methodology, a new requirement for this round of planning.

Several key documents were used to develop our resource zone supply forecasts including:

- Water Resources Planning Guideline (Environment Agency, Water Resources Planning Guideline, 2021);
- Water Resources Planning Guideline Supplementary Guidance – Resource Zone Integrity (Environment Agency, 2021);
- Water Resources Planning Guideline Supplementary Guidance – Outage (Environment Agency, 2021);
- Water Resources Planning Guideline Supplementary Guidance – 1 in 500 (Environment Agency, 2021);
- Water Resources Planning Guideline Supplementary Guidance – Stochastics (Environment Agency, 2021);
- Water Resources Planning Guideline Supplementary Guidance – Climate Change (Environment Agency, 2021);
- Water Resources Planning Guideline Supplementary Guidance – Long-Term Destination (Environment Agency, 2020);
- WRMP19 Methods – Risk Based Planning (UKWIR, WRMP 2019 - Methods - Risk Based Planning [16/WR/02/11], 2016);
- WR27a Handbook of Source Yield Methodologies (UKWIR, 2014);
- Outage Allowances for Water Resource Planning (UKWIR, 1995);
- Long-term planning for the quality of drinking water supplies (Drinking Water Inspectorate, 2020); and
- Resilience of water supplies in water resource planning (a supplementary note to long-term planning for the quality of drinking water supplies) (Drinking Water Inspectorate, 2021).

We engaged with regulators early in the planning process, both through company and WRW regulator liaison meetings. We shared details of our regional and company methodologies and ensured feedback was considered. We also held special interest sessions on specific technical topics such as water resources modelling and climate change.

As required in the Water Resources Planning Guideline (Environment Agency, 2021), this report provides a detailed breakdown of our system response-based supply forecasts including:

(1) An assessment of baseline deployable output per resource zone;

(2) Quantification of the impacts on resource zone deployable output due to:

   a. Future changes to deployable output from sustainability changes, long-term environmental destination, climate change, and any other changes;

   b. Existing transfers and schemes where planning permission is already in place;

   c. Short-term, losses of supply and source vulnerability known as outage; and,

   d. Operational use of water or loss of water through the abstraction-treatment process

(3) A calculation that combines all the above elements into Water Available For Use (WAFU)

1.1 Changes from draft to revised draft WRMP

Table 1 Changes from draft to revised draft

Change	Reason	Update(s)	Relevant section(s)
Added detail of demand profiles applied in our Strategic RZ models	Minor issue (1.9) raised by the Environment Agency	Updated text on improved approach for WRMP24	Section 2.3
Summary of baseline deployable output for the 2024 plan	Improvements	We have updated our baseline deployable output assessment, as well as updating the sustainability reductions and Environmental Destination scenarios and impacts.	Table 9
Explained system response to extreme drought events	Issue (2.2) raised by the Environment Agency	Added additional narrative around the impacts of extreme drought events	Section 4.4.5
Summary of baseline deployable output for the 2024 plan	Improvements	We have updated our baseline deployable output assessment, as well as updating the sustainability reductions and Environmental Destination scenarios and impacts.	Table 11
Change to narrative around table 16	Minor issue (1.5) raised by the Environment Agency	Updated text to ensure the narrative and table contents are consistent	Section 7.2.2
Updated import and export arrangements with other water companies and New Appointments and Variations (NAVs)	For consistency of assumptions with neighbouring water companies	Included an export from the Strategic Resource Zone to Severn Trent Water	Table 26
Added detail on the assessment of Haweswater Aqueduct Resilience Programme (HARP)	Issue (1.5) raised by the Environment Agency	Updated text	Section 9.2

1.2 Changes from revised draft to final WRMP

Table 2 Changes from revised draft to final

Change	Reason	Update(s)	Relevant section(s)
Emergency storage section	Issue (1) raised by the Environment Agency in response to Revised Draft WRMP	New section to outline rationale for excluding emergency storage	Section 4.6
Realistic supply modelling section	Issue (3) raised by Defra granting permission to publish	New section to outline the additional modelling completed at the request of the Environment Agency	Section 4.7

2. Defining our water resource zones

We supply water to over seven 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. In our region, in a typical year 93 per cent of the water we supply comes from river or reservoir sources, and only seven per cent comes 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 a 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 Water Resource Zone Integrity supplementary guideline (Environment Agency, 2021). We shared the first draft of our Water Resource Zone Integrity Report with the Environment Agency in September 2020 and updated our report by late October 2020 to account for feedback[1].

The review has been completed as a detailed desktop exercise completed by several of our staff, predominantly the Water Resources Modeller, Senior Water Resources Modeller, and Water Resources Manager. The analysis has been completed at a Demand Management Zone (DMZ) level. Where a change has occurred at DMZ level that requires more detailed explanation or justification, Asset Managers and the Production Planning team (who manage the supply system operationally) have been consulted. When appraising our WRZs for WRMP24, the following process was followed:

(1) Review previous WRZ Integrity Report from our 2019 Water Resources Management Plan (WRMP19);

(2) Conduct a desktop review of detailed operational schematics for each Demand Management Zone (DMZ) to identify any areas of the WRZs that schematically are isolated from the main system or appear 'separate' from the system in terms of operational management; and,

(3) Complete DMZ mass-balance calculations for the more complex Strategic Resource Zone (SRZ), including WRMP19 dry year demands and local deployable outputs to demonstrate interconnectivity of the system (which may not be readily apparent from Item 2). Where appropriate, data and information collected during previous dry weather events, has been used to inform supply system capability.

The aim of this exercise is to identify WRZ boundaries within our region that adhere to the industry standard definition:

"The largest possible zone in which all resources, including external transfers, can be shared, and hence, the zone in which all customers will experience the same risk of supply failure from a resource shortfall" (UKWIR, 2012) (Environment Agency, 2021).

Sub-zones are defined as areas of a water supply system with limited connectivity to the main WRZ supply network. Where any sub-zones have been identified, we have applied the minimum threshold provided in the Water Resource Zone Integrity supplementary guideline (Environment Agency, 2021). This guidance states that sub-zones, which meet the following criteria, are exempt from zonal separation:

- isolated rural communities with less than one per cent of the WRZ customers, or less than 5,000 customers (whichever is the smallest); or
- where the demand from the sub-zone is <1 Ml/d of Total WAFU.

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[1] We developed the early drafts using the draft supplementary guidance, published in 2020. We have subsequently reviewed the final Water Resource Zone Integrity supplementary guideline published in 2021.

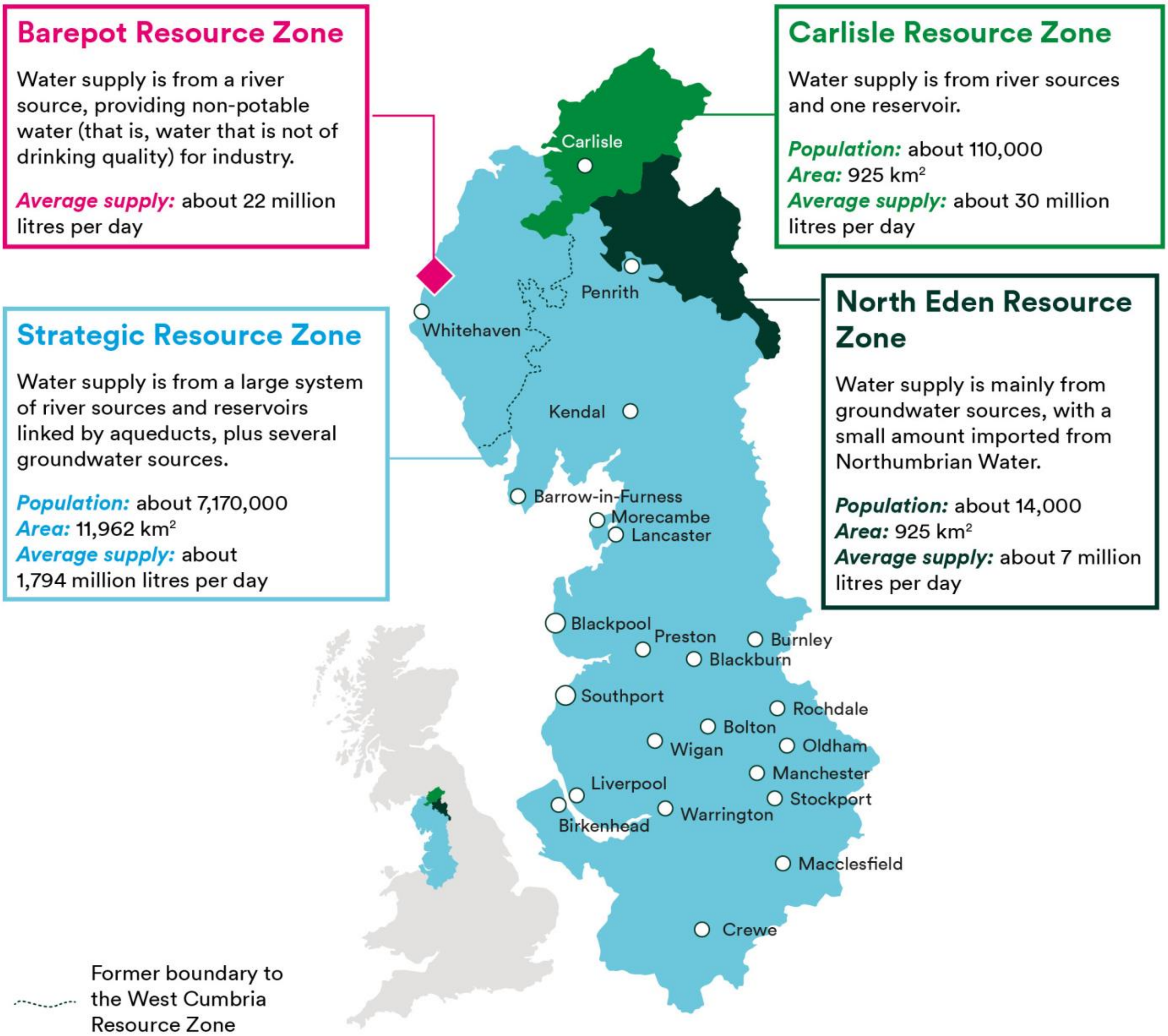
2.2 Water resource zones for our 2024 plan

For our 2019 plan we identified four separate WRZs, and through our appraisal of water resource zone integrity for WRMP24, we concluded that these four zones remain applicable for the 2025-2050 planning horizon. Our supply area is divided into four separate WRZs, with limited connectivity between them. One of these consists solely of a non-potable water supply to an industrial customer (Barepot WRZ).

Since our last Water Resources Management Plan was published, in August 2019, we have completed construction of a raw water pipeline linking two of our previous water resource zones on which we reported in our 2014 Water Resources Management Plan. These were the Integrated WRZ and West Cumbria WRZ, which have now been linked by the Thirlmere transfer pipeline completed in 2022, to form a new combined WRZ known as the Strategic WRZ. We reported on the Strategic WRZ in WRMP19, as the merge was due to take place during the early years of that plan, and we continue to report on the new combined WRZ in this current plan.

The characteristics and boundaries of our current water resource zones are shown in Figure 1.

Figure 1 Geographical locations of our water resource zones



Barepot Resource Zone

Water supply is from a river source, providing non-potable water (that is, water that is not of drinking quality) for industry.

Average supply: about 22 million litres per day

Carlisle Resource Zone

Water supply is from river sources and one reservoir.

Population: about 110,000
Area: 925 km²
Average supply: about 30 million litres per day

Strategic Resource Zone

Water supply is from a large system of river sources and reservoirs linked by aqueducts, plus several groundwater sources.

Population: about 7,170,000
Area: 11,962 km²
Average supply: about 1,794 million litres per day

North Eden Resource Zone

Water supply is mainly from groundwater sources, with a small amount imported from Northumbrian Water.

Population: about 14,000
Area: 925 km²
Average supply: about 7 million litres per day

The following is a brief description of each of our resources and how they meet the definition of a water resource zone:

- **Strategic Resource Zone –** The largest of our WRZs comprising more than 98% of the total population served. The resource zone is centred upon aqueducts, which deliver water from the Lake District to Keswick, Penrith, South and West Cumbria, Lancashire and Greater Manchester, and from Lake Vyrnwy 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 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 regional sources.
- **Carlisle Resource Zone –** This zone serves a population of approximately 110,000 in the Carlisle local authority area and a small part of the Allerdale District. It is served by two sources: the River Gelt via Castle Carrock Reservoir and the River Eden at Cumwhinton.
- **North Eden Resource Zone –** This resource zone serves a population of approximately 14,000 in the rural northern part of the Eden District of Cumbria. Most of the zone is supplied from boreholes in the Sherwood Sandstone aquifer, while the Alston area is supplied from a bulk water supply from Northumbrian Water.
- **Barepot Resource Zone –** This serves a small number non-potable industrial customers.

2.3 Developments in our water resources capability since our 2019 plan

As described in section 2.2 the Thirlmere Transfer Scheme is now complete and connects customers in the former West Cumbria Resource Zone to Thirlmere Reservoir via a new pipeline and a new water treatment works near Redmain. This marks a big step forward in terms of supply and sustainability to the West Cumbria area; once supply is fully transferred over to Thirlmere Reservoir then abstraction from sources in West Cumbria will cease and abstraction licences will be revoked.

No supply options were selected in our WRMP19, however there have been further changes in our Strategic Resource Zone in the intervening period to improve our supply capability. These have been reported via the Annual Water Resources Review process. The key changes accounted for in our baseline supply forecast for WRMP24 are:

Supply schemes:

- Conversion of borehole sources in Cheshire from a drought-only supply-side option to sources used in normal operation (completed in 2021/22);
- An increase in the transfer capacity from a group of reservoirs to a water treatment works in North Lancashire; and
- An increase in the capacity of a pipeline between Merseyside and Greater Manchester, increasing the amount of water which can be transferred across our network from South area sources to the South East of our region

Updated capacity assumptions based on new information:

- An increase in the hydraulic maximum treatment capacity at our [✄] Water Treatment Works;
- An increase in the transfer capacity from our Thirlmere Aqueduct into the Lancaster supply area;
- Our modelling approach for Haweswater Reservoir has been reviewed and updated to better reflect current operating rules; and
- An increase in the capacity of the Denton to Hazel Grove main to improve the resilience of the Stockport and Macclesfield area.

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. This work will continue in the future and will include a project to clean the Vyrnwy Aqueduct during 2023-2028.

In our Carlisle Resource Zone we have implemented an operational enhancement that provides increased capacity for the pumped transfer from the River Eden to Castle Carrock Reservoir.

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.

We have also improved the representation of these new and existing assets in our water resources models Hydro-Logic® Aquator and Pywr, and following our experience of dry weather in 2018, we completed a validation exercise to check the performance of our models compared to reality. Model review and development is a continuous improvement activity, which includes making updates to represent changes to our assets for example, but also includes migrating our models to the latest software versions. Since our 2019 plan we carried out a significant upgrade of our Hydro-Logic® Aquator modelling software to version Aquator XV making sure we have the best available tool for water resources modelling.

Another model improvement of note in our Strategic Resource Zone model is the move from a resource zone wide monthly demand profile, to the application of monthly demand profiles at a Demand Management Zone (DMZ) level. Applying demand profiles this way allows us to better account for the impact of local demand variances on system response (i.e. impact from temporary higher demand due to local tourism or dry weather impacts). The 33 monthly factor profiles were calculated using average weekly demand and then applied to DMZ demand centres within Aquator to reflect the change in demand through the year. Factors for winter months typically have a factor of less than one; while during the summer, factors will mostly be above one, however this will always average out to one across the year.

3. Developing our supply forecast

The purpose of a supply forecast is to set out how much water there will be in the future, and how this will change throughout the WRMP24 planning period (2025-2050). We also forecast beyond this up to 2085 for the Water Resources West Regional Water Resource Plan. The following sections of this document, set out how we have assessed our future supply capability in accordance with the Planning Guidelines (Environment Agency, 2021).

3.1 1 in 500 drought resilience

The latest Water Resources Planning Guideline (Environment Agency, 2021) introduced a new drought resilience standard for WRMP24. For this plan we must make sure that our baseline supplies are resilient to more severe droughts, so that we will not use exceptional demand restrictions, such as Emergency Drought Orders, more than once every 500 years (or 0.2% annual chance of occurrence). This is a step change from WRMP19, which focused on planning to be resilient to the worst historic drought on record. For example, in WRMP19, this was the 1984 drought for the Strategic Resource Zone, which had approximately a 1 in 100 return period (or 1% annual chance of occurrence). Section 4 outlines our detailed assessments of 1 in 500-year baseline supply capability for each resource zone.

3.2 Planning scenarios

Supply forecasts (and resource zone supply-demand balances) are prepared for specific planning scenarios representing different conditions. As a minimum, a water resource zone supply forecast is required for a baseline scenario where supplies are low and demand is high. This design scenario is referred to as the Dry Year Annual Average (DYAA) scenario. The Water Resources Planning Guideline (Environment Agency, 2021) also allows for additional scenarios to be included in WRMPs; such as a Dry Year Critical Period (DYCP) scenario, which represents a period of peak strain on a supply system.

Dry year critical period planning scenarios are typically used to assess resource zones which can be susceptible to short-term shocks, such as a short period of elevated demand, under longer-term stress conditions. Longer-term stresses can include events such as an exceptional shortage of rainfall over a number of consecutive months. Resource zones that rely on direct river abstraction, with little raw water storage within the zone, are particularly vulnerable to short-term peaks in demand. This vulnerability is due to limitations on abstraction due to low flows within a river. We completed an initial review of the need for a dry year critical period planning scenario in all resource zones and categorised each zone as follows:

- **Carlisle Resource Zone** – dry year critical period required due to small number of water sources and reliance on direct river abstraction.
- **Strategic Resource Zone** – selected for supply system sensitivity assessment to peak week demands to determine if a dry year critical period planning scenario is required.
- **North Eden Resource Zone** – dry year critical period not required as there is sufficient spare production capacity and groundwater yield to meet temporary increases in demand.
- **Barepot Resource Zone** – dry year critical period not required as this zone consists of a single river abstraction supplying a small number of industrial customers. No history of short-term increases in demand leading to stress on the raw water system.

The planning scenarios chosen for each of our water resource zones in both our previous and new plan are shown in Table 3. To be compliant with the planning guidelines, a DYAA scenario is adopted for each zone. For WRMP19 a DYCP scenario was included for Carlisle Resource Zone, based on the characteristics of the sources, which can go from full to empty in a few months (approximately 14 weeks). The time taken for this to happen is known as the 'critical period', which represents a potential period of peak stress on the system. For our previous plan, the deployable output for the resource zone was determined by Castle Carrock reservoir reaching emergency storage level in 1976, the worst historic drought on record for the area. This deployable output value was used for both the DYAA and DYCP scenarios. The difference in the two supply demand balances for these planning scenarios therefore came from a difference in demand. Using the critical period (14 weeks), a factor was derived to uplift demand by comparing the average demand over the critical period with the average annual demand for water each year. As the critical period can coincide with the hottest and driest months of the year, the uplift applied to demand is even higher than for the dry year demand. Using a period of several weeks as the period of peak strain on the supply system was an uncommon approach for determining a DYCP supply forecast and supply-demand balance. The more common approach is to assess the maximum deployable output for a short period. As such, after confirming there is still a requirement for this planning scenario for the Carlisle Resource Zone, we reviewed and improved on our previous approach. One key improvement for WRMP24 is the inclusion of demand profiles (monthly factors that vary demands in the models to reflect variations in demand based on FY19) in our Hydro-Logic® Aquator models. These allow us to stress the system over the critical 14-week period now as part of our DYAA planning scenario. For this plan, the DYCP supply is now based on the maximum deployable output from the supply system over a one-week period, which is consistent with the common industry approach and definition of a critical period. Details of the new assessment can be found in Section 4.1.2 and Section 4.4 includes a summary table of baseline deployable output for each resource zone and planning scenario.

Table 3 Water resource zone planning scenarios for WRMP19 and WRMP24

	WRMP19		WRMP24	
Water resource zone	**Dry Year Annual Average (DYAA)**	**Dry Year Critical Period (DYCP)**	**Dry Year Annual Average (DYAA)**	**Dry Year Critical Period (DYCP)**
Strategic	✓	✗	✓	✗
Carlisle	✓	✓	✓	✓
North Eden	✓	✗	✓	✗
Barepot	✓	✗	✓	✗

3.2.1 Strategic Resource Zone system level testing for dry year critical period

The Strategic Resource Zone consists of many sources which are predominately surface water storage, in addition to boreholes and direct river abstractions. Given the large volume of raw water storage in impounding reservoirs, within the zone, short-term shocks such as high demand during spells of hot weather and freeze thaw events, do not lead to a risk of rapid drawdowns of raw water storage.

Longer-term stress, such as prolonged dry weather, can however lead to drawdowns of reservoirs within this zone. Prolonged dry weather conditions are covered by the dry year annual average planning scenario and are not considered as part of the dry year critical period planning scenarios for WRMP24. Over recent dry weather events, the Strategic Zone has experienced periods of elevated demand, particularly peaks occurring for a duration of around one week.

For the Strategic Resource Zone, it was, therefore, decided that a sensitivity analysis would be completed to stress test the supply system against acute demand peaks. This system level testing would assess whether forecasted peak week demands could be accommodated by the system after making an allowance for:

- Population growth;
- Outage leading to temporary reduction in treatment capacity; and
- Uncertainty within the supply-demand planning process.

Our water supply system, including the full source to tap system of water treatment works, regional trunk mains and service reservoirs is designed to manage peak week demands. Shorter-term peaks in demands, such as over a number of days or within a day, are managed by local and regional potable service reservoir storage, which are linked to company asset design standards.

We have used our MISER water resources model to complete this stress test of our supply system for dry year peak week demand risk. To quantify any risk to supply, we have adopted our existing production planning mass balance model, as the basis of our assessment. The existing model contains all water treatment works (WTWs), large diameter trunk mains (LDTMs) and strategic service reservoirs.

This sensitivity analysis involved three phases, where phase one was a review of the baseline model to ensure it was suitable for dry year critical period modelling. Phase 2 involved applying demand uplift factors to represent future forecast demands, target headroom and outage allowance. The final phase consisted of detailed analysis of the results to quantify any supply risk.

Phase 1 – MISER model review and setup

MISER is a water network management modelling package for operational resource planning, widely used in the UK water industry. We use MISER as a business-as-usual production planning tool, primarily targeting the distribution of regional resources for short-term week-to-week forecasts. The model has a slightly finer resolution than our Hydro-Logic® Aquator model for demand modelling, but less hydrological detail. Our MISER model doesn’t include local treated water storage as this is not generally necessary for regional resource production planning. Since MISER contains a greater resolution of supply system detail, it was deemed to be the best tool to use for the stress test. The MISER model would be able to identify any sub-zonal areas, applicable at a production planning level, which could be operated at or above maximum capacity during future critical period conditions.

We took a copy of the existing production planning model and completed a review of the model against our WRMP24 Aquator model. This included updating asset capacities for consistency with WRMP24 asset data, which include planned investment over AMP7 and therefore reflect expected asset capacities at the start of AMP8 (2025). Since peak week demand events are unpredictable in the long term, the impacts are dependent on a range of factors such as regional system configuration, actual outage at the time of the event and service reservoir storage. We have updated the MISER model to account for a range of system conditions. These are summarised in Table 4.

Table 4 MISER model setup for DYCP sensitivity analysis for the Strategic Resource Zone

Criteria	Detail
Demand Data	District Meter Zone (DMZ) level weekly demand data Normal Year (Average) and Dry Year (Peak) demands applied Based on WRMP demand forecast
Leakage/Losses	Included within DMZ level demand figures Separate allocation of losses to our network of large diameter trunk mains
Water treatment work capacities	Consistent with WRMP supply assessment as the maximum operationally sustainable capacity and minimum flow
Raw Water Components (based on the Hydro-Logic® Aquator model used for dry year assessment)	Raw water inflow sequences – historic inflows into raw water impounding reservoirs (IRs) used
	Abstraction Licences – Annual (Ml/y) and daily (Ml/d) raw water abstraction constraints apply
	Impounding Reservoir control curves – operational policies that help to balance drawdown of individual reservoirs across the resource zone
	Impounding Reservoir capacities and starting levels – Historic impounding reservoir storage sequences used
	Hands-off flow (HoF) – minimal river flows below which abstraction cannot take place
	Compensation flows – Fixed Ml/d release requirements from our impounding reservoirs, typically for environmental provision

Criteria	Detail
MISER Optimisation	Week by week – management of resource to meet demand on a week-by-week basis
Raw Water + Process Losses and operational use	Losses in raw water transfer mains up to the water treatment works and losses as a result of the treatment process at the water treatment works are accounted for

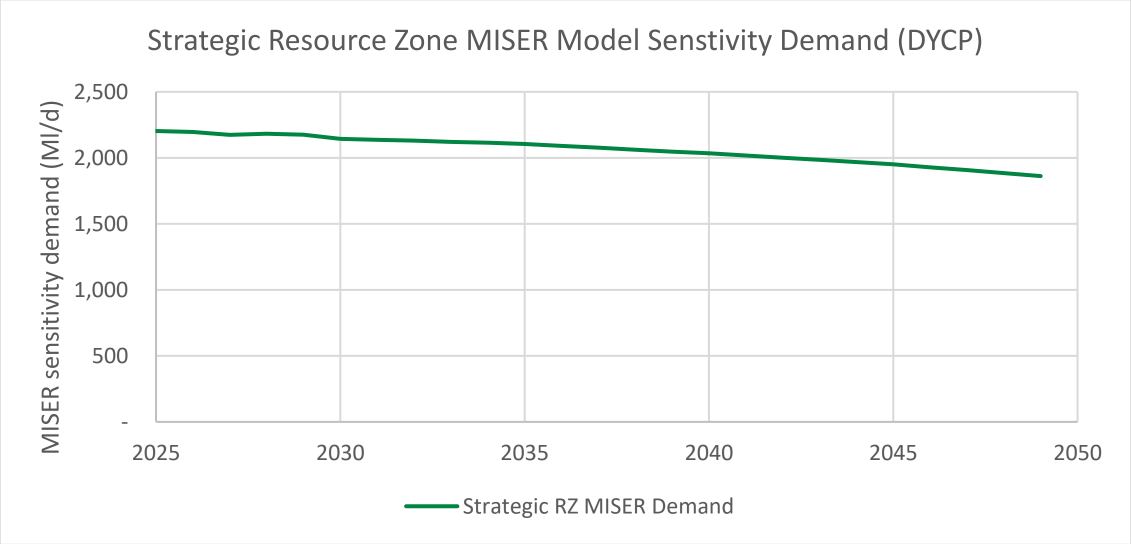
Phase 2 – Apportioning demand and application of peak week uplift factors

The aim of the whole water supply system stress test for the Strategic Resource Zone is to determine if there are any constraints which lead to a supply risk under a future scenario of, future population and property growth, changes in non-household demand, water efficiency, leakage reduction and unknown future supply system outages.

The method chosen to complete this analysis was to apply a demand uplift factor at various points in time across the planning period. The demand for MISER modelling was calculated by adding the outage allowance (Section 9) and target headroom[2] to the final planning dry year annual average demand forecast[3]. This sum for the resource zone will be referred to as the 'MISER sensitivity demand', as summarised in Figure 2. The result of this calculation is provided in Figure 3 with a decreasing trend across the planning period.

Figure 2 Calculation of MISER demand for DYCP sensitivity analysis

Figure 3 MISER demand 2025 to 2050



The MISER model had baseline annual average demand uplifted to correspond to the calculated MISER sensitivity demand for a given year. A peak week uplift factor of 17% was then applied to a single week during the model run to simulate a single peak week demand event occurring in the summer. This peak week uplift factor was based

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[2] Target headroom is explained within the document WRMP24 Technical Report – Allowing for uncertainty

[3] The demand forecast is covered within the document WRMP24 Technical Report – Demand for water

upon actual peak week demand seen during FY19 and is explained further in Section 7.4 of the document *Revised Draft WRMP24 Technical Report – Demand for Water.*

Since the year 2025 corresponds to the highest MISER sensitivity demand, the first scenario was to run the MISER model under the system conditions provided in Table 4, with baseline demand distributed between Demand Management Zones (DMZs) in line with the baseline WRMP24 demand forecast for that year. The overall annual average system demand within the model was then uplifted to correspond to the MISER sensitivity demand for 2025. The model was then run for a 16-week duration, over the summer months starting in May with a single week of elevated demand further uplifted by 17% at the end of June. This is consistent with the timing of a peak week demand event during dry weather in FY19.

Although the MISER sensitivity demand decreases across the planning period at a resource zone level, an additional run was completed for 2030 to check for any local increases in demand (at a DMZ level or below), due to new developments. This could occur from large developments concentrated in specific areas, offsetting demand reductions from water efficiency and leakage reduction. This second scenario for the year 2030 was setup in the same way as the 2025 scenario, except the baseline DMZ demand distribution was updated to be consistent with the baseline WRMP24 demand forecast for that year.

Phase 3 – analysis of results

There was a small deficit of 0.02 Ml/d within the Strategic Zone for the scenario covering the year 2030. Upon further investigation this 0.02 Ml/d was a single demand centre, supplied by a water treatment works, which is a sub-zonal area of the Rochdale DMZ. This deficit would in practice be met through an operational contingency plan (e.g. tankering) or local storage not fully modelled in the analysis. Following review of the water treatment works contingency plan, it became apparent that a temporary network rezone can be implemented. This rezone is capable of meeting this 0.02 Ml/d, during short duration peak demand events.

Based on the assumptions applied in our modelling there are no demand deficits which cannot be resolved through contingency planning, or the use of local storage. Under the planning assumptions for this sensitivity analysis, the Strategic Resource Zone is capable of operating at forecast peak week conditions, for 2025 and 2030. Since modelled DYCP demand is forecast to decrease further from 2030 (as shown in Figure 3), a sensitivity test of peak week demand conditions was not required for the period 2030 to 2050.

In conclusion, we are confident in the peak week demand resilience of our supply system. We have concluded that a dry year critical period planning scenario is not required for the Strategic Resource Zone in WRMP24.

3.3 Supply components

There are two key metrics associated with supply forecasting: deployable output (DO) and water available for use (WAFU), which are referred to throughout this report. They are calculated at resource zone level for each planning scenario (e.g. Dry Year Annual Average). Definitions of DO and WAFU are included in Sections 3.3.1 and 3.3.2. Details of these and the remaining components involved in preparing the WRMP24 supply forecast can be found in the sections listed below:

Section 4 – Deployable output

Section 5 – Sustainable abstraction

Section 6 – Environmental destination

Section 7 – Climate Change

Section 8 – Water transfers

Section 9 – Outage allowance

Section 10 – Raw water and process losses

Section 11 – Water available for use

3.3.1 Baseline deployable output

The UKWIR 'Handbook of source yield methodologies' (UKWIR, 2014) defines deployable output as:

The output of a commissioned source or group of sources or of bulk supply as constrained by:

- License if applicable;
- Pumping plant and well aquifer properties;
- Raw water mains and aqueducts;
- Transfer and output restrictions;
- Treatment; and
- Water quality

For specified conditions and appropriate demand profiles to capture variations in demand over the year.

The Environment Agency's guidance (Environment Agency, 2021) requires companies to determine the baseline deployable output for the design drought. For this WRMP, the design drought is based on 1 in 500-year drought resilience from 2039. Baseline deployable output excludes contributions from demand (e.g. Temporary Use Ban) or supply (e.g. drought permits) drought measures. Section 4 provides further details on how baseline deployable output has been calculated for this plan; including a summary of deployable output for each resource zone and how this has changed since our last plan.

3.3.2 Water Available For Use (WAFU)

Water Available for Use (WAFU) is a key supply forecast metric that takes into account:

- 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 is calculated in two stages as defined by 'Water resources planning tools' (UKWIR, 2012):

WAFU own sources:

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

Total WAFU:

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

Total WAFU represents the supply side of resource zone supply-demand balances in WRMPs.

Section 11 provides a summary of Total WAFU calculated for each of our water resource zones and how this has changed since our last plan.

4. Baseline deployable output

The Water Resources Planning Guideline (Environment Agency, 2021) requires system response-based assessments of deployable output for each resource zone, demonstrating resilience to a 1 in 500-year (or 0.2% annual chance of) failure caused by a drought. In order to calculate this type of deployable output, new methods, tools and data have been developed, which are described in detail in Sections 4.1 to 4.3. Section 4.4 summarises the baseline deployable outputs calculated for this plan and the key constraints on deployable output for each resource zone and Section 4.5 summarises the change in deployable output since our 2019 plan.

We also followed the UKWIR 2016 Risk Based Planning methodology to help determine the hydrological input data requirements. As explained in the following sections this led us to use stochastic datasets derived by a 'Weather Generator' in our surface water dominated resource zones.

4.1 Deployable output approach

Deployable output has been assessed for all four of our water resource zones in line with the good practice principles and methodologies outlined in Section 0. Different approaches have been adopted depending on the characteristics of the zone and their suitability for demonstrating the supply system is resilient to a 0.2% annual chance of failure caused by a drought, and our other Levels of Service (e.g. Temporary Use Ban 1 in every 20 years). The Strategic and Carlisle Resource Zones are conjunctive-use supply systems whereby local sources operate in a conjunctive manner with the regional sources; particularly in the Strategic Resource Zone, so that risk can be balanced, in their use relative to the regional sources. Due to the complex nature of how these resource zones work, more sophisticated approaches and tools are required to determine the deployable outputs for each level of service, including the 1 in 500 deployable output (0.2% annual chance of failure). For both of these zones, water resources models have been used to simulate system behaviour. Conversely, more simple approaches and tools are required to determine the deployable outputs for the North Eden and Barepot Resource Zones because they have a smaller number of sources and each source supplies a discrete demand with no interconnectivity. Table 5 summarises the deployable output approach, tools used for each resource zone assessment and the constraints on deployable output.

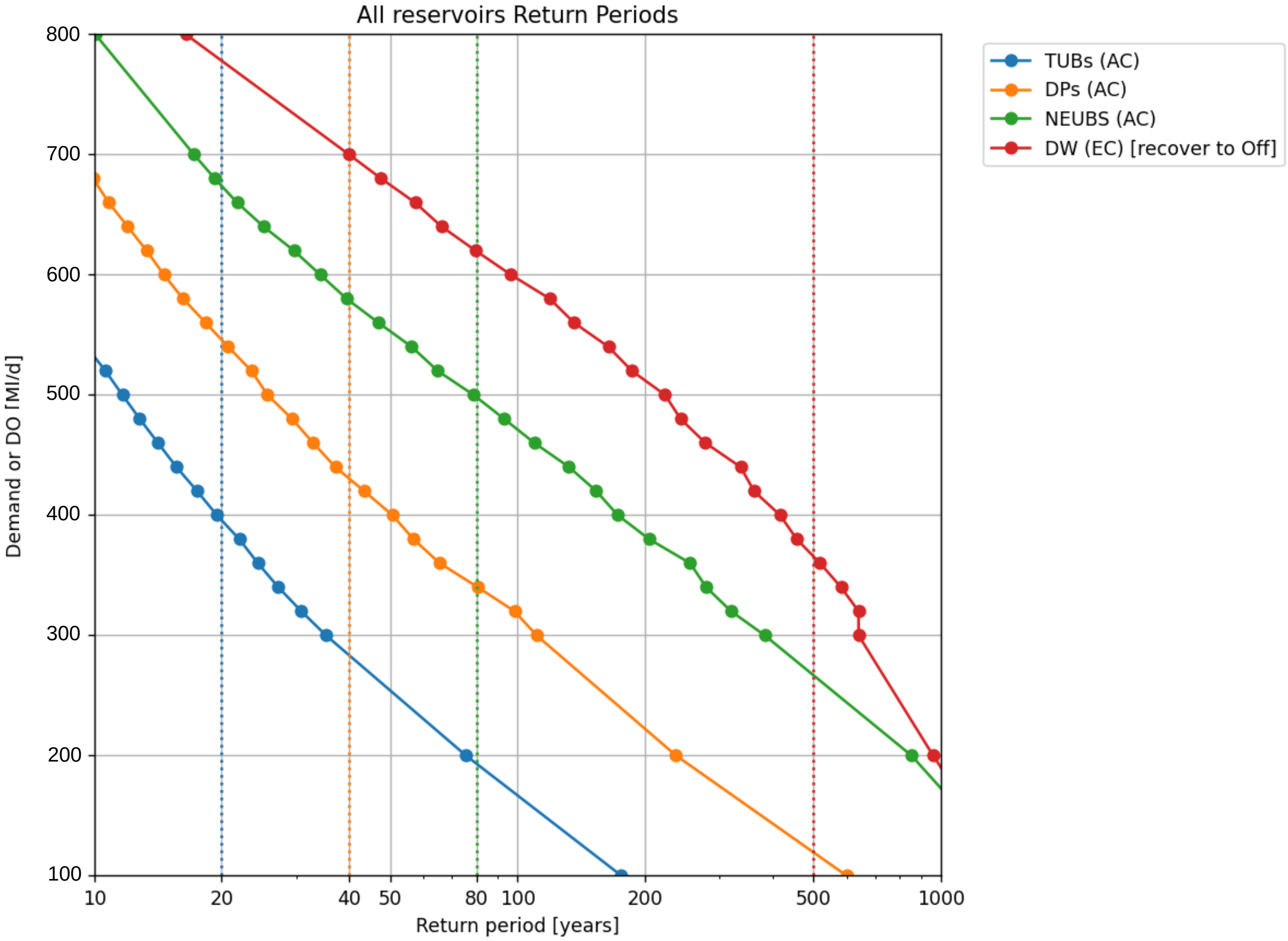
Table 5 Deployable output approaches for WRMP24

	Strategic Resource Zone	**Carlisle Resource Zone**	**North Eden Resource Zone**	**Barepot Resource Zone**
Deployable output assessment type	Conjunctive-use system response simulation	Conjunctive-use system response simulation	Simple system source deployable output	Simple system source deployable output
Tools to use in assessment	Hydro-Logic® Aquator and Pywr software	Hydro-Logic® Aquator software	Output from source yield assessment	Output from source yield assessment
Deployable output constraints	Drought magnitude and frequency	Drought magnitude and frequency	Asset capacities and abstraction licence limits	Abstraction licence limit

4.1.1 Strategic and Carlisle Resource Zones – dry year annual average

To calculate reliable system response-based deployable outputs for the Strategic and Carlisle Resource Zones, the water resources models are set up to run according to the system response deployable output method (previously known as the Scottish method). This approach is designed to calculate deployable output based on frequency of failure. The models are run multiple times using a large stochastic hydrological dataset and incrementally increasing demand. The number of years with a failure is counted at each demand step and presented on a deployable output versus return period graph (Figure 4). For example, with a stochastic hydrological record of 19,200 years, 38 dead water failure events are required to determine the 1 in 500 deployable output (19,200/38 = 1 in 500 return period). The demand at which 38 events occur is the 1 in 500 deployable output, which can be identified from the return period versus DO plot, where the 1 in 500 DO line (solid red dotted line in Figure 4) intersects the 1 in 500 return period line (red dashed line in Figure 4). Using this methodology, the deployable output for all other levels of service can be calculated (e.g. the 1 in 20 TUBs level of service is determined by the level of demand at which approximately 900 Drought Level 2 events occur). Plotting deployable output for all levels of service means the one constraining the overall resource zone deployable output can be easily identified by whichever solid dotted line (DO) crosses its corresponding dashed line (return period) first. For example, Figure 4 shows that the 1 in 500 DO line (red solid dotted line) is the first level of service to cross its corresponding return period (red dashed) line at approximately 370 Ml/d, defining the resource zone DO, and the TUBS DO therefore is approximately 400 Ml/d etc.

Figure 4 Example return period vs deployable output plot for all levels of service metrics



For this round of regional and company water resources planning, a new large (19,200 year) regionally coherent stochastic hydrological dataset was produced by Atkins for all companies and regional planning groups (Atkins, 2021). Further details of the stochastic dataset are included in Section 4.3.1. The models were run with the stochastic replicates (48 years x 400) as a single long time series at a range of different demands. To count the number of years (stochastic replicates) with failures at each demand step, and build the deployable output versus return period curves, a set of failure criteria had to be defined.

For our previous plan (WRMP19) the failure criteria included: a reservoir reaching emergency storage level, a shortage of water at a demand centre, or a drought trigger being breached more often than the level of service stated to customers. If one or more of these conditions were met, then a failure was identified. The deployable output value reached just before the system failed, represented the maximum supply available. The drought resilience standard for WRMP19, in accordance with the Environment Agency's guidance at that time, was to be resilient to the worst historic drought on record. Our deployable output assessment for the Strategic Resource

Zone for example, identified the 1984 event as the design drought, with the deployable output for the zone being defined by Haweswater reservoir reaching emergency storage in September 1984. Having the reservoir failure condition prescribed at emergency storage level meant that the resource zone had additional supply available in the event of a worse than historic drought occurring (Section 4.6).

For this plan, the Water Resources Planning Guideline (Environment Agency, 2021) introduced a new drought resilience standard, requiring companies to plan to be resilient to more severe droughts (1 in 500-year return period or 0.2% annual chance for implementation of Emergency Drought Orders) than those that may have been experienced in the historic observed hydrological period (e.g. 1927-present for the Strategic Resource Zone). As such, the system failure criteria were reviewed and updated to: a reservoir reaching dead water level, a shortage of water at a demand centre, and a drought level being breached more often than the level of service stated to customers. If one or more of these conditions are met, then a failure is identified. These failure conditions correspond to the simulated implementation of Emergency Drought Orders (EDOs).

The deployable output assessment for the Strategic Resource Zone was undertaken using both our Pywr and Hydro-Logic® Aquator water resource models. Aquator is our longstanding water resources model and we currently view it as the more accurate of the two. It was used to calculate all the absolute DO results in the WRMP, for example the baseline Strategic Resource Zone DO. The Pywr model has the same network structure as Aquator but runs around 100 times faster. It was introduced in WRMP19 to support the climate assessment and since then has been used extensively in our Final Drought Plan 2022. While our confidence in the outputs is now very high, and approaching Aquator levels, we have constrained its use to producing relative results (i.e. where we are comparing two resource zone-level DO results), for example the DO benefit of options.

We only have a Hydro-Logic® Aquator model of the Carlisle Resource Zone, as it is much smaller than the Strategic Resource Zone. Despite this, it was still possible to undertake the detailed Scottish DO assessment for the zone using the full stochastic hydrological dataset, as the lower complexity of the model meant that this was feasible. These deployable output assessments were undertaken for the Dry Year Annual Average planning scenario.

4.1.2 Carlisle Resource Zone – dry year critical period

For this plan we have adopted an improved approach for calculating deployable output for the Carlisle Dry Year Critical Period (DYCP) scenario (Section 3.2). The approach involves the following two stages:

(1) Analysis of available abstraction from the River Eden using a simulated historic flow time series to determine if there is a peak week flow constraint on the downstream water treatment works; and

(2) Performing an English and Welsh deployable output run for the first of January when reservoir storage is plentiful (potential limitations from River Eden availability will have already been considered as part of the first stage) to determine the maximum available supply that can be supplied to all demand centres.

In following this approach the deployable output may be constrained by the minimum River Eden flow available and/or maximum asset capacity. These constraints determine the maximum supply available (i.e. deployable output) for a peak week critical period scenario.

The DYCP deployable output was determined using our Carlisle Hydro-Logic® Aquator model. The model was set up to run for one week with all the constraints relevant to this planning scenario outlined in Table 6 applied. Asset capacities, daily abstraction licences and the spatial distribution of demand (based on the FY19 demand centre proportions of total demand) are the main constraints applicable to this type of DO assessment. River flow levels are also theoretically applicable, however our analysis of simulated river flows showed that levels in the River Eden for example, did not reach the Hands-off Flow (HoF) level. Hydrological constraints and annual abstraction licence amounts are not applicable to the one-week assessment, but are accounted for in our DYAA scenario. The model run showed that DYCP DO is constrained by asset capacity and the spatial distribution of demand. To calculate the DYCP supply-demand balance, a one-week uplift factor was applied to demand rather than a 14-week uplift factor used in WRMP19.

Table 6 Model constraints applied in the Carlisle DYCP deployable output assessment

Constraint	Planning scenario	Justification
Asset capacity	DYCP & DYAA	
Daily abstraction licence	DYCP & DYAA	
Annual abstraction licence	DYAA	Not applicable to peak week scenario
Spatial distribution of demand	DYCP & DYAA	In peak week scenario the full asset capacity is not matched to demand centre demand
River flow levels	DYCP & DYAA	The River Eden is always above HoF therefore it is not a constraint on peak week DO
Reservoir storage	DYAA	Not applicable in peak week scenario

4.1.3 North Eden Resource Zone – dry year annual average

For the North Eden Resource Zone, deployable output is primarily determined by our review of all groundwater source yields and as part of our climate change assessment. These projects include an assessment of the historic yield of individual sources and associated impact of climate change under 1 in 500 events (or 0.2% annual chance), which is then extended, where applicable, to determine the impact of 1 in 500 events on the output of borehole groups supplying a downstream water treatment works (details of calculating groundwater yields can be found in Section 4.3.3). The outcome of the groundwater yield review is a set of average and peak yields for individual groundwater source. The project outputs demonstrated that these yields were constrained by physical asset capacities or licence conditions rather than hydrological constraints, even under 1 in 500 year drought conditions. For this zone, these are simply summed together to give the overall deployable output for the resource zone. The assessment of the potential change in deployable output under various climate change projections showed there was minimal impact from climate change on deployable output.

4.1.4 Barepot Resource Zone – dry year annual average

For the Barepot Resource Zone the deployable output assessment is relatively straightforward as there is only one source of water, the River Derwent. Water is abstracted from the River Derwent and distributed via a supply network to deliver non-potable water to a customer. Deployable output for the resource zone is calculated by examining the constraints around this source. Aspects include, abstraction licence limits; historical river flow; and infrastructure constraints.

4.2 Modelling software

Two water resource modelling tools, Hydro-Logic® Aquator and Pywr, have been used extensively in the development of the supply forecast for our Strategic and Carlisle Resource Zones. Hydro-Logic® Aquator software for water resources modelling is widely used across the UK water industry and has been used in three of our previous WRMPs: WRMP09, WRMP15, and WRMP19. While Aquator remains a state-of-the-art water resources modelling tool, the introduction of a new drought design standard for this round of planning presented new technical and methodological challenges for water resources deployable output modelling; in particular, the need to perform lots of model runs quickly using large quantities of data.

Pywr is a rapid simulation modelling tool and its principal application is to solve resource allocation problems in water supply networks. It has many similarities with other software packages, such as Aquator, but also has some significant differences. One of the key differences is that it is designed to be fast enough to handle large stochastic datasets and a large number of scenarios and function evaluations required by advanced decision making methodologies. As such, the Pywr modelling software has also been used alongside Aquator, creating a suite of modelling tools. Pywr modelling software was also used in the development of our previous plan (WRMP19) in two areas: climate change assessment (sub-sampling of probabilistic projects based on deployable output ranking) and the extended methods trading pathway system simulation assessment. For this plan, Pywr has been used more extensively as detailed in various sections throughout this document.

Hydro-Logic® Aquator and Pywr explained

Aquator XV is a new release from Hydro-Logic® Aquator (superseding Aquator 4.3) with speed improvements. Aquator XV also embeds Microsoft Visual Basic for Applications (VBA) as a customisation tool, used in the Microsoft Office suite of applications. With this tool, it is possible to modify/replace the standard built-in algorithms in Aquator XV. 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, AquaSolver2; however, the basic order of calculation is as follows

- 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 Hydro-Logic® Aquator is therefore 'Resource State', which determines respective resource health[4]. Essentially, this is a factor to allow sources to be viewed relative to each other and balance resources. Anything above a value of one is deemed healthy, and anything at or below one is deemed unhealthy, down to a value of zero being totally unavailable. The variance against a value of one 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 as '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; and
- 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.

Pywr (Tomlinson, 2020) is a general open-source water resources modelling library for Python. It was developed to support fast simulation for multi-scenario datasets and optimisation. As a Python library Pywr also supports custom extensions to create bespoke model specific behaviour. Pywr is open-source software, is available for anyone to use and runs on both Microsoft Windows and Linux platforms.

Pywr incorporates a novel simulation method that allows for efficient evaluation of multiple scenarios in a single model run. This is particularly relevant when performing Scottish method deployable output (DO) analysis with stochastic weather datasets.

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[4] While 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).

The core algorithm used by Pywr determines the allocation water resources at every timestep. This allocation determines how available water resources are distributed around the supply system and is typically undertaken at a daily timestep. Use of resources in one timestep will have consequences for the following timesteps. For example, by drawing down reservoir stocks or consuming abstraction licences. By performing a simulation of many timesteps over many years Pywr can assess the resilience of the water resource system using various metrics. It is important to note that Pywr is not a ‘perfect foresight’ model, but instead progresses through a simulation of many timesteps.

Pywr uses linear programming to determine the optimal resource allocation at each timestep. The water resources system and its current state are encoded into a linear programme which is solved using standard mathematical optimisation methods (i.e., the revised Simplex method). Resources are given a penalty cost that is dependent on their current state (e.g., a reservoir close to dead water may have a high penalty cost). Pywr will therefore seek to balance the use of resources every timestep but is constrained by the capacity and connectivity of the resource system. In other words, supply network constraints may cause some sources to become depleted before others.

Various system performance and failure metrics can be recorded by Pywr. This includes the configuration and tracking of drought trigger levels and dead water events at system as well as individual source or demand centre level. Pywr outputs can be readily evaluated using data science tools provided by the wider Python community.

Pywr provides the modeller a lot of freedom in the choice of penalty costs and resource allocation constraints. Our Pywr model of the Strategic Resource Zone includes several custom extensions to simulate bespoke behaviour unique to the system. For example, operational rules around Vyrnwy and its water bank, and Windermere and Ullswater pump activation. It has been closely developed alongside the Aquator model to perform a robust evaluation of the water supply system.

We have Hydro-Logic® Aquator models of our Strategic and Carlisle Resource Zones, and a Pywr model of our Strategic Resource Zone. The models represent the key components of a supply network (e.g. reservoirs, rivers, boreholes, pipes, water treatment works and demand areas) and connect them together to simulate the behaviour of a resource zone as a whole (example Aquator and Pywr schematics are shown in Figure 5 and Figure 6). Crucially, the models contain key constraints including hydrological conditions, abstraction licences and physical constraints such as pipe or water treatment work capacities and reservoir dead water storage levels. Details of the main inputs to the models are provided in Sections 4.3.1 to 4.3.10. Both modelling software packages are highly customisable (using Visual Basic for Applications, or VBA, for Aquator and Python programming language for Pywr) to help define the system rules and logic for representation in the models.

Figure 5 An example Hydro-Logic® Aquator schematic

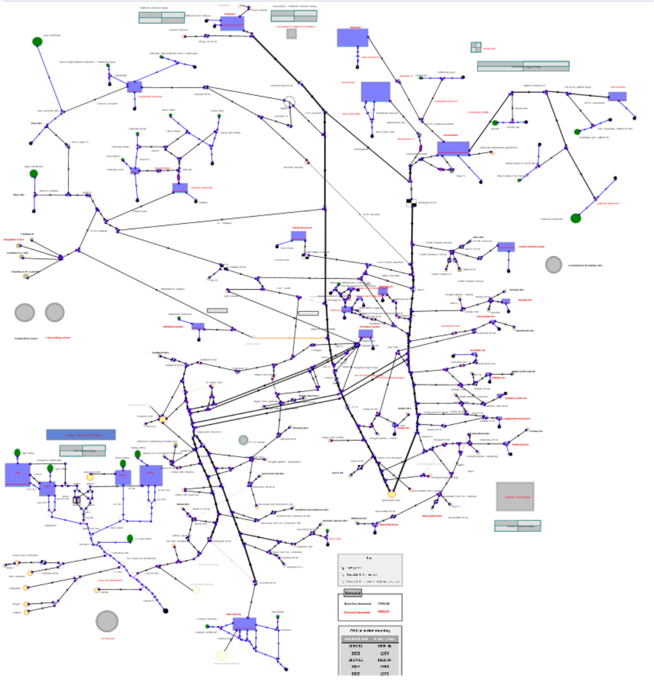
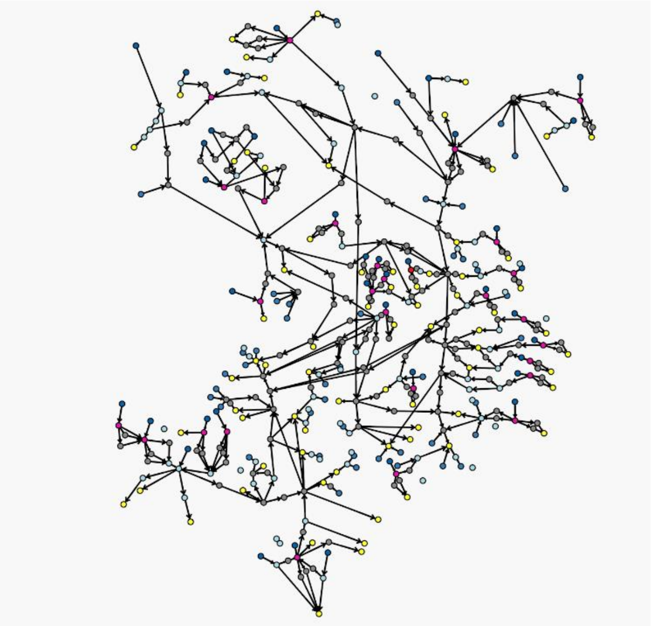


Figure 6 An example Pywr schematic



As these models are used for water resource zone scale strategic assessments, there is a balance to strike in terms of detail represented and maintaining the computational efficiency required to derive 1 in 500 deployable outputs. In order to undertake these assessments, it is necessary to simplify the representation of supply systems and operating principles. It is also difficult to represent the human element of how supply systems operate on a day-to-day basis (for example, operational decisions made based on short-term weather forecast) because they are highly dynamic. Nevertheless, we recognise the importance of accurately representing how our supply systems work and also ensuring our operational decisions are in line with our strategic water resources management plan. Consequently, by working with colleagues from across the organisation, our models are reviewed and updated on a regular basis to make sure that changes to the supply system or operating rules are captured, and that the outcomes of our modelling assessments are shared and incorporated into operational decision making and plans. All model changes are under strict governance with a strong internal audit and sign off process. In preparation for this plan, all of our models have been developed extensively since WRMP19 to ensure we have accurate representations of our supply systems.

4.3 Model input data and key operational rules

4.3.1 Hydrological data

Hydrological data input (reservoir inflows) is vitally important in water resources planning. In the past, this has mostly been based on utilising historic hydrological datasets in order to test the response of our water resource systems to extreme weather events. Reliable, high-quality hydrological datasets (rainfall and evaporation) have only been available in the 20th century giving us around 100 years of data with considerably less for gauged flows. This historical data provides us with several droughts to test, however, it is not possible to derive return periods for events of differing severity with sufficient certainty given the length of the historic record.

To mitigate these data limitations a technique for developing long time series of stochastic weather, which could be converted into flow sequences, was developed. We commissioned Atkins to generate 19,200 years of weather, and subsequently inflow series for the Carlisle Resource Zone (CRZ) and the Strategic Resource Zone (SRZ). The large datasets of stochastically generated flows (19,200 years) will provide greater confidence in our risk-based analyses of the water supply system through the analysis of return periods and different drought events, such as deployable output in a 1 in 500-year event based on system response.

The key outputs are:

Generation of inflow series for the 29 catchments represented in the Strategic and Carlisle Resource Zone Hydro-Logic® Aquator models, based on our 24 Catchmod hydrological models.

Generation of inflow series for Vyrnwy direct, Cownwy and Marchnant by running through GR6J hydrological models provided by Severn Trent/Mott MacDonald for this shared resource. GR6J is a rainfall-runoff model which is gaining popularity across the industry.

**The scope for Atkins was to use existing hydrological models due to insufficient time in the programme to recalibrate the rainfall-runoff models (with the exception to the Stocks inflows)*

Stochastic weather data

The stochastic weather generator is an empirical model and takes the observed relationship between data and regional climatic drivers between 1950 and 1997. This relationship looked at the underlying precipitation behaviour in relation to the climatic drivers and random change. This allows for a wider range of conditions that might have occurred given the climatic drivers when considering the historic record provides only one set of weather conditions (i.e. the one that has occurred). Regional, spatially coherent weather data was generated for WRW which included precipitation, average temperature and potential evaporation.

MORECs PET data were used as the new EA 1km PET data was not ready in time for our assessment. When the dataset was later released, analysis was undertaken to compare the MORECS datasets to the new data to understand the sensitivity on model outputs for selected catchments (e.g. Dee sub-catchments, Windermere and Rivington). This demonstrated there were no significant issues with regards to using the MORECS PET data.

Transposition from sites to catchments

Stochastic precipitation was generated at several point locations across the United Utilities region corresponding to weather stations or gauges with high-quality historic data. This was converted to catchment averaged 'areal' data using the Thiessen polygon method. The equation to calculate catchment rainfall is given by (example):

$$P_{Celyn} = \left(\frac{X}{A_{Celyn}} \times P_{151}\right) + \left(\frac{Y}{A_{Celyn}} \times P_{153}\right)$$

Where A_Celyn is the area of Celyn catchment and A_Celyn = X+Y. (i.e. X is the proportion of the catchment in the Thiessen polygon related to point data site 151).

P151 is precipitation at site 151 and P153 is precipitation at site 153.

Stochastic precipitation was adjusted (multiplying it by the ratio between mean historic precipitation and the mean of the stochastic precipitation**) in order to minimise the difference in characteristics between the stochastic and HadUK precipitation with the calibration datasets.

** This is the precipitation timeseries used to calibrate Catchmod

Flow modelling

Batch running of the 400 stochastic time series was done through PyCatchmod (a version of Catchmod written in Python). For GR6J, a version was written in Python by Mott MacDonald for Vyrnwy Direct, Cownwy and Marchnant.

4.3.2 Groundwater sources

Groundwater sources provide between 6%-9% of the total amount of water we supply to customers (the proportion 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 predominately 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 that 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 nationally approved guidelines written by UKWIR (2012), and further updated in 2018. The UKWIR 2012 methodology was adopted by the Environment Agency (EA) in their 2020 water resource planning guidelines (WRPG). 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). Hydro-Logic® Aquator simulations include all surface water and groundwater sources within the modelled resource zones. 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.

4.3.3 Calculating groundwater yield impacts

For the WRMP24 review of groundwater source yields, the revised deployable output method[5], has been considered as an overarching methodology and adopted, where appropriate, based on the risk and impact on wider system deployable output. The groundwater yield review was split into three phases:

- phase one covered data collection for each source;
- phase two involved a review of methodologies and application of these methodologies to calculate the historic yield of individual sources and associated impact of climate change under 1 in 500 events; and
- phase three then extended this individual source yield assessment to determine the impact of 1 in 500 events on the output of borehole groups supplying a downstream water treatment works.

For WRMP24, a principal piece of work was around the assessment of climate change impacts on the groundwater sources. Yields can be affected by the prevailing climatic conditions. Changes in the pattern, distribution and intensity of rainfall events, along with factors that affect evaporation, such as temperature and wind speed, can affect the amount of water available for abstraction, primarily by affecting groundwater level. This means that climate change, which could affect the factors given, could affect the amount of groundwater available for supply, which would have a knock-on effect on the supply system as a whole.

The source vulnerability to climate change methodology for groundwater involves predicting the maximum groundwater level reduction at each borehole under various future climate scenarios. This reduction is then used to determine whether the source DO may decrease in the future, due to the groundwater level falling below the pump intake (or some other critical depth within the borehole).

Future climate change scenarios were generated by coupling a range of UKCP18 climate projections with historical and stochastic time series. Section 7 gives a detailed description of the techniques that were used for assessing the impacts of climate change on deployable output.

Phase 1: Review of source data

This phase constituted a review of the base data used to establish deployable output values (e.g. source outputs, changes to licence conditions, operational water levels). A review of each source has been completed and amendments made, as required, to reflect changes that could affect the deployable output of each source. The checks and necessary amendments included:

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[5] As outlined in UKWIR (2012) and referred to in EA (2020)

(1) Source details and constraints, including pump size, network capacity and treatment capacity.

(2) Recent CCTV/geophysical survey results and pumping test data, where applicable to inform Deepest Advisable Pumping Water Level (DAPWL). Updates to yield vs drawdown relationships have been made and added to the deployable output diagrams, where appropriate.

(3) Licence conditions, such as a review of existing hands-off groundwater levels.

(4) Water quality constraints, for example to ensure compliance with regulations for chemical parameters. An allowance for risk of gradual onset of pollution of borehole sources, has been made within our Target Headroom assessment (*WRMP24 Technical Report – Allowing for uncertainty*).

Phase 2: Review of new methodology documents

UKWIR (2012) proposes a risk-based approach to groundwater deployable output assessment and is flexible to the individual needs of the water company. There are five main steps and within each are identified a number of individual processes for consideration. These steps and the processes relevant for this review of groundwater source yields are identified and discussed below. It is considered appropriate that only certain components of the UKWIR (2012) approach are adopted for the review of groundwater source yields and the reasons why will be explained within the text.

- STEP 1: Choose a deployable output assessment framework
    - Identify sources, water resource zones and aquifer units
    - Characterise constraints
    - Select deployable output assessment framework
- STEP 2: Assess vulnerability to climate change
    - Select deployable output assessment tool for climate change risks
- STEP 3: Establish deployable output assessment data set
    - Hydrogeological data
- STEP 4: Calculate deployable output (links with STEP 2 of the Economics of Balancing Supply and Demand Options Appraisal Process) with a confidence label
    - Confidence labelling
- STEP 5: Report deployable output assessment

A key message detailed in UKWIR (2012) is the requirement to assess deployable output against a reliable long-term record of resource conditions that date back to at least 1920. However, flexibility to utilise records post-1920 is an option depending on the nature of the source and the supply system. UKWIR (2012) states:

“Hindcasting or future predictions of groundwater levels (and flows) is potentially data and time-demanding and therefore should be proportional to needs and planning issues following the principles of the revised DO method which is risk-based.”

We have taken the decision not to follow this hindcasting approach for the assessment of groundwater deployable output values for two main reasons:

(1) The groundwater deployable output values are predominately constrained by the assets themselves (pump, treatment, water quality, abstraction licence), rather than natural hydrogeological conditions. This is demonstrable based on the observed records which include highest severity events (e.g. 1995/96 drought). Extrapolation of groundwater levels and hence deployable output values back to 1920 is not considered to offer any additional benefit in quantification of deployable output. However, future predictions of the sensitivity of deployable output values in response to climate change scenarios have been considered, which further support this conclusion; and

(2) The total groundwater deployable output for our supply region varies between 10% (average year) and 15% (dry year) and, therefore, small changes in individual groundwater deployable output values are less significant in terms of overall resource zone deployable output.

Choose a deployable output assessment framework (STEP 1)

The groundwater sources in our supply area comprise a mixture of boreholes, wells with adits, mine sources and springs, the majority of which abstract groundwater from the Permian-Triassic Sandstone aquifer. The deployable output constraints relate to the asset rather than the hydrogeological system from which they abstract. These constraints can be either pump capacity, water treatment works capacity, water quality or in in majority of cases, the abstraction licence conditions. Establishing further source constraints (such as deepest advisable pumping water levels, DAPWLs) on a routine basis for every source is not considered a prerequisite to determine source deployable output values, as the borehole outputs are not constrained by hydrogeological factors.

Therefore, in summary, the source assessment framework from the 2012 report has been adopted as there are low to medium constraints (single, stand-alone sources with simple constraints, no inter-connection or partial connection) and the outputs of the assessment are deployable output numbers, with an evidence base to provide justification.

Assess vulnerability to climate change (STEP 2)

We assessed the vulnerability of our groundwater sources to climate change. This work complements the work completed for our surface water dominated supply system, as documented in Section 7. Both pieces of work have been carried out in accordance with the WRPG.

The objective of the groundwater component of the climate change assessment was to provide an assessment of the potential change in deployable output under various climate change projections. A sample of 20 climate scenarios from 3,000 UKCP18 projections for the 2080s were selected for the purposes of the whole assessment.

The deployable output assessment methodology for groundwater involves predicting the maximum groundwater level reduction at each borehole under various future climate scenarios. This reduction is then used to determine whether the deployable output input to water resources models might need to be decreased in order to prevent the groundwater level from falling below the pump intake (or some other critical depth within the borehole). Three techniques are available for estimating the groundwater level reductions:

- **GR1** is the simplest approach and requires the development of a statistical Multiple Linear Regression (MLR) model relating historical precipitation to groundwater level minima. The tool is based on previous work by Bloomfield et al. (2003).
- **GR2** involves lumped calculations of recharge and groundwater level from a spreadsheet tool completed as part of the UKWIR CL/04/C project.
- **GR3** is the most complicated approach and requires the use of existing regional groundwater models and perturbed climate data to assess the impact of climate change on groundwater levels.

The assessment presented in this report uses a combination of the GR1 and GR3 methodologies and represents an update of the assessment for our previous WRMP. Depending on the source and selected modelling technique, we analysed up to 128 UKCP18 scenarios, selecting a subset of 32 for further analysis as part of this project. Scenarios were ranked by deployable output for the Strategic Resource Zone, calculated using Pywr. The subset of 20 scenarios was selected to be representative of the whole range, with more scenarios selected at the lower and higher ends.

The groundwater analysis was split into two components: numerical modelling and analytical modelling. Numerical modelling was used wherever a source lay within an Environment Agency regional groundwater model. All 32 sub-samples were run through the analytical models for the majority of groundwater source groups. The North Eden and South Eden source groups were an exception where a smaller data set was run through the analytical model, consisting of ten baseline stochastic replicates.

Due to the time intensive nature of numerical groundwater modelling, a further sub-sample of five UKCP18 projections was selected from the sample of 32. Numerical modelling was then undertaken for these five scenarios only. Groundwater levels modelled for the region across the different climate change scenarios, are summarised in Table 7.

Table 7 Summary of groundwater levels from model output.

Modelling Method	Model Name	Model Type	Maximum predicted GWL change (stochastic) (m)
Numerical	East Cheshire	GR3	-1.11
	Fylde		-18.32
	Lower Mersey		-4.99
	Wirral		-10.12
Analytical	Barrow	GR1	-14.74
	Bearstone		-1.62
	Bowland		-0.65
	Simmonds Hill		-21.28
	South Cheshire		-10.16
	South Egremont		-9.62
	Warrington		-10.47
	West Cumbria		-2.19
	North Eden		-0.54
	South Eden		-1.71

Once groundwater levels were established for different climate change scenarios a deployable output assessment was carried out to establish the deployable output for each source under the maximum groundwater level fall predicated by the modelling. The Bolton, Burnley and Rochdale Groups are located within the Millstone Grit for which there is little groundwater monitoring data. Therefore, an alternative method for deployable output assessment was completed.

An assessment was then made of whether existing deployable output could be maintained by lowering existing pumps further within the borehole. The borehole groups that were identified as potentially having decreased deployable output under one or more of the climate scenarios, where output cannot be maintained by lowering the pump intake were:

- Barrow group
- South Cheshire group
- Warrington group
- Lower Mersey group
- Wirral group
- Fylde group

Establish deployable assessment data set (STEP 3)

The data set used for the assessment of the deployable output values has been maintained throughout WRMP09, WRMP15 and WRMP19. As mentioned above, the calculation of DAPWLs on a routine basis for every source is not considered a prerequisite to determine source deployable output values as the borehole outputs are not constrained by hydrogeological factors.

Although the UKWIR (2012) approach has been adopted, the data used to define deployable assessment for each source have been reassessed in line with the guidance document from UKWIR (1995) and the subsequent updates to this original methodology. This includes defining source reliable outputs for groundwater sources by plotting the groundwater level and discharge at various points in time to define deployable output (Figure 7 and Figure 8 for examples). In this report, the drought condition is defined as the year groundwater levels fell to their all-time minimum values in the area of the source as indicated by long-term records. Therefore, the drought condition as specified above is not only influenced by periods of low aquifer recharge such as 1995-96 but also by the long-term abstraction regime. Average and peak deployable output values have been established.

Figure 7 Source reliable output diagram for a groundwater source in the Strategic Resource Zone.

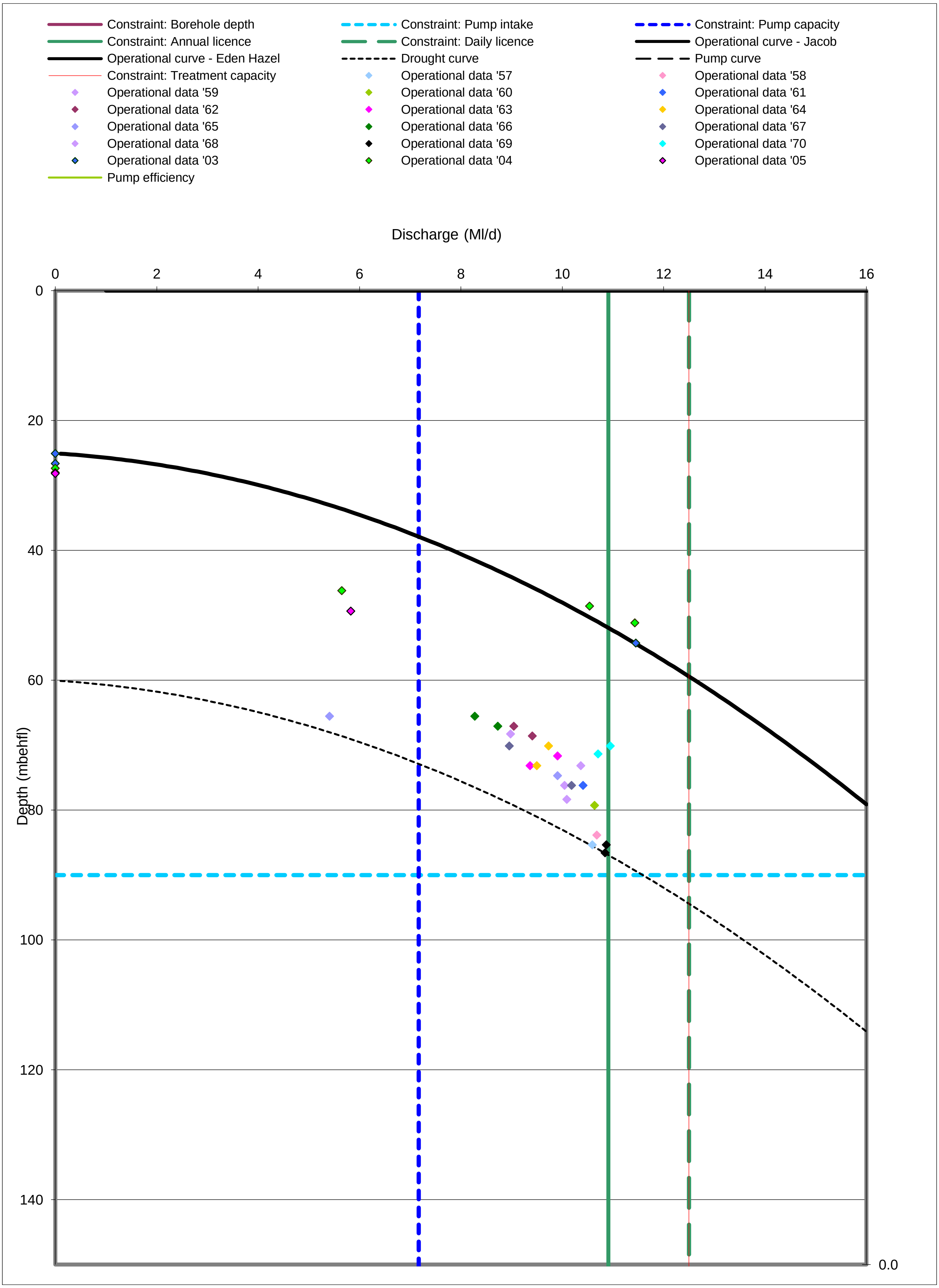
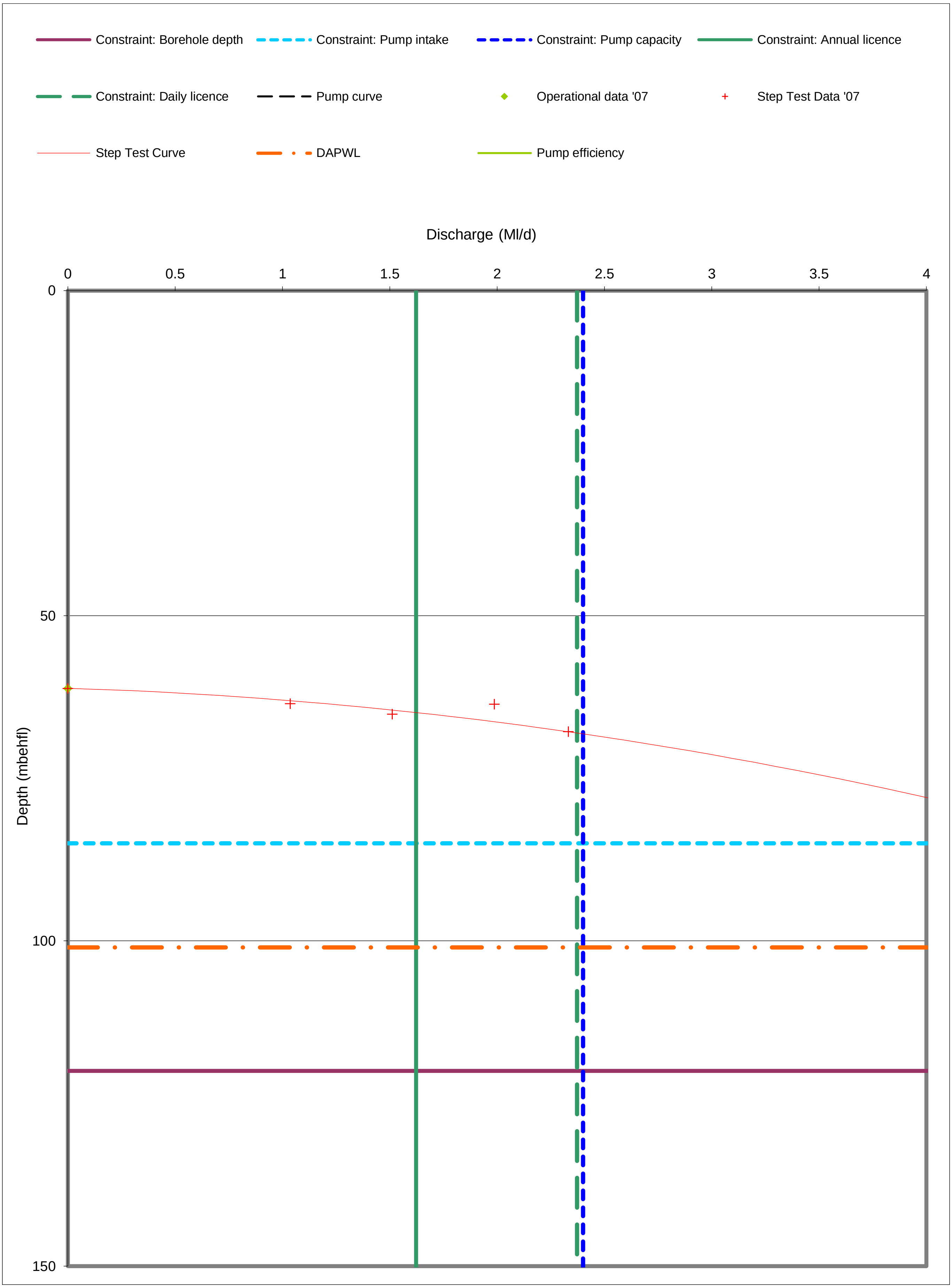


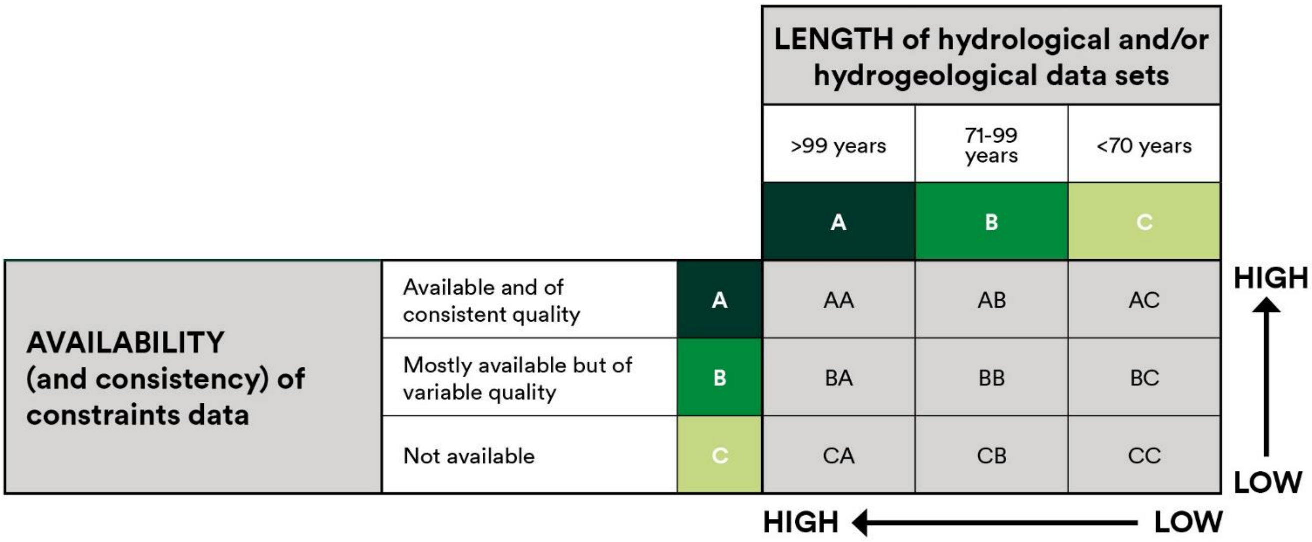
Figure 8 Source reliable output diagram for a groundwater source in the North Eden Resource Zone



Calculate deployable output with a confidence label (STEP 4)

UKWIR (2012), Section 5.3 pertains to the allocation of confidence labelling for deployable output assessment, using the matrix provided in Figure 9.

Figure 9 UKWIR confidence labelling for deployable output matrix.



			LENGTH of hydrological and/or hydrogeological data sets		
			>99 years	71-99 years	<70 years
			A	B	C
AVAILABILITY (and consistency) of constraints data	Available and of consistent quality	A	AA	AB	AC
	Mostly available but of variable quality	B	BA	BB	BC
	Not available	C	CA	CB	CC

The document states that the validity of deployable output assessments is related to the length of records used in deployable output calculations. However, for reasons already discussed in previous sections, hindcasting of groundwater levels in order to verify deployable output values is not considered of significant additional value. Given that our deployable output assessments are influenced by asset constraints, it has been decided to apply a single confidence grade to the entire population of groundwater sources rather than for each individual source. This seems a pragmatic approach to take given the lack of sensitivity of the groundwater sources to changes in deployable output in relation to water level, as demonstrated by the forecast changes in deployable output due to climate change.

Therefore, using the above matrix, the confidence label allocated for the entire groundwater source population deployable output is AC. This indicates that the hydrogeological data sets used are in the majority of cases <70 years but that the availability and consistency of data is good. It is acknowledged that the data for some groundwater sources are of variable quality, but it is important to recognise that this does not indicate a lack of confidence in the overall assessment of deployable output, particularly in the light of sensitivity checks. Following the climate change analysis of groundwater deployable output which indicated no change to any individual source deployable output values, it has been concluded that the length of hydrogeological record is not significant and that the confidence label should be AA.

In conclusion, we are confident that our assessment of deployable output for each groundwater source is accurate and that the exact position of the confidence label on the above matrix does not influence the overall conclusions of deployable output that are fed into the water resources models.

Phase 3: Assessment of borehole groups under 1 in 500 events

The final phase of the groundwater yield review was to consider boreholes in the context of groups, supplying a downstream water treatment works and account for any treatment and network constraints.

This final review identified that the only reduction required to groundwater source to represent a 1 in 500 baseline yield, was a 0.3 Ml/d in peak deployable output at Franklaw B (Fylde group). All other sources are able to maintain the current downstream treatment capacities under both a 1 in 500 baseline and under climate change.

Functionality was added to our Hydro-Logic® Aquator water resources model to reduce the peak and average deployable output values for groundwater components in years considered to have a 1 in 250-year system response or greater (i.e. more severe). The change in groundwater deployable output values is triggered from an annual time series of return periods added to the model and matched to each stochastic replicate for each climate change scenario. These return periods were calculated from model runs of our Pywr model, with the perturbed flow inputs for each scenario, and a strategic regional storage metric was used to identify the return period of each stochastic year.

Testing with and without a 0.3 Ml/d climate change impact on the DO of the Aquator component representing Franklaw B boreholes was completed prior to this reduction being confirmed as a baseline change. The modelling resulted in no overall impact on system deployable output due to other system constraints meaning the borehole did not operate at peak, because other sources were prioritised on the basis of resource state, in this instance Whitebull reservoir.

4.3.4 Asset constraints and licences

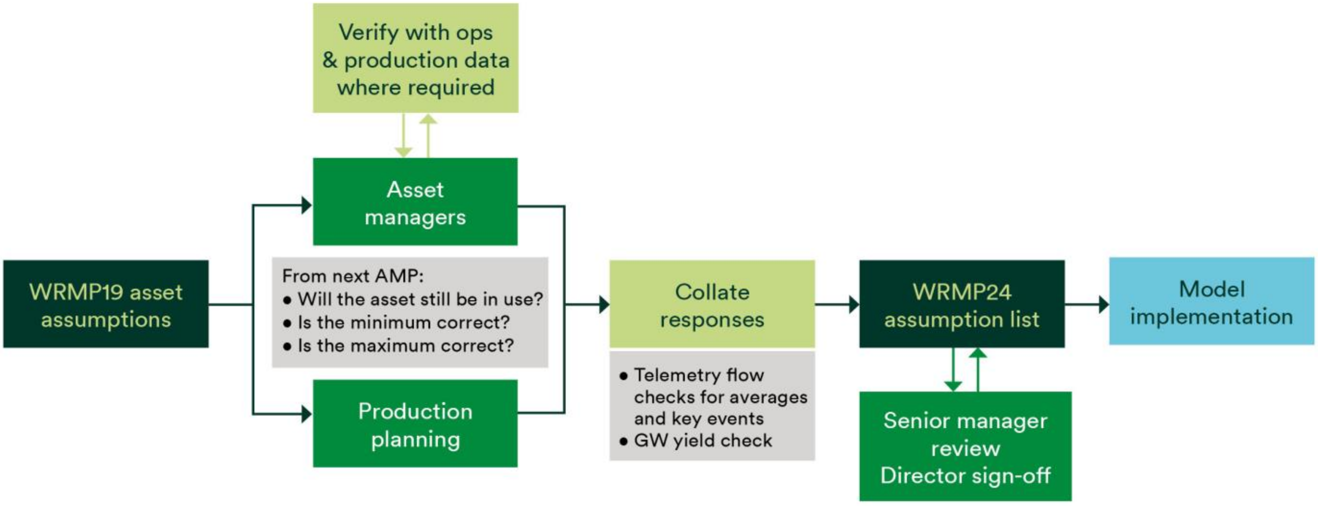
In deriving asset capability for this WRMP we completed a thorough review of our asset base and licences to ensure that DO calculations account for these constraints. In some instances these have been undertaken as part of sub-assessments (e.g. the groundwater review) and in others they are included within our resource zone models (where relevant) to ensure robust simulation.

The asset capability in this WRMP accounts for:

- AMP8. Our approach for WRMP24 is that assets should reflect available capability at the beginning of the planning horizon (April 2025, start of AMP8). This is the same principle applied for our previous plan (WRMP19); and
- 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).

The process to collate asset capability follows on from the previous planning round. The WRMP19 asset capabilities were used as a starting point, with any deviation away from these values being justified and signed off within the business. The asset assumptions for WRMP24 have been reviewed with Asset Managers, Area Production Managers and Area Business Managers. The process followed to derive asset capability for WRMP24 is shown in Figure 10.

Figure 10 Process followed to determine WRMP24 asset capability



Daily and annual licenced volumes are represented in our deployable output assessments in either our water resource models or supply assessment. We also reflect other licence conditions, such as 'hands-off flows', and we assume that provided the conditions of the licences are represented (and adhered to on our models) they are sustainable and that their use will not cause deterioration.

We have 38 individual time-limited licences across the region with expiry dates ranging between 2022 and 2037, the majority of these located in the Strategic Resource Zone. All newly granted licences are time limited. The main change since our WRMP19 has been the update to the Thirlmere licence to accommodate the West Cumbria transfer by increasing abstraction allowed at Bridge End (noting that the overall daily and annual abstraction limit on Thirlmere is unchanged). We also have a new Section 20 agreement for Habitats Regulations mitigation for the revised licence and the releases that we make from Thirlmere for the purposes of providing additional flood storage. The Section 20 includes provision of flow releases from Thirlmere to introduce some flow variability and implementing habitat improvements in the river channel downstream (delivered by a third-party project officer). The mitigation Section 20 expires on 31 March 2026 (coinciding with the expiry of the time limit on the Thirlmere abstraction licences).

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). For our draft WRMP24, we had no indication from the Environment Agency that any of our time limited licences were environmentally damaging and assumed that they would be renewed on a like-for-like basis. From dialogue to date, we consider that the draft WRMP24 position of assumed renewal is appropriate to all abstraction licences and thus no additional allowance is needed in the WRMP24 submission in this regard. We understand the policy that the Environment Agency cannot guarantee licence renewals on a like for like basis as new information regarding environmental impacts can come to light, however for our existing sources, the risk of a renewal not being granted is low.

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 1.83 Ml/d (5.4% of 1 in 500 baseline deployable output).

4.3.5 Water quality

As mentioned in the previous section our assessment of asset capabilities accounts for the minimum and maximum flow values that can be sustained in a dry event. Detail of how water quality uncertainty has been applied in our target headroom allowance can be found in our *WRMP24 Technical Report – Allowing for uncertainty.*

4.3.6 Reservoir compensation over-release

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. We are working on improving the accuracy of measuring releases and reducing the overall volume released, so that we minimise the amount of water unnecessarily released from our reservoirs during dry weather. Where appropriate, and since our 2015 plan, we have accounted for compensation over-releases in our deployable output assessments to reflect this additional 'lost' water. WRMP19 marked an improvement in the application of these losses by accounting for them directly in our models. For WRMP24 we have retained and refined this approach further. Since the development of our previous Water Resources Management Plan, we have experienced dry events in 2018, 2020 and 2021. Following the dry event of 2020, we added more telemetry points in our region at sites that were previously unmonitored to improve our understanding around the releases made. Analysis is now based on examining data series from 60 different monitoring points, compared to 28 points in our last plan. Data gathered during dry events has helped to refine the assumptions around compensation over-releases that were included in our WRMP19, to improve our understanding of the amounts over-released during dry weather.

The analysis comprised data from April to September for the years 2018, 2020 and 2021; representing periods where compensation was finely managed due to dry weather. In addition, the use of dry year release data can produce more accurate calculations that could stand up to scrutiny from a statistical perspective. Statistical analysis was used to identify outliers where there was a significant difference to the summer release values. In these instances it prompted further investigation and erroneous data was discounted from the analysis.

The results indicate a total daily over release of 34.26 Ml/d across all reservoirs (noting that reservoirs in our region that are compensation only and not used for public water supply are excluded from this analysis and also from our supply forecasts). Importantly, the individual compensation over release for summer 2018 (33.76 Ml/d), summer 2020 (35.39 Ml/d) and summer 2021 (39.42 Ml/d) are similar in magnitude.

4.3.7 Losses

Our approach for assessing the impact of losses has been improved for WRMP24. We have included them in our water resource models directly, and in doing so the impact is accounted for in the areas of the system where the water treatment works are located to promote realistic model behaviour. The DO values output from the water resources models are therefore inclusive of the impact of losses. However, in order to make sure we don't double count this impact when calculating WAFU (own sources), the losses impact is added back onto modelled DO.

More information on how our losses have been calculated is included in Section 10. We have also used sensitivity testing around our loss values to inform the calculation of our target headroom allowance, for more information please see our *WRMP24 Technical Report – Allowing for uncertainty*.

4.3.8 Reservoir dead water volume

Initially, in AMP3-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 WRMP24 all dead water values have been checked for consistency and updated where appropriate, for example where new bathymetry data has been produced. As reported in our Drought Plan 2022 we have revised the Haweswater dead water assumption from 12,386 Ml gross storage to 2,885 Ml.

We are planning to undertake several reservoir bathymetry surveys during 2025-2030 and these will be used to update our reservoir storage and dead water volumes for WRMP29.

Note that emergency storage is no longer used in our water resources management plan due to the move away from English and Welsh DO to system response.

4.3.9 Drought levels and control curves

The drought levels included in our models align to those introduced in our Final Drought Plan 2022. These assumptions mark a change from our previous water resources management plan due to the changes in government guidance, recent dry weather experience and more sophisticated modelling techniques that were used in producing our Drought Plan. When setting the drought levels, we considered the likelihood of crossing drought levels and the time each drought level would need to be in place before we took drought management actions. The timescales were calculated using historic and stochastic data sets to maximise resilience and confidence in the new drought levels.

4.3.10 Levels of service

Our current minimum levels of service for water supply are outlined in Table 8. They apply throughout the region and cover both statutory water use restrictions (known as temporary use bans or TUBs, and formerly known as hosepipe bans), drought permits and drought orders. They are typically implemented at resource zone level, based on the zone's resource position relative to our drought levels. More information about our drought measures and levels is provided in our Drought Plan, and the estimated benefits are presented in Section 12. The Drought Plan also outlines our assumptions around the implementation of restrictions, for example:

- TUBs are not implemented during winter because there is very limited use of hosepipes and paddling pools then; and
- We assume that restrictions would not be implemented for a period of five days or less. We can reliably forecast rainfall within a five-day window, and, therefore, predict when restrictions are unnecessary, i.e. that we will only remain below the respective drought level for a few days.

As introduced in Section 4.1.1, despite the widely publicised move to 1 in 500-year resilience for emergency drought orders (EDO), all levels of service are applied within our deployable output calculation. This is the WRMP mechanism by which we ensure we can meet our levels of service in the future. In the decision making process we simultaneously solve separate supply demand balances for each level of service (Section 3.2.1.1 in the *WRMP24 Technical report – Deciding on Future Options*). These are then combined into single supply demand balances, sometimes with different levels of service defining supply at different times. For example, excluding the benefits of drought measures, during 2025-39 the 1 in 200-year EDO levels of service is more constraining, in terms of the level of demand we can meet, than the 1 in 20-year TUBs level of service, and it therefore defines supply. From 2040, however, we move to a 1 in 500-year level of service for EDO. This is more constraining than 1 in 20 TUBs in our baseline supply-demand balance, hence becomes the defining metric.

Table 8 Current minimum Levels of Service

Restriction/measure	Type	Minimum level of service	
		Return period	Annual chance
Temporary use ban	Water use restriction	1 in 20 years	5%
Drought permit	Permit	1 in 40 years	2.5%
Non-essential use ban	Drought order	1 in 80 years	1.25%
Emergency drought order	Drought order	1 in 200 years	0.5%

4.4 Summary of baseline deployable output for our 2024 plan

Table 9 shows the summary of deployable output resulting from detailed assessment, which is based on the approach and assumptions set out in Section 4. More detail on the changes between our 2019 and 2024 plans (reflecting changes to baseline deployable output prior to any sustainability reductions or reductions due to climate change impacts etc.) can be found in Section 4.5.

The Water Resources Planning Guideline (Environment Agency, 2021) states that we should clearly explain which factors constrain deployable output; this is included in Table 9. The benefits of drought measures (e.g. drought permits and Temporary Use Bans) are not included in the baseline deployable output assessment, and are assessed separately; these are also included in Table 9.

Table 9 Summary of baseline deployable output for the 2024 plan

	2025/26		2049/50		
Resource Zone	Baseline deployable output at (Ml/d)	Benefits of drought measures (Ml/d)	Baseline deployable output at (Ml/d)	Benefits of drought measures (Ml/d)	Constraint on deployable output
Strategic	2006[6]	+106	1901	+136	Drought magnitude and frequency 2025-2038 1 in 200 LoS[7] 2039-2050 1 in 500 LoS

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[6] Excludes losses impact

[7] Level of Service (LoS)

	2025/26		2049/50		
Resource Zone	**Baseline deployable output at (Ml/d)**	**Benefits of drought measures (Ml/d)**	**Baseline deployable output at (Ml/d)**	**Benefits of drought measures (Ml/d)**	**Constraint on deployable output**
Carlisle (DYAA)	35.5[8]	+2.3	34.5	+2.1	Drought magnitude and frequency 2025-2038 1 in 200 LoS 2039-2050 1 in 500 LoS
Carlisle (DYCP)	39.5	+2.3	39.5	+2.1	Asset maximum capacity
North Eden	8.0	3.4	8.0	3.4	Asset capacities and abstraction licence limits
Barepot	34.1	N/A	34.1	N/A	Abstraction licence limits

The Water Resources 1 in 500 Supplementary Planning Guideline (Environment Agency, 2021) states that the 1 in 500 drought resilience standard should be achieved as early as possible, or by 2039 at the latest. Until 1 in 500 resilience is achieved, we are required to plan to a minimum of 1 in 200 level of resilience (in other words a 1 in 200 level of service). It is also important that existing levels of service for TUBs for example are maintained.

Taking into consideration existing level of service commitments and the differing levels of drought resilience required across the planning horizon, means that for some resource zones, there are different baseline deployable outputs depending on which level of service/drought resilience standard is the overall constraint for a particular period. Sections 4.4.1 to 4.4.4 outline the key constraints on baseline deployable output for each resource zone.

4.4.1 Strategic Resource Zone

The Strategic Resource Zone baseline DO is constrained by drought magnitude and frequency. At the start of the planning horizon in 2025, in the baseline, DO is constrained by 1 in 200 drought resilience. Our calculated 1 in 20 TUBs DO is higher than our 1 in 200, meaning we have 1 in 200 drought resilience, while also maintaining our commitment to not implement TUBs more than 1 in 20 years on average. Our calculated 1 in 500 DO was lower than both the TUBs and 1 in 200 DO, so from 2039 this level of service constrains our DO, and all other levels of service are met. As a consequence of DO varying across the planning horizon, the benefits of drought measures also vary. In 2025, when 1 in 200 drought resilience constrains DO, implementation of drought measures yields a 106 Ml/d benefit. From 2039, when 1 in 500 drought resilience becomes the constraint on DO, the benefit of drought measures increases to 136 Ml/d. The DO benefits of drought measures are a function of the scale of the drought measure (e.g. 5% demand saving from a Non-essential use ban, NEUB) and the length of time the measure is implemented for. As more drought measures are implemented, the benefit to DO increases. This is why the total benefit for 1 in 500 year events is greater than the 1 in 200.

4.4.2 Carlisle Resource Zone

The Carlisle DYAA baseline DO is also constrained by drought magnitude and frequency. Between 2025 and 2050 DO is constrained by 1 in 500 drought resilience (as it is the lowest DO of all those calculated for each level of service). However, we have chosen to adopt the 1 in 200 DO as the baseline DO between 2025 and 2038, and 1 in 500 DO from 2039 in order to keep levels of service in line with the Strategic Resource Zone. As such, the benefits of drought measures vary across the planning period as a result of varying baseline DO.

For the Carlisle Dry Year Critical Period scenario, the baseline deployable output is constrained by asset maximum capacity and not by drought magnitude or frequency, therefore, baseline DO and drought measure benefits are

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[8] Excludes losses impact

static values for the entire planning horizon; 2025-2050 and is the maximum supply available in a peak demand week.

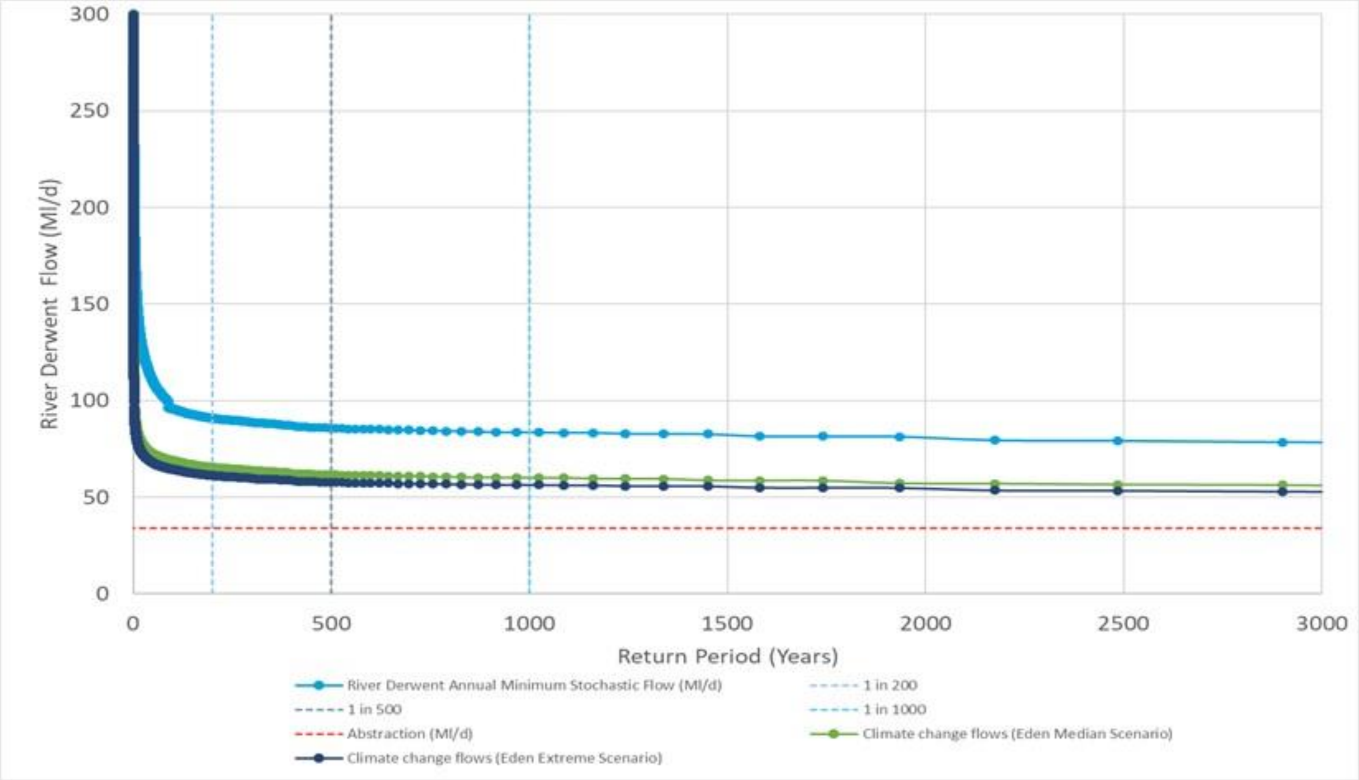
4.4.3 North Eden Resource Zone

The North Eden Resource Zone baseline DO is constrained by asset capacities and abstraction licences and is, therefore, a static value for the planning horizon; 2025-2050, along with drought measure benefits. The baseline DO is a 1 in 500 DO determined by the climate change assessment, which identified minimal impact of climate change on groundwater yields.

4.4.4 Barepot Resource Zone

For our latest Drought Plan we analysed a flow duration curve with the impacts of climate change for the River Derwent to confirm that there is no plausible drought risk in this zone (the zone was screened out of our drought vulnerability framework assessment on this basis). The flow duration curve shown in Figure 11 is a way to visualise the full spectrum of river flow at the Barepot intake on the River Derwent in Workington (the sole abstraction in this RZ). Even when combining the most severe events in the stochastic record (a return period of up to 1 in 3,000 years is shown here) with extreme climate change flow factors, flow remains well above the required abstraction amount.

Figure 11 River Derwent Flow Duration Curve also showing the impacts of climate change



The Barepot Resource Zone DO is, therefore, constrained by the River Derwent abstraction licence and is a minimum of 1 in 500 DO for 2025 to 2050. There is no drought measure for this resource zone.

4.4.5 Extreme drought events

For this plan, in line with regulatory guidelines, we have assessed how resilient our supply systems are to a 1 in 500-year drought (0.2 per cent annual chance of occurrence), using stochastic data series to simulate plausible droughts more severe than those experienced in our historic record. Our stochastic hydrological dataset is 19,200 years in length, and was produced by a weather generator. This provides a large range of plausible droughts, including many with a severity worse that 1 in 500 years, against which our system is tested to calculate reliable system response-based deployable outputs. Through these assessments, and for those resource zones with a water resources model, we have an understanding of the relationship between deployable output and return period. The results in Table 10 show the impacts of a 1 in 1000-year event (0.01% annual chance of occurrence).

Note that for our North Eden and Barepot resource zones the deployable output is constrained by asset capacities and abstraction licences, as described in the previous sections (4.4.3 and 4.4.4).

Table 10 Deployable output impact of a 1 in 1000-year event

	1 in 500 Emergency Drought Order DO (Ml/d)	1 in 1000 Emergency Drought Order DO (Ml/d)	Impact (Ml/d)
Strategic Resource Zone	1901	1860	-41
Carlisle Resource Zone	33.64	33.18	-0.47

*Numbers may not sum due to rounding

4.5 Development of deployable output since our 2019 plan

Our WRMP24 deployable output assessment is a markedly different evaluation of resource zone supply capability compared to those undertaken for previous WRMPs. In accordance with the latest water resources planning guideline (Environment Agency, 2021), deployable output is now calculated as the maximum supply available, such that Emergency Drought Orders (EDO) are implemented (when sources reach dead water level) no more frequently than 1 in every 500 years (in other words there is an 0.2% annual chance of implementing EDOs), while also ensuring resilience to all our other levels of service. Previously, DO assessments represented the maximum supply available during a repeat of the worst historic drought on record, defined by key sources reaching emergency storage level. This determined the Temporary Use Ban (TUB) level of service as 1 in every 20 years. Therefore, the major difference in assessments of deployable output between plans, is that they represent different drought resilience standards; each calculated with different methodologies, input data and tools. Table 11 provides details of the change in deployable output for each resource zone from our 2019 plan.

Table 11 High level breakdown of changes in deployable output from the 2019 plan to the baseline for our 2024 plan (excludes benefits from supply measures and demand restrictions)

	Strategic Resource Zone (deployable output Ml/d)		Carlisle Resource Zone DYAA (deployable output Ml/d)		Carlisle Resource Zone DYCP (deployable output Ml/d)	North Eden Resource Zone (deployable output Ml/d)	Barepot Resource Zone (deployable output Ml/d)
	1 in 20	1 in 500[9]	Historic[10]	1 in 500			
WRMP19	2073[11]		35.9		35.9	9.0	34.1
Model development activities	+51		-0.1		N/A	N/A	N/A
WRMP24 data refresh	-112		-0.6		N/A	-1	N/A

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[9] WRMP19 used either system failure at reaching emergency storage, or a breach of level of service to define DO. Data is populated is for the equivalent measure of 1 in 20 TUBs implementation tracing through WRMP19 to WRMP24. The corresponding baseline WRMP24 DO is a 1 in 500 EDO event as the new drought resilience standard for WRMP24.

[10] WRMP19 baseline DO was defined by Castle Carrock reservoir reaching emergency storage in 1976, rather than the 1 in 20 TUBs level of service. The TUBs level of service was greater than 1 in 20 for this resource zone.

[11] WRMP19 baseline DO was 2,112 Ml/d, which included the benefit of demand savings. This value excludes all drought measures and is from WRMP19 Final Planning Table 10. WRMP19 DO is based on English and Welsh assessment using historic hydrology. WRMP24 DO uses stochastic hydrology but is based on the same 1 in 20 TUBs level of service.

	Strategic Resource Zone (deployable output Ml/d)		Carlisle Resource Zone DYAA (deployable output Ml/d)		Carlisle Resource Zone DYCP (deployable output Ml/d)	North Eden Resource Zone (deployable output Ml/d)	Barepot Resource Zone (deployable output Ml/d)
	1 in 20	**1 in 500[9]**	**Historic[10]**	**1 in 500**			
Change in methodology	-68		-0.2		-0.4	N/A	N/A
WRMP24	1944	1799	35.0	34.5	39.5	8.0	34.1
Change from our 2019 plan	-6.2 %	N/A	-2.5 %	N/A	+10 %	-11 %	0%

It should be recognised that while we have tracked and audited model changes between and during the planning rounds 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 as the net change of multiple isolated developments using the three categories stated; model development activities; WRMP24 data refresh; and change in methodology.

As mentioned above, at WRMP19 the assessment of DO was based on reservoir levels reaching emergency storage while ensuring that we maintained our agreed levels of service (for instance TUBs implementation no more than once in 20 years on average). While we used stochastic inflows to stress test our WRMP19 plan, the DO assessment was based on our historic inflows which were between 55 and 88 years in length. This approach, following the guidance in place at the time, meant that the design drought was limited to one event – the worst in our historic record. As mentioned in Section 4.3.1, using our stochastic inflows of 19,200 years for WRMP24 marks a significant step change in the robustness of our DO assessment. The large datasets of stochastically generated flows provide greater confidence in our risk-based analyses of the water supply system through the analysis of return periods and different drought events. We have developed our models to be optimal across the wider range of drought severities, and in doing so we test the system behaviour in a greater range of events. This means that from WRMP19, as expected, DO has changed as we move from models conditioned to perform well during the worst historic defined event, to models that are optimised and maintain our levels of service during a wider range of more severe events. This is combined with a new drought resilience standard WRMP24, requiring companies to plan to be resilient to more severe droughts (1 in 500-year return period, or 0.2% annual chance, for implementation of Emergency Drought Orders) than those that may have been experienced in the historic observed hydrological period (e.g. 1927-present for the Strategic Resource Zone). The new drought resilience standard plus stochastic dataset have been substantial in the change in DO that we see from WRMP19 to WRMP24.

4.6 Emergency storage

As detailed in Section 4.5, emergency storage played a crucial role in the DO assessment for previous WRMPs. By maintaining an emergency storage allocation of 20 days in the Strategic Resource Zone and 30 days in the other resource zones, our planning anticipated droughts of longer duration and greater severity than any historically recorded.

For WRMP24, we transitioned to a synthetic stochastic hydrological dataset, which includes a variety of severe droughts. This shift aligns with the new 1 in 500-year resilience standard and the system response DO method. According to EA planning guidance, the failure point should correspond to the implementation of Level 4 restrictions or emergency drought orders, such as standpipes or rota cuts. The actual implementation point, to be determined by the company and subject to Board approval, was set at the dead water storage level. This decision reflects the severity of the droughts in our hydrological sequences and the interconnected nature of our supply system, which benefits from substantial reservoir storage across North West England and North Wales. In our water resources models, we adopted a very conservative approach: if any reservoir node reached dead water storage, it triggered a resource-zone level failure, even though only a portion of customers would experience Level 4 restrictions.

The EA provided feedback on our draft and revised draft WRMPs, advising us to reinstate emergency storage as the failure point. In response, we collaborated with the EA to clarify our approach and demonstrate how it ensures customer resilience. Working closely with the EA, as well as representatives from Ofwat and Defra, we were able to directly address the feedback received and reach a resolution by:

1. Demonstrating that our approach offers 1 in 500-year resilience for customers.
2. Defining an operational threshold to begin preparations for Level 4 restrictions.
3. Completing scenario analysis to demonstrate the implications of reintroducing emergency storage.
4. Committing to develop area emergency response plans.

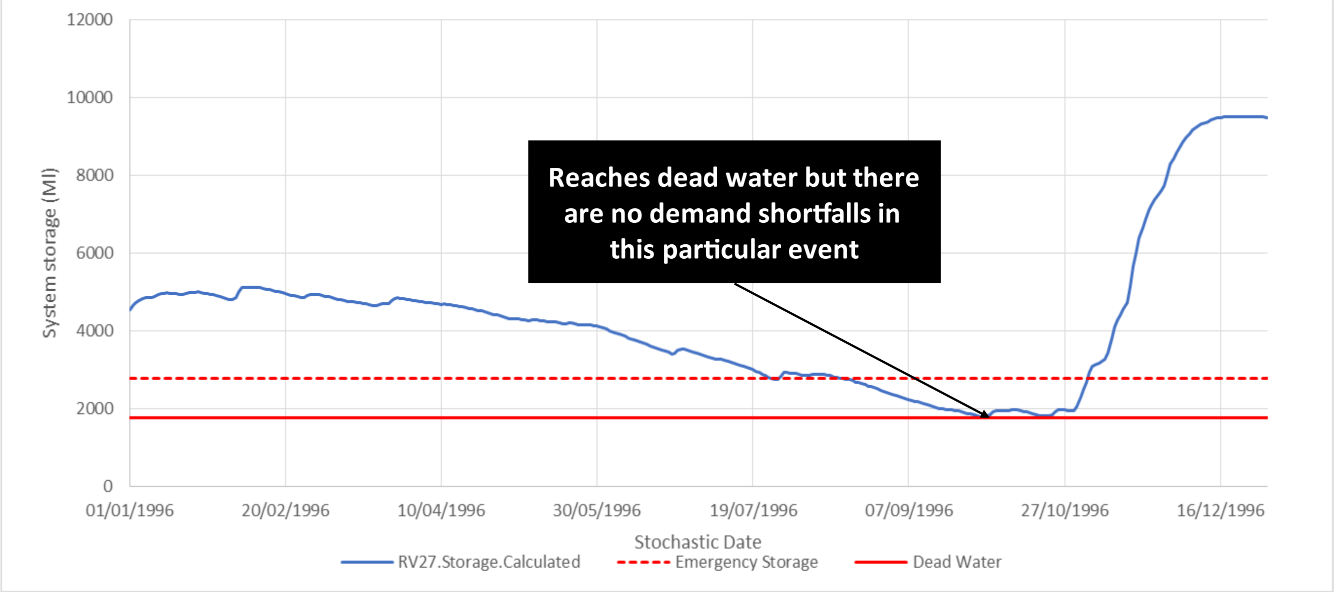
4.6.1 Demonstrating our 1 in 500-year resilience

This section provides a summary of the key points reviewed with the EA whilst demonstrating our 1 in 500-year resilience. Figure 12 illustrates the failure that defines our 1 in 500-year DO. This failure occurs at the Wybersley impounding reservoir group, reaching dead water without necessitating supply via standpipes or rota cuts. This outcome is due to two factors stipulated by the EA guidance: (i) the failure point being set at the implementation of emergency restrictions and (ii) the system response DO approach. When assessing DO using this approach, the model identifies the lowest incremental level of demand that causes a failure. As a result, at the DO level of demand storage recovers before supply via standpipes or rota cuts is required.

At the point of failure, there is still storage available at other reservoirs, as shown in Table 12. Although our supply system is highly interconnected, network constraints inherent in all conjunctive supply systems prevent us from perfectly balancing supplies. Presenting failure in terms of total aggregated storage is an approach often used by water companies with significant reservoir storage. Figure 13 offers this alternative perspective, demonstrating that, based on this approach, we still have a 20-day emergency storage allocation. In other words, during a 1 in 500-year drought event, total aggregated storage does not fall below the total emergency storage level. We believe the approach we have taken offers a more robust and transparent view of the drought resilience of our complex supply system.

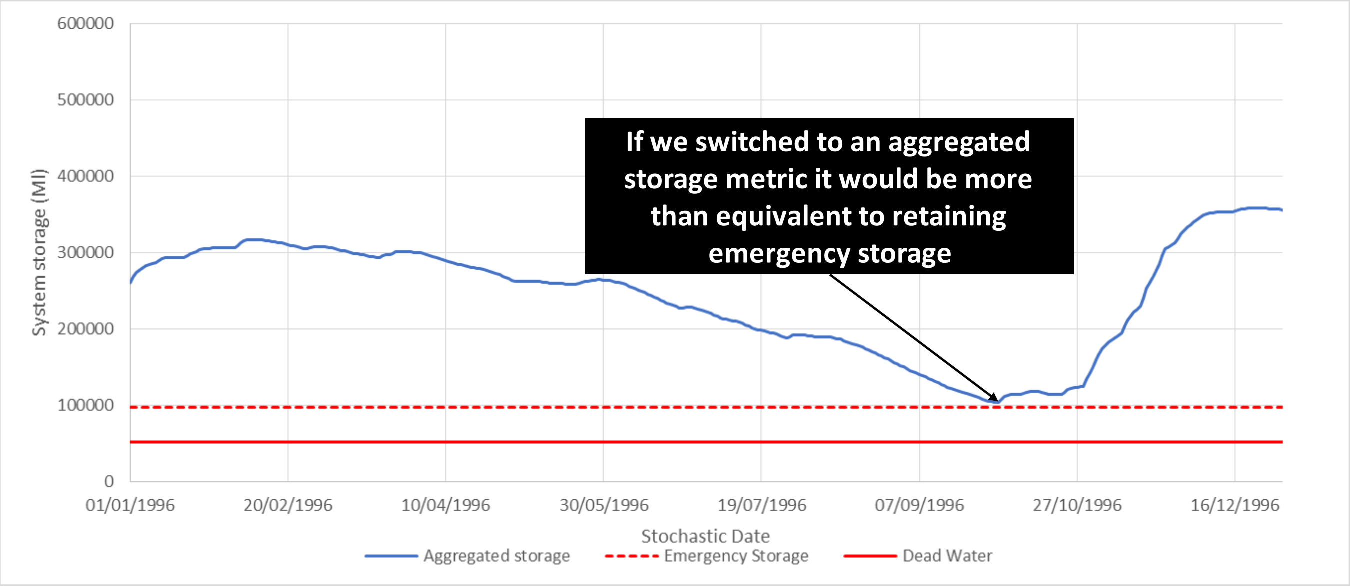
Unlike other restrictions like, for example, TUBs we would not implement emergency restrictions across the whole resource zone unless it was absolutely necessary. This means that while the annual risk of emergency restrictions occurring somewhere in the resource zone is 1 in 500, the risk for each individual customer is lower. Table 13 presents the risk of emergency restrictions being triggered by reservoirs in different parts of the Strategic Resource Zone.

Figure 12 1 in 500-year failure at Wybersley impounding reservoir group



Reaches dead water but there are no demand shortfalls in this particular event

Figure 13 1 in 500-year failure through the lens of total system storage



If we switched to an aggregated storage metric it would be more than equivalent to retaining emergency storage

Table 12 Storage remaining in each location at point of failure in the 1 in 500 year drought event

Source	**Remaining useable storage at point of failure in the 1 in 500 year drought event (Ml)**	**Percentage gross storage (%)**
[✂]	7346	8.7
[✂]	13123	21.1
[✂]	2238	4.0
[✂]	23914	16.8
[✂]	234	1.9
[✂]	66	1.4
[✂]	117	2.1
[✂]	20	2.5

Source	Remaining useable storage at point of failure in the 1 in 500 year drought event (Ml)	Percentage gross storage (%)
[✂ [redacted]]	66	4.6
[✂ [redacted]]	97	1.7
[✂ [redacted]]	408	3.0
[✂ [redacted]]	583	5.4
[✂ [redacted]]	164	1.5
[✂ [redacted]]	273	2.9
[✂ [redacted]]	1615	6.4
[✂ [redacted]]	375	2.3
[✂ [redacted]]	1109	29.3
[✂ [redacted]]	32	2.3
[✂ [redacted]]	956	44.6
[✂ [redacted]]	0	0.0
[✂ [redacted]]	10	0.3
Total	52747	10.9

Table 13 Simulated risk of Level 4 restrictions at each location

Source	Return period of Level 4 restrictions (years)	Total number of failures across all events
[✂ [redacted]]	1 in 1477	13
[[redacted]]	1 in 2400	8
[✂ [redacted]]	1 in 914	21
[✂ [redacted]]	1 in 914	21
[✂ [redacted]]	1 in 1129	17
[✂ [redacted]]	1 in 1371	14
[✂ [redacted]]	1 in 9600	2
[✂ [redacted]]	1 in 1011	19
[✂ [redacted]]	1 in 1371	14
[✂ [redacted]]	1 in 1745	11
[✂ [redacted]]	1 in 2133	9
[✂ [redacted]]	1 in 1011	19
[✂ [redacted]]	1 in 1200	16
[✂ [redacted]]	1 in 2133	9
[✂ [redacted]]	1 in 835	23
[✂ [redacted]]	1 in 1011	19
[✂ [redacted]]	1 in 1600	12
[✂ [redacted]]	Better than 1 in 19200	0

Source	Return period of Level 4 restrictions (years)	Total number of failures across all events
[✄]	Better than 1 in 19200	0
[✄]	1 in 873	22
[✄]	1 in 960	20

4.6.2 Operational threshold for Level 4 preparations

We will maintain the implementation point for Level 4 restrictions at dead water storage. However, we have now introduced an operational threshold to initiate preparations for Level 4 restrictions. This threshold will be indicated on reservoir storage graphs for clarity. Currently, we have set this operational threshold at our previous emergency storage level, as illustrated for the Wybersley impounding reservoirs in Figure 12. This threshold will be a crucial element of our new emergency response plans (Section 4.6.4) and may be adjusted as these plans are further developed. We will collaborate with the Environment Agency during the production of the plans on the approach and assumptions, for example the operational threshold level.

Note that this operational threshold relates solely to Level 4 restrictions, which may be implemented only for certain customers in the resource zone (depending on the spatial extent of the drought). Customer restrictions associated with Levels 1 to 3 would be implemented across the whole resource zone, therefore are triggered only by the Haweswater and Dee drought levels.

4.6.3 Emergency storage scenario

We carried out scenario analysis to assess the effects of reintroducing emergency storage. Similar to other water companies that rely heavily on reservoir storage, we calculated an aggregated emergency storage value, indicated by the dashed red line in Figure 13.

We then ran our water resources model at the 1 in 500-year deployable output demand level. As shown in Figure 13, emergency storage was not breached, indicating that reintroducing system-level emergency storage has no impact on deployable output or the supply-demand balance. From a customer perspective, our method of implementing emergency restrictions at dead water for individual reservoirs provides a comparable level of resilience to maintaining an aggregated emergency storage allocation at the resource zone level and applying restrictions at that scale.

4.6.4 Emergency drought response plans

As outlined above, the EA guidance specifies the failure point for 1 in 500-year resilience as the implementation of Level 4 restrictions. While this means that supplying water via standpipes or rota cuts falls outside the scope of the WRMP (and has an expected annual risk of less than 1 in 500), it is still crucial to have identified the necessary actions to manage the situation should it arise.

Therefore, we have agreed with the Environment Agency that we will establish new emergency drought response plans for areas in our water network. These plans will be designed to offer a clear roadmap for action under extreme drought scenarios and aim to provide the ongoing protection of customer water supply and the environment beyond the action set out in our Drought Plan. By committing to these plans, we aim to reassure regulators, stakeholders, and customers that the necessary steps will be taken promptly and effectively.

For the development of these plans, we will prioritise the parts of our system with relatively lower resilience, noting that individually every customer has an annual risk of emergency restrictions better than 1 in 800. Table 13 gives an indication of the likely priority order for each area; the lower return period the higher the priority. We are collaborating closely with internal and external stakeholders on these plans. In particular, we are drawing from the experiences of [✄]. The final definition and contents of these plans is inherently dependent on the forthcoming guidance from the Environment Agency, which will be instrumental in shaping our approach. Workshops planned by the Environment Agency in winter 2024/25 will provide insight needed to refine our approach and align it to regulatory expectations. These workshops will also facilitate collaboration with other water companies and stakeholders, ensuring that our plan benefits from shared expertise and regional experiences.

Given the reliance on this forthcoming guidance, we have tentatively outlined key dates in the production of the first of the Emergency Drought Response Plans, subject to adjustment as necessary:

- **Autumn/Winter 2024:** Engage with industry stakeholders (including South West Water) through meetings and participate in workshops led by the Environment Agency.
- **Winter/Spring 2025:** Develop the outline methodology using Environment Agency guidance, prioritise critical areas.
- **Spring/Summer 2025:** Work with Local Resilience Forums (LRFs) and other relevant stakeholders to draft the initial plan.
- **Autumn 2025:** Review and refine the draft with feedback from stakeholders and regulators.
- **Spring 2026:** Finalise and submit the plan, followed by communication and training.
- **Post-March 2026:** Ongoing review and update of the plan with expansion to other areas.

While we have set a provisional delivery date of March 2026, it is important to recognise that this timeline is contingent upon the timely release of the Environment Agency's guidance. As such, we remain flexible and will adjust our programme as necessary to ensure that our Emergency Drought Response Plans are fully aligned with the latest regulatory standards.

We will develop the next update of the Drought Plan in parallel with the Emergency Drought Response Plans, and any relevant information will be shared between these plans to ensure a coherent response to any developing droughts.

4.7 Realistic supply modelling

In February 2024 we provided further information to regulators in support of our Statement of Response[12]. At the request of the Environment Agency we completed additional modelling to assess the implications of scenarios where there is a delay to the delivery of asset improvements. We include this information as part of our final supply forecast technical report.

4.7.1 Model parameters

The parameters in our modelling systems are based on realistic constraints. For each regulatory submission, including WRMP24, these parameters undergo a full update and comprehensive review. This entails compiling data from operational teams and conducting meticulous checks. Crucially, our models are tailored for WRMPs to simulate the future supply system, aligning with the start of the planning period, which is 2025 for WRMP24. With regards to ongoing capital projects aimed at increasing or restoring operational capacity for assets like the West East Link Main (WELM) and Lune-Wyre, we have factored these into our models. The following sections provide a detailed overview of the current status of these projects to address the request for additional reassurance around the realistic availability of modelled capacities.

4.7.2 Lune and Wyre project

The Lune and Wyre asset capacities have now been fully restored after experiencing an outage due to penstock issues. Both penstocks underwent refurbishment.

On 26 April 2023, site work commenced with setup, silt clearance, and the installation of access and health and safety infrastructure. The refurbishment of the north penstock started on 17 July 2023, and the south penstock on 15 August 2023. All on-site activities were successfully completed by 21 September 2023.

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[12] https://www.unitedutilities.com/globalassets/documents/corporate-documents/wrmp24_uu_further-information-in-support-of-statement-of-response_redacted.pdf

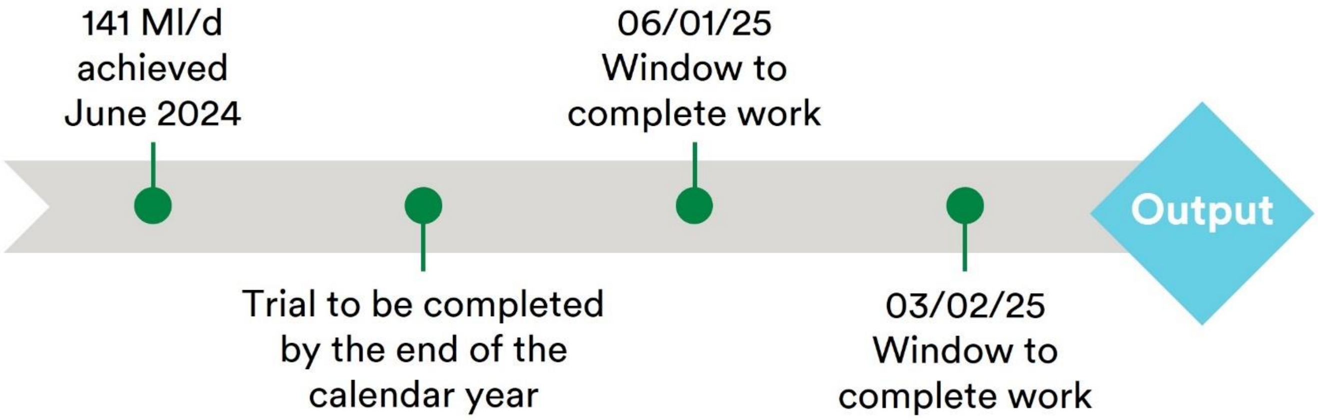
A technical assurance visit to the Lune-Wyre pumps and Water Treatment Works (WTW) A was conducted on 20 October 2023, with the participation of Environment Agency water resources and catchment colleagues. Our team addressed various technical inquiries related to asset performance and maintenance. Subsequently, on 19 December 2023, another session was held with the Environment Agency and one of our senior process engineers. This session focused on reviewing asset capacity and design, including presenting a modelled scenario demonstrating that both the pumping station and WTW can operate at their maximum output of 220 Ml/d when conditions require.

4.7.3 West-East Link Main (WELM) project

We are investing £8.8 million to enhance the resilience of our supply system by increasing the flow volume to 150 Ml/d through the WELM from WTW E to WTW G. The WELM 150 project includes upgrades to our chlorine dosing booster station at [✂], changes to pipework arrangements within WTW E, enhancements to power assets, installation of water quality monitoring instruments, and relevant software control modifications.

The commissioning phase of the project, initiated in November 2023, is underway (see Figure 14 below). While planned outage dates on the WELM are subject to water production requirements and regional availability, efforts will be made to minimise risks through regular outage requirement discussions. Outages are meticulously managed through our production planning team and production outage permit system, with plans made well in advance.

Figure 14 WELM Commissioning timeline



The commissioning program remains on track, with project completion in 2024/25. We achieved a proven output of 141 Ml/d in June 2024, with the next windows to complete work scheduled for Early January and February 2025. To demonstrate project completion and assure outputs, telemetry trend information will be used to show the WELM operating at flows of 150 Ml/d for approximately 24 hours, as measured by flowmeters at WTW E and WTW G.

During our session on 19 December 2023 with the EA, in addition to discussing the Lune-Wyre project, we shared details of the WELM 150 work to date, including the outages that occurred in November 2023 as part of the planned works.

We anticipate that the investment in WELM capacity will offer both dry weather and broader strategic benefits to our customers. For example, over the next 15-20 years, we have outlined a programme to increase the resilience of our Haweswater Aqueduct (HARP). The additional capacity provided by the WELM ensures our ability to meet customer demand during this period, contingent on water availability in the south area of the UUW region. Full capacities at WTW D and the aqueduct A are forecast to be restored by 2028, providing extra water to support demand during these outages. We will provide a regular update to the EA as part of our routine liaison meetings.

4.7.4 Ongoing communications around asset capability

Quarterly, we convene the dry weather planning and operational sub-group meeting, facilitating collaboration between UUW and the Environment Agency's water resources and hydrology colleagues. Discussions within this group inform the quarterly Environment Strategy Group (ESG) meeting. The sub-group meeting frequency is adjusted based on dry weather conditions. The standard agenda includes key outages planned for the financial year, reservoir drawdowns, dry weather response, operational matters, updates on compensation-only reservoirs, and any other relevant topics.

Our interaction with Environment Agency colleagues occurs face-to-face and during site visits to enhance mutual understanding of assets and their contributions to water resources in the northwest of England. For example, the February 2024 sub-group meeting incorporated a site visit showcasing our investments in increased resilience in the water resources supply system in Bowland. The visit encompassed a tour of the new filters at WTW B and the weir raising project at Stocks Reservoir for enhanced capacity.

4.7.5 Model realism

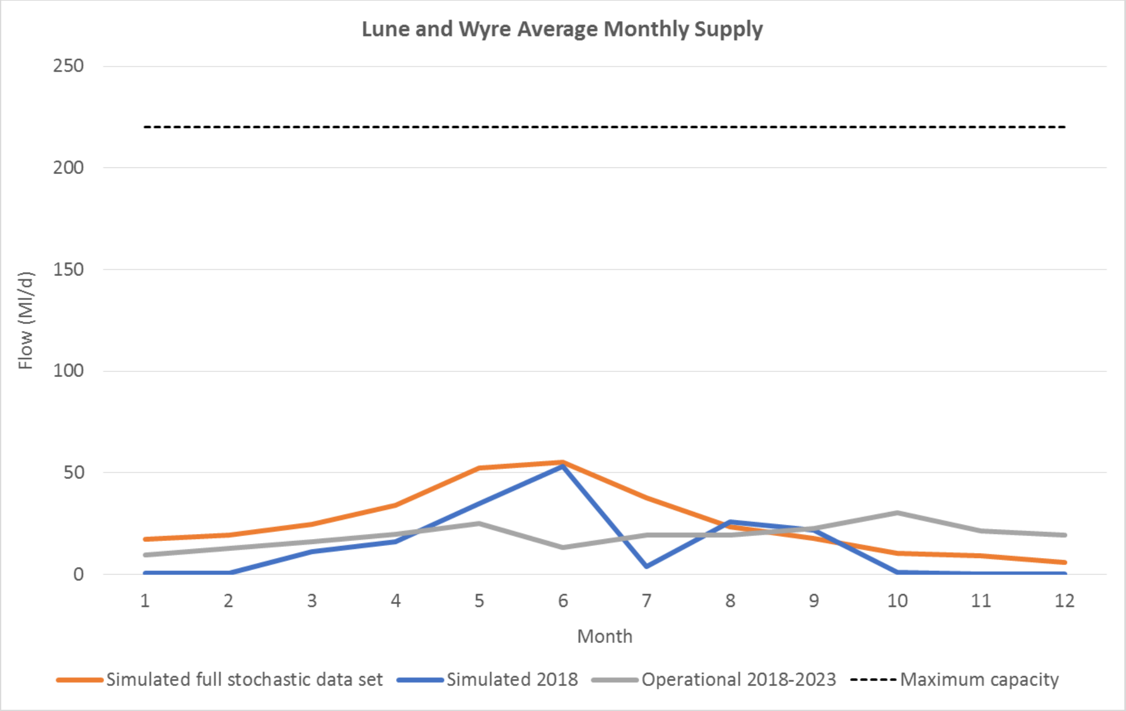
We incorporate various constraints into our models, with asset capacity being a significant factor. However, it is important to note that it is incorrect to equate asset capacity to available supply. Our models consider numerous other constraints, including raw water availability, abstraction licence conditions (with "hands-off-flows" on the Rivers Lune and Wyre), downstream network capacities, and spatially and temporally varying customer demands. Additionally, the models reflect real-life operational decisions, allocating daily abstraction to different sources based on their healthiness and cost. Consequently, few sources operate continuously at their maximum capacity.

The Lune and Wyre are components of the sources supplying WTW A, which includes boreholes, rivers, and reservoirs. The WELM serves as a bidirectional link that, during dry weather, provides a north-south balancing function. The flow direction and volume depend on prevailing supply-demand conditions at the time.

To illustrate how the Lune and Wyre sources are utilised in the model, we conducted new modelling focused on 2018, the most recent Dry Year for which we possess a complete hydrological dataset. This modelling assumed the full 220 Ml/d capacity was in place, aligning to the start of the WRMP24 planning period. Figure 15 presents combined Lune and Wyre average monthly supply for:

- A simulation of the full 19,200 year Water Resources West stochastic dataset using the WRMP24 model with the full 220 Ml/d capacity in place (orange line);
- A simulation of 2018, the latest year for which we currently hold hydrological data, with the full 220 Ml/d capacity in place (blue line); and
- Actual operational data for the period 2018-2023 (grey line).

Figure 15 Lune and Wyre simulated and operational supply



These results demonstrate that:

- The model does not routinely utilise the Lune and Wyre sources at high levels, due to the range of constraints outlined above. The orange line showing the simulation of the full stochastic dataset, with the maximum asset capacity in place, provides a much more appropriate benchmark against which to compare operational use than maximum asset capacity;
- Simulated use in winter is typically constrained by cost as the model can opt for cheaper reservoir sources that are healthy and, potentially, spilling;
- Once storage in these reservoirs starts to decline, use of the Lune and Wyre increases. However, dry year use can become constrained by the hands-off-flow conditions, particularly in July and August.

4.7.6 Scenario modelling

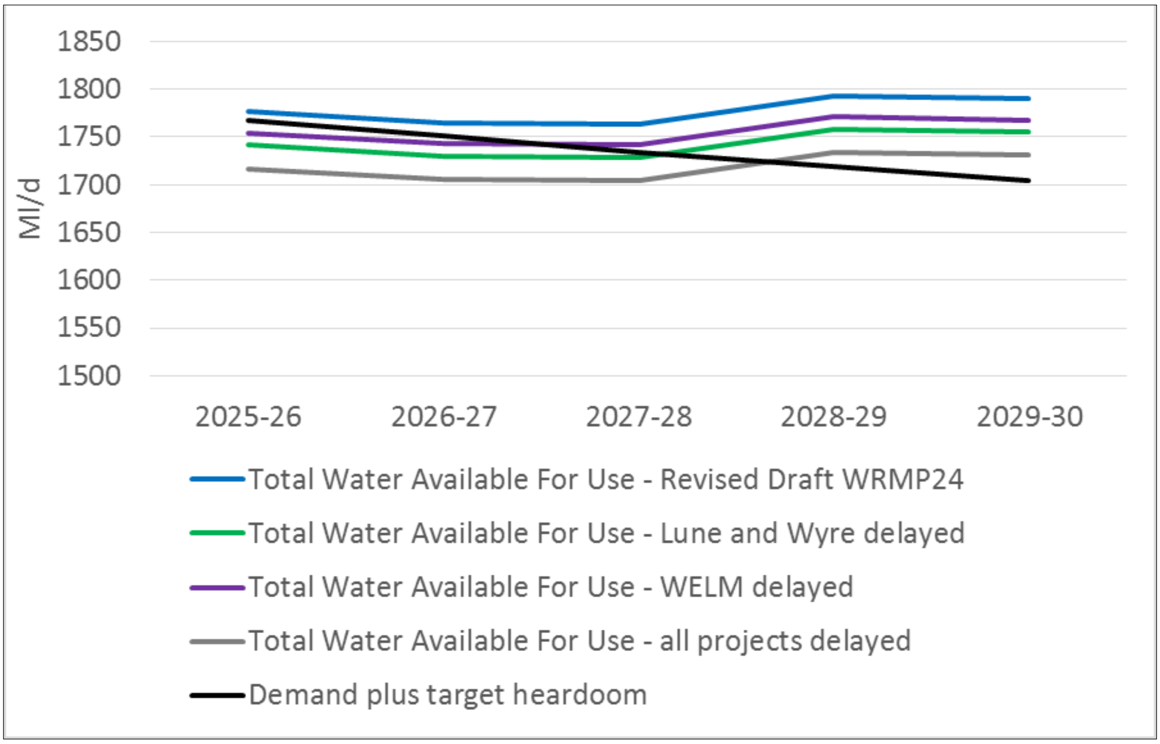
In response to the request for information, we simulated various scenarios to evaluate the potential consequences of a five-year delay to the Lune and Wyre and WELM projects. The assumption used within this scenario was that delivery of each project would be postponed until 2030, although, in reality, the Lune and Wyre project has already been completed. We examined the impact of these projects on deployable output and the WRMP24 supply-demand balance, considering both individual and combined effects. The estimated reductions specified in the Defra request for information were incorporated, with capacities set to 50 Ml/d for Lune and Wyre and 90 Ml/d for WELM.

Table 14 outlines the results of the deployable impact for both projects individually and combined. Additionally, Figure 16 illustrates the impact on the revised draft WRMP24 "dry year annual average final planning" supply-demand balance during 2025-2030. Any delay in either project would result in a supply-demand deficit for the initial 2-3 years of the planning period. Recognising the critical importance of these projects, exhaustive efforts were undertaken to complete the Lune-Wyre project, and to ensure the WELM remains on track for completion in 2024/25.

Table 14 Scenario testing of deployable output impact

Scenario	Deployable output impact (Ml/d)
Lune and Wyre delayed until 2030	34.9
WELM delayed until 2030	22.4
All projects delayed until 2030	59.6

Figure 16 Impact of 5-year project delays on WRMP24 supply-demand balance



4.7.7 Conclusions

Our response to this issue can be summarised as follows:

- Our models incorporate accurate system constraints, which in some cases are necessarily a forecast of a future position;
- Our models are configured to reflect operational behaviour as realistically as possible. Constraints such as cost reflect the need to minimise the impact of operating our supply network on customer bills. Ignoring these constraints would lead to an overly-optimistic supply forecast;
- We advise that operational use of assets is benchmarked against simulated / expected levels of supply rather than maximum asset capacity; and
- The Lune and Wyre project is complete and the WELM project is on-track to be completed by March 2025. Therefore, we have a very high level of confidence that our WRMP24 assumptions are correct. As requested, we have completed several scenarios to demonstrate the impacts of a hypothetical five-year delay to any or all of these projects.

5. 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.

Our *WRMP24 Technical Report – Environmental destination* provides full details of the sustainability changes that are included in this plan. This section provides a summary of these changes and how we have modelled them to calculate their impact on resource zone deployable output. The DO impacts, known as a 'sustainability reductions' are included in the calculation of resource zone baseline WAFU.

5.1 Sustainable abstraction background

In line with the guidance, we have liaised with the Environment Agency and Natural Resources Wales to determine if we have any abstractions from water bodies that are at risk from deterioration, and included the requirements set out in the WINEP, which sets out measures needed to protect and improve the environment.

In our WRMP19 we included two sustainability changes[13] and in the AMP7 investment period (2020-2025) period we are investing to implement them. These sustainability changes have, therefore, been accounted for when assessing our baseline supply forecast for WRMP24.

In discussion with the Environment Agency and Natural Resources Wales, there are a number of potential sustainability reductions in future AMPs, which we need to take account of in our calculations of WAFU for this plan, 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).

WINEP

The EA issued us with WINEP for AMP8 (2025-2030), which we have subsequently reviewed and discussed with them. It includes licence changes arising from:

- Ongoing AMP7 investigations[14]
- Time limited licences due for renewal during the AMP8 period
- Unused licences
- New non-compliant waterbodies (i.e. where associated river flows fail to meet their environmental flow indicator due to abstraction); and,
- Review of measures identified during preparation of the AMP7 WINEP, but which did not make it through

Several potential sustainability changes were identified for the Strategic Resource Zone; these are summarised in Section 5.2 and further information can be found in our *WRMP24 Technical Report – Environmental destination.*

No-deterioration

The EA also released supplementary guidance on preventing deterioration (Environment Agency, 2021), which sets out how abstraction licences may be changed in future to prevent deterioration of water bodies. Using this

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[13] New compensation flows at Dean Clough Reservoir and Grizedale Reservoir in the Strategic Resource Zone

[14] all with exception of Wirral and West Cheshire investigations have been agreed with the EA – due March 2023

guidance we have assessed each water body in our region and assigned a risk category to each. Our *WRMP24 Technical Report – Environmental destination* includes full details of this assessment. Four surface water bodies in the Strategic Resource Zone have been identified as moderate risk whereby maximum annual abstraction licence caps may be required to prevent deterioration in future. These licence changes are assumed to come into effect in AMP9 (2030-2035) and are summarised in Section 5.2. Note that there are no potential sustainability changes for the Carlisle, North Eden and Barepot Resource Zones.

5.2 Future potential changes in the Strategic Resource Zone

We have identified potential future sustainability changes (from WINEP and No-deterioration) for the Strategic Resource Zone, which are summarised in Table 15 and Table 16. These were input to our Hydro-Logic® Aquator water resources model of the Strategic Resource Zone to calculate the potential impact on deployable output. The same modelling approach (Stochastic Scottish DO) that was used to determine baseline DO was used also used to calculate the impact of sustainability reductions.

Table 15 Details of licence changes from AMP7 WINEP investigations

Source	Surface water (SW) or Groundwater (GW) impact	Licence change modelled
Laneshaw, Corn Close boreholes and Trawden Springs	SW	New six-year aggregate rolling abstraction volume limit of 7,314 Ml across the two Corn Close boreholes
Fylde aquifer	SW	
Franklaw B (P1-2 ad Q1-2) Franklaw A (L1-2) Franklaw A (L3-4 and M1-6) Broughton B (K1-2) Broughton B (EE1-2, G1-2, H1-2, J1-2) Franklaw A (W2 and Z2) Franklaw B (W1 and Z1)	SW	Concluded no impact to surface water bodies based on recent actual abstraction. AMP8 no deterioration investigation required to review impact to Fylde Aquifer. **Therefore no licence change has been modelled for AMP8**
Furness aquifer: Schneider Rd Thorncliffe Rd	GW	New six-year aggregate rolling abstraction volume limit of 15,987 Ml across the two licences
Wirral and West Cheshire aquifers: Eaton boreholes Sandyford borehole Cotebrook no.1 borehole Cotebrook no.2 borehole Delamere boreholes Eddisbury borehole Organsdale Farm borehole Mouldsworth boreholes Ashton borehole Hooton borehole	Both	**Delamere group:** New 10-year rolling abstraction volume limit of: 23,521 Ml A rolling aggregate condition limiting total abstraction across all sources within the Delamere group: Eddisbury (2568001159), Cotebrook 1 (2568001156), Sandiford (2568001155), Organsdale Farm (2568001180), Cotebrook 2 (2568001184) and Delamere (2568001158). Relinquish Eaton BH **Wirral BHs** Reduce annual limit for Newton and Grange (2568008030) reduced from 2,500 Ml/a to 1,537 Ml/a. No change to daily limit at Newton or Grange. Apply 6-year rolling period to 20'166 Ml to Prenton. No changes to annual or daily limits for Prenton. Relinquish Hooton and Springhill BHs (unused) **Investigation has been extended to December 2024 to allow time for spot flow gauging, subsequent model validation and update (if required) and identifying suitable solutions to prevent deterioration.**

Source	Surface water (SW) or Groundwater (GW) impact	Licence change modelled
Wirral and West Cheshire Permo-Triassic Sandstone aquifers: Foxhill Manley Quarry (Low Farm) Manley Common (Four Lane Ends) Newton Hollow Helsby	GW	New ten-year rolling abstraction volume limit of: 52,961 Ml This includes Manley Common (Four Lane Ends) (2568006087), Manley Quarry (Low Farm) (2568005011), Five Crosses (licence 2568003091), Foxhill (2568005009) and Mouldsworth (2568006082) Conjunctive use aggregate for West Cheshire uses would be expanded to include the Mouldsworth licence Relinquish Helsby, Newton Hollow and Ashton BHs **Investigation has been extended to December 2024 to allow time for spot flow gauging, subsequent model validation and update (if required) and identifying suitable solutions to prevent deterioration.**
Eccleston Hill borehole impact on Windle Brook	SW	Reduce annual licence limit from 1,161.526 Ml/yr to 876 Ml/yr and reduce daily limit from 3.182 Ml/d to 2.4 Ml/d. Set six-year rolling abstraction volume limit of 1,656 Ml.
Bearstone boreholes	Both	Set six-year rolling abstraction volume limit of 3,197.4 Ml

Table 16 Provisional details of licence changes from AMP9 No-deterioration

Source	Surface water (SW) or Groundwater (GW) impact	Licence change modelled
Whitebull System: Langden and Hareden	SW	Updated inflows and reservoir yields corresponding to new hands off flow (Q95) on minor intakes. Currently, hands off flows exists at the two main intakes at Langden and Hareden **Detail of actual change required will be subject to AMP8 WINEP. However to note the investigation may be removed from the WINEP as it has not yet been agreed with the EA, therefore model changes may be removed for final submission.**
River Dane/Hug Bridge boreholes	Both	We have assumed no abstraction can occur below the existing hands off flow in the current licence agreement (70 Ml/d). Currently, we do not abstraction from the Hug Bridge BHs therefore is not included in any modelling **Specific licence changes for no deterioration will be investigated and agreed with the EA as part of AMP8 WINEP.**

Source	Surface water (SW) or Groundwater (GW) impact	Licence change modelled
Franklaw borehole group	GW	New 6-year rolling limits based on recent actual abstraction volumes (2015- 2019 period) 65,997 Ml 6 year rolling limit applied across all BHs in the group in line with Environment Agency No deterioration guidance. The above totals are equivalent to a daily average abstraction rate of 30.14 Ml/d; the recent actual abstraction over the 2015-2019 period. **Specific licence changes for no deterioration will be investigated and agreed with the EA during AMP8 WINEP.**
Trawden	GW	Licence cap to 540 Ml/d based on recent actual abstraction volumes (2015- 2019 period). **However not modelled as licence cap is higher than WRMP24 baseline source yield.** **Specific licence changes for no deterioration will be investigated and agreed with the EA during AMP8 WINEP.**
Aughertree Springs/Longlands mine adit	GW	730 Ml/year for Aughertree Springs (same as existing annual licence limit) and 102 Ml/year at Longlands mine adit. This is based on recent actual abstraction volumes (2015- 2019 period). **Not modelled as currently, these sources are not included in our baseline Hydro-Logic® Aquator model as the licences are being considered for revocation as part of the Thirlmere transfer project.**

The model results show that there is a 6.1 Ml/d reduction in DO from the AMP8 (2025-2030) WINEP sustainability changes, and a 11.4 Ml/d (inclusive of AMP8 impacts) reduction from the AMP9 (2030-2035) no-deterioration changes (Table 17). These DO impacts are included as sustainability reductions in our determination of baseline WAFU for the resource zone.

Table 17 Strategic Resource Zone DO impact of sustainability changes

Scenario	DO impact Ml/d (cumulative)	
	2025-30	2030-35
WINEP (AMP8)	6.1	6.1
No-deterioration (AMP9) (including AMP8 licence changes)	N/A	11.4

6. Developing our long-term environmental destination

Environmental destination is a new concept whereby regional planning groups and water companies must develop a destination for sustainable water resources management for the long term, to 2050. We have developed our environmental destination in collaboration with WRW and it has been informed by the latest planning guidelines and engagement with stakeholders and regulators. Our WRMP24 Technical Report – Environmental destination provides full details of how we have developed our environmental destination for this plan. This section provides a summary of our environmental destination and how we have modelled future potential abstraction licence changes to calculate their impact on resource zone deployable output. These impacts are included in the calculation of resource zone baseline WAFU.

6.1 Long-term environmental destination background

In previous Water Resources Management Plans, changes to abstraction have been primarily via the Water Industry National Environment Programme (WINEP). The 25-Year Environment Plan, published by Defra in 2018, set out an ambitious environmental agenda, including ambitious targets for sustainable abstraction. In March 2020, the Environment Agency published their expectations for sustainable abstraction in the National Framework for Water Resources. The framework set out abstraction reduction targets at whole catchment level (rather than for individual licences) for different sectors (i.e. agriculture and public water supply), under various scenarios covering different levels of environmental protection. In order to understand the impact on individual abstraction licences, and thus impact on DO, the catchment-scale reductions were translated to licence scale. This was done using the Waterbody Abstraction Tool for all water bodies in the WRW region and for three scenarios (based on fully licenced reductions[15]):

- ‘Business as usual plus’ (BAU+): the same percentage of natural flows for the environment that currently applies continues for the future. Uneconomic waterbodies, where reducing abstraction would imply a significant investment, were initially discarded. A further assessment was made for CSMG catchments as whether additional specific licence reductions would need to be made by 2050. This scenario will form our baseline WRMP supply forecast;
- ‘Enhance’: a greater level of environmental protection for protected areas and Sites of Special Scientific Interest (SSSI) rivers and wetlands, and principal salmon and chalk rivers, is achieved by applying the most restrictive ASB; and
- ‘Ofwat low’: removal of the highly uncertain licence reductions from BAU+ scenario. Retain licence reductions that are predicted to fall within Band 3 compliance level at Q95 by 2050. This was discussed with local Environment Agency staff and changes made if necessary, for example one source in a waterbody with Band 2 compliance by 2050 was more certain than one in Band 3 and therefore was swapped in.

The potential licence reductions for each scenario were input to our Hydro-Logic® Aquator water resources models to calculate their impact on DO. The BAU+ scenario DO impacts only were used in the calculation of baseline WAFU, which is consistent with WRW. Impacts for other scenarios will be used in our adaptive plan (*WRMP24 Technical Report – Deciding on Future Options*).

6.2 Future potential changes in the Strategic Resource Zone

We have identified potential future environmental destination reductions (for each scenario for the fully licenced abstraction rate) for the Strategic Resource Zone, which are summarised in (Table 18). These were input to our Hydro-Logic® Aquator water resources model of the Strategic Zone to calculate the potential impact on

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[15] The National Framework set out different scenarios with differing levels of environment protection (e.g. Business as Usual), and also two different abstraction rates to consider: future predicted and fully licenced. Future predicted was determined by recent actual abstraction licence use and applying a growth factor, and fully licenced is defined as abstraction licences being utilised to their maximum capacities.

deployable output. The same modelling approach (Stochastic Scottish DO) that was used to determine baseline DO was used also used to calculate the impact of environmental destination changes.

Table 18 Potential licence reductions by source in the Strategic Resource Zone between 2035 and 2050 (where licence reductions are less than WRMP24 baseline yield[16])

Scenario	Source and licence reduction (Ml/d)					
	2035-40		2040-45		2050	
Ofwat Low			Scales	0.25	Woodford	8.66
			Millbrook	1.72	Butterworth Hall	9.3
BAU+	Scales	0.25	Woodford	8.66	Rushton Spencer	0.25
	Millbrook	1.72	Butterworth Hall	9.3	Lymm	8.64
					Wigan West BH Group	31.4
Enhanced	Scales	0.25	Woodford	8.66	Rushton Spencer	0.25
	Millbrook	1.72	Butterworth Hall	9.3	Lymm	8.64
					Wigan West BH Group	31.4
					Bearstone	0.96
					Simmonds Hill group	4.35

The impact was modelled for 2050, and includes all identified licence reductions from WINEP (for AMP8, 2025-30), no-deterioration (for AMP9, 2030-35), and environmental destination (for 2050). The 2050 environmental destination DO impacts were then profiled over 2035-50 for each five-year AMP period (2035-40 and 2040-45) by proportioning the DO impact at 2050 by the total licence reductions for each period (Table 19). Licence reductions were assigned to AMP periods based on a high-level uncertainty assessment.

Table 19 Strategic Resource Zone environmental destination licence reduction 1 in 500 DO impacts (including sustainability and no deterioration reductions)

Scenario	DO impact (Ml/d)		
	2035-40	2040-45	2050
Ofwat Low	11.4	23.2	131.6
BAU+	**15.3**	**50.8**	**131.6**
Enhanced	14.9	47.2	129.0

6.3 Future potential changes in the Carlisle Resource Zone

The River Gelt has been flagged for licence reductions as part of the environmental destination. There is uncertainty around whether existing and new prescribed flows are sufficient to ensure the waterbody status remains good. For example, recent WINEP investigations have led to a significant increase of prescribed flows in the Gelt catchment. We have discussed with the Environment Agency whether our AMP6 investigation is sufficient to meet environment destination objectives. It was assumed by the Environment Agency, within the

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[16] There are additional licences that have been flagged for licence reductions (including unused licences) that do not impact our DO (i.e. potential new long-term licence volume is higher than baseline yield). However they will be assessed as part of our option development work stream where more detailed investigations may need to be accelerated to better understand long-term risk of deterioration.

National Framework, that prescribed flow constraints are sufficient to support good (hydrology status) in the associated waterbody. Therefore, we have screened out specific licence reductions which are constrained by local prescribed flows, however we will look to apply future prescribed flows for abstractions within a licence that don’t have one; for example, for the Old Water tributary in the Gelt catchment in Carlisle Resource Zone. This future potential change for the Old Water tributary was input to the Carlisle Hydro-Logic® Aquator model to determine if it has an impact on resource zone DO. The result of the modelling was a 0.06 Ml/d impact on 1 in 500 DO at 2050.

Note that there are no potential environmental destination changes for the North Eden and Barepot Resource Zones.

7. Climate Change

7.1 Approach

An assessment of the potential impacts of climate change on supply has been completed for all of our water resource zones. The assessment follows the Water Resources Planning Guideline (Environment Agency, 2021), including the Supplementary Guideline on Climate Change (Environment Agency, 2021). The approach set out in the guidance includes four stages:

(1) Complete a vulnerability assessment;

(2) Calculate the impact on water availability;

(3) Calculate the impact on water supplies; and

(4) Integrate results into the WRMP (including scaling and uncertainty)

The stages of the climate change assessment are described in detail in the following section (Section 7).

7.2 Assessment

7.2.1 Basic Vulnerability Assessment

The first stage of the climate change assessment is to complete a Basic Vulnerability Assessment (BVA) and we commissioned HR Wallingford to undertake this. The approach set out in the previous Water Resources Planning Guideline (Environment Agency, 2013) for undertaking a BVA has not changed, and so the same approach has been followed for this plan. A BVA was completed for all four water resource zones.

The BVA was completed using current knowledge of our system and our previous climate change assessments. It included completion of the vulnerability scoring matrix shown in Table 20 for each resource zone to inform the determination of climate change vulnerability as ‘High’, ‘Medium’, or ‘Low’. It also guided the decision as to the level of detail required for the climate change impacts assessment.

Table 20 Vulnerability scoring matrix

	Mid scenario (DO % impact)			
Uncertainty range (Wet-Dry % change)	**<-5%**	**<-10%**	**<-15%**	**>15%**
<5%	Low	Medium	Medium	High
<10%	Low	Medium	Medium	High
<15%	Medium	Medium	High	High
>15%	High	High	High	High

Source: adapted from Environment Agency 2013

For our WRMP19 climate change assessment UKCP09 (Murphy, 2009) probabilistic scenarios for the 2080s under a medium emissions scenario were used. A weighted sub-sample of 20 scenarios were modelled to quantify impact on deployable output. The Water Resources Guideline does not specify the time horizon at which the vulnerability matrix should be applied. For this assessment, both the 2045 (25-year planning horizon) and the 2080s have been considered, with the results summarised in Table 21.

Table 21 Summary of DO impact of 20 climate change scenarios modelled for each resource zone for WRMP19

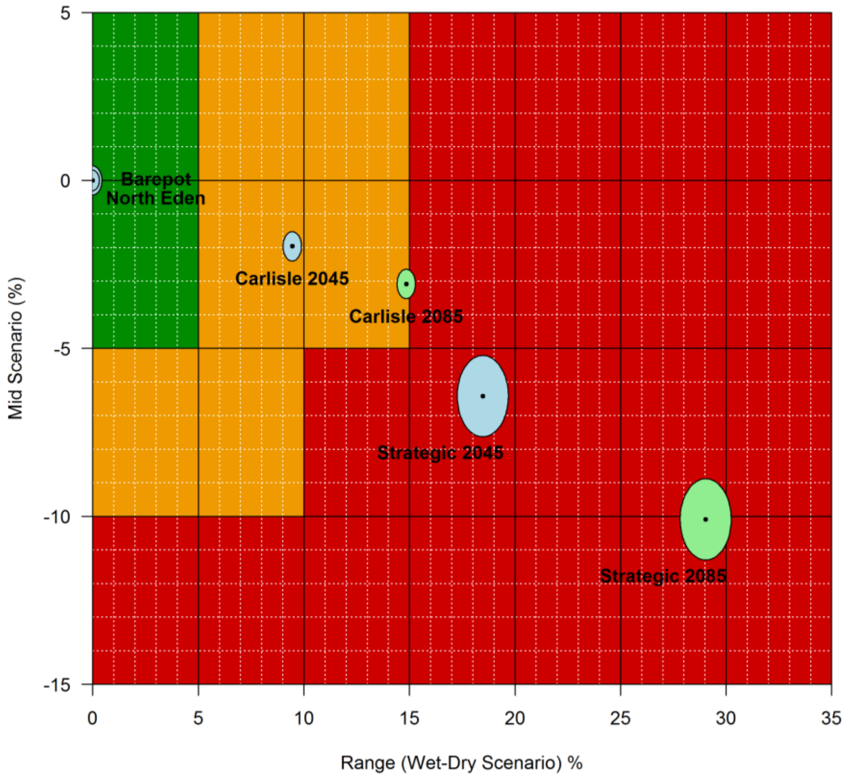
Water Resource Zone	Baseline DO (Ml/d)	50th Percentile impact (2045)	50th Percentile impact (2085)	Least severe impact (2085)	Most severe impact (2085)
Strategic	2118	-6%	-10%	+7%	-23%
Carlisle	35.7	-2%	-3%	+3%	-12%
North Eden	34.1	0%	0%	0%	0%
Barepot	8.7	0%	0%	0%	0%

Source: United Utilities Water Table 9, WRMP19

The uncertainty ranges and the mid scenario DO percentage change used to determine the vulnerability classification for each RZ are plotted as a magnitude versus sensitivity plot in Figure 17. This plot shows that the Strategic Resource Zone has high vulnerability, Carlisle Resource Zone medium vulnerability and North Eden and Barepot Resource Zones have low vulnerability classification. This analysis was supplemented with the following additional information (available at the time writing) to inform the appropriate tier for the detailed climate change impact assessment:

- Our experience of recent hot and dry summers in 2018 and 2020 and the resultant lessons learnt;
- There have been significant changes in some of our operational practices through the development of new drought levels, which supersede the previous drought triggers that were included in WRMP19, and publication of our Final Drought Plan 2022;
- There have been no significant changes to our water resource zone integrity or several related aspects that may materially change a resource zone's vulnerability; however, demand has been elevated above the levels forecast in WRMP19; and
- Potential intra-regional (Water Resources West) and inter-regional water transfers are important factors to consider for WRMP24.

Figure 17 Climate change magnitude-sensitivity plot for all RZs for 2045 and 2085



Taking the results of the vulnerability scoring matrix and additional information into account the following approaches were selected for the detailed climate change assessment:

- A tier 3 (Environment Agency, 2021) approach for the Strategic and Carlisle resource zones, which involves a new climate change assessment using the full range of uncertainty within UKCP18. Carlisle Resource Zone is medium vulnerability and so a tier 2 approach could have been adopted; however, given a tier 3 approach was chosen for the Strategic Resource Zone it was more efficient to apply the same approach for Carlisle.
- A tier 1 (Environment Agency, 2021) approach for North Eden and Barepot Resource Zones, which can re-use the WRMP19 assessment provided there are no significant differences between UKCP09 and UKCP18 probabilistic projections.

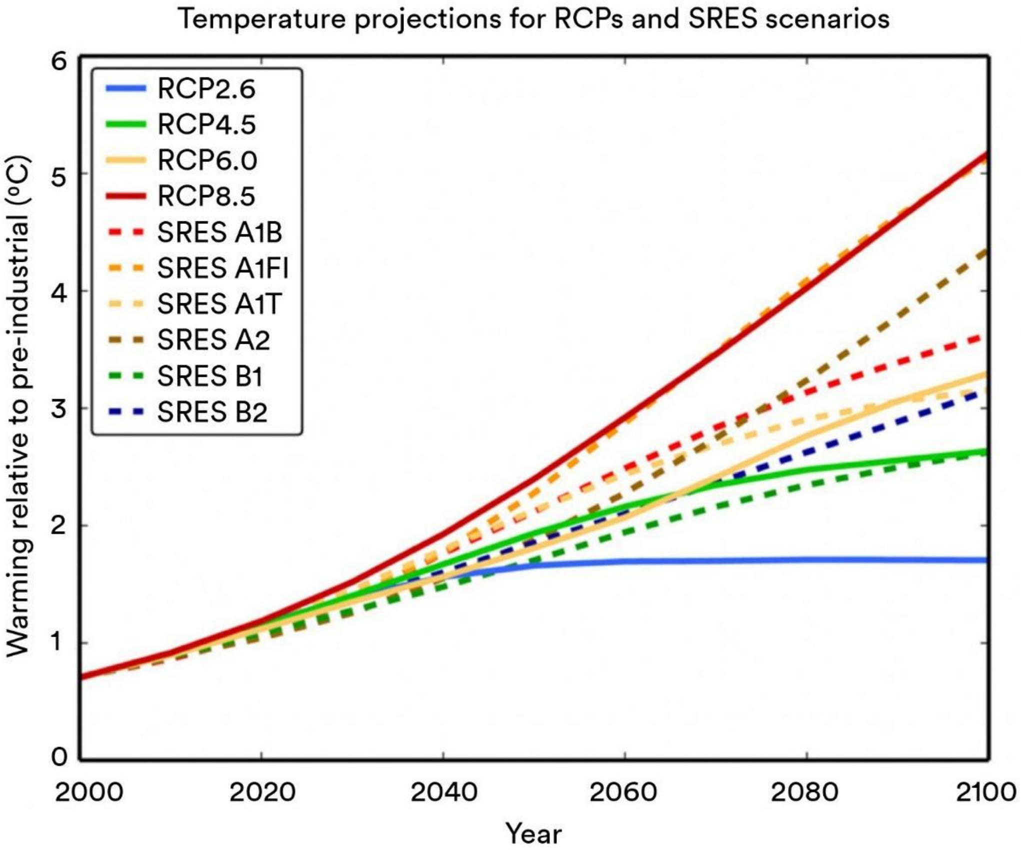
7.2.1.1 Rapid assessment of UKCP18 products

A rapid assessment of the UKCP18 climate projections in the context of our supply area was undertaken to inform the selected approaches for delivering the climate change assessments for this plan. This work was undertaken by HR Wallingford who also authored the EA WRPG.

UKCP18, published by the UK Meteorological Office (2018), uses newer, higher resolution climate models, additional observations and the latest Intergovernmental Panel on Climate Change (IPCC) emission scenarios used for the fifth Assessment Report (AR%). The improvements in the modelling are considered by the Met Office to increase the confidence in the ranges of future climate of the UK. The general trends projected for the UK over the 21st Century are broadly consistent with the previous projections (UKCP09), with a tendency towards hotter, drier summers and warmer, wetter winters in the future.

The UKCP09 projections, used in our climate change assessment for WRMP19, were based on the SRES (Special Report on Emissions Scenarios, (Nakicenovic, 2000)). The SRES were a set of socio-economic projections for the future up to 2100 and the corresponding emissions of greenhouse gases based on four storylines each describing how world population, economies and political systems may evolve. For UKCP18, the latest emissions scenarios termed Representative Concentration Pathways (RCPs (van Vuuren, 2011)) included in the Fifth Assessment Report from the IPCC were used. Each RCP follows a different emission trajectory and cumulative emission concentration by 2100. There are four RCPs expressed according to future radiative forcing targets in 2100: 2.6, 4.5, 6.0, and 8.5 watts per square metre (Lowe, 2019). A comparison of the trajectory of global warming associated with the different emission scenarios used in the UKCP09 and UKCP18 climate change projections is shown in Figure 18. The medium emission scenario (SRES-A1B) from UKCP09 used in our WRMP19 climate change assessment falls between RCP 6.0 and RCP 8.5. UKCP18 includes an additional ensemble based on SRES-A1B to allow a direct comparison between the two sets of projections.

Figure 18 Global mean temperature projections from a climate model (called MAGICC6) relative to a pre-industrial average (1850-1900) for RCP2.6 (blue), RCP 4.5 (green), RCP 6.0 (yellow), and RCP 8.5 (red) and the older SRES scenarios (dashed coloured lines). Source: UK Met Office (2018)



UKCP18 comprises a range of different products, each providing different realisations of the future climate. Each product has different features and limitations for water resources planning. The UKCP18 Regional and Global projections are spatially coherent but were only available for the highest emission scenario, RCP 8.5 when our detailed climate change assessment was undertaken[17]. Conversely, the UKCP18 Probabilistic projections are available for all emissions pathways (i.e. all RCPs), but they are not spatially coherent. The lack of spatial coherence in the probabilistic projections is a limitation for regional water resources planning, because companies within a regional group need to be able to undertake joined-up assessments of climate change, particularly where transfers are being investigated. Along with the use of our spatially coherent regional stochastic dataset, this means that conditions simulated at each of the transfer are matched together, just as they would be if we were simulating a historical event. The downside of RCPs is that there are only 12 in number, which makes it difficult to assess uncertainty. The UKCP18 probabilistic projections, while not spatially coherent, total 3,000 in number and provide invaluable additional information to help inform how climate change uncertainty is represented in target headroom.

7.2.1.2 Comparison of selected UKCP09 and UKCP18 products

The key climate variables for water resources planning are precipitation and evapotranspiration. A comparison of seasonal changes in precipitation and temperature (a key variable driving evapotranspiration) using selected UKCP09 and UKCP18 products was undertaken to determine if there are any significant differences in the changes forecast between the two sets of projections. Figure 19 and Figure 20 compare selected projections for the North West river basin for the 2070-2099 future period relative to a 1961-1990 baseline as used for our WRMP19 climate change assessment (the UK Regional Projections were not included as they are only available from 1981-2080).

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[17] Spatially coherent Global projections for RCP 2.6 were subsequently released by the UK Met Office in 2020

Key messages from the comparison of projections in relation to rainfall are:

- The UKCP18 Probabilistic Projections under a medium emission scenario (SRES – A1B) cover similar ranges to the equivalent product from UKCP09 (with wider uncertainty ranges in relation to changes in spring and autumn);
- Comparing the UKCP18 Probabilistic Projections under the RCP 8.5 emission scenario with those under a Medium emission scenario demonstrate larger reductions in summer rainfall and larger increases in autumn and winter; and
- For winter, spring, and summer the UKCP18 Global Projections cover a large part of the uncertainty range covered by the UKCP18 Probabilistic Projections under both a medium and RCP 8.5 emissions scenarios. In autumn the wetter probabilistic projections are not well covered by the UKCP Global projections.

For temperature changes the key messages are:

- The UKCP18 Probabilistic Projections under a Medium emission scenario (SRES-A1B) are cooler than the equivalent product from UKCP09, with the UKCP18 Probabilistic Projections driven by RCP 8.5 emissions scenario significantly warmer than both; and
- The cooler projections from the UKCP18 Probabilistic Projections are not well represented in the UKCP18 Global Projections.

Figure 19 Change in seasonal rainfall for the UKCP18 North-West river basin. Changes are for the 2070-2099 future period relative to a 1961-1990 baseline, as used for WRMP19. Model type CMIP5 and PPE are types of global climate models. Source: Met Office 2019, United Utilities Water WRMP19

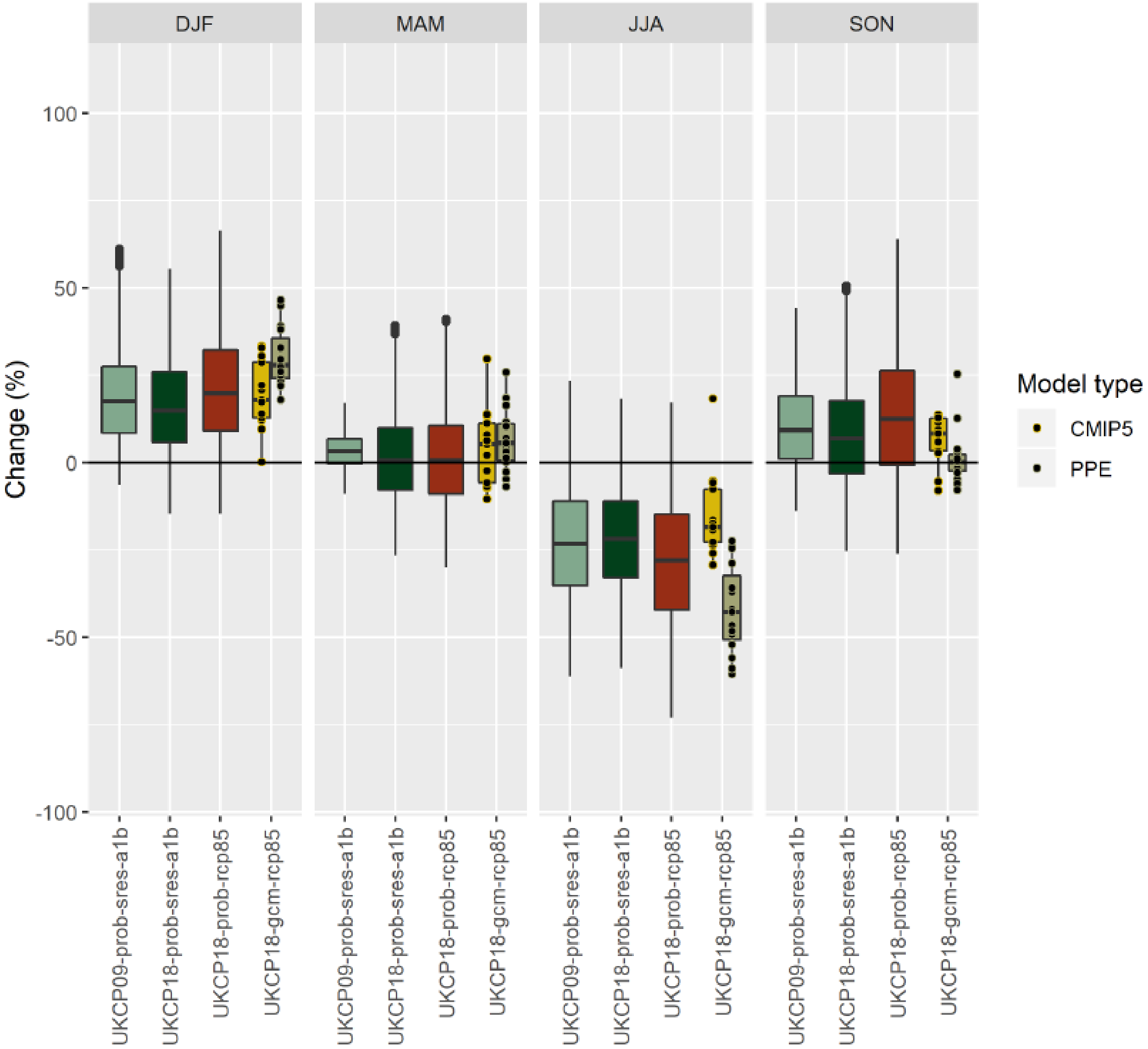


Figure 20 Changes in seasonal temperature for the UKCP18 North-West river basin. Changes are for the 2060-2079 future period relative to a 1981-2000 baseline. Model type CMIP5 and PPE are types of global climate models. Source: Met Office 2019, United Utilities Water WRMP19

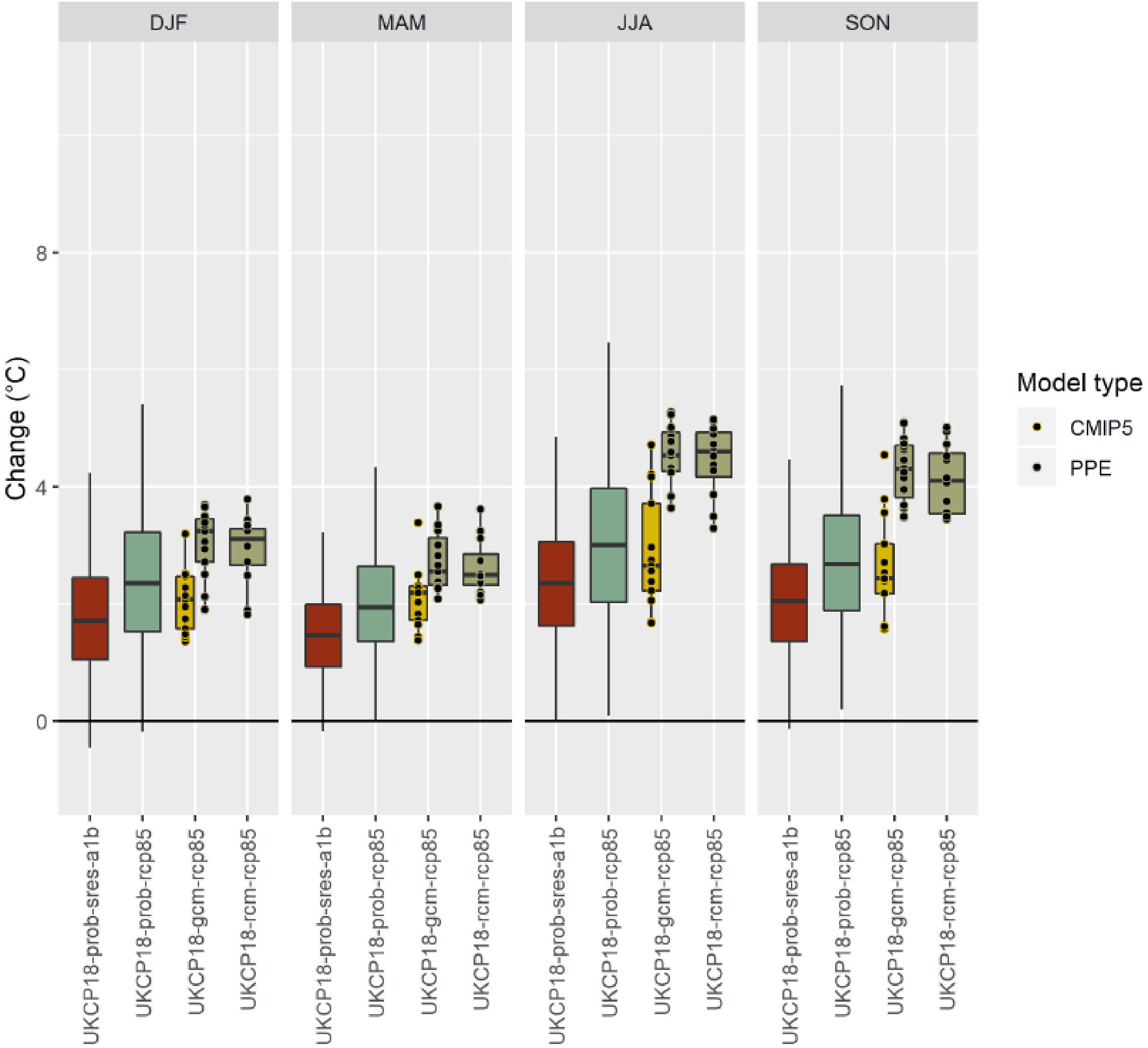


Figure 19, Figure 20 and Figure 21 show the projected changes (in summer and autumn rainfall and temperature) across the range of UKCP18 products for the same emission scenario for the North West river basin area. These figures demonstrate the differences across the UKCP18 products, and in particular that one of the two global climate models (the Perturbed Physical Ensemble, PPE model) has a different climate sensitivity to emission inputs (Andrews, 2019). This results in a notable warmer and drier future than shown by the other global climate model (CMIP5) projections that underpin the UKCP18 probabilistic projections.

Figure 21 Changes in summer (5b autumn) temperature and precipitation for the UKCP18 North-West river basin. Changes are for the 2060-2079 future period relative to a 1981-2000 baseline. Probabilistic Projections are shown by grey circles, Regional Projection are shown in orange circle, CMPI5-13 Global Projections are shown in blue circles, and the HadGEM3-GC3.05 Global Projections in red circles. Source: Met Office 2019

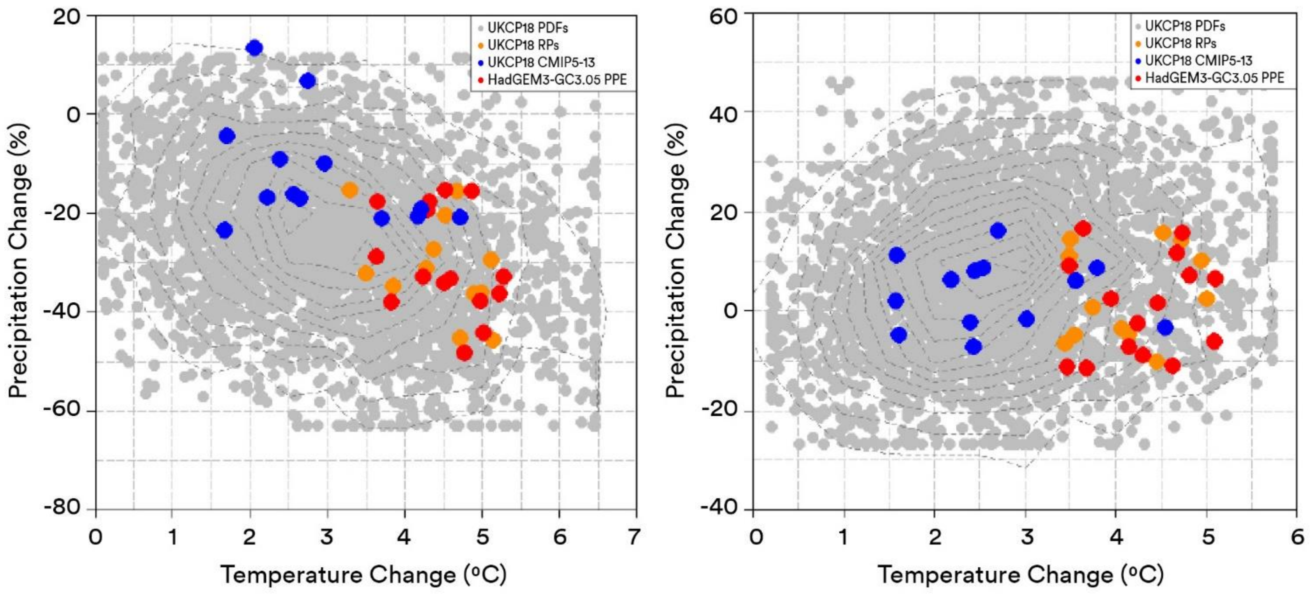


Chart A **Chart B**

7.2.1.3 Impact on critical historical droughts

Two historical droughts were selected to assess the difference in how the UKCP09 and UKCP18 probabilistic climate change projections would impact the types of droughts that are key for our largest water resource zone, the Strategic Zone. The 1984 drought was a single season event of approximately seven months durations. This drought defined the deployable output of the Strategic Resource Zone in our 2019 plan (United Utilities Water Limited, 2019). The 1995-96 drought was a two-season event covering the period 1995-96 was a significant event affecting the Pennines region.

The comparison was based on the methodology presented in the Drought Vulnerability Framework (UKWIR, 2018) and used the UKCP09 and UKCP18 probabilistic projections under a medium emission scenario for the UKCP18 North West river basin. Figure 22 shows how the rainfall deficit (relative to the long-term average over the 1961-2010 period) for the 1984 drought is affected by each set of projections. The projections presented in Figure 22 are for the 2070-2099 future period relative to a 1961-1990 baseline, as used in WRMP19.

Figure 22 suggests that the UKCP18 Probabilistic Projections would have a broadly similar impact on the 1984 drought as the UKCP09 Probabilistic Projections, but with a wider uncertainty range particularly at the drier end. It is interesting to note that the three-month period ending in July 2018 was drier relative to 1984.

Figure 22 Drought Response Surface showing rainfall percentages of LTA (1961-2010) to July 1984 for selected durations (dashed line) and the impact of UKCP09 (blue box plots) and UKCP18 Probabilistic Projections (grey box plots) under a medium emissions scenario (2070-2099 relative to a 1961-1990 baseline) on these values for 1984.

Black stars are rainfall percentages for different years (to July) in the historical record from 1961-2018.

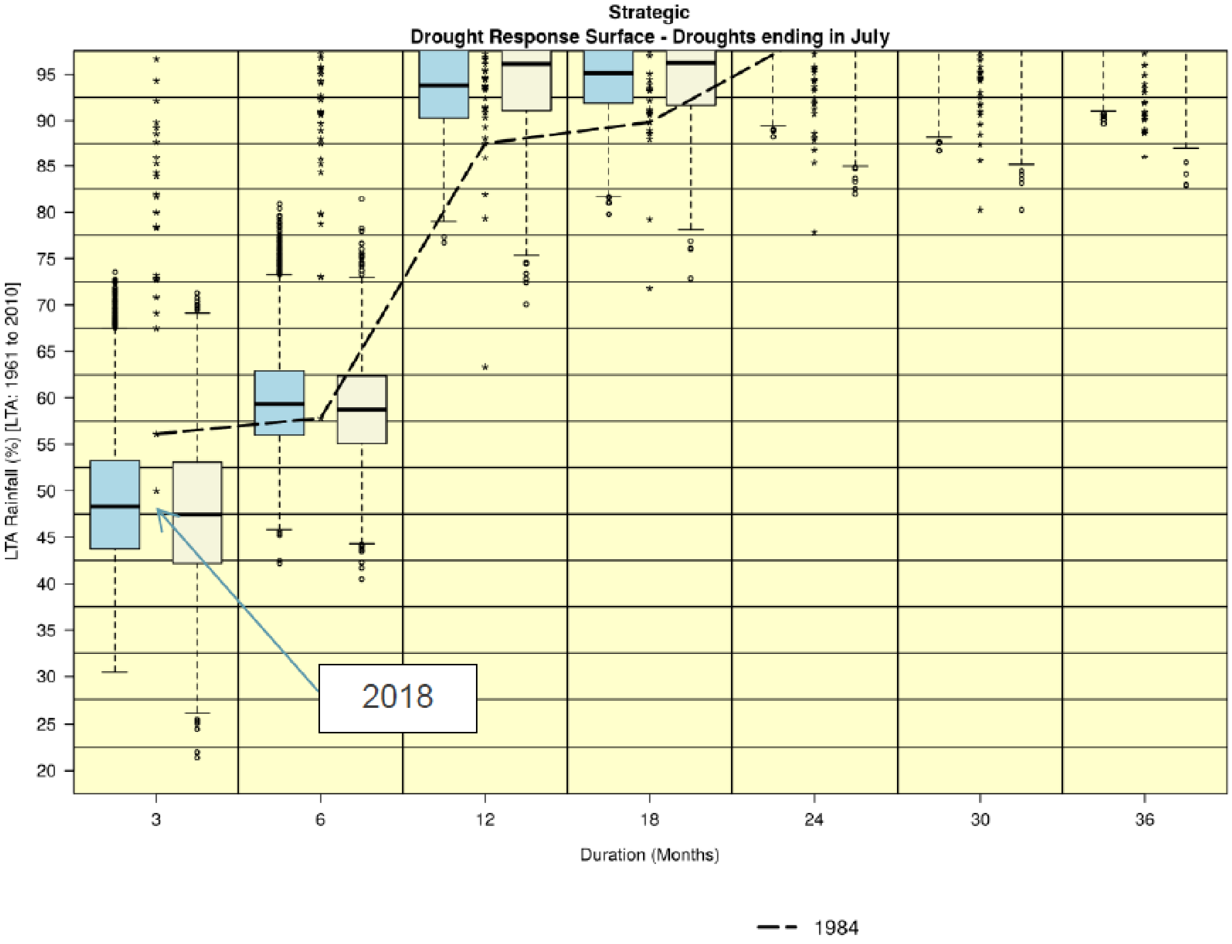


Figure 23 presents a similar plot but compares the UKCP18 Probabilistic Projections under RCP8.5 with the UKCP18 Regional Projections for the 2060-2079 future period relative to a 1981-2000 period. This shows that the UKCP18 Regional Projections are towards the drier end of the probabilistic, but only cover a small part of the uncertainty range associated with the UKCP18 Probabilistic Projections.

Figure 23 Drought Response Surface showing rainfall percentages of LTA (1961-2010) to July 1984 for selected durations (dashed line) and the impact of UKCP18 Probabilistic Projections (blue box plots) and UKCP18 Regional Projections (grey box plots) under RCP 8.5 emission scenario (2060-2079 relative to a 1981-2000 baseline) on these values for 1984.

Blue dots and yellow dots indicate specific scenarios. Black stars are rainfall percentages for different years (to July) in the historical record from 1961 to 2018.

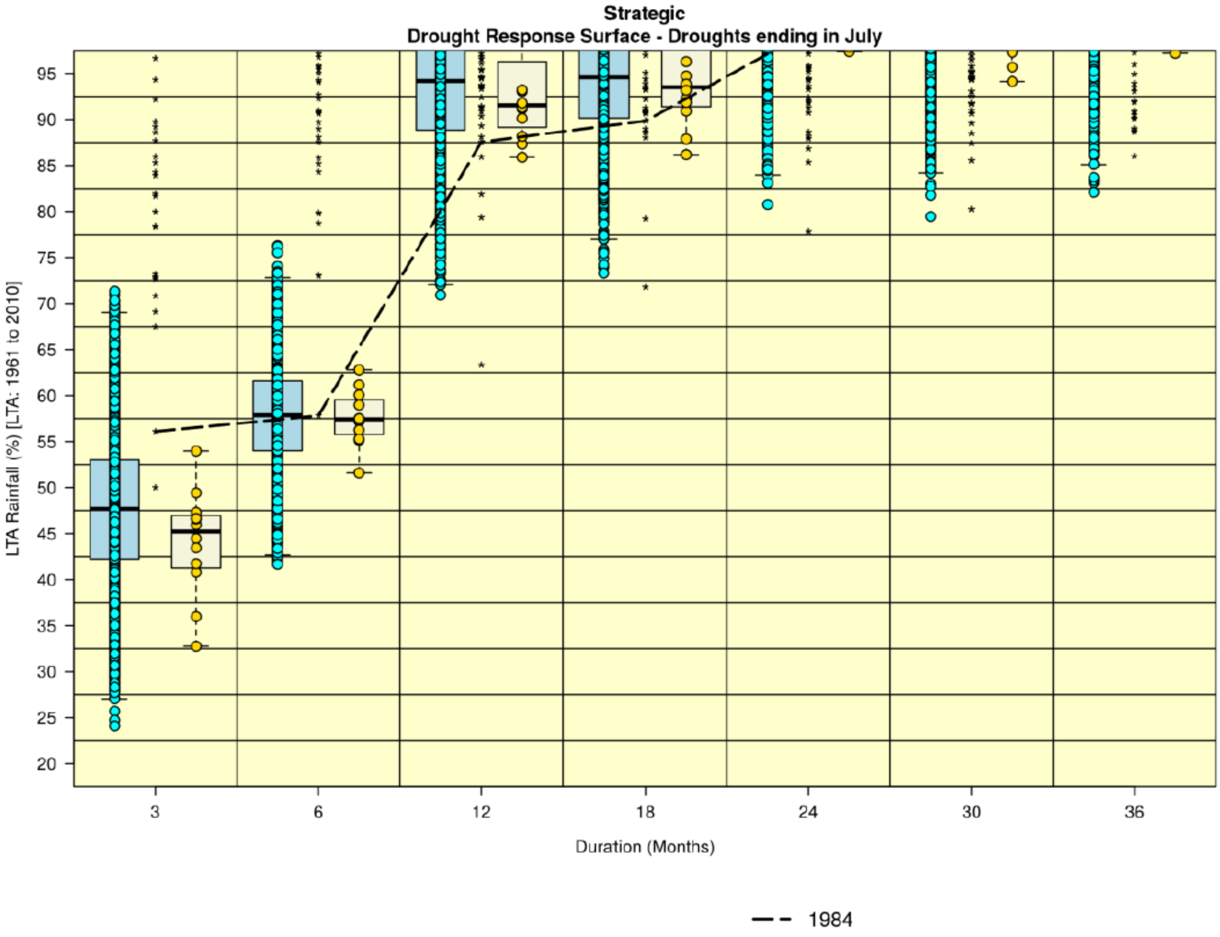


Figure 24 presents the Drought Response Surface for the 1995-96 drought. This plot suggests that the UKCP18 Probabilistic Projections may have a slightly greater impact on this two-season drought than the UKCP09 Probabilistic Projections. The uncertainty range is also larger under the UKCP18 Probabilistic Projections. Figure 25 presents a similar plot but compares the UKCP18 Probabilistic Projections under RCP8.5 with the Regional Projections for the 2060 to 2079 future period relative to a 1981 to 2000 period. Similarly to Figure 23, this shows the UKCP18 Regional Projections are towards the drier end of the probabilistic in terms of the impact on this two season drought, but only cover a relatively narrow portion of the uncertainty range covered by the UKCP18 Probabilistic Projections.

Figure 24 Drought Response Surface showing rainfall percentages of LTA (1961 to 2010) to September 1996 for selected durations (dashed line) and the impact of UKCP09 (blue box plots) and UKCP18 Probabilistic Projections (grey box plots) under a medium emission scenario (2070-2099 relative to a 1961-1990 baseline) on these values for 1995 to 1996.

Black stars are rainfall percentages for different years (to September) in the historical record from 1961 to 2018.

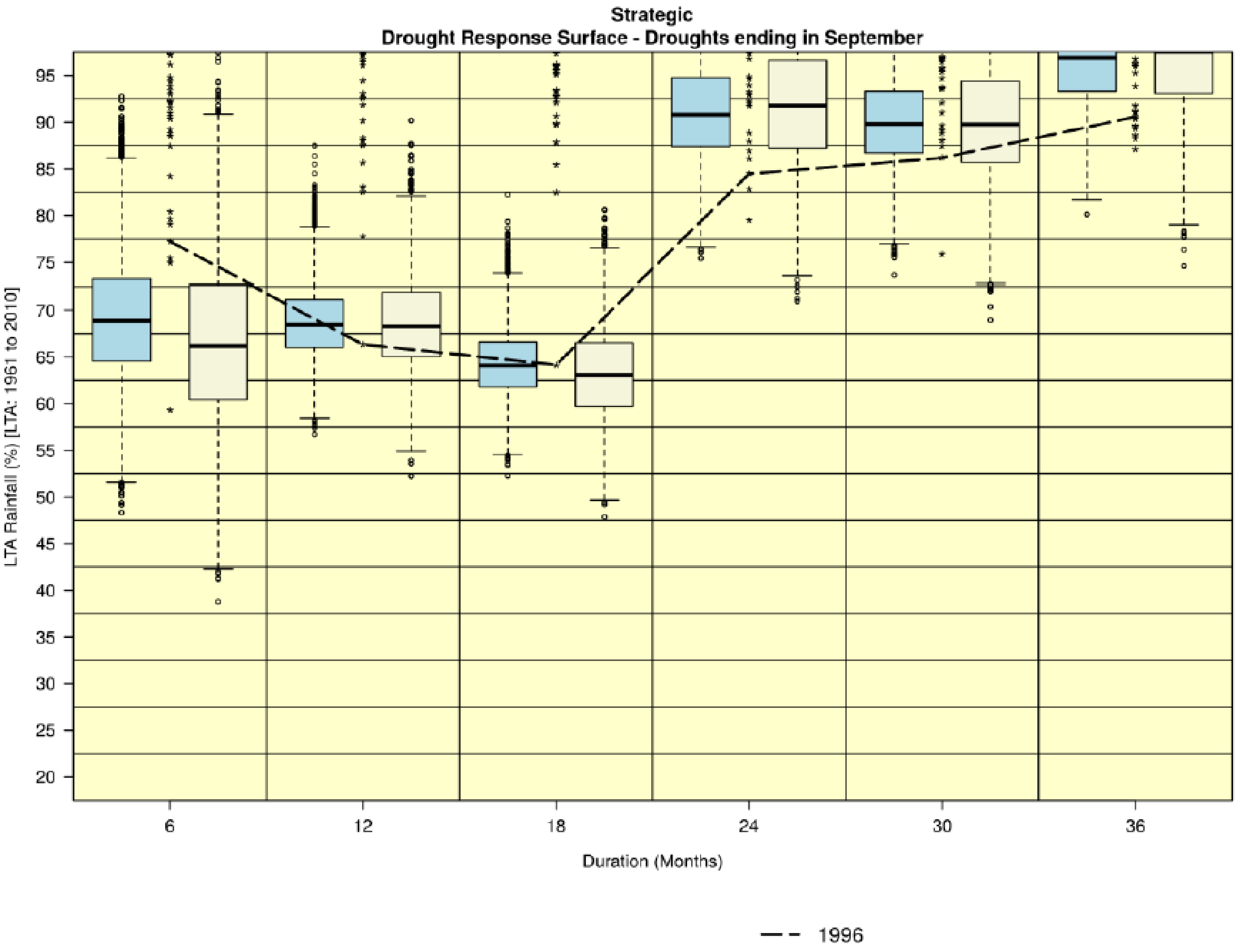
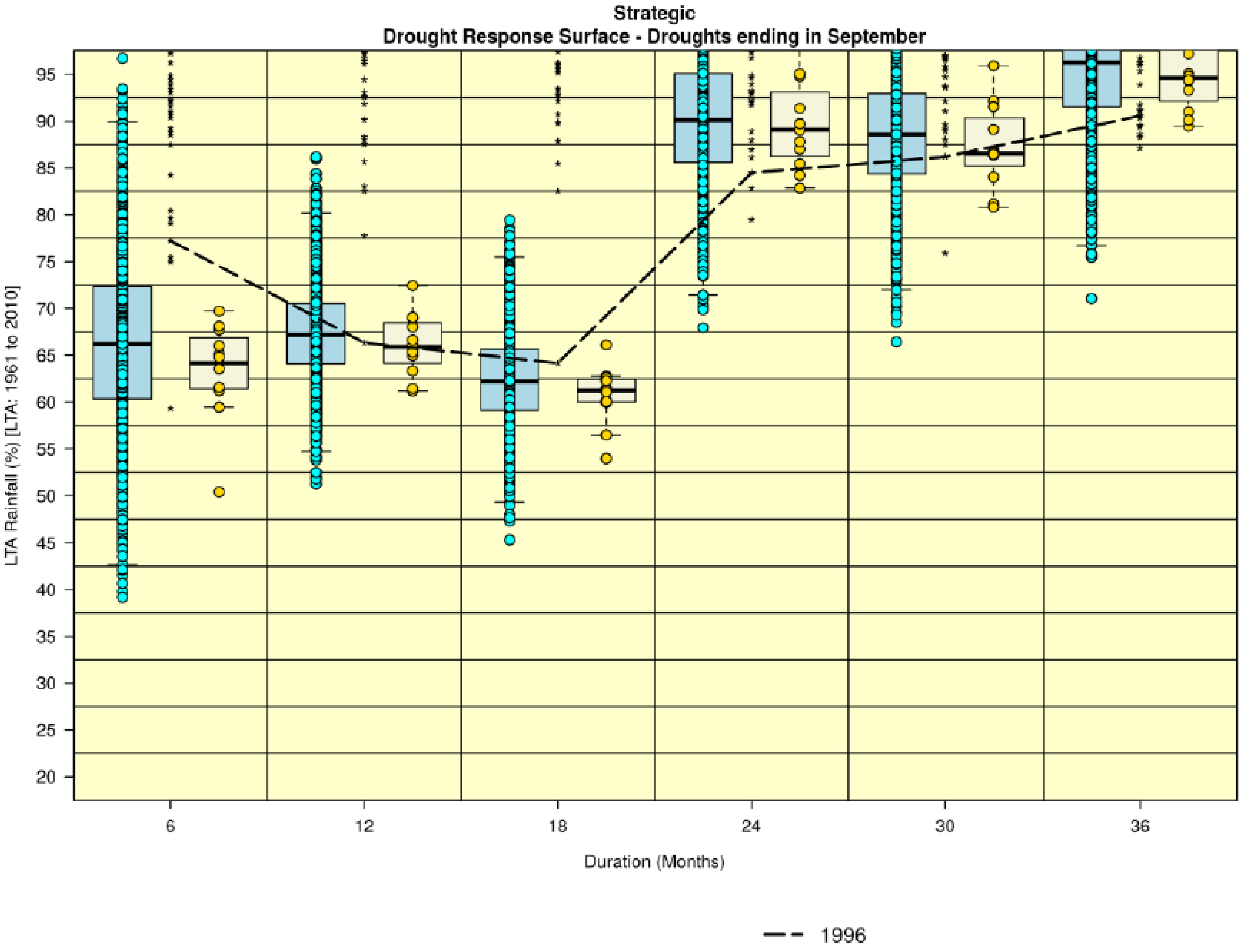


Figure 25 Drought Response Surface showing rainfall percentages of LTA (1961 to 2010) to September 1996 for selected durations (dashed line) and the impact of UKCP18 Probabilistic (blue box plots) and UKCP18 Regional Projections (grey box plots) under RCP 8.5 emissions scenario (2060-2079 relative to a 1981-2000 baseline) on these values for 1995 to 1996. Blue dots and yellow dots indicate specific scenarios.

Black stars are rainfall percentages for different years (to September) in the historical record from 1961 to 2018



7.2.1.4 UKCP18 products selected for our 2024 climate change assessment

In accordance with the Water Resources Supplementary Planning Guideline (Environment Agency, 2021), a range of UKCP18 products were used in our Tier 3 detailed climate change assessment for the Strategic and Carlisle Resource Zones. Using a range of climate change evidence ensures our assessment shows the range of potential climate change impacts on supply for each resource zone from impacts modelling, and that climate change uncertainty is adequately represented. In order to meet the requirements of regional planning, the Regional Climate Model projections were used by all member companies of Water Resources West regional planning group. The Regional Climate Model Projections were chosen rather than the also spatially coherent Global Climate Model Projections because they are available at finer resolution (12km) than the Global Projections (60Km), which is beneficial as they could contain more drought information; particularly for catchments that depend on orographic rainfall which are prevalent in north west England and Wales. While the Regional Climate Model Projections are spatially coherent, they were only available at RCP 8.5 (when completing the climate change assessment for this plan), which is the highest emission trajectory included in UKCP18. Therefore, in order to understand the full range of possible climate change impacts, the Probabilistic Projections were also used to provide inputs to our target headroom assessment.

7.2.2 Impact on water availability

The new climate change (Tier 3) assessment for the Strategic and Carlisle Resource Zones, as described above, began with calculating the impact on water availability using climate change factors, hydrological and groundwater models.

A total of 3112 UKCP18 climate change projections were processed to derive climate change factors representing the 2061-2080 future period (Table 22). The Regional Climate Data Tools project undertaken by Atkins provided 'bias corrected' and 'raw' future climate change factors based on Regional Climate Model (RCM) Projections under RCM 8.5 and HadUK precipitation and average daily temperature. The latter was then used to determine a corresponding set of Potential Evapotranspiration (PET) factors. While the bias corrected change factors are similar to the raw factors, they have two main advantages:

(1) Bias corrected factors will be used by most companies in England as they have been provided as part of the Atkins Regional Stochastics project, so by using them in our climate change assessment, the results will align with potential water transfers or regional partners; and,

(2) The bias corrected data are consistent with the HadUK observations and also provide time series that can be used for other modelling applications

Figure 26 and Figure 27 compare the bias corrected and raw factors for the Alwen basin demonstrating their similarity, and the advantage of the bias corrected factors shown by the raw and bias corrected annual average temperature time series.

Figure 26 Comparison of bias corrected monthly change factors (red) and raw factors (black) for the Alwen basin for precipitation (pr) and average temperature (tas)

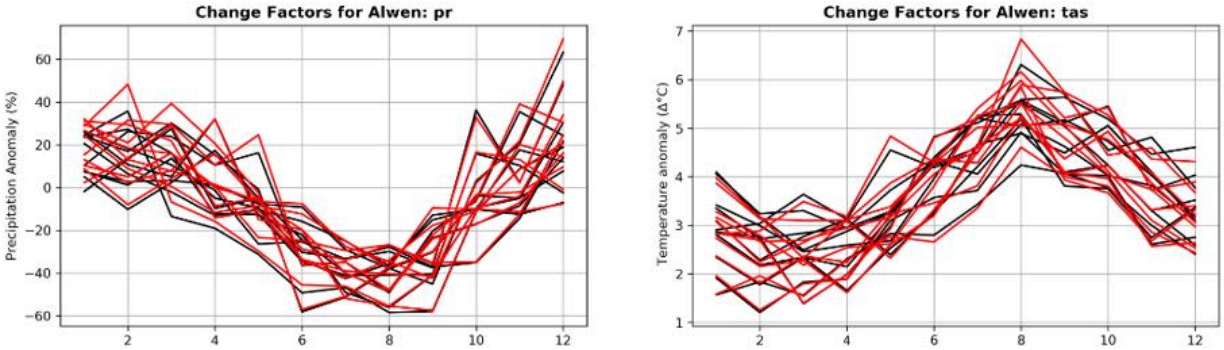
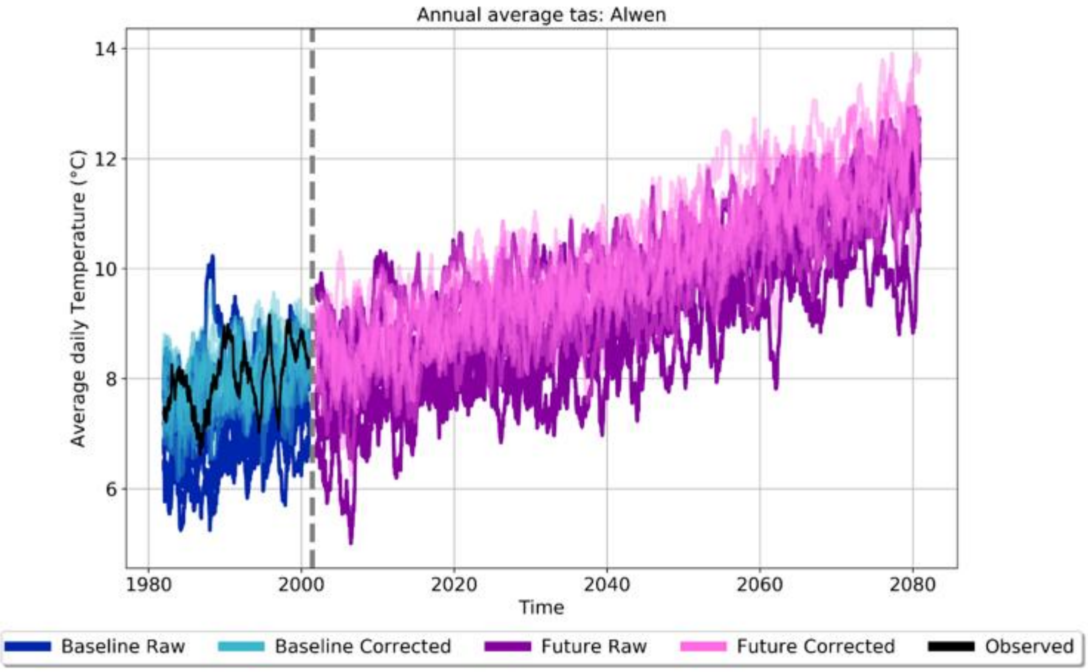


Figure 27 Bias corrected time series for the Alwen basin, highlighting underlying errors in the raw data, which is too cool for the baseline period



Additionally, climate change factors were derived for our groundwater catchments using the same methodology from the Regional Climate Data Tools project.

As part of the Regional climate Data Tools project 100 Probabilistic Projections for the England and Wales (E&W) region were provided to Water Resources West companies to ensure spatial coherence and facilitate assessments of water transfer options. In addition, climate change factors for 3000 Probabilistic projections for the North West England (NWE) river basin were also derived. Factors for E&W have been widely used for the purposes of regional planning, but the NWE factors may better encapsulate the climatology of the region and of our water resource zones. Water resource models were run with the 100 E&W projections to inform sampling down to 20 projections. This was also based on the representativeness of the distribution of system response from the 3000 NWE projections. Table 22 is a summary of UKCP18 Climate change datasets used in the detailed assessment.

Table 22 Summary of UKCP18 Climate change datasets used for Tier 3 climate change assessment

Product	UKCP18 Regional Climate Model Projections	UKCP18 Probabilistic Projections
Source	Bias corrected monthly change factors for x12 projections provided by Atkins via the Regional Climate Data Tools Project[18]	x100 England and Wales (E&W) projections[19] x20 E&W sampled from 100 E&W[20] x3000 projections for the North West England (NWE) river basins[21]

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[18] Regional Climate Data Tool, Atkins, February 2021

[19] Data for 100 Probabilistic projections were provided to WRW as part of the Regional Climate Data Tools project completed by Atkins. These were for the England and Wales (E&W) region to ensure spatial coherence across England and Wales, which is important if these scenarios are used to test Strategic Resource Options (SROs) of national importance.

[20] Sampling based on simulated system response of x100 E&W projections and representativeness of the distribution of results from x3000 NEW projections.

[21] 3000 NEW river basin projections were also extracted. Although these lack the required spatial coherence for regional planning, they are thought to best encapsulate the climatology of UUW river basins and are therefore useful for examining the full range of UKCP18 impacts.

Product	UKCP18 Regional Climate Model Projections	UKCP18 Probabilistic Projections
RCP	8.5	8.5
Time horizon	2061-2080	2070s
Climate variables	Average temperature, precipitation and potential evapotranspiration	

The climate change factors representing the climate for the 2061-2080 future period were used to perturb our historical climate data for the 1981-2000 baseline reference period and our stochastic climate data[22]. Surface water hydrological rainfall run-off models were then run to simulate flow in the future period using the perturbed climate data. These flows were compared with the simulated baseline flows to calculate catchment monthly flow factors for each climate change projection. The monthly flow factors were then used to perturb inflows for water resource system models.

A similar process was undertaken using a smaller number of climate change scenarios[23] and groundwater models to derive perturbed historical and stochastic groundwater yields (further details provided in Section 8.2.3.1). Both the climate change perturbed surface water inflows and groundwater yields were then implemented into water resources system models to calculate the impact of climate change on future water supply.

7.2.3 Impact on water supplies

Our suite of water resource models was used to calculate the potential impacts of climate change on future water supply. The first step in the modelling process, summarised in Figure 30, involved a rapid simulation of the full dataset of perturbed stochastic surface water inflows for all 3,112 climate change scenarios (19,200 x 3,112) in the Strategic Resource Zone Pywr model. The model was run at a fixed demand[24], which made it possible to run all 3,112 climate change scenarios with the full stochastic dataset (requiring the simulation of 60.3 million years of daily data). The frequency of Emergency Drought Order implementation at this demand, based on sources reaching dead water, was used to rank the different scenarios of each climate change product (i.e. the ranking of the 12 RCMs only considered the results of each RCM simulated) based on system response. The probability of exceedance for each return period was then calculated from the ranking (Figure 28). These results were primarily used to sample an appropriate selection of scenarios based on system response for more detailed modelling, but they also demonstrate the potential differences in system response from each climate change product. Figure 28 shows that the RCMs are the most severe projections followed by the 100 E&W Probabilistic Projections selected for regional planning and the 3000 NWE Probabilistic Projections. The NWE projections may be more representative of the likely climate change to be experienced in North West England. Therefore, to retain the regional effects while remaining consistent with other companies, the distribution of the 3000 NWE projections to inform sampling of the 100 E&W projections down to 20. The 20 E&W Probabilistic Projections and either all 12 or five RCMs, evenly spread across the distribution, were taken forward for the more computationally intensive groundwater and detailed Hydro-Logic® Aquator simulations.

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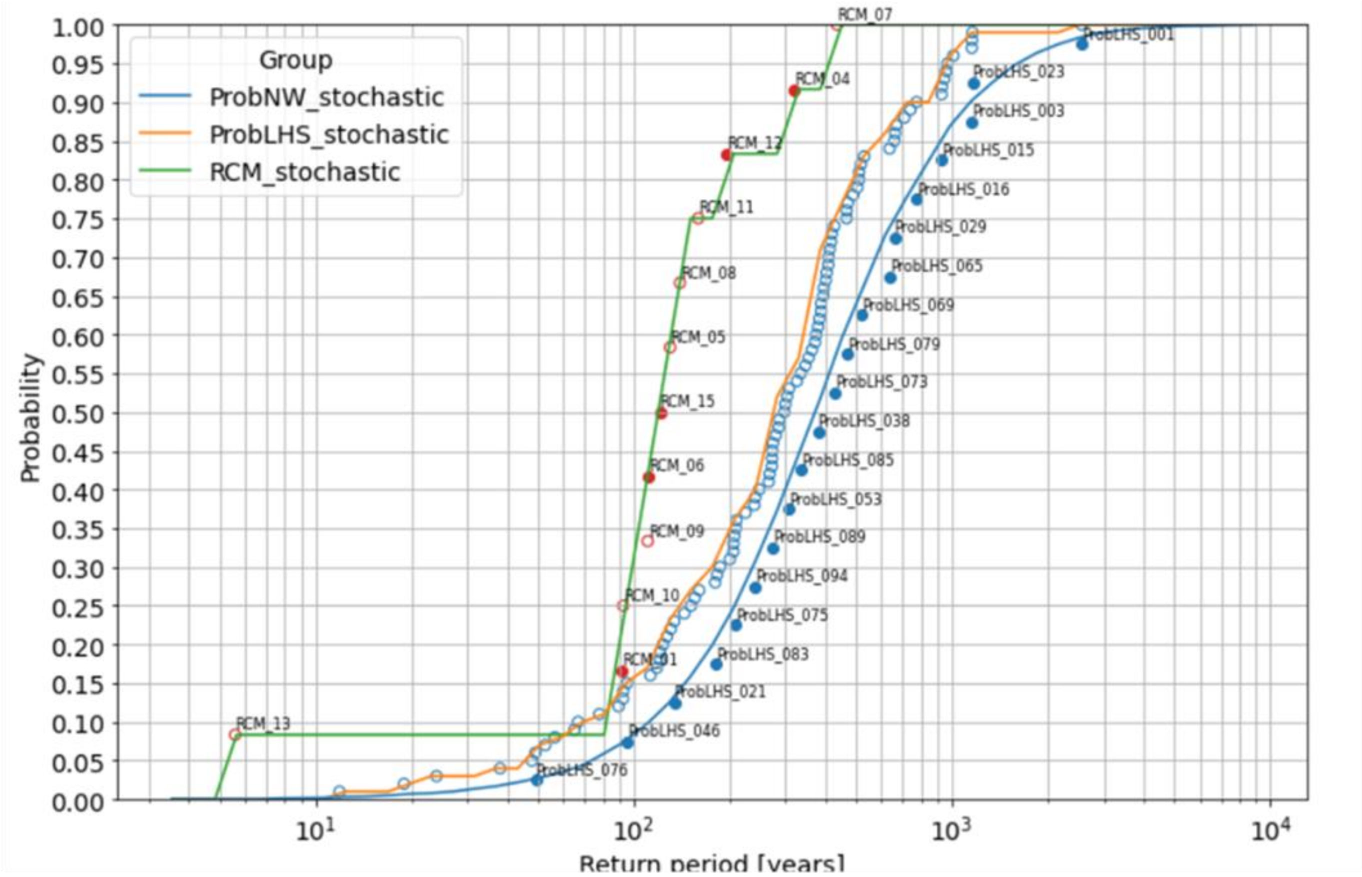
[22] Our stochastic weather data, generated by the Atkins Regional Climate Data Tools Project, is 400 model replicates of the 1950-1997 climate providing a 19,200-year stochastic weather dataset, which enables the assessment of resilience to 1 in 500-year drought events. Using this data, Atkins subsequently produced a stochastic flow dataset.

[23] A smaller number of climate change scenarios were used due to computational limitations of the groundwater models.

[24] It was infeasible to carry out full Scottish DO runs with all 3112 climate change scenarios and the full stochastic dataset within the timeframe set for delivering the climate change assessment.

Figure 28 Distribution of EDO return period for all climate scenarios, simulated at a demand of 1800 Ml/d. ProbLHS_stochastic refers to the 100 selected WRW factors for E&W, the solid blue circles show the ProbLHS scenarios once mapped to the distribution of the 3000 ProbNW scenarios



7.2.3.1 Groundwater modelling

To assess potential changes in groundwater levels under various UKCP18 climate change projections and identify any reductions in peak and average groundwater source deployable outputs, both GR3 and GR1 groundwater models were used depending on what model was available for a particular groundwater source and the level of vulnerability. The Environment Agency's GR3 regional groundwater models are complex, and there are four available covering our region: Lower Mersey, East Cheshire, Fylde and Wirral. The following runs were undertaken for the GR3 models:

- Historical climate data perturbed with five RCMs (evenly spread across the distribution of 12 RCMs)
- Five stochastic replicates, individually selected to contain an event with a system response of 1 in 500 years, were perturbed with the five RCMs sampled

The GR1 models are simpler, Multiple Linear Regression (MLR) models, which relate historical precipitation to groundwater level minima by generating MLR relationships based on historic weather and groundwater level data. GR1 modelling was completed for ten source groups, each with its own MLR model. The impacts of climate change were only assessed for eight out of the ten source groups, as the remaining two (North and South Eden) form part of the North Eden Resource Zone, which was classified as 'low vulnerability' in the Basic Vulnerability Assessment (hence a new climate change assessment is not required). The following runs were undertaken for the GR1 models:

- Historical climate data perturbed with 100 E&W Probabilistic Projections and 12 RCMS
- Ten stochastic replicates, individually selected to contain an event with a system response of 1 in 500 years, were perturbed with 20 E&W Probabilistic Projections and 12 RCMS

The models were run with the perturbed climate data to assess the impact on groundwater levels. Groundwater level changes were then used to estimate the impact on groundwater deployable outputs. The DO values for the climate scenarios were compared to the baseline average and peak DO values as defined by our AMP8 yield review (Section 4.3.3) to quantify any impact, so that these could be included in the Strategic Resource Zone water resource models[25].

Both the GR3 and GR1 modelling identified a small number of borehole sources with potential DO variability caused by changes in climatic inputs when compared to the baseline (AMP8 yield review). However, this did not result in a change in DO entered into in the water resource models groundwater nodes as the overall site DO could still be achieved by operating boreholes in combination with others, or the minimum DO was still greater than downstream operational constraints such as the maximum capacity of the associated water treatment works (WTW) (Table 23). Therefore, no decreases to deployable outputs were required, and no changes were made to the AMP8 average and peak deployable outputs included in the water resource models due to climate change[26].

Table 23 Example of GR1 source DO modelling

Hydro-Logic® Aquator DO (Ml/d)	Average/Peak DO	AMP8 yield review DO Ml/d	Groundwater source	Min DO of climate scenarios Ml/d	50% Ml/d	Max Ml/d	Potential DO loss (AMP8 DO minus combined Min DO of climate scenarios)
Peak DO 11.2 WTW Max 9.5	DrPkDO[27]	3.8	Thorncliffe Road	3.8	3.8	3.8	0
	DrPkDO	3.7	Schneider Road 3	3.25	3.7	3.7	0.45
	DrPkDO	3.7	Schneider Road 1	2.6	3.7	3.7	1.1
	Combined operational DO	11.2	Combined	9.65	11.2	11.2	1.55
	Water resources model DO			Despite the potential loss in peak DO of 1.55 Ml/d across the climate scenarios there is no loss into supply due to a WTW constraint of 9.5 Ml/d (1.7 Ml/d less than the source DO). This also constrains any impact on average deployable output. No change was made to the water resource models.			

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[25] There are no groundwater sources in the Carlisle or Barepot Resource Zones and the impact of climate change on groundwater sources in North Eden is not required due to the zone being identified as low vulnerability as a result of the Basic Vulnerability Assessment

[26] During the GR3 assessment of Fylde boreholes a 0.3 Ml/d reduction to the baseline deployable output for Franklaw_B_P1 borehole was identified and made to the GW2 borehole Hydro-Logic® Aquator component. The maximum simulated depth differed from the baseline AMP8 yield review. No further reduction due to climate change was required since the source can achieve its baseline average and peak DO for all climate change scenarios.

[27] DrPkDO is an acronym for Drought Peak DO. These values are taken from the drought curve of the source summary diagrams after groundwater levels are perturbed.

7.2.3.2 Deployable output impact modelling

Strategic Resource Zone

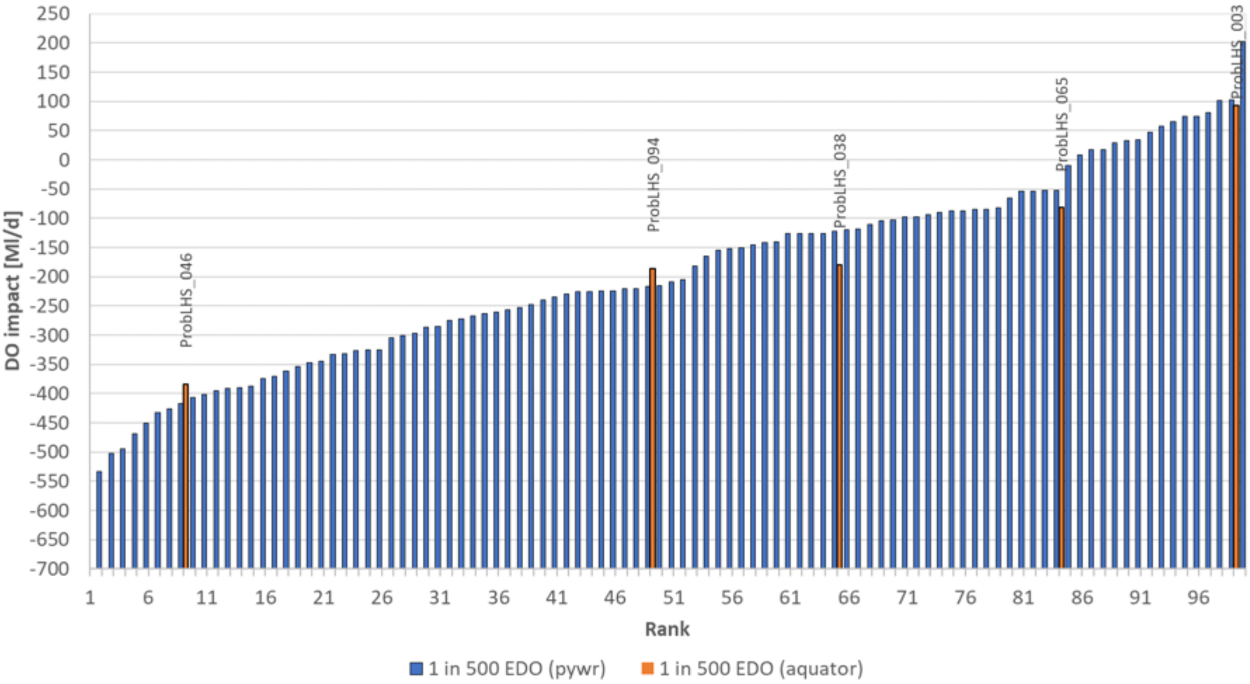
All 12 RCMs and 100 probabilistic projections were modelled in Pywr and five RCMs were modelled in Hydro-Logic® Aquator using the Scottish DO approach. Pywr was run with wider demand steps (50 Ml/d increments) for each RCM to show the full range of potential impacts of climate change on DO. In order to maximise the precision of the final DO impact, Aquator was run at much finer demand increments (<20 Ml/d), but for only five RCMs, which were selected from the initial round of Pywr modelling. All modelling was completed using the full 19,200-year stochastic hydrology dataset. The DO results were compared to baseline DO to calculate the impact of climate change for each scenario. The DO impacts from each model were ranked according to 1 in 500 DO impact in order to identify the median scenario. RCM_06 and RCM_15 were selected as the median scenarios based on both sets of results (Table 24).

Table 24 Final RCM DO results for Pywr and Hydro-Logic(R) Aquator. The median scenario from the scenario sampling and Aquator results is in bold

Rank	Scenario	Pywr 1 in 500 EDO DO impact (Ml/d)	Hydro-Logic® Aquator 1 in 500 EDO DO impact (Ml/d)
N/A	Baseline		
1	RCM_13	-592	
2	RCM_10	-391	
3	RCM_01	-390	-381
4	RCM_05	-299	
5	RCM_08	-297	
6	**RCM_15**	**-276**	**-226**
7	**RCM_06**	**-257**	**-215**
8	RCM_11	-245	
9	RCM_09	-241	
10	RCM_12	-224	-202
11	RCM_04	-90	-79
12	RCM_07	-88	

Figure 29 shows the final ranked DO impact results from modelling the 100 E&W Probabilistic Projections in Pywr and Hydro-Logic® Aquator. The rank of the median selected scenario is 65/100. This scenarios was selected based on the distribution of the less severe NWE projections, and is similar to the initial ranking based on the rapid Pywr run at fixed demand. The DO impact of ProbLHS_038 is -122 Ml/d in Pywr and -180 Ml/d in Aquator.

Figure 29 DO impact for Pywr and Hydro-Logic® Aquator Probabilistic results



Abstraction from the River Dee catchment is governed by rules referred to as the 'Dee General Directions' (DGD), which are agreed between abstractors and Natural Resources Wales (NRW). During dry conditions, abstraction 'cut-backs' are progressively applied to protect Dee catchment reservoir storage and maintain regulation of the river. In the future, these cutbacks may need to be reduced due to climate change. For WRMP19, NRW simulated the impacts of climate change (UKCP09 projections) on the Dee system and then provided water companies with reduced cutbacks to incorporate into their climate change deployable output (DO) assessments. Unfortunately, updated UKCK18 cutbacks were not available in time for United Utilities' WRMP24 assessment. However, by including climate change perturbed Dee inflows, the United Utilities Hydro-Logic® Aquator and Pywr water resources models in effect applied their own cut-backs in response to the reduced inflows and a corresponding decrease in 'resource state'. Resource state is used by the models to allocate abstraction to sources in dry conditions.

Subsequent to the assessment, NRW provided a single cut-back of 26% (specifically, a 26% reduction to the 'safe yield' and then retain the same offsets to the Stages 1-3 cut-backs) to apply to the median climate change projection. Unfortunately, it was too late in the WRMP programme to repeat the six-month duration climate change assessment, and in any case further cut-backs would have been required from NRW for other projections too. Therefore, sensitivity testing was performed using the median projection to check if the Hydro-Logic® Aquator water resources model had effectively cut back abstraction. DO was calculated with the 26% DGD reduction in place and compared to the original result. As expected, this showed that the model had largely applied the NRW cut-back. There was a minor additional impact of the NRW cut-back of 14 Ml/d (RCP8.5 in 2070). Once scaled to RCP6.0 and across the planning period, the impacts ranged between 2.6-4.8 Ml/d from 2025-2050 respectively. The range was applied as a correction to the climate change DO impact in the Strategic Resource Zone supply-demand balance to ensure the assessment was in line with NRW's modelling.

Carlisle Resource Zone

All 12 RCMs and five Probabilistic Projections were modelled in Aquator using the Scottish DO approach and full stochastic hydrological dataset. It was feasible to model all 12 RCMs in the Carlisle Resource Zone Aquator model as it is much smaller in scale and not as computationally expensive to complete the runs compared to the Strategic Resource Zone model. The DO results were compared to baseline DO to calculate the impact of climate change for each scenario. The impacts on 1 in 500 DO are shown in Table 25. The median RCM impact was -0.45 Ml/d and the median Probabilistic impact was -0.4 Ml/d.

Table 25 Carlisle Resource Zone Hydro-Logic® Aquator DO impact from climate change. The median scenarios are in bold.

Climate change projection	1 in 500 DO impact (Ml/d)
RCM_01	-1
RCM_04	+0.3
RCM_05	-1.3
RCM_06	-0.8
RCM_07	+0.6
RCM_08	-0.6
RCM_09	-0.2
RCM_10	-0.3
RCM_11	0
RCM_12	-1.5
RCM_13	-1.4
RCM_15	-0.1
ProbLHS_003	+1
ProbLHS_038	-0.4
ProbLHS_046	-1.9
ProbLHS_065	0.4
ProbLHS_094	-1.2
Minimum (all 10 scenarios)	-1.9
Maximum (all 10 scenarios)	+1.0
Median (5 ProbLHS)	-0.4
Median (12 RCM)	-0.45

North Eden

Climate change impacts on water availability in the North Eden Resource Zone were not reassessed for this plan based on the categorisation of the zone as having low vulnerability to climate change, and no significant differences found from the rapid assessment of UKCP09 and UKCP18 climate change projections. As such, the results of the WRMP19 climate change assessment have been reused in this plan. For WRMP19 the assessment was based around assessing groundwater yields under 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.

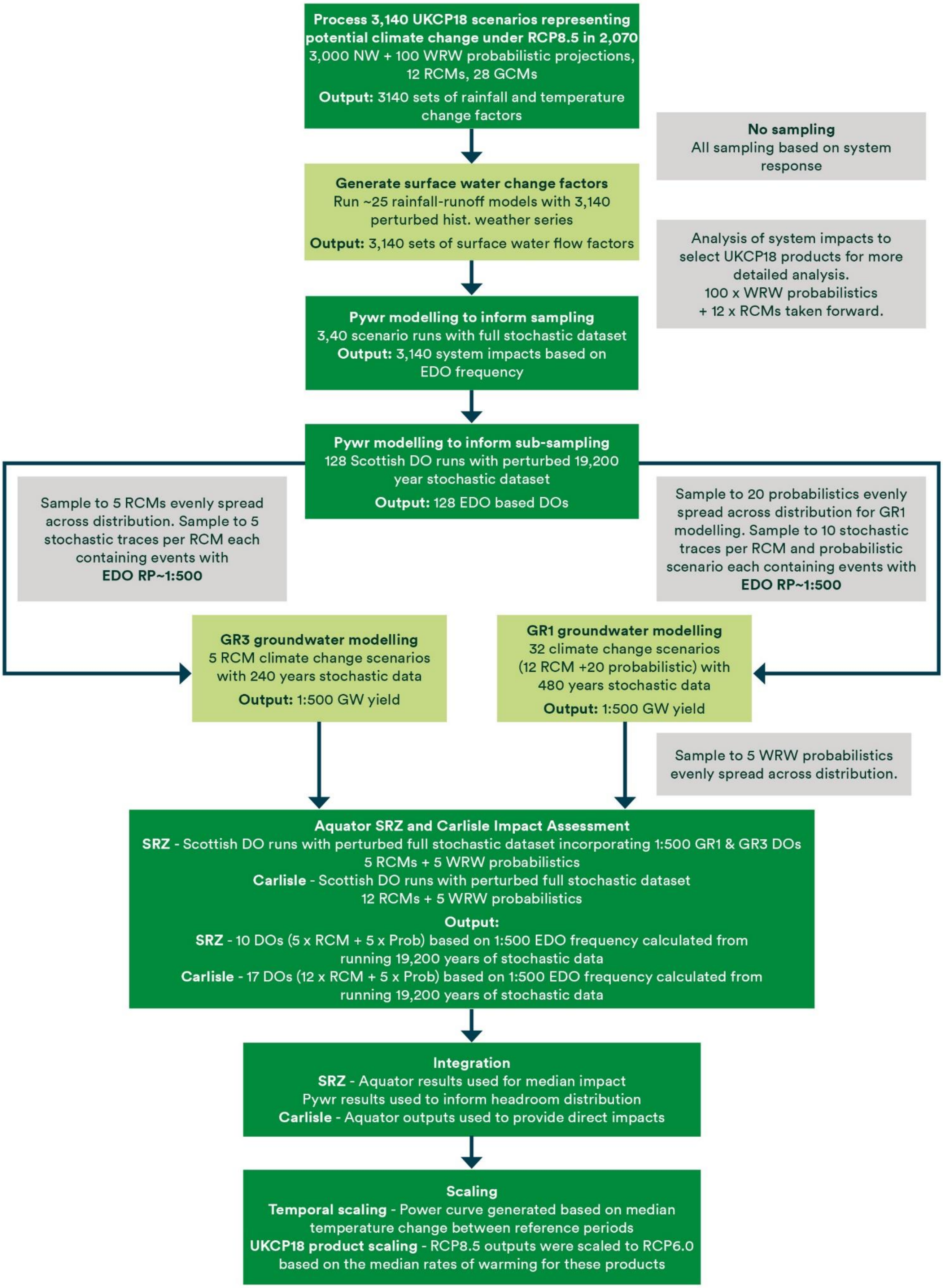
Barepot

Climate change impacts on water availability in the Barepot Resource Zone were not reassessed for this plan based on the categorisation of the zone as having low vulnerability to climate change, and no significant differences found from the rapid assessment of UKCP09 and UKCP18 climate change projections. For the WRMP19 climate change assessment for this 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. Work completed for the Final Drought Plan 2022 also concluded that the resource zone was resilient to climate change. Therefore, the climate change impacts are not a constraining factor on the resource zone deployable output of 34.1 Ml/d.

Outcome

The first three stages of the climate change assessment (outlined in Section 8.1) have shown that the Strategic and Carlisle Resource Zones are vulnerable to future climates, while the North Eden and Barepot Resource Zones are not, similarly to our WRMP19 climate change assessment. As such, the median RCM climate change impacts for the Strategic and Carlisle Resource Zones were then taken forward for scaling and integration into our WRMP24 supply forecast. The DO results of the Probabilistic scenarios modelled provided a distribution of impacts for our target headroom assessment (*WRMP24 Technical Report – Allowing for uncertainty*).

Figure 30 Summary of modelling workflow for assessing climate change



Process 3,140 UKCP18 scenarios representing potential climate change under RCP8.5 in 2,070
3,000 NW + 100 WRW probabilistic projections, 12 RCMs, 28 GCMs
Output: 3140 sets of rainfall and temperature change factors

No sampling
All sampling based on system response

Generate surface water change factors
Run ~25 rainfall-runoff models with 3,140 perturbed hist. weather series
Output: 3,140 sets of surface water flow factors

Analysis of system impacts to select UKCP18 products for more detailed analysis.
100 x WRW probabilistics + 12 x RCMs taken forward.

Pywr modelling to inform sampling
3,40 scenario runs with full stochastic dataset
Output: 3,140 system impacts based on EDO frequency

Pywr modelling to inform sub-sampling
128 Scottish DO runs with perturbed 19,200 year stochastic dataset
Output: 128 EDO based DOs

Sample to 5 RCMs evenly spread across distribution. Sample to 5 stochastic traces per RCM each containing events with **EDO RP~1:500**

Sample to 20 probabilistics evenly spread across distribution for GR1 modelling. Sample to 10 stochastic traces per RCM and probabilistic scenario each containing events with **EDO RP~1:500**

GR3 groundwater modelling
5 RCM climate change scenarios with 240 years stochastic data
Output: 1:500 GW yield

GR1 groundwater modelling
32 climate change scenarios (12 RCM +20 probabilistic) with 480 years stochastic data
Output: 1:500 GW yield

Sample to 5 WRW probabilistics evenly spread across distribution.

Aquator SRZ and Carlisle Impact Assessment
SRZ - Scottish DO runs with perturbed full stochastic dataset incorporating 1:500 GR1 & GR3 DOs
5 RCMs + 5 WRW probabilistics
Carlisle - Scottish DO runs with perturbed full stochastic dataset
12 RCMs + 5 WRW probabilistics
Output:
SRZ - 10 DOs (5 x RCM + 5 x Prob) based on 1:500 EDO frequency calculated from running 19,200 years of stochastic data
Carlisle - 17 DOs (12 x RCM + 5 x Prob) based on 1:500 EDO frequency calculated from running 19,200 years of stochastic data

Integration
SRZ - Aquator results used for median impact
Pywr results used to inform headroom distribution
Carlisle - Aquator outputs used to provide direct impacts

Scaling
Temporal scaling - Power curve generated based on median temperature change between reference periods
UKCP18 product scaling - RCP8.5 outputs were scaled to RCP6.0 based on the median rates of warming for these products

7.2.4 Integrating results into WRMP24

The key outputs of our impacts modelling were RCM climate change impacts at RCP 8.5 for 2070 for the Strategic and Carlisle Resource Zones. RCP 8.5 is the highest emission scenario of those available in UKCP18 data, with RCP 6.0 thought to be the nearest equivalent to the medium emissions scenario used by most water companies for WRMP19. Our choice of emission scenario for WRMP24 was carefully considered in the context of pertinent literature (e.g. the third Climate Change Risk Assessment, CCRA[28]) and discussed within our regional planning group (WRW). RCP 6.0 was selected, based on its representativeness of the range of warming predicted based on current commitments and ambitions on global warming, and for consistency with WRMP19. The UKCP09 medium emissions scenario is also being used for our Drainage and Wastewater Management Plan (DWMP), therefore, selecting RCP 6.0 for WRMP24 ensures consistency between subsequent water resource plans and also with our first DWMP.

Unfortunately, as mentioned previously, it was impossible to assess RCP 6.0 directly due to the lack of a spatially coherent UKCP18 product. Therefore, temperature-based scaling was used to translate the DO impacts from RCP8.5 to 6.0.

In addition to scaling climate change impacts to different emissions scenarios, in order to fully integrate them into the WRMP, they must also be scaled through the planning horizon; from the future reference period 2070, back to the start of the planning period, 2025. While the guidance continues to recommend a simple linear scaling method, this approach remains flexible, and alternatives can be explored. As such, scaling relationships based on temperature, derived by Atkins[29] for water companies in England and Wales, were used to estimate climate change impacts in scenarios for which water resources modelling was not undertaken (i.e. for other RCPs such as 6.0)[30] and to scale from 2070. Using this approach, the median RCM climate change impacts for RCP 8.5 were scaled to Probabilistic RCP 6.0 equivalent impacts, and from 2070 back to 2025.

Following scaling, median climate change impacts were input into resource zone supply-demand balances, which are summarised in Table 26 for key years in the WRMP24 planning horizon and beyond. Outputs from our water resources modelling utilising the 100 E&W probabilistic projections and the full stochastic dataset have fed into Target Headroom modelling to represent climate change uncertainty.

Table 26 Summary of Hydro-Logic® Aquator climate change impacts included in the WRMP24 supply forecast

Resource zone	Climate change 1 in 500 DO impact scaled to RCP 6.0 (Ml/d)[31]
Strategic	**-45 Ml/d** at the year 2025 **-82 Ml/d** at the year 2050 -**115** Ml/d at the year 2070
Carlisle	**-0.09** Ml/d at the year 2025 **-0.16** Ml/d at the year 2050 **-0.22** Ml/d at the year 2070
North Eden	N/A
Barepot	N/A

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[28] Betts, R.A. and Brown, K.(2021) Introduction. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A.,Haward, A.B. and Pearson, K.V.(eds.)]. Prepared for the Climate Change Committee, London.

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

[30] Noting spatially coherent RCMs were required for regional planning and were only available at the time of modelling for RCP8.5. Other RCPs were modelled using probabilistic projects, but only to inform sampling and Target Headroom uncertainty distributions.

[31] Values for the Strategic Resource Zone are inclusive of the subsequent Dee climate change assessment.

8. Water transfers

8.1 Existing transfers

We do not have any inter-resource zone water transfers that are used during normal operations, only a small number of inter-connections for emergency use only. All of our existing transfers are with neighbouring water companies and New Appointments and Variations (NAVs). We share water resources with other water undertakers. The quantities and transfer amounts are used to determine deployable output and WAFU and are not anticipated to change significantly during the course of the WRMP planning period. Details of all of our existing transfers are included in Table 27 and summarised below.

There are three water companies from which we import potable water to supply customers within our geographical area. These are: Hafren Dyfrdwy, Severn Trent Water Ltd and Northumbrian Water Ltd. The amounts imported from Hafren Dyfrdwy and Severn Trent Ltd are very small (<0.1 Ml/d) and are based on the FY19 (2018-19) dry year annual average amounts. In some cases, the actual transfer capacity may be higher (governed by either the inter-company agreement or by network constraints), which could impact resource zone DO and WAFU, however these transfers are so small they are insignificant to overall DO of the Resource Zone. The import from Northumbrian water Ltd. into our North Eden Resource Zone is larger and the amount included within this plan is the maximum amount (1.3 Ml/d) stated in the inter-company contract. We contacted the other water companies and they confirmed the amounts we specified are mirrored in their WRMP tables.

We also export raw and potable water to eight companies including: Dŵr Cymru Welsh Water, Hafren Dyfrdwy, Northumbrian Water Ltd, Severn Trent Water Ltd, ESP Water Ltd, Leep Water Networks Ltd, Icosa Water Services Ltd and Independent Water Networks Ltd. Within our region, ESP Water Ltd, Leep Water Networks Ltd, Icosa Water Services Ltd and Independent Water Networks Ltd operate as Inset Appointees.

Our largest export is to Dŵr Cymru Welsh Water and the amount stated is based on contractual maximum (28 Ml/d), which we have confirmed is mirrored in each company's plan for WRMP24. This raw water export and some of our other non-potable bulk supplies (109.3 Ml/d in total based on WRMP24 Dee non-potable demand forecast, of which 28 Ml/d corresponds to the export to Welsh Water) are supplied from the River Dee and are included in the Hydro-Logic® Aquator and Pywr models for the determination of deployable output for the Strategic Resource Zone. This means that we can be sure that this quantity of water can be reliably supplied at this point in the network during 1 in 500-year drought events. All of our potable exports are much smaller (<1 Ml/d per individual connection), and the amounts are based on the FY19 dry year annual average or recent average provided by our Market Services Team; and for recently appointed (New Appointments and Variations (NAV)) connections, the amount is based on our WRMP24 Per-Household Consumption (PHC) forecast.

All of our existing continuous imports and exports are uni-directional in the direction stated in Table 27. There have been no changes to infrastructure since our last plan which affect the quantity of the water being transferred. We also have a number of emergency-only connections, however, these are not included in deployable output and WAFU, since they are only used by exception.

Since our last plan, we have aligned our potable water exports and baseline and final plan demand forecast with NAV revised draft WRMPs (Table 1 and 18). When a new NAV connection (export) has been approved, the Drinking Water Safety Plan for the supplying water supply zone is reviewed. This has involved collating and supplying information on the chemical quality of water being transferred to the inset appointee.

Table 27 Summary of existing import and export arrangements with other water companies and NAVs

Water undertaker	Resource Zone	Amount (Ml/d)	Information	Change since our 2019 plan
Imports				
Hafren Dyfrdwy	Strategic	<0.1	Potable supply, Crewe by Farndon	Average transfer amount updated using FY19 dry year annual average reported data
Severn Trent Water Ltd	Strategic	<0.1	Potable supply, Mow Cop	Average transfer amount updated using FY19 dry year annual average reported data
Severn Trent Water Ltd	Strategic	<0.1	Potable supply, Oven Hill Road	Average transfer amount updated using FY19 dry year annual average reported data
Northumbrian Water Ltd	North Eden	1.3	Potable supply from Burnhope Reservoir. Based on contractual maximum amount	No change to contractual maximum amount
Exports				
Dŵr Cymru Welsh Water	Strategic	28.0	Raw water transfer from the River Dee at Heronbridge	No change to contractual maximum amount
Hafren Dyfrdwy[32]	Strategic	<0.1 Ml/d	Potable supply Bowens Hall Farm	Average transfer volume updated based on information from Market Services Team
Severn Trent Water Ltd[33]	Strategic	<0.1 Ml/d	Potable supply Congleton Edge Rd	Average transfer amount updated using FY19 dry year annual average reported data
Severn Trent Water Ltd	Strategic	0.20 Ml/d	Potable supply from Huntington WTW to Chester Resource Zone	Assumed to start from 2025. Operational requirement
Icosa Water Services Ltd.	Strategic	1.66 Ml/d	Potable supply Bolton	23 NAV connections (Icosa Table 18)
Independent Water Networks Ltd.	Strategic	2.70 Ml/d	Potable supply at multiple locations	52 NAV connections (IWNL rdWRMP24 Table 18)
Independent Water Networks Ltd.	North Eden	<0.1 Ml/d		1 NAV connection (IWNL rdWRMP24 Table 18)
ESP Water Ltd.	Strategic	0.52 Ml/ds		6 NAV connections (ESP rdWRMP24 Table 18).

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[32] At WRMP19 there was an additional continuous export to Hafren Dyfrdwy of 1.2 Ml/d at Gredington. Hafren Dyfrdwy has since confirmed that this connection is now an emergency-only connection. The Gredington connection has therefore, been excluded for this plan.

[33] At WRMP19 there was an additional continuous export to Severn Trent Water Ltd of 0.3 Ml/d at LLanforda. Seven Trent Water Ltd has since confirmed that this connection would be used by exception, during emergencies only. The LLanforda connection has, therefore, been excluded for this plan.

Water undertaker	Resource Zone	Amount (Ml/d)	Information	Change since our 2019 plan
Leep Water Networks Ltd	Strategic	1.85 Ml/d	Potable supply Inset Appointee for: • Media City UK • Liverpool International Business Park • No.1 Old Trafford • Ten other sites (each 500 properties or less)	24 NAV connections (Leep rdWRMP24 Table 18)
Northumbrian Water Ltd	Carlisle	<0.1 Ml/d	Potable supply Raeygarth	Average transfer amount updated using FY19 dry year annual average reported data

8.1.1 Operation of imports and exports during 1 in 500-year events

Section 8.1 describes our existing imports and exports during normal operation, but we must also consider the operation of any water transfers during 1 in 500-year drought events for this plan. During times of drought where water use restrictions have been implemented for customers within our region, ESP Water Ltd, Icosa Water Services Ltd, Independent Water Networks Ltd and Leep Water Networks Ltd have agreed to work with us on a co-ordinated response, further information is provided in Table 28. For all other connections customers would be subject to water use restrictions imposed by the company who they pay their bill to, rather than the company that physically supplies their water.

Table 28 Summary of water use restrictions implementation for NAVs

NAV	Extract from NAV Drought Plan
ESP Water Ltd	Before proceeding with a TUB, we must be satisfied that our supply system “is experiencing, or may experience, a serious shortage of water for distribution” in accordance with the legislation. We will work with the incumbent water company and other relevant bodies in England to review the drought situation; we will assess the water saving benefits of a TUB relative to any benefits already achieved through requests made at Level 1 to customers to maximise water conservation efforts. In line with legislation and best-practice guidance and, in tandem with the Incumbent water company, we will publicly announce our intention to introduce a TUB and provide customers and stakeholders with a 2 or 3-week period for making any representations on the uses of water to be included in the ban and our proposed exemptions and concessions. Details on how representations may be made will be included in the formal legal notice to be published on our website (as well as being advertised in local newspapers, as required by legislation). In our discussions with the Incumbent water company, we will consider all representations that we have received to ensure a consistency of approach as far as is possible.

NAV	Extract from NAV Drought Plan
ICOSA Water[34]	Temporary use ban restrictions would be imposed for the minimum period required (such period to be determined in consultation with the regional incumbent water company) and would be lifted with immediate effect once the situation had stabilised. Icosa Water will mirror the relevant regional incumbent water company's implementation of non-essential use drought orders.
Independent Water Networks Ltd[35]	Implementation of TUBs will only occur following confirmation from our incumbent supplier that they are implementing TUBs; this is to ensure there is appropriate consistency of messaging and approach to avoid confusion for customers. IWNL will mirror our incumbent water supplier about the implementation of NEUBs under the Drought Direction 2011. IWNL will mirror our incumbent water supplier extreme drought management actions where we can, for example match the release date of shared customer communication.
Leep Water Networks Ltd[36]	LWNL will work with the bulk supplier to ensure a co-ordinated response to protect both customers and the environment. In line with legislation and best-practice guidance and, in tandem with the bulk supplier, we will publicly announce our intention to introduce a Temporary Use Ban and provide customers and stakeholders with a three week period for making any representations on the uses of water to be included in the ban and our proposed exemptions and concessions. The Temporary Use Ban will be lifted in tandem with the relevant bulk supplier when water resources have returned to a normal level of risk.

During drought conditions we plan to maintain exports to neighbouring water companies and Inset Appointees/NAVs for as long as possible; however, during an extreme drought it may be necessary to reduce the supply. This would be considered as part of all potential extreme drought measures detailed in Appendix K or our Final Drought Plan 2022[37]. If it was considered necessary to vary the maximum rate of flow, the receiving water company would be consulted, in line with any dry weather conditions present within the contract covering the connection.

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[34] https://www.icosawater.co.uk/useful-information/

[35] https://www.iwnl.co.uk/help-and-advice/drought-plan/

[36] https://www.leeputilities.co.uk/regulatory-statements

[37] https://www.unitedutilities.com/corporate/about-us/our-future-plans/water-resources/drought-plan/

9. Outage allowance

In our analysis of forecasting the supply-demand balance for each of our water resource zones, we need to make allowances for outages. These are short-term reductions in asset capacities, which will occur from time to time and which may temporarily reduce the supply capacity of our system.

Outages occur for a variety of reasons such as seasonal and event-driven deterioration in raw water quality, asset failure (requiring emergency repairs), essential routine maintenance, pollution events, and third-party impacts. Outages may be planned, such as scheduled maintenance and asset upgrades, or unplanned. Where planned, a risk assessment is undertaken for each outage request to consider hydrology, headroom, resilience and contingency. The outage planning process is designed to minimise the risk to water resources and the supply-demand balance while at the same time enabling essential repair and maintenance work to be undertaken.

9.1 Planned and unplanned outages

Outage allowance includes both planned and unplanned outages for all assets that have potential to impact supply system deployable output during severe drought events. This includes Impounding reservoirs, abstraction infrastructure, strategic raw water aqueducts, water treatment works and strategic potable aqueducts.

The various assets and outage event types included within outage allowance are summarised in Table 29.

Table 29 Water supply asset categories and outage events

Asset category	Planned/Unplanned Outage	Outage event
Abstraction infrastructure and pumping stations	Planned	Maintenance.
	Unplanned	Asset failure such as blockage of intake screens or failure of pumping stations.
Impounding reservoirs	Planned	Reservoir remedial works, as there will always be a programme of work at our reservoirs for maintenance and risk reduction projects.
	Unplanned	Unplanned reservoir remedial works based on experience of unplanned outages during AMP6 and AMP7 (FY16 –FY21).
Water Treatment Works (including boreholes)	Planned	Maintenance which would still occur during drought conditions, since not all planned maintenance can be deferred during a drought.
	Unplanned	Raw water asset failure, such as failure of a borehole pump.
	Unplanned	Potable water asset failure, such as failure of part of a treatment process.

Asset category	Planned/Unplanned Outage	Outage event
	Unplanned	Water quality, such as seasonal variations in water quality parameters which are outside of the treatment capability of a water treatment works.
Strategic potable aqueducts and pumping stations	Unplanned	Aqueduct burst risk and failure of pumping stations.

9.2 Planned capital programmes

For the majority of planned outage, we predominately calculate an allowance based upon our experience of planned outages during AMP6 and AMP7 (FY16 –FY21), 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.

A major change in the planning guidelines for WRMP24 is the requirement to plan for capital programmes of work, where any planned projects of greater than six months duration should be included directly within the supply-demand balance as a deployable output reduction, rather than within outage allowance.

At the time of data collection, there were no planned capital projects for the Barepot, Carlisle and North Eden Resource Zones. There were two large capital projects (longer than six months) planned for the Strategic Resource Zone:

- Vyrnwy Aqueduct Maintenance and Oswestry WTW programme, which is a legal undertaking with the Drinking Water Inspectorate to improve potable water quality.
- Haweswater Aqueduct Resilience Programme, which involves the replacement of all six tunnel sections along the length of the aqueduct and may require temporary outages to construct.

During data collection for WRMP24, both of these capital projects were still at the planning stage and, therefore, details of outages required to complete the projects are subject to change. The latest data available in December 2021 was used to inform water resource modelling to calculate the impact of these projects. In line with the water resource planning guidance, these impacts have been included within the supply-demand balance in the form of temporary deployable output reductions, rather than within outage allowance. A summary of the impact included within the supply-demand balance is provided in Table 21. This has increased slightly from our draft WRMP24 submission due to refinement of the available treatment work capacity during the outage which was subsequently remodelled for our revised draft submission.

Table 30 Deployable output reductions due to planned capital programmes

Capital Project	Deployable output reduction (Ml/d)	Duration	Comments
Vyrnwy aqueduct maintenance and Oswestry WTW programme	8	FY23 –FY29	The deployable output impact is based upon the 1 in 200 EDO level of service.

The water resource impact of the Haweswater Aqueduct Resilience Programme (HARP) has been assessed in line with the good practice principles and methodologies outlined in section 0. The Strategic Resource Zone is a conjunctive-use supply system whereby local sources operate in a conjunctive manner with the regional sources. The Aquator water resources modelling software has been used to calculate impact of HARP on deployable output (DO), in line with the method discussed in section 4.1. This method includes calculating the DO impact for all levels of service, such as; 1 in 20 Temporary Use Bans (TUBs), 1 in 40 TUBs, and 1:500 Emergency Drought Orders (EDO).

Specific plans for HARP are still being formulated with procurement scheduled to be completed in early 2024. Based on our current understanding of the requirements we applied the following assumptions:

- A partial flow restriction in the Haweswater Aqueduct;
- Duration of 10 weeks over summer (24th June to 1st September); and
- Applied during 2028, 2029 and 2030.

Based on the 1 in 20 and 1 in 40 TUBs metrics, there was no impact of HARP on DO, i.e. HARP is not expected to increase the frequency of TUBs. Based on the EDO metric there was an impact on DO of 8 Ml/d. These results demonstrate that the Strategic Resource Zone, with its conjunctive nature and significant volume of storage, can effectively mitigate this type of temporary outage.

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.

9.3 Methodology and assessment

9.3.1 Data sources

Our outage management process is underpinned by a comprehensive database of recorded outage events, known as the Production Outage Permit System (POPS). The system has been recording outages since late 2015, and we invested in a major upgrade to the system in 2020. Therefore, we have just over six years of outage data records to use in our calculation of outage allowance for WRMP24. This is an increase of four years compared to the available length of data record used in 2017 to calculate the allowance for our 2019 plan. The longer data set acts as an evidence-based substitution for some of the assumptions, based on local knowledge and expertise, which were included for the Strategic Resource Zone assessment in our 2019 plan. The POPS system is also used as the base data set for the derivation of our unplanned outage performance commitment.

A further source of information is our corporate system PIONEER, which is risk of failure software. PIONEER has been used to determine the burst risks on strategic raw and potable water mains. This covers strategic water mains which may not directly restrict the output of a single water treatment works, yet may have an effect on deployable output, due to the nature of the conjunctive supply system for the Strategic Zone. However, data on borehole failure from PIONEER has been excluded from the assessment to avoid double-counting, as this data is captured in the POPS database.

For the Carlisle and North Eden Resource Zones, data would also be gathered in POPs system for these RZs, however, due to the nature of the supply zones (i.e. sole supply sources to customers) it is rare for the assets to experience many outages or outages of a significant duration. Therefore, we have to rely on technical knowledge and local expertise, where the asset capacity or source deployable output is used to estimate the impact of individual outages. These capacities and deployable outputs have been updated to their AMP8 values, as collected as part of the Supply Forecasting work-stream.

9.3.2 Planning assumptions

During both data collection and subsequent derivation of the WRMP24 outage allowance, a number of planning assumptions have been made. These assumptions and their justification are summarised in Table 31.

Table 31 Planning assumptions for derivation of outage allowance for our resource zones

Planning assumption	Justification
The impact on deployable output does not directly equate to the total loss of production capacity at water treatment works	Deployable output is defined as the supply capability for a water resources system under specified conditions, as constrained by hydrological yield; licensed quantities; the environment (via licence constraints); abstraction assets; raw water assets; transfer and/or output assets; treatment capability; water quality; and levels of service, as defined by the Water Resources Planning Guidelines.
Extreme events such as catastrophic failure of Impounding reservoirs have been excluded.	The Water Resources Planning Guidelines[38] state that extreme events should not be considered within outage allowance.
Only legitimate outages are included	Not all outages cause a loss of deployable output, for example where an outage restricts the production capacity of a water treatment works, however the capacity remains greater than the source yield supplying the works. Further information on how legitimate outages are identified is included in Section 9.3.3.

9.3.3 Calculation of outage allowance

The impact on deployable output does not directly equate to the total loss of production capacity at water treatment works. For local sources (e.g. Pennines sources), the reduction in capacity is assessed against the latest assessments of source yield. However, the impact on deployable output at sources (e.g. Haweswater, Dee) has been assessed by modelling the effect of asset capacity reductions during a 1 in 500 drought scenario, using the Strategic Resource Zone Hydro-Logic® Aquator model. This is a key methodology change since the 2019 plan and involves determining average flows from a 1 in 500 deployable output run of the baseline Aquator model (using the 'Scottish' deployable output method, defined in section 4.1).The average flow is calculated from 'dead water' events which is defined by the average of all events from first crossing drought Level 1 (as per our Final Drought Plan 2022) to first hitting dead water at either Haweswater reservoir or River Dee system storage (Brenig and Celyn).

The outage allowance determined for our Water Resources Management Plan takes into account any outage events which would affect the ability to supply during a 1 in 500 'dry year' (termed legitimate outage events) and is determined in accordance with the Environment Agency's water resources planning guidelines. The guidance recommends the use of risk-based planning methods as set out in 'Risk-based planning methods' (UKWIR, 2016) and ' (UKWIR, Uncertainty and Risk in Supply & Demand Forecasting, 2002), and also following the guiding principles in 'Outage allowances for water resources planning' (UKWIR, 1995). The analysis uses a statistical technique known as Monte-Carlo simulation to combine probabilities of individual events, by multiple random sampling, into an overall probability distribution representing the combined impact of all potential events together.

For each water resource zone, the following steps are undertaken in order to calculate an outage allowance at an appropriate level of risk:

- Identify outages (planned and unplanned) that will have an impact on deployable output, as mentioned above these are termed legitimate outage events, or scenarios. An outage event is classed as legitimate if all four of the following criteria are met:
    - Is a source works impacted? **Yes**
    - Is the restricted output less than the local source yield or strategic source average flow during 1 in 500 drought events? **Yes**

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[38] (UKWIR, Outage allowances for water resources planning, 1995).

  - Is the loss non-recoverable? (For example, borehole and river abstractions are always non-recoverable. Whereas temporary outage at impounding reservoir sources can be recoverable since the lost production volume remains within the reservoir) **Yes**
  - Would this outage happen during a drought (some planned maintenance can be deferred during drought conditions) **Yes**
- Assign frequencies (probabilities) and durations to each category of outage, applied to individual source assets or groups of assets where appropriate. These form the parameters of probability distributions representing the range of likely impact of each outage and are based on known data from the POPS and PIONEER databases as referred to above, along with data from source yield reviews and local knowledge and expertise where appropriate.
- Carry out Monte-Carlo simulations to randomly sample the probability distributions defined as above for all the legitimate outage scenarios. Each iteration will generate an overall deployable output impact for the resource zone. The Monte-Carlo simulations are undertaken using the '@RISK' software add-on for Microsoft Excel and are repeated for a large number of iterations (100,000) in order to derive a probability distribution for deployable output reductions due to asset outages in the resource zone.
- Select a risk percentile and identify the corresponding Ml/d outage allowance from the combined probability distribution generated from the Monte-Carlo simulation. A combined distribution is calculated for each year across the planning period, and the risk percentile adopted may be constant or may vary as a profile if a higher level of risk is acceptable in future years.

9.3.4 Our percentile choice

In selecting the percentile from which to identify the outage allowance, we need to balance an appropriate level of risk management with a need to avoid over-investment in our supply system, taking into account the connectivity and flexibility of our supply system which allows us to minimise the impact of outage events. We have selected the 80th percentile (corresponding to a 20% risk) for the assessment of outage allowances for our 2024 Water Resources Management Plan, which is consistent with our 2019 plan. This percentile choice is in the middle of the range of 75% - 90% recommended in 'Risk-based planning methods' (UKWIR, 2016), and also aligns with the regional planning methodology agreed by the Water Resources West group for consistency between companies.

Figure 31, Figure 32 and Figure 33 show the sensitivity of our outage allowance values to the selected percentile from the relevant combined probability distributions, within the UKWIR range. The difference in outage allowance between the 80th and 90th percentile is around 6 Ml/d for the Strategic Resource Zone, so the sensitivity of our plan to the percentile selection is low.

Figure 31 Carlisle Resource Zone - Outage allowances at different percentiles

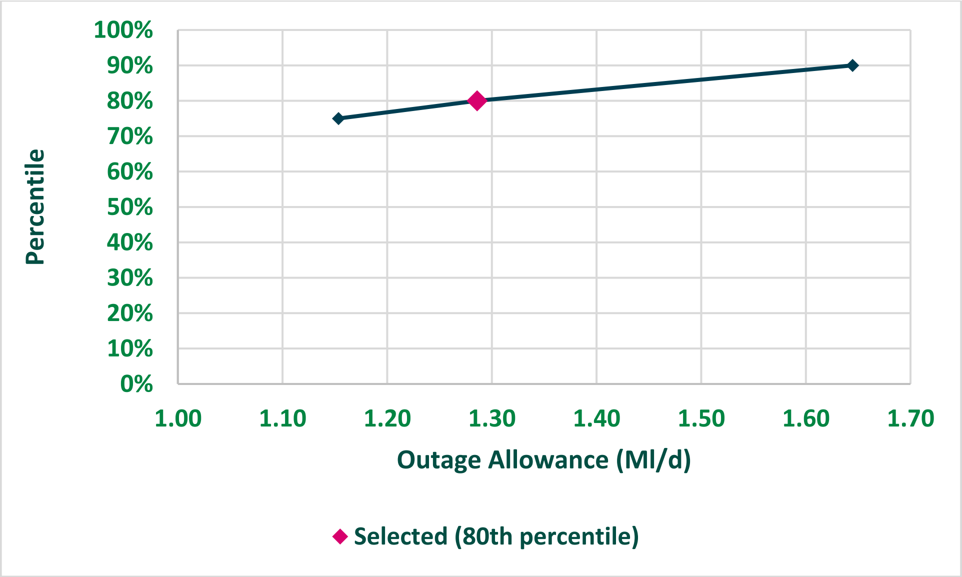


Figure 32 North Eden Resource Zone - Outage allowances at different percentiles

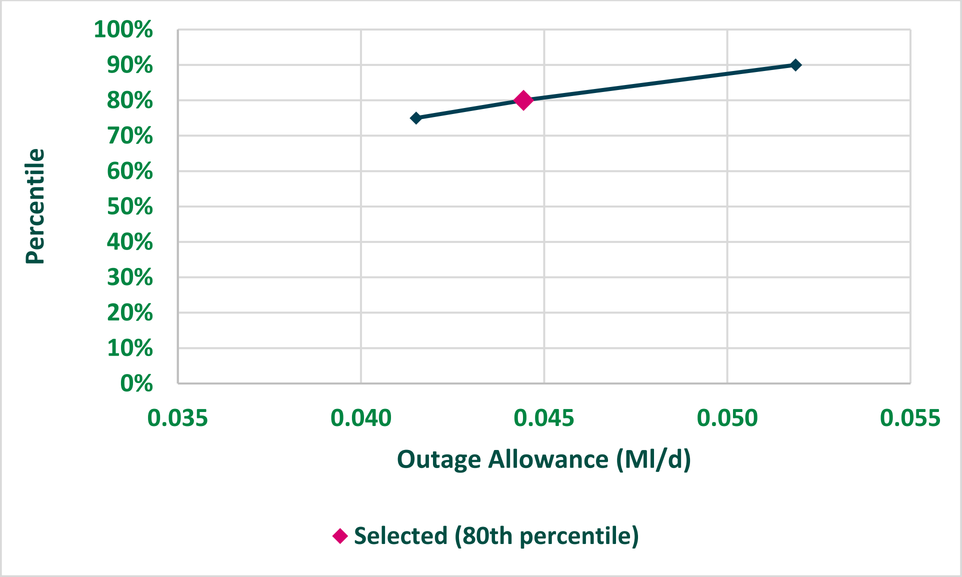
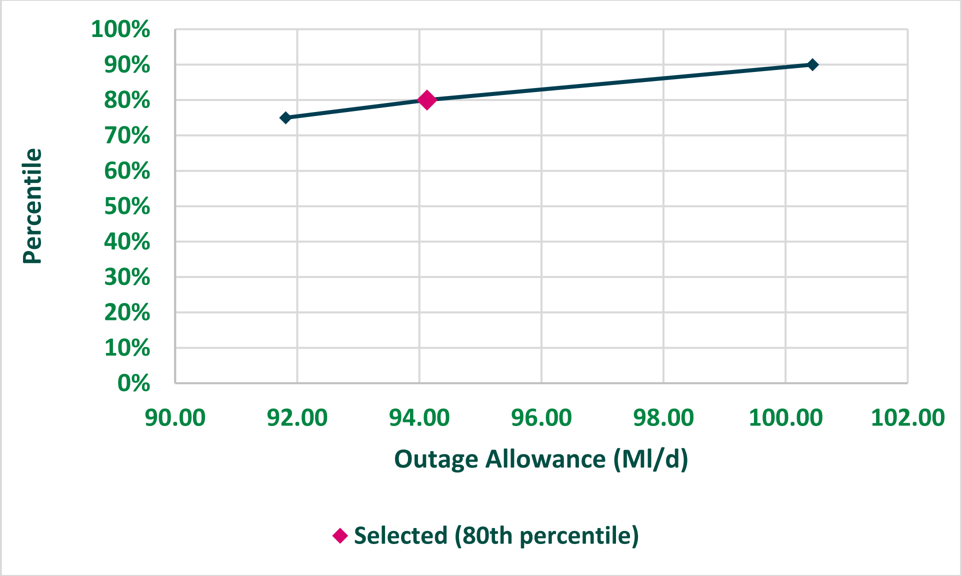


Figure 33 Strategic Resource Zone - Outage allowances at different percentiles



9.3.5 Dry year critical period outage allowance

We have assessed the sensitivity of outage allowance to different planning scenarios. As demonstrated in Table 3 (section 3.2), all resource zones have a dry year annual average (DYAA) planning scenario. The only additional planning scenario considered as part of this plan is the dry year critical period (DYCP) scenario for the Carlisle Resource Zone, which represents a peak week demand event.

The DYCP scenario of peak week demands can occur at short notice, since these events are often driven by a sudden period of hot dry weather. It can, therefore, be difficult to forecast these events and there may be insufficient time to either cancel future planned outages or withdraw from live outages. Consequently, to calculate an outage allowance applicable for this DYCP scenario, the only changed required to the method described in section 9.3.3 is the removal of the step 'Would this outage happen during a drought' (some planned maintenance can be deferred during drought conditions), used to determine legitimate outage events.

When the data set used to calculate the DYAA outage allowance was reviewed, for the Carlisle Resource Zone, there were no historic outage events that had been removed on the basis of having potential to be deferred during drought conditions. Therefore the DYAA outage allowance is also applicable to the DYCP planning scenario.

9.4 WRMP24 outage allowance

The resulting profiles of outage allowances for each of our water resource zones, with a comparison to WRMP19, are shown in Table 32. In line with section 9.3.5, the outage allowance calculated for the Carlisle zone is applicable to both the dry year annual average (DYAA) and dry year critical period (DYCP) planning scenarios.

Table 32 Outage allowance calculated for our WRMP24 compared to our previous allowance

	Outage allowance (M/d)	
Water resource zone	WRMP19	WRMP24
Strategic	101.3	94.13
Carlisle	1.55	1.29
North Eden	0.05	0.04
Barepot[39]	0.00	0.00

The forecast outage allowances, as shown in Table 32 above, are subtracted from the modelled deployable output values, as a component of the calculation for Water Available for Use for each water resource zone.

The deployable output reduction due to the planned capital programmes discussed in section 9.2, is also subtracted from the modelled deployable output values, as a component of the calculation for Water Available for Use for the Strategic Resource Zone.

9.5 Change since our 2019 plan

There has been a number of changes to the data sources and methodology used to calculate outage allowance between our 2019 plan and this WRMP24. The most significant changes to the Outage Allowance are for the Strategic Resource Zone:

- Use of 1 in 500 average flow for strategic sources to assess the daily impact of individual POPs (explained further in section 9.3.3).
- Planned capital projects (of duration greater than six months) have been included within the supply-demand balance as a deployable output adjustment, termed ’change in deployable output from prolonged outage reduction’.

There were also a number of other changes, which had a smaller impact on the allowance:

- Removal of allowance for Heltondale Section 20 fish migration release event. This release can be made via the scour, enabling Ullswater PS to remain in operation during the Section 20 fish migration releases.
- Removal of borehole failure based upon PIONEER data, since this is now captured by the POP system and would be double counting.
- Removal of failure of raw water abstraction pumps and non-potable aqueducts, where their failure would restrict the output of a water treatment works as these are represented by data within the POP system.
- Removal of extreme/rare events, such as catastrophic failure of impounding reservoirs, since the Water Resources Planning Guidelines state that extreme events should not be considered within outage allowance.

The small change in outage allowance for the Carlisle Resource Zone is a result of transition from using technical assumptions for outage related to Cumwhinton Water Treatment Works, to using observed data from the POPS system.

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[39] There is no history or perceived risk of outage within the Barepot Resource Zone. Therefore, we do not propose including an allowance for outage within the supply-demand balance for this zone.

10. Raw water and process losses and operational use

This section outlines our approach in assessing the operational use of water or losses through the abstraction to treatment process. In calculating Water Available for Use (WAFU), raw water/process losses and operational use are subtracted from deployable output to represent the water lost between source and demand. For our 2019 Water Resources Management Plan, our forecast allowances for raw water losses were calculated from the Burst and Background Estimation (BABE) approach (used to calculate leakage in pressurised pipes). Process or treated water losses were estimated using information from questionnaires completed by process technical officers for each site. Consideration was given to using metered data to calculate raw and treated losses, however, this was not feasible at that time due to the limited length of data record, with data being missing or incomplete for some sites.

In line with the Environment Agency's definition of the new Supply-Demand Balance Index (SDBI) metric, we are now required to report recorded or observed raw and treated water losses as a component of this metric within our annual Environmental Performance Assessment returns. As part of the preparation for our 2024 Water Resources Management Plan we have, therefore, calculated these losses using metered data from our operational assets. Our forecast allowances for these components in this latest plan are based on an analysis of this operational data as outlined below.

10.1 Methodology

Abstraction, transfer, inlet, outlet, and wash water metered data, for the seven-year period from 2015-2021, has been collated and analysed for all our treatment works. The resulting calculations of raw and treated water losses should be treated with a degree of caution, however, due to the following factors:

- The majority of sites do not have an inlet meter;
- At several of our borehole sites the same meter is currently used to record both abstraction and water put into supply; and
- At some sites the calculated percentage losses are within the typical flow meter accuracy of +/- 5%.

The average volume of raw water and process losses at an individual site does not translate directly to a reduction in Water Available for Use, as this will depend on many factors such as seasonal patterns of demand, network constraints and utilisation of maximum treatment capacity at each site. Output from the metered data calculations[40] is, therefore, added to individual water treatment works components in our Hydro-Logic® Aquator and Pywr water resources models, in order to simulate the overall net impact on supply of the combined losses at all sites within a resource zone. This approach has been used to assess the direct impact of losses on baseline deployable output for the Strategic and Carlisle Resource Zones. We do not have water resource models of the North Eden and Barepot Resource Zones due to their low complexity. Therefore, for the North Eden Resource Zone, the recorded or observed average raw water and process losses for each site are simply summed to calculate a loss allowance for the zone. For Barepot Resource Zone there are no process losses as the water supply is non-potable. The loss allowance therefore represents a raw water loss only. The raw water loss included in WRMP19 was determined by using the BABE method. This method has been retained for this plan, as metered data is unavailable for this site.

Applying these methods, the combined raw water and process loss allowances for each water resource zone are shown in Table 5. These allowances are static across the planning horizon. During AMP7 (2020-2025) we are

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[40] The 2015-2021 average metered raw water losses and process losses are summed to create a combined losses value for each water treatment work. The percentage of combined losses of average water treatment work production (2015-2021) is then calculated. For the Strategic and Carlisle Zones, these values are then added to the water treatment work components in our water resources models and are, therefore, included in baseline deployable output simulations. For the North Eden and Barepot Zones the combined losses as a percentage of average production are summed to calculate a losses allowance per zone. The lower and upper losses are also calculated as a percentage of average production and are included in our Target Headroom assessment of supply uncertainty.

carrying out a losses reduction programme to minimise the amount of raw and process water lost from our abstraction and treatment system. This involves our central operations, field based operational and engineering teams working together to verify our measured data and identify any solutions to issues such as replacing a broken or inaccurate meter and fixing leaks. The effects of this programme will be captured in our measured losses data over AMP7. At the time of writing this data is unavailable for inclusion in our assessment of losses for WRMP24. It may be possible to use this information to reassess losses for our final WRMP24, and it will form the basis of our losses assessment for WRMP29.

Table 33 Summary of raw water and process losses by water resource zone

	Raw water and process loss allowance (Ml/d) for year:					
Water resource zone	2024/25	2029/30	2034/35	2039/40	2044/45	2049/50
Strategic	74.00	74.00	74.00	74.00	74.00	74.00
Carlisle	0.86	0.86	0.86	0.86	0.86	0.86
North Eden	0.16	0.16	0.16	0.16	0.16	0.16
Barepot	0.03	0.03	0.03	0.03	0.03	0.03

Following the model-based approach, where losses are included directly in our water resources models, the simulated baseline deployable output for the Strategic and Carlisle Resource Zones is inclusive of the effects of losses. Therefore the Water Available for Use (own sources) calculation must be adjusted (i.e. omit the subtraction of losses in the calculation) so as not to double count the impact of losses in the resource zone. For the North Eden and Barepot Resource Zones, the allowances shown in Table 33, are subtracted from the deployable output values as part of the Water Available for Use (own sources) calculation for each water resource zone.

10.2 Change since our 2019 plan

The overall change in loss allowances between WRMP19 and WRMP24 is shown in Table 34 for each resource zone. Compared to the assessment of losses for WRMP19, for this assessment there are several differences, including:

- The questionnaire data for process losses and Burst and Background Estimates (BABE) data for raw water losses used in WRMP19 is no longer used. Observed or recorded abstraction, transfer, inlet, outlet, and wash water metered data, for the seven-year period from 2015-2021, has been collated for all water treatment works to be used in this assessment.
- The seven-year average combined metered losses calculated as a percentage of average water treatment work production are input to the Strategic and Carlisle water resources models and included in baseline deployable output simulations. Deployable output model runs including and excluding losses are completed and the difference between the deployable outputs is the loss allowance for the resource zone.

Table 34 Summary of loss allowance for WRMP19 and WRMP24

Water resource zone	**Loss allowance**		
	WRMP19 (Ml/d)	**WRMP24 (Ml/d)**	**Change (Ml/d)**
Strategic	41.96	74.00	+32.04
Carlisle	0.55	0.86	+0.31
North Eden	0.04	0.16	+0.12

Water resource zone	Loss allowance		
	WRMP19 (Ml/d)	WRMP24 (Ml/d)	Change (Ml/d)
Barepot	0.03	0.03	0.00
Total	42.58	75.05	

11. Water available for use

Table 35 presents a summary of the baseline WAFU calculation, showing the effects of forecast changes to deployable output (climate change impacts and sustainability changes to our licences) and the allowances for outage and raw and treated water losses. The final calculation of Total Water Available for Use includes the effects of imports and exports (raw and/or treated water) from or to each resource zone, where applicable, as shown in the table. Barepot resource zone is a non-potable water supply, therefore has its own non-potable supply demand balance.

Table 35 Components and calculation of baseline Water Available for Use. **(numbers may not sum exactly due to rounding)**

		Water Available for Use calculation (Ml/d) for year:					
Resource Zone	**Component (Ml/d)**	**2025/26**	**2030/31**	**2035/36**	**2040/41**	**2045/46**	**2049/50**
Strategic	Baseline deployable output	2006.4	2006.4	2006.4	1901.4	1901.4	1901.4
	+ Baseline forecast changes to deployable output	- 76.9	-59.1	-71.3	-82.3	-127.2	-212.7
	- Outage allowance	94.1	94.1	94.1	94.1	94.1	94.1
	- Raw water and process loss allowance	74.0	74.0	74.0	74.0	74.0	74.0
	= Water Available for Use (own sources)	1769.0	1779.1	1766.9	1651.0	1606.0	1520.6
	+ Raw and potable imports	0.05	0.05	0.05	0.05	0.05	0.05
	- Raw and potable exports	33.6	-34.5	-34.8	-34.7	-34.6	-34.4
	= Total Water Available for Use	1727.7	1744.7	1732.1	1616.3	1571.5	1486.2
Carlisle	Baseline deployable output	35.5	35.5	35.5	34.5	34.5	34.5
	+ Baseline forecast changes to deployable output	-0.09	-0.10	-0.18	-0.19	-0.21	-0.22
	- Outage allowance	1.3	1.3	1.3	1.3	1.3	1.3
	- Raw water and process loss allowance	0.9	0.9	0.9	0.9	0.9	0.9
	= Water Available for Use (own sources)	33.3	33.3	33.2	32.2	32.1	32.1
	+ Raw and potable imports	0.0	0.0	0.0	0.0	0.0	0.0
	- Raw and potable exports	0.0	0.0	0.0	0.0	0.0	0.0
	= Total Water Available for Use	33.3	33.2	33.2	32.2	32.1	32.1
North Eden	Baseline deployable output	8.0	8.0	8.0	8.0	8.0	8.0
	+ Baseline forecast changes to deployable output	0.0	0.0	0.0	0.0	0.0	0.0
	- Outage allowance	0.04	0.04	0.04	0.04	0.04	0.04
	- Raw water and process loss allowance	0.16	0.16	0.16	0.16	0.16	0.16
	= Water Available for Use (own sources)	7.8	7.8	7.8	7.8	7.8	7.8
	+ Raw and potable imports	1.3	1.3	1.3	1.3	1.3	1.3
	- Raw and potable exports	0.0	0.0	0.0	0.0	0.0	0.0
	= Total Water Available for Use	9.0	9.0	9.0	9.0	9.0	9.0

12. Drought measures

Drought measures provide a DO benefit during dry weather, either by reducing demand or increasing supply. For WRMP24 we have followed the EA WRPG and excluded the benefits of drought measures from the baseline. Our drought measures are in-effect treated like options and their benefits are included in our final planning supply demand balances. We used our water resources models to help estimate the benefit of each type of measure in the Strategic and Carlisle Resource Zones (i.e. the modelled zones), and the results are provided in Table 36 and Table 37.

Step-by-step, each type of measure was added to the model and the incremental DO benefit recorded. We calculated the benefit under each DO metric and in each year, but the results shown here correspond to 1 in 500 year EDO for the base year only. Full results for all metrics and all planning years are provided separately in the EA Drought Plan Links Table 6. More information about our drought measures is provided in our Drought Plan.

Table 36 Strategic Resource Zone DO benefit of drought measures

Drought Measure	Description	Base year 1 in 500 year EDO DO benefit (Ml/d)
Appeals for restraint	1.00/2.00% (winter/summer) savings when an appeal for restraint is implemented (VUR)	9.0
Licensed drought only sources	N/A	N/A
Other level 1 drought measures	0.69% savings when pressure reduction 1 implemented	6.0
Temporary Use Bans	0.00%/3.00% (winter/summer) demand savings when a Temporary Use Ban is implemented	23.1
Level 2 Drought Permits/Orders	Drought permits implemented when the control curve is crossed: Longdendale Lune Windermere Scenario 1 Dovestone Ullswater Vyrnwy Jumbles Fernilee Delph White Coppice Brinscall	56.3
Other level 2 drought measures	0.38% savings when pressure reduction 2 implemented	5.9
Non-essential use bans	5.00% demand savings when a non-essential use ban is implemented	16.3
Level 3 Drought Permits/Orders	Drought sources/sites brought online when the level 3 control curve is crossed: Longdendale Lune Dovestone Jumbles	15.7
Other level 3 drought measures	1.13% savings when pressure reduction 3 implemented	3.7
TOTAL BENEFIT	**Combined benefit from above drought measures for the drought scenario**	**136.0**

Table 37 Carlisle Resource Zone DO benefit of drought measures

Drought Measure	Description	Base year 1 in 500 year EDO DO benefit (Ml/d)
Appeals for restraint	1.00%/2.00% (winter/summer) savings when an appeal for restraint is implemented (VUR)	0.02
Licensed drought only sources	N/A	N/A
Other level 1 drought measures	0.69% savings when pressure reduction 1 implemented	0.01
Temporary Use Bans	0.00%/3.00% (winter/summer) demand savings when a Temporary Use Ban is implemented	0.04
Level 2 Drought Permits/Orders	N/A	N/A
Other level 2 drought measures	0.38% savings when pressure reduction 2 implemented	0.01
Non-essential use bans	5.00% demand savings when a non-essential use ban is implemented	0.03
Level 3 Drought Permits/Orders	N/A	N/A
Other level 3 drought measures	1.13% savings when pressure reduction 3 implemented Use Castle Carrock dead water storage (end of Level 3)	2.01
TOTAL BENEFIT	**Combined benefit from above drought measures for the drought scenario**	**2.12**

There are no drought measures in our Barepot Resource Zone.

As we do not have water resource models for our North Eden Resource Zone the benefits of each drought measure were calculated. For the demand measures and ‘other’ drought measures this involved calculating the benefits as a percentage of the demand forecast for the year stated in this non-modelled resource zone. The baseline year is 2019/20 and from this point includes the final planning leakage profile. The demand forecast values vary slightly over time however when displayed to two decimal places there is minimal difference over the planning horizon. The drought permit conditions in the North Eden Resource Zone increase the annual licence limit at the relevant sites. Their benefit was calculated as the sum of the associated drought permit benefits, with the assumed benefit remaining static across the planning horizon.

13. Final planning Levels of Service

In line with the strategic choices made in WRMP24 (Section 7 in the main WRMP document), we are proposing an improvement to the minimum level of service for TUBs from 1 in 20 years (5% annual chance) to 1 in 40 years (2.5% annual chance) in 2031. This change has the secondary benefit of improving the minimum level of service for drought permits from 1 in 40 years (2.5% annual chance) to 1 in 50 years (2% annual chance) at the same time. To meet government requirements, we are also planning to improve the minimum level of service for EDO from 1 in 200 years (0.5%) to 1 in 500 years (0.2%) by 2039.

In quoting a *minimum* level of service we must ensure that it can be delivered across a wide range of future conditions, for example more severe climate change than anticipated. It is therefore necessarily a conservative estimate. For our modelled resource zones we also forecasted the level of service under 'most likely' future conditions, in line with the assumptions used in our WRMP24 baseline, for example RCP6.0 climate change projections.

Our Pywr water resources model was used to simulate the expected frequency of each type of restriction over the course of the planning period. The results for the Strategic Resource Zone are shown in Table 38 at five-yearly intervals from 2025-2085. The other three resource zones all have the same minimum level of service and an equivalent or better forecast level of service. The modelling included the effects of our preferred plan, i.e. leakage reduction, demand management, improving levels of service for TUBs and water transfers. Once the number of events simulated reaches very low levels the results can become overly sensitive and unreliable. Therefore, we introduced a minimum threshold of 1% for TUBs and drought permits and 0.1% for NEUBs and EDO.

We also used this modelling exercise to perform portfolio testing of the preferred plan, particularly the subsets of options selected for different phases of water transfers by our ValueStream decision making tool (more information is in our *WRMP24 Technical Report – Deciding on future options*). Overall we were very satisfied with the results with all minimum levels of service exceeded.

Table 38 Strategic Resource Zone levels of service (minimum and modelled annual percentage risk)

Restriction	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085
Temporary Use Bans (modelled)	2.60%	2.60%	2.50%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%
Temporary Use Bans (minimum)	5.00%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
Drought Permits/Orders (modelled)	1.30%	1.30%	1.30%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%	<1.00%
Drought Permits/Orders (minimum)	2.50%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Non-Essential Use Bans (modelled)	0.50%	0.50%	0.50%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Non-Essential Use Bans (minimum)	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%
Emergency Drought Orders (modelled)	0.20%	0.20%	0.20%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Emergency Drought Orders (minimum)	0.50%	0.50%	0.50%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%

14. Water quality protected areas

We own over 46,000 hectares of catchment land in North West England, providing raw water into our reservoirs and other sources, and we work with third parties to ensure that the remaining 550,000 hectares of our catchment land not in our ownership is managed to the same high standard. Together this land provides a resilient water supply and protection against downstream flooding as well as wider environmental and social benefits including biodiversity, carbon sequestration and recreational opportunities.

We ensure that our plans continue to meet drinking water quality standards now and in the long term, while also making sure that there is no deterioration in the quality of the water which is supplied. This is in line with the guidance issued by the Drinking Water Inspectorate, on long-term planning[41] and the latest supplementary note on resilience of water supplies[42].

Our raw water protection strategy is to, where possible, use catchment management techniques to reduce the number of drinking water failures and minimise or delay future water treatment expenditure due to raw water quality deterioration. This will be achieved through collaboration with the Environment Agency, Drinking Water Inspectorate and Ofwat, along with other key stakeholders and catchment partnerships. It will also deliver our obligations under the Water Framework Directive (WFD), further enhance catchment risk assessments that support our drinking water safety plans (DWSPs) and reduce carbon usage.

14.1 Drinking water protected areas and safeguard zones

The Water Framework Directive specifies that where water is taken for human consumption, the areas where that water drains from (i.e. the catchments) must be designated as Drinking Water Protected Areas (DWPAs). The Environment Agency is required to monitor these areas and coordinate measures to prevent deterioration in water quality. In DWPAs where water quality is shown to be deteriorating due to human activity, the Water Framework Directive allows the Environment Agency to establish safeguard zones. We have worked with the Environment Agency to provide evidence for safeguard zones to be applied to a number of catchments in the North West. Safeguard zone action plans have been drawn up by the Environment Agency, listing measures that can prevent further deterioration, so that the need for additional water treatment is avoided and the level of treatment can be reduced over time.

We follow a number of national best practice and company-specific innovative techniques to understand the risks to DWPAs. As part of the risk assessment process required by Regulation 27 (in England) of the Water Supply (Water Quality) Regulations 2016, we identify any actual or potential risks to human health within the catchments of raw water sources and established a raw water monitoring programme accordingly. Risks to raw water quality are also identified through a variety of other mechanisms, including information and data gathered by the Environment Agency. Data gathered for operational purposes (i.e. operational raw water monitoring) is used by ourselves and the Environment Agency to monitor risks in DWPAs. Where catchment measures are considered the most appropriate to protect supplies against long-term risks of pollution, we work with the Environment Agency to designate safeguard zones for both surface and groundwater sources. Safeguard zones require voluntary action by third parties to prevent deterioration with a view to reducing the level of treatment required. We have in-house catchment teams that manage over 46,000 hectares of catchment land in our ownership as well as working with third parties to encourage the adoption of best practices on the remaining 550,000 hectares of non-owned catchment land.

Risk assessments, investigations and operational monitoring data is used to support the identification of Safeguard Zones and the appraisal of measures to manage and reduce risks to raw water quality. Data is shared between the Environment Agency and ourselves to assess and manage the risk to raw water quality. Local

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[41] Long-term planning for the quality of drinking water supplies, Drinking Water Inspectorate, June 2020.

[42] Resilience of water supplies in water resource planning (a supplementary note to long-term planning for the quality of drinking water supplies), Drinking Water Inspectorate, July 2021.

partners are engaged to implement catchment measures where appropriate and can often be involved at the start of the process where their local expertise is used to assist with risk assessments and investigations. Raw water monitoring is useful in establishing Safeguard Zones and as evidence to support measures that are considered necessary in those Safeguard Zones.

14.2 Catchment Systems Thinking (CaST)

Understanding the interactions between the land and the water is crucial to the successful management of our essential water resources. Catchment management investigates these interactions and works to combat or mitigate the activities in the catchment that are detrimental to the sustainability of the water quality and biodiversity, as well as reducing the risk of flooding to downstream communities. We continue to manage water catchments in the most effective, efficient and responsible manner to protect and improve raw water quality and quantity. We manage our catchments in partnership with our tenants and other landowners to enable the restoration of the upland ecosystems to deliver multiple benefits in terms of water quality, quantity, biodiversity, access and recreation. In non-owned catchment land, we work creatively with landowners and tenants to influence the land management practices and enhance water quality. Opportunities to strengthen partnership working to improve catchment management will be explored as part of trials of Placed Based Planning, discussed further in Section 2.5 - Working in partnership and local area planning, of our main WRMP24 report.

Through the delivery of our innovative and ground-breaking ‘Sustainable Catchment Management Programme’ (SCaMP), which began in 2005 and aims to secure multiple benefits at a landscape scale, we are recognised within the UK water industry as being at the forefront of catchment management. Working with the Environment Agency, we have evolved our SCaMP approach in the 2015 to 2020 period to focus on 31 drinking water ‘Safeguard zones’, protecting water sources from pollution regardless of land ownership. Our integrated catchment programme supports Defra’s catchment-based approach to improving rivers and bathing waters. Safeguard zones and other catchment initiatives rely heavily on partnership working with landowners and other stakeholders to deliver sustainable and resilient catchments.

Examples of some of the activities taking place as part of our sustainable catchment management programme include:

- Employment of catchment advisers to provide encouragement and support to farmers in adopting best practice;
- Subsidised metaldehyde product substitution;
- Free pesticide sprayer, and pelleter testing and calibration;
- Free services: weed wiper hire, sprayer training, pesticide amnesty, farm health checks;
- Passive and spot water quality monitoring to identify the level of risk by sub-catchment and to monitor the benefits of the interventions; and
- Use of geographical information (land use cover, erosion potential etc.) to model the highest risk areas and the potential effectiveness of mitigation measures.

In the future, catchment resilience will be key. Catchment resilience is an important issue given recent experiences, such as Storm Desmond in December 2015, which caused severe flooding in parts of Cumbria, and the fact that the UK climate projections (UKCP18) are predicting more frequent, intense storm events.

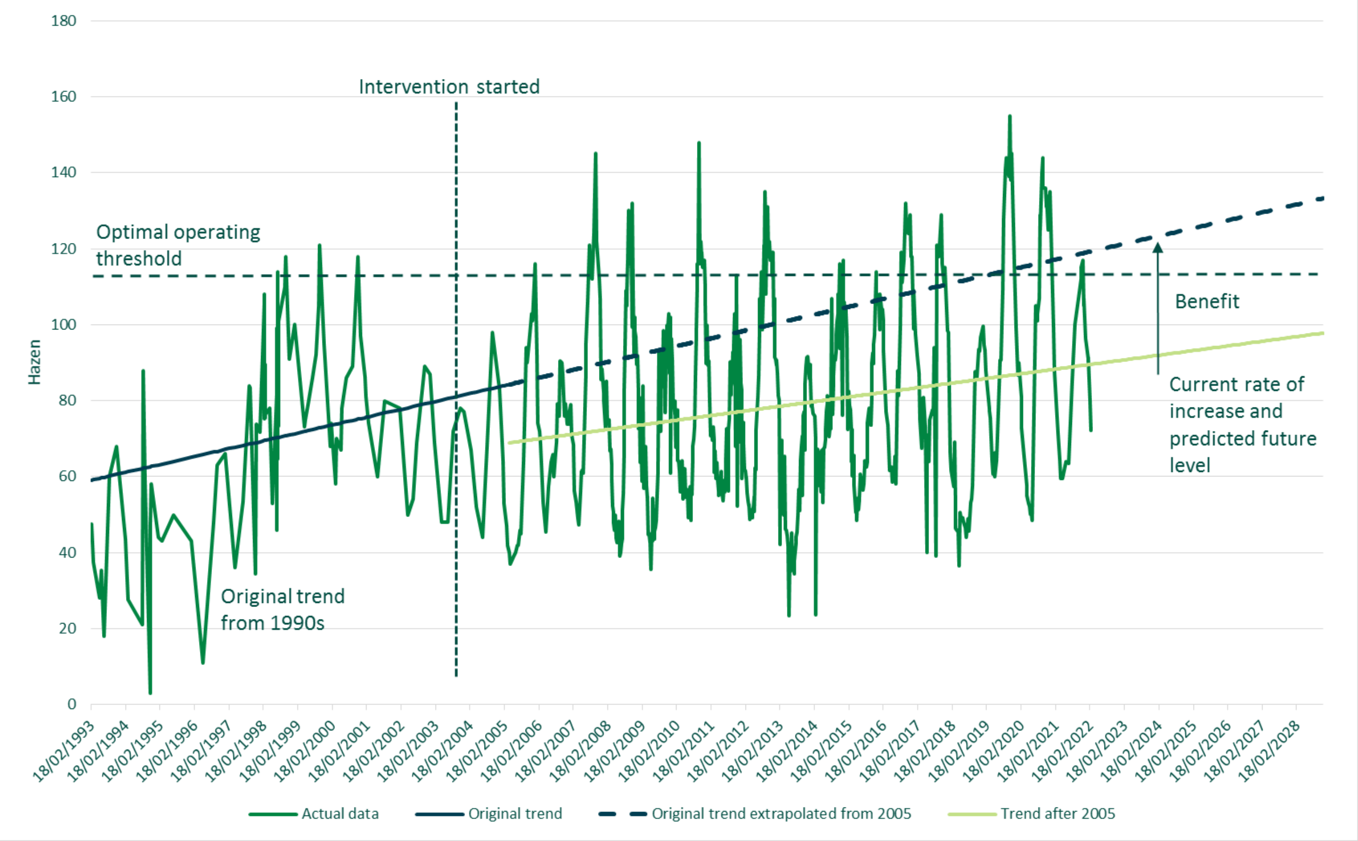
14.2.1 Case study – the benefit of catchment management on the Longdendale Catchment

Peatland restoration involves interventions on the ground to improve the hydrological integrity of peat soil by blocking artificial drainage features, stabilising erosion and planting a diverse range of vegetation including bog-forming mosses. Restored peatland delivers multiple benefits including: reduced carbon emissions from degraded peatland and maximise carbon storage from restored peat soil; reduced risk of wildfire and improved resilience to drought due to wetter soils; improved raw water quality due to less erosion; increased natural flood management due to water retention; and enhanced biodiversity due to the number of plant and animal species supported by a flourishing peatland habitat.

The alternative to peatland restoration in terms of reducing the impact of eroded peat soil (dissolved organic carbon) on drinking water quality is to upgrade the water treatment works' clarification and sludge treatment processes. The increasing levels of dissolved organic carbon for [✂], are shown in Figure 34. Without an upgrade the water treatment works may have to operate on a reduced throughput to remove the increase in dissolved organic carbon load. This has an impact on the volume of the output of the water treatment works, which may have a knock on impact on local and regional supply and demand.

Peatland restoration helps to mitigate the impact of climate change and slow the rate of deterioration. An example is shown in Figure 34, which shows Colour (hazen) measured at the inlet to [✂] and the predicted future trend. [✂]is supplied by the [✂]system. The rate of change has reduced since peatland restoration began in 2005, however, the trend is still increasing. Extremes in weather such as long dry periods followed by intense storms has the effect of flushing the dry peat into the downstream reservoirs and we experience peaks in concentrations above the design envelope of the works. In this situation the throughput has to be reduced, which can have impact on the supply-demand balance of the local area and Strategic Resource Zone. Increasing intensity of spikes as well as the overall increase does not demonstrate a resilient system and, therefore, we have co-created a package of peatland restoration works for the Longdendale area with our partners at RSPB and Moors for the Future.

Figure 34 Colour (hazen) measured at [✂] inlet and the predicted future trend



Post-SCaMP monitoring demonstrates the success these interventions can have at slowing the rate of deterioration in raw water quality. Although catchment management has slowed the rate of deterioration, the overall trend in colour is still increasing and, therefore, seasonal reductions in water treatment works throughput are likely to be required. This case study demonstrated that with further investment this deterioration will be able to be slowed and reversed. It is also key, however, as it contributes to the wider research base to inform our understanding of peatland chemistry so that we can act now to mitigate the impacts, such as the FREEDOM project by the Centre for Ecology and Hydrology.

14.2.2 Case study – maize under-sowing trial at Delamere boreholes

Underlying Cheshire's productive sandy-loam soil is porous sandstone. This forms part of one of the most important aquifers in the country and is an integral part of the North West's drinking water supply. In recent years though, we've been detecting rising levels of nitrates in some of the groundwater we abstract water from.

One cause is the growing of forage maize by dairy and beef farms in the area to use as feed. Forage maize is a crop where the potential for nitrate leaching loss to water is high due to the amount of nitrogen applied both from mineral fertilisers and applications of organic manures. In addition to nitrate loss, environmental and water quality issues associated with late harvesting of maize into the autumn, with bare soil left exposed over winter, can also cause pesticide pollution of surface water.

One way of tackling this issue is by under-sowing the maize with grass. Establishing a 'nurse crop' of grass during the maize establishment period is considered to be a valuable method of providing a post-harvest 'mop' to reduce nitrate loss through the soil profile. To test the viability of this solution, our Southern Catchment Area Team have conducted a trial within a nitrate-sensitive water catchment zone near Delamere.

The trial was run on 30 plots over 90 acres and consists of ten individual plot treatments featuring different methods for growing forage maize including:

- The technique of under-sowing the crop with different grass species at different times
- The use of a nitrification inhibitor to reduce nitrate loss
- Establishing groundcover 'catch crops' post-harvest

Under-sowing maize benefits farmers by saving them money and improving their soils. It benefits us by helping us achieve our water quality and environmental objectives in Cheshire. Results from the trial indicate that sowing grass at the same as maize is the most effective and, in some cases, reduced nitrate leaching by up to 80%, helping to reduce the amount of nitrate being lost to groundwater. This is a good example of how catchment management can help to safeguard and protect our raw water sources into the future.

14.3 Water quality, system operation and production planning

Catchment management is successful at reducing deterioration of raw water quality and over time has the potential to reverse declining water quality trends, as demonstrated by the case studies for the Longdendale Catchment and Delamere BHs in sections 14.2.1 and 14.2.2. However, many catchment management techniques, such as fully functioning peatland hydrology can take several decades to form.

Despite an extensive on-going programme of catchment management activities, seasonal spikes in water quality parameters can still occur, which require restrictions on the throughput of a water treatment works. During recent dry weather events in 2018, 2020 and 2021, we have seen increasing quantities of algae leading to unacceptable concentrations of Geosmin and 2-MIB. This has included these compounds occurring in some of our reservoirs for the first time.

We plan for and respond to poor raw water quality events using a variety of proactive and reactive measures. Where there is a clear seasonal pattern emerging, we implement operational planning measures, such as optimising reservoir control curves to allow increased abstraction during periods of good quality and reduced abstraction during seasonal spikes in raw water quality parameters. Where appropriate, we invest in permanent water treatment works process improvements. Reactive interventions follow an assessment of the impact on treated water quality and water resources at the time of the incident, to determine the best intervention. These include blending of multiple raw water sources; additional temporary chemical dosing such as Powdered Activated Carbon (PAC); and temporary throughput restrictions for the water treatment works. During AMP7, we are also installing Granular Activated Carbon filters at a number of our water treatment works to improve resilience to poor water quality events.

We have also experienced customer contacts relating to treated water quality, such as due to a change in water hardness. We operate a conjunctive supply system, where abstraction from groundwater sources is balanced against surface water and river abstractions in times of dry weather. We assess the impact on water hardness, prior to increasing abstraction from boreholes across the region. Where we identify a notable change hardness, we proactively communicate this to customers, before adjusting the blend of water that they receive. We are reviewing customer acceptability of water in further detail, to ensure that the blend of water sources is acceptable to customers, during both normal and drought conditions.

Production planning is undertaken to minimise the risk of both seasonal variation in raw water quality and customer contacts due to treated water quality on water resources by:

- Adhering to standard operating procedures, which look at blending of borehole water with softer water sources, to address customer acceptability concerns.
- We use MISER as a business-as-usual production planning tool, primarily targeting the distribution of regional resources for short-term week-to-week forecasts. The model has a slightly finer resolution than our Hydro-Logic® Aquator model for demand modelling, but less hydrological detail. Any key water quality restrictions are included within the final weekly production plan.
- Optimising the way we use some reservoirs to proactively manage seasonal water quality variation. For example, for reservoirs that are highly prone to seasonal spikes in geosmin or 2-MIB, we are able increase abstraction outside of these high concentration periods and then reduce abstraction during peaks in concentration, to minimise the impact on water resources.

14.4 Water quality within our WRMP

It is a WRMP requirement to consider the impact of water quality on outage. Although a wide range of proactive and reactive measures are taken to mitigate the risk of water quality leading to an impact on deployable output, as outlined in section 14.3, from time-to-time outages are required to resolve temporary water quality issues.

We have reviewed operational data and incorporated this as a component within the outage allowance for our water resource zones. This allowance recognises that some sources will temporarily become unavailable during the planning period due to events such as:

- Short-term shutdowns, and subsequent start up to waste, to safeguard the quality of the water entering supply; and
- Raw water deterioration which can occur seasonally or may occur for the first time in a raw water reservoir.

Further information on the derivation of our outage allowance for each resource zone can be found in Section 9. We recognise that there are a number of factors such as climate change, changes in land use and better understanding of emerging contaminants such as PFAS and micro plastics which could cause deterioration to raw water quality in the future. To reflect this risk, in our target headroom assessment, we have made an allowance for sources at risk of gradual pollution and worsening water quality. This is for sources where worsening water quality will affect the ability of the source to maintain the current deployable output, in the future. Further information on the methodology can be found within section 3.1.1 – S5: Gradual Pollution of sources causing a reduction in abstraction, in our *WRMP24 Technical Report – Allowing for uncertainty*.

14.5 Water quality research and innovation

We work with organisations such as the Water Research Council (WRC) and UK Water Industry Research (UKWIR) on innovative research to understand the mechanisms driving water quality deterioration. Seasonal variation in water quality is generally related to complex natural biological changes in the sources, resulting in the production of geosmin or 2 MIB, or changes in turbidity and colour. De-acidification and long-term impacts of farming as well as dry weather events are leading to changes in water chemistry, which we are investigating in more detail.

We were a sponsor of the research project 'Water quality in water resources planning' by the Water Research Council (WRC), which is aiming to strengthen the current assessment of water quality completed as part of water resource planning. This is be achieved by producing a risk management framework, which provides improved integration between the Drinking Safety Plan and the Water Resources Management plan. As part of the project, water quality data has been collected by WRC from six different water companies to investigate long-term trends and correlation between climatic conditions and water quality parameters such as Colour, Conductivity, Iron, Pesticides and Geosmin. This analysis will assist with the production of a Best Practice Monitoring guide to be shared between water companies.

15. Invasive non-native species

Invasive non-native species (INNS) are broadly defined as any species introduced outside of its natural range (past or present), which may negatively impact upon the environment, the economy, or human health (Environment Agency, 2019). 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 has been the subject of a Water Industry National Environment Programme (WINEP) investigation in AMP7. We will be working with the Environment Agency to develop a prioritised list of actions to address the risks identified. Options that have been considered for this plan have been assessed and the risk of potential inter-catchment transfers 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 *WRMP24 Technical Report – Deciding on future options*.

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