Draft Water Resources Management Plan 2024

Appendix A: Supply - how much water we have

WONDERFUL ON TAP

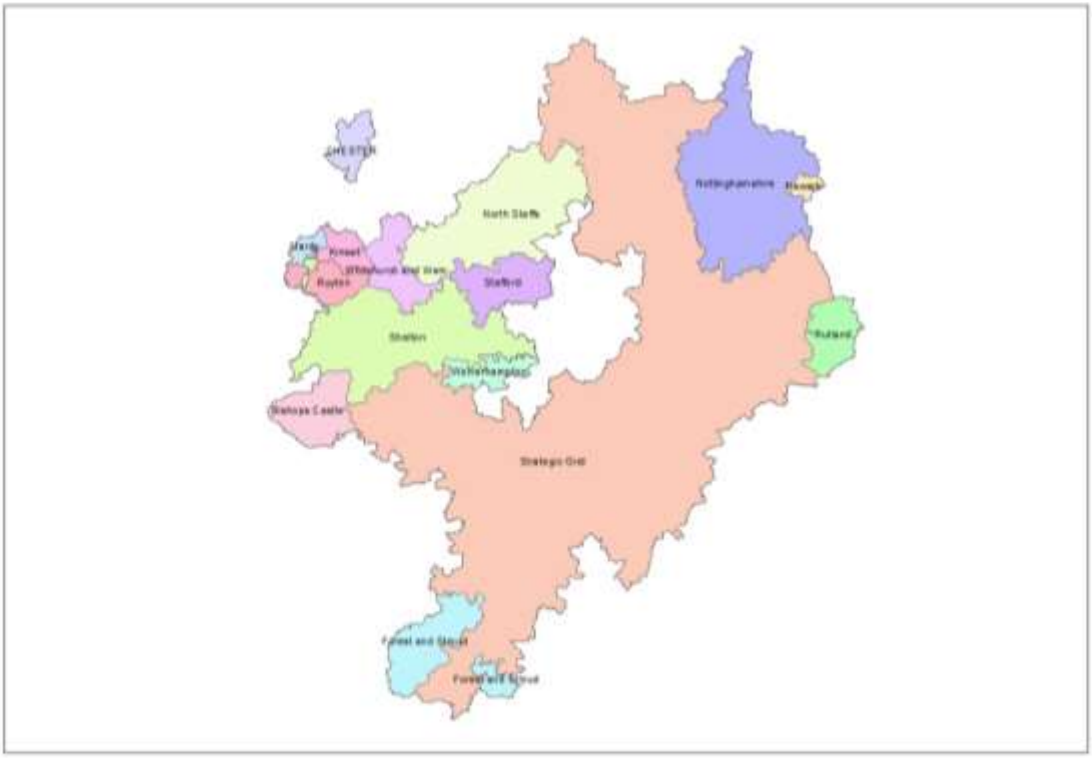
SEVERN TRENT

Appendix A: Supply - How much water we have

A1 Our Water Resource Zones

Changes on our water resource zones (WRZs) associated with the acquisition of Dee Valley Water have been presented in the 2019 WRMP (WRMP19) and no other changes have been made on WRZs since then. Figure A1.1 shows the 15 WRZs that have been amended in 2019 to reflect the new company boundaries and are used in WRMP19. During preparations for our draft 2024 WRMP (dWRMP24) we have reviewed whether the WRZs that we used in our PR19 plans are still appropriate. We have concluded that they are still appropriate zones in which to manage our water resources, so we will continue to use the same WRZs described in our WRMP19.

Figure A1.1: Severn Trent Water Resource Zones



A1.1 Characteristics of our Water Resource Zones

These 15 zones vary widely in scale, from the Strategic Grid zone which supplies the majority of our customers, to the small zones of Mardy and Bishops Castle, which supply much smaller populated areas. These zones have very different water resources challenges, with some requiring significant investment in the long term to ensure secure supplies. These future pressures are explained throughout Appendices A, B and C of this dWRMP24, while the narrative in the main dWRMP24 sets out our long term plans to ensure sufficient supplies are available in each of these zones. Table A1.1 shows the data characteristics for 2021-22 for our 15 water resource zones.

Table A1.1: Characteristics of our 15 water resource zones in 2021-22

WRZ Name	WRMP24 1 in 500 Deployable Output (Ml/d)	Total Properties (000's)	Total Population (000's)	Leakage (Ml/d)	Distribution Input (Ml/d)
Bishops Castle	4.11	2.89	5.86	1.31	2.58
Chester	28.5	44.95	105.69	2.64	22.59
Forest & Stroud	38.82	57.76	132.97	18.31	43.58
Kinsall	5.00	5.62	12.25	1.84	4.40
Mardy	3.5	3.26	7.38	1.37	3.00
Newark	14.57	21.47	48.74	2.81	11.93
North Staffordshire	140.27	230.20	532.51	27.91	124.49
Nottinghamshire	256.32	452.94	1087.9	50.23	242.64
Rutland	0.00	12.42	27.23	4.23	9.75
Ruyton	5.32	5.12	12.35	3.00	5.54
Shelton	138	204.54	497.18	24.97	111.57
Stafford	25.8	41.98	95.52	5.65	20.38
Strategic Grid	1377.40	2172.80	5616.04	277.80	1264.08
Whitchurch & Wem	12.73	13.07	29.30	2.58	8.77
Wolverhampton	65.95	101.21	254.96	20.26	65.76

A2 Calculating Deployable Output

Deployable Output (DO) is defined in the Environment Agency’s Water Resources Planning Guidelines as:

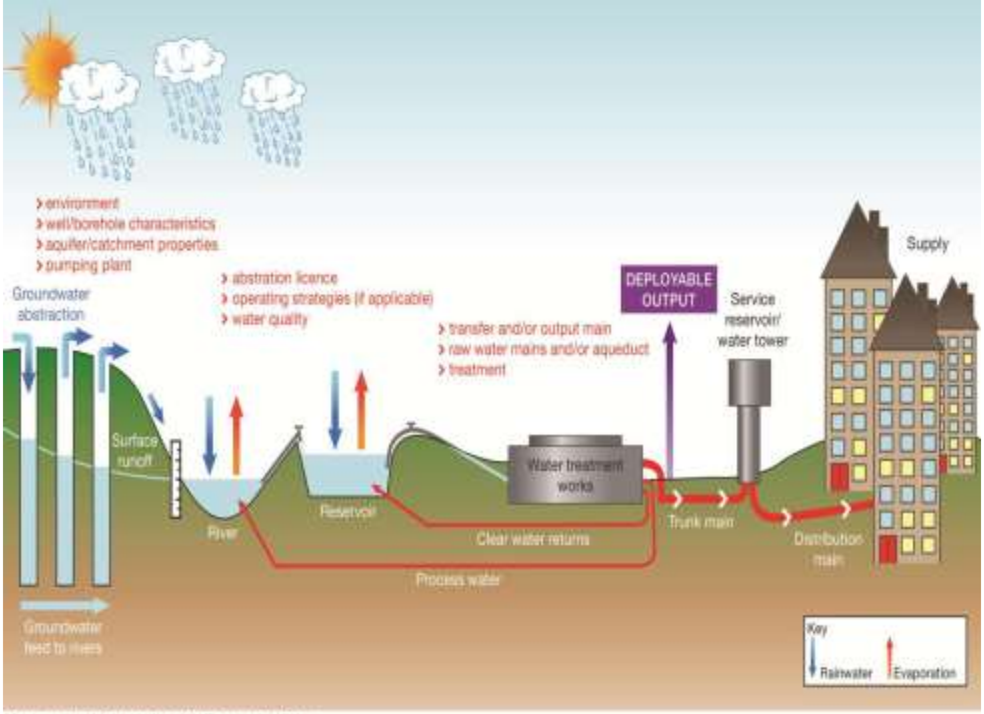
The output of a commissioned source or group of sources or of bulk supply as constrained by:

- *hydrological yield*
- *licence quantities*
- *environment (represented through licence constraints)*
- *pumping plant and/or well/aquifer properties*
- *raw water mains and/or aqueducts*
- *transfer and/or output main*
- *treatment*
- *water quality*

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

As a concept it is described in Figure A2.1 extracted from *UKWIR WR27 Water Resources Planning Tools 2012 guidance* (Akande *et al*., 2011).

Figure A2.1: Deployable Output Concept



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As described in Section A1.1, we have 15 water resource zones. These are divided into conjunctive use zones and groundwater only zones. The DO for the zones is calculated differently depending on which type of zone they are. The zones, types and methods used to calculate DO are shown in Table A2.1.

Table A2.1: Deployable Output Methodologies Used

WRZ Name	Type	Method	Reason
Strategic Grid	Conjunctive Use	Aquator modelling	Both groundwater and surface water supplies with a complex network.
Nottinghamshire	Conjunctive Use	Aquator Modelling	Both groundwater with surface water imports from Strategic Grid zone.
Shelton	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
Wolverhampton	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
Forest and Stroud	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
North Staffordshire	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies
Newark	Conjunctive Use	Aquator Modelling	Groundwater with imports from the Nottinghamshire zone.
Chester	Conjunctive Use	Aquator Modelling	Surface water and groundwater supplies
Stafford	Groundwater Only	UKWIR Assessment	Historically part of the Aquator Model
Bishops Castle	Groundwater Only	UKWIR Assessment	Groundwater Only
Mardy	Groundwater Only	UKWIR Assessment	Groundwater Only
Kinsall	Groundwater Only	UKWIR Assessment	Groundwater Only
Whitchurch and Wem	Groundwater Only	UKWIR Assessment	Groundwater Only
Ruyton	Groundwater Only	UKWIR Assessment	Groundwater Only
Rutland	Bulk Import	Agreed Import amount	Import from Anglian Water

The risk composition for each zone and how this affects the DO modelling methods used is described further in Section A7. The following sections explain how we derived the DO for our WRZs, firstly for groundwater and then for the conjunctive use zones.

A2.1 Groundwater Deployable Output Method

The deployable outputs (DO) of all of our operational groundwater sources were reassessed in 2020 in accordance with the UK Water Industry Research (UKWIR) methodology documents (UKWIR, 1995, 2000) to inform WRMP24. This review builds on those completed for WRMP14 and WRMP19.

For the latest assessment, we have updated all available groundwater datasets to mid-2020. Our assessment of groundwater DO incorporated the recent 2011/12 drought, which represented some of the lowest groundwater levels recorded in the Sherwood Sandstone Group aquifer across our supply area. Since mid-2012, groundwater levels have recovered to expected normal ranges in many areas and therefore the WRMP24 DO update (like the previous WRMP19 DO update) does not introduce new drought operational empirical data that could change the shape or positioning of the drought curves in the Source Performance Diagrams (SPDs). The WRMP24 DO assessment update is based on recent operational data (to inform an assessment of the effective operational pump capacities), infrastructure constraint information (e.g., pumps, treatment processes and network restrictions) and water quality trends. Consideration has also been given to the potential impacts of climate change and EA sustainability changes on groundwater DO. The SPD diagrams were derived for each borehole source to determine the drought year average deployable yield and the peak week deployable yield. In this document the drought year average DO will be referred to as 'average DO' and the drought year peak week DO as 'peak week DO'.

The latest review of groundwater DO was carried out in seven stages:

Stage 1: Review of previous WRMP19 DO assessment
We reviewed the groundwater source information reported for WRMP19. This forms part of the audit trail for our WRMP24 groundwater DO values.

Stage 2: Abstraction licence verification
We verified the average daily and daily peak abstraction licence details reported in WRMP19 for each groundwater source. Several sites were identified as having minor licence changes since the WRMP19 assessment and these were updated.

Stage 3: Confirmation of DO changes
We confirmed changes to source DO capacities from recently delivered capital schemes. We also provided assumed changes to DO due to delivery of these schemes by the end of 2025, i.e., all those PR19 schemes to be completed in AMP7 within the Borehole Capital Maintenance programme that are set to secure WRMP19 DO values.

Stage 4: Pump capacity assessment
We identified the output capacities of all borehole pumps for all operational boreholes. Some pumps are fixed speed; others are variable speed. These data form the basis for many of the DO records as a significant number of boreholes (primarily those completed in the Sherwood Sandstone Group aquifer) show no yield reductions in historical drought events and the pumping capacity becomes the primary driver that defines the DO value of the source.

Stage 5: Review of all treatment and network constraints
We re-reviewed all treatment work process constraints and verified the output capacities of each. Likewise, all downstream network constraints, which impact a given source's ability to put water into supply, were verified. These include booster pumping stations, water mains restrictions and treated water service reservoir capacity limitations that could affect the source output.

Stage 6: Blending constraint reviews
We reviewed our key water quality blends that are required to ensure we supply water that meets the drinking water quality standards. These are primarily for nitrate. We have reviewed concentration trend profiles, and the consequent impact on source DO up to 2050 and a series of blend scenarios were evaluated to determine the impact that rising concentrations of target determinands would have on source DO over this period without interventions (where multiple sources of water feed into the same storage system).[1]

It was assumed that any other water quality compliance challenges would be resolved by treatment or other solutions being implemented through the company business plan and that there will therefore be no impact on DO values.

Stage 7: Groundwater level data
The final dataset used to inform and update the SPDs were groundwater level dip records. These manual measurements are recorded at regular intervals by the on-site operations teams and provide key evidence to

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[1] Potential WQ impacts on available DO between 2025-2050 has not been considered to cause deterioration as we assume these would be invested in future business planning cycles.

assess overall borehole yield. Groundwater level dip data is plotted on SPDs in the form: abstraction flow rate vs. groundwater level.[2]

Stage 8: Source Performance Diagrams update

We completed a systematic update of the SPDs on a site-by-site basis, by compiling the data collated from the previous stages 2 to 7. The updated curves were then used to determine the current year and predicted 2025 average and peak deployable output capacities.

Other groundwater considerations for DO calculations

- **Groundwater treatment process losses:**

  Many water treatment plant processes (e.g., for nitrate or cryptosporidium) are designed with a requirement for waste flow diversion. As found in the WRMP19 DO assessment, no process water losses have been accounted for in the DO numbers reported. This is because the effective losses from these processes are small in comparison with the groundwater output (generally <1%, but up to 4.5%). For the small number of sites where process losses are applicable, we do not consider them to be significant on a water resource zone scale.

- **Sources with compensation requirements:**

  Eight sources have conjunctive usage requirements - public water supply and compensation - which may restrict the source output for WRMP24 DO assessment.

Groundwater Source Inputs to Aquator

For conjunctive use zones, groundwater annual average and peak day yields have been updated as part of the overall groundwater deployable output review discussed above. These updated yields have been incorporated into the Aquator model as annual yield constraints and daily maximum capacities respectively. An example of this is shown in Figure A2.2.

Figure A2.2: Updating Annual Yields in Aquator

Group	Name	Units	V	Value
Options	Fire events			☐
Yield	Enforce			☑
	Amount	Ml		803.00
	Report resource state			☑
	Renewal month		■	January

For spring sources, the monthly profile of yield during the drought year has been input into Aquator as a ‘monthly’ daily maximum capacity, as the effective DO of these sources changes across the year.

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[2] Historical (pre-2008) dip data was extracted from the previous SPDs templates and transferred to the master dip database for centralised usage going forward.

A2.2 Deployable Output Method for conjunctive use zones

For our conjunctive use zones, we derive zonal DO in line with the best practice guidance found in "*The handbook of source yield methodologies*" (Aldrick et al., 2014). To do this we use the Aquator water resources simulation model. Aquator is a powerful application for developing and running simulation models of natural river and water supply systems. The simulation package facilitates the construction of models comprising a range of components to represent sources, demand centres and their linkages. These components can then be customised so that simulations can be produced over a wide range of scenarios and operating rules.

We use Aquator to model the complex nature of our water resources system. Our model includes the following components and constraints:

- **Surface water sources:**
  The raw water sources, or groups of sources, are represented within each zone. Input data includes their output capacities and details of any limitations due to abstraction licence, resource availability, pump capacity, treatment capacity or transfer capacity. Where a source is supplied by a reservoir, the control rules for that reservoir are used to define the safe output from the source over the year. For run-of-river sources any abstraction licence or prescribed flow limitations are taken into account in the model. Each reservoir and river on the model has catchments associated with it, these each have stochastic daily inflow series ascribed to them. There are 78 catchment points in our Aquator model that covers areas across the Severn, Trent and Wye catchments and each consist 19,200 years of inflow series (400 scenarios of 48 years). This inflow data series is derived using 104 GR6J (in French, modèle du Génie Rural à 6 paramètres Journalier) rainfall runoff models with the outputs of these models being grouped together and adjusted to allow them to be used in our Aquator model.

- **Groundwater sources:**
  The source yield of each of our operational groundwater sources are included as an individual source or a group of sources. This process of assessing individual groundwater source DO is summarised in Section A2.1. For groundwater sources dry year average and peak deployable output yield have been calculated and included in the groundwater Aquator component. The abstraction licence can have daily, annual or multi-year conditions; these are represented in the Aquator model as appropriate. Additionally, some blending requirements for water quality purposes in multi-source locations are incorporated into the model as operating controls.

- **Aqueducts and distribution linkages:**
  Aqueducts and distribution linkages are included between sources and demand centres and their maximum capacities are entered. The model allows us to identify where distribution constraints limit our ability to deploy water to where it is needed.

- **Imports and exports:**
  These operational import and export transfers are represented between zones and for bulk supplies to/from other companies.

- **Demand centres:**
  There may be one or many demand centres represented in a zone. These represent areas where both our domestic and industrial customers exist and use water.

In previous WRMPs, our historic level of service has been to make sure we experience no more than three hosepipe bans every 100 years. So, all our conjunctive use water resource zones (WRZs) were historically modelled using the Aquator inbuilt English and Welsh method to estimate deployable outputs based on 100 years of historical flow data. The WRMP24 guidelines require our systems to be resilient to more extreme drought events and resilience is assessed against a predefined drought resilience standard. The new 1 in 500 resilience standard makes sure that exceptional demand restrictions, such as Emergency Drought Orders are not required due to drought more than once every 500 years on average (i.e. systems should be resilient with a 0.2% annual chance of stand pipes and rota cut implementation). The 1 in 500 year supplementary guidance advises the use of system response (Scottish method) based approach to estimate deployable output versus return period relationships linked to Level 4 restrictions (i.e. standpipes and rota cuts). The UKWIR risk-based planning system outlines different methods to look at the relationship between the deployable output and the return period of failures. Due to the specific requirements for estimating the WRMP24 DO using large stochastic time series, the Scottish DO method was adopted for DO analysis of our conjunctive use zones. This method enabled us to run our Aquator model through the stochastic dataset at different levels of demand and record number of failure years associated with each demand level and the kind of restrictions imposed in the model in each year (level 4, 3 or 2 restrictions). The Scottish DO analysis model run outputs (different demand levels and number of failure years) are then post-processed to create the DO vs return period relationships, thus enabling us to estimate DO based on return periods associated with different levels of system failures. DO estimated based on level 2 and 3 restrictions (1 in 33 years TUBs and NEUBs level of service) are compared with the 1 in 500 DO and the lowest DO is adopted for our WRMP24 planning. This ensures our WRZ's systems compliance to both the 1 in 500 resilience metric and our existing Temporary Use Bans (TUB) and Non-Essential Use Bans (NEUB) level of services.

As described in Table A2.1, water resource systems of eight conjunctive use WRZs (Strategic Grid, Nottingham, Forest & Stroud, Newark, Wolverhampton, Shelton, Chester and North Staffordshire) are modelled using Aquator. These WRZs are spread across the Severn, Trent, Wye and Dee basins covering the STWL region. Apart from Chester, all the other seven WRZs are interconnected in some way, although the level and nature of interdependence/connectivity between the WRZs differs. In previous WRMPs, a running order approach was adopted when calculating DO for the six interconnected WRZs. In the running order approach the demand in the surrounding zones is kept static while the demand in the zone being analysed is increased. Once the deployable output of the first zone has been derived, this is then set as its DO level and the next zone is analysed and so on. Due to the connected nature of the zones, the order in which the DO is modelled can have an effect on the DO of the individual zones and the order may also need changing for different scenarios (e.g. climate change).

For the purposes of Scottish DO assessment, the running order approach is considered unsuitable and impractical, and a global scaling approach is adopted. In the global scaling approach, demand across all six interconnected WRZs is incrementally increased in small steps and the analyser runs the model in daily steps across the stochastic dataset years of our catchment inflow series. Strategic Grid, Nottingham and Newark are well interconnected zones in our region and for the Scottish DO modelling purpose these three zones are treated as one, referred to here as the Global zone. Any crossings of TUB and NEUB curves and Emergency Drought Order (EDO) failures along with the corresponding failure dates are recorded for the Global zone and the other three interconnected zones (Shelton, Wolverhampton and Forest & Stroud zones) individually. These modelling outputs are analysed in post processing to create the relationship between deployable output and return periods of system failures (failures based on implementing Level 4, 3 or 2 restrictions) for the Global, Forest & Stroud, Newark and Wolverhampton zones. Definitions of level 4 failures at which EDO restrictions would be imposed are described below. The global scaling approach has helped to avoid existing issues such as the need to 'optimise' the running order under multitude of scenarios being completed and the order followed influencing estimated WRZ DO values. Moreover, the global scaling approach enables us to carry out a wider system level assessment of our water resource network and more accurately represent the operational situation of the complex and conjunctive use nature of the interconnected zones system.

The same Scottish DO method is applied directly for North Staffordshire as it is a standalone zone.

The DO assessment for Chester zone follows a bespoke approach that requires the simulations of two models in sequence. The first step to calculate the Chester zone stochastic DO is the simulation of NRW's River Dee model for the stochastic record. This is completed at a defined target demand (set based on storage levels in the Dee system) with the specific cut-backs applied in the model depending on the scenario. This simulation was carried out individually for each selected scenarios (e.g. baseline stochastic, climate change RCM, climate change probabilistic) applying the specific cutback levels for each scenario. A bespoke variable called 'combined failures' is created to record model outputs from the Dee Model such as daily data on Dee General Directions (DGD) state crossings (cutback levels), storage crossing below emergency level and hitting dead storage level in the Dee storage system. On the second stage, this variable was imported into the Chester zone Aquator model and used to inform the amount of abstraction volumes available each day.

Modelling work was carried out by NRW with a view to identify how the operation of the Dee system may have to change to accommodate the 1 in 500 year resilience target, and adapt to the likely impacts of UKCP18 climate change projections. The steer from the Dee Consultative Committee, as with previous climate change work, was also to identify the likely scale of change to available supply whist retaining the current levels of service (LoS). Output from NRW's modelling work showed that the introduction of the stochastically generated data (to enable long return period resilience testing) to water resources modelling of the Dee has reduced baseline levels of service as compared to previously calculated based on historical data. The system was shown to meet the 1 in 500 resilience target at the current Safe Yield, but other levels of service specified in the DGD are not met. A 5% reduction in safe yield abstraction would be required to meet current levels of service. It's been agreed with NRW that the use of the stochastic dataset is not expected to cause such kind of change in system behaviour and there is uncertainty in the modelling results. Thus, NRW recommended that changes to abstraction allocations identified by the modelling using the stochastics data are deferred until they are more confident that it is a good representation of baseline hydrology. Consequently, we have used existing safe yield and cutback values when calculating baseline deployable output using the stochastic dataset.

The frequency of Pen-Y-Cae reservoirs failing to release augmentation flows to the River Dee is recorded in the Wrexham model. During these augmentation failure days, the model reduces the Bangor on Dee abstraction volume to compensate for any DGD net cutbacks that are not fulfilled through augmentation. The number of years in which Pen-Y-Cae reservoirs fail to release the required augmentation flows are used to calculate return period of augmentation failures. This information is used to determine the type of DO calculation method required for Chester WRZ. Outputs from the baseline stochastic model run for the Wrexham zone have showed that augmentation release failures meet the 1 in 500 resilience metric (return periods of augmentation failures are higher than 1 in 500 years). Thus, to determine 1 in 500 DO for the Chester WRZ, the Chester Aquator model was run using the English and Welsh DO calculation method as Chester zone is constrained by safe yield cutback condition only (other DGD staged cutbacks are fulfilled by augmentation release from Pen-Y-Cae reservoirs) and there are no other surface water sources in Chester zone.

For each of the conjunctive use zones that are modelled in Aquator, transfers between zones are as listed in section A5. Treatment losses are incorporated within the model for all surface water treatment works.

Our Aquator model represents several interconnected and interdependent zones and has evolved over many years, previously with the application of English and Welsh DO analysis in mind using historic (or climate impacted historic) hydrological data. However, the use of the 19,200 years of stochastic data is now required to assess 1 in 500 year DO for EDO events, which has been driven by new regulatory guidance and fundamentally changes the modelling approach required from previous WRMP rounds. To enable the use of stochastic hydrology, refinements have been made to the model in particular to set appropriate failure criteria linked to EDO failures, allow suitable access to emergency storage during dry conditions, and implement suitable resetting of model states every 48 years (at the end of every stochastic scenario) to enable continuous DO simulation across all the stochastic scenarios.

Full stochastic dataset of 19,200 years are used in the Scottish method to estimate baseline DO initially. Given the sheer volume of stochastic data combined with the range of model runs required for model updates and the range of scenarios, along with the additional computational demands of Scottish DO assessment, there is balance to be struck between the extent of the stochastic data used across all assessments and the breadth of scenarios to be assessed. Thus, selection of a representative subset of the stochastic dataset was required to efficiently carry out DO assessment across a high number of climate change and other scenarios (e.g., WINEP scenarios and DO assessments following model updates). We have adopted the following two different methods for selecting subset of the stochastic dataset for running DO analysis for scenarios.

I. To identify the most representative section of the stochastics data, the full dataset was divided into 8 batches of 2400 years each and Scottish method analysis was carried out for each batch. Estimated DO from each batch was compared to the DO estimated using the full stochastic dataset and the two batches (4800 years of data) that provided the closest DO to the DO estimated with full dataset are selected as the most representative subset of the stochastic dataset. Estimation of DO for the range of climate change scenarios has used these selected 4800 years of dataset.
II. As discussed previously, the full stochastic dataset has 400 sequences each depicting different realisations of the weather patterns over the 48 years covering 1950 – 1997. Model simulation at 1 in 500 DO would normally contains around 39 failure years that are spread across 39 or less sequences over the stochastic dataset. We run our Aquator model at higher demand levels than the 1 in 500 DO and the stochastic sequences that resulted in EDO failures are selected until sequences that cover a quarter of the stochastic dataset (100 sequences – 4800 years) are selected. This resulted in a subset of the stochastic dataset that includes all drought events that are likely to cause any drought related model failures at 1 in 500 DO level. The whole 19200 years was used as the total number of years when calculating return period for DO estimated using these selected subset of the stochastic dataset as the rest of the stochastic years are assumed to cause no failures. These subset of the stochastic dataset are used for estimating DO using a range of scenarios including WINEP, model updates, options modelling.

Failure condition

The 1 in 500 supplementary guidance states the following about failure condition.

You should be resilient to drought so that you do not use exceptional demand restrictions, such as with emergency drought orders more than 1 in 500 years on average. Failure is considered to be the point at which you would need to implement these emergency drought orders.

You will not be considered to have met the required level of resilience if you are planning that this failure will happen with a frequency greater than 0.2% per annum.

The point at which such restrictions would come into force will vary from company to company. You should therefore identify the trigger point at which you would actually implement emergency drought orders. You should clearly state this point in your WRMP. This could be at the point at which emergency storage is reached, or a specific groundwater level. You should be able to relate this to the modelling used to generate the '1 in 500' drought events, irrespective of the trigger used. The triggers used for your WRMP should be related and consistent with the operational triggers defined in your drought plan.

We defined the point at which EDO restrictions would come into force as follow:

- Strategic reservoirs hitting dead water level
- Major demand centre failures

Definition of major demand centre failures

Multiple demand centre failures caused by a single drought are considered as major failures. These failures are considered to require imposing EDO restrictions even if dead water level has not been hit in our strategic reservoirs. Failures at a single demand centre caused by a single drought are also considered as major failures if one of the following applies

- Failure amounts of 10 Ml/d or more are recorded for any number of days
- Failure amounts of less than 10 Ml/d are recorded for 10 or more days.

Water Resource Zones and Model Structure

The structure of our Water Resource Zones in our model used for WRMP24 remains consistent with that used for our previous WMRP in 2019. For further information on the structure please refer to section A1.

A2.3 Aquator Model Updates since WRMP19

We have updated and reviewed a number of the components/data parameters within our model. This includes a review of any changed surface and groundwater licences that are used as constraints in the model, as well as a review of the maximum capacities at our Water Treatment Works. We worked with our operational teams to get the latest information on the capacities of the water treatment works across our network.

Additional updates to our model and reviews of current information have also been carried out as outlined as follows.

Model transfer to the latest Aquator Version

We have transferred our model to the latest version of Aquator (Aquator XV). This involved transfer of all model schematic, parameters, timeseries data and customisation codes. Benchmarking and validation of selected model variables have been conducted to ensure that existing representation of the system is maintained in the Aquator XV version of the model.

Model structure updates

Sewage treatment work discharges and non-public water supplies in the model are split out from catchment components and are represented separately in the model. This better reflects the network structure and enables to carry out model scenario runs that are designed to assess impacts of changes in discharges or non-public water supplies on water resources availability. An example of this is model scenario runs required to assess water resource impacts of SRO schemes that involve diversion of Minworth effluent.

New infrastructure

Where there has been changes to our assets we have updated the model to incorporate these changes. Examples of this include the incorporation of additional capacities to abstraction licences, pipeline and water treatment work capacities associated with the green recovery scheme, which will be completed in AMP7 (2020-2025).

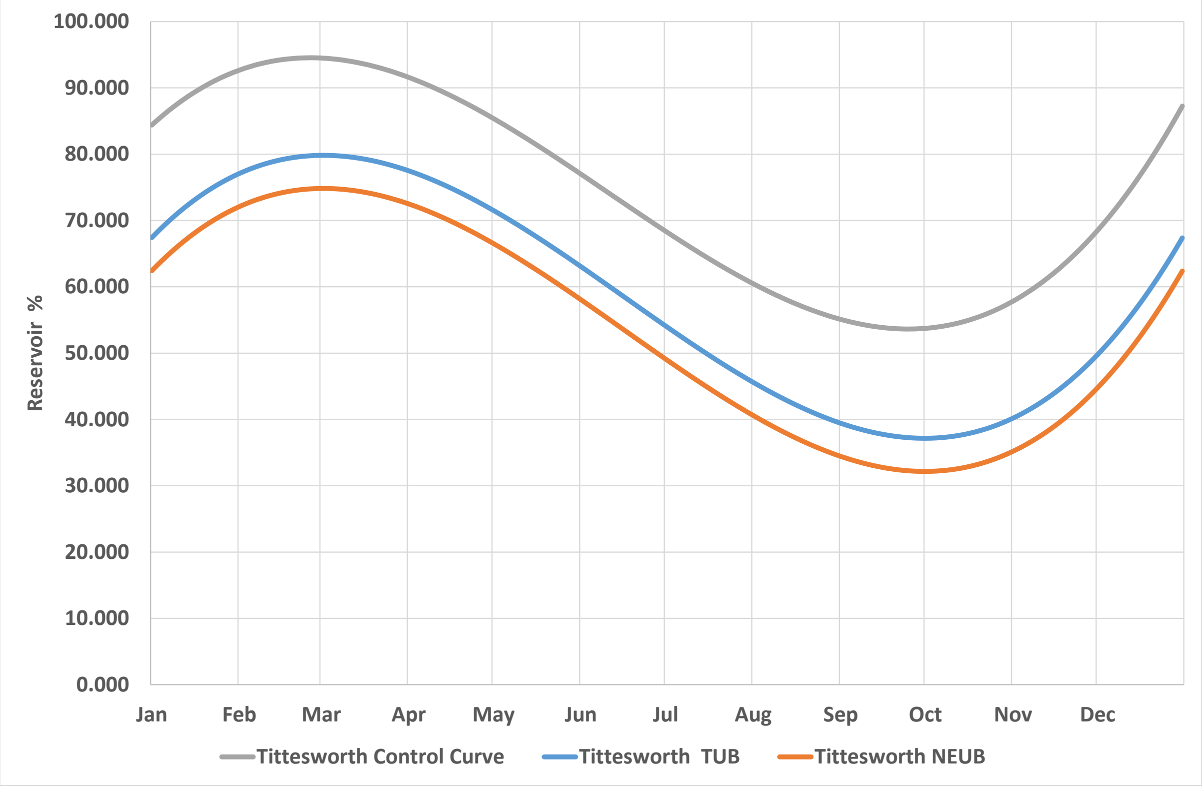
Water Quality Effects on DO

Where current raw water quality has the potential to affect the abstraction at a source we have tested and incorporated this into our model. The effect of not being able to abstract for approximately 15 days a year between September and December due to metaldehyde pollution risk at Eathorpe abstraction has been added to the model in WRMP19. Other effects of changes to water quality are modelled in our headroom uncertainty analysis as discussed in Appendix C.

Reservoir Control Curves

We have reviewed our key reservoirs and updated the various control curves in the model. We have and will use these for both our WRMP24 and our 2022 drought plan. As well as the Level 2 (TUB) and 3 (NEUB) thresholds which were used to calculate level of service, we have also updated the main control curve which Aquator uses to balance when and how to use the reservoirs in preference to other resources in the network. Figure A2.3 provides a graphical representation of the updated control lines for Tittesworth Reservoir. Shown are the Control Curve and the level 2 and level 3 threshold curves that the model uses to simulate the timing and effects of imposing demand restrictions.

Figure A2.3: Aquator output graph of Tittesworth Reservoir Control Curves



Demand Saving Groups

Our model is set to calculate the zonal level of service. We can derive level of service using the Aquator "Demand Saving Group" component, which allows us to model "Demand Savings", such as Temporary Use Bans (TUB) and Non-Essential Use Bans (NEUB) for a selection of demand centres, and therefore at water resource zone level.

We have set up demand saving groups in the model for the Strategic Grid Zone (using Elan Valley reservoirs, Derwent Valley reservoirs, Carsington/Ogston and Draycote reservoir), the Forest and Stroud Zone (using the Elan Valley reservoirs) and the North Staffordshire zone (using Tittesworth reservoir). Each of these reservoirs has both a TUB trigger line and a NEUB trigger line. These trigger lines are set on the model to activate demand savings. If the reservoir storage drops below the TUB line for 7 days or more between April and the end of September, a 5% demand reduction is introduced across the zone. If reservoir storage continues to fall and drops through the NEUB line for 7 days or more between April and the end of October, a further reduction of 5% is introduced giving a total demand reduction of 10%. The highest level of reduction reached will stay in place in the model for up to 180 days. These simulate the effects that imposing TUBs or NEUBs would have on demand in a real-life situation.

Our baseline modelling does not include any supply side drought interventions such as drought permits or drought orders. The modelling of these is discussed further in Appendix A7.

Inflow Series Update

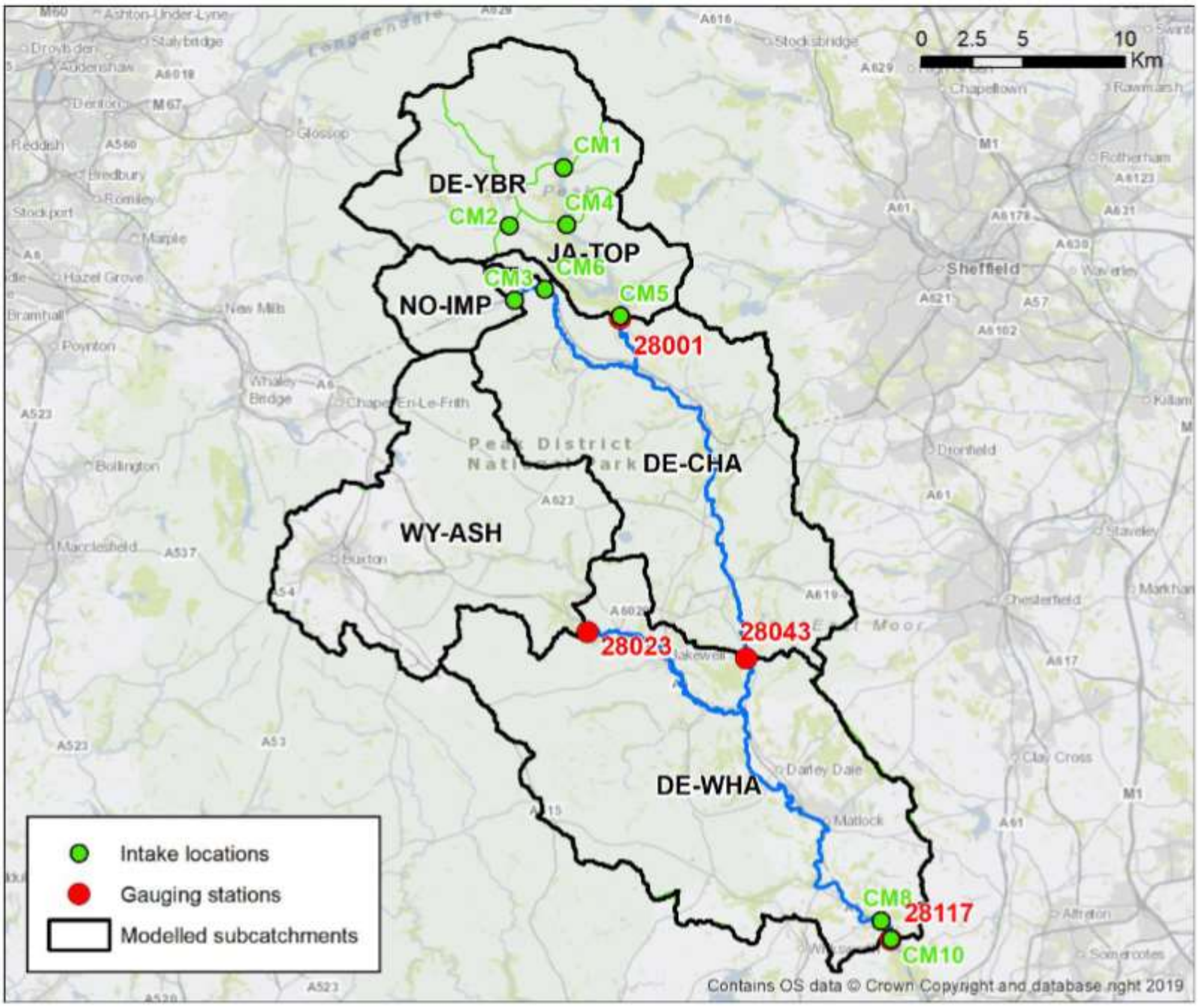
A key update we have undertaken since our previous plan (WRMP19) is a review and update of the catchment flow series that are used in our Aquator model.

Scoping Study

We conducted a scoping study to review recommendations made on our previous plan and take account of recent developments in rainfall-runoff modelling approaches, input data and compatibility with the UK Climate Projections 2018 (UKCP18). The HYSIM rainfall-runoff model was used in previous planning periods, but we have now investigated the performance of six rainfall-runoff models in the scoping study with a view to address longevity and practicality issues associated with HYSIM and to address modelling requirements in current the guidelines.

The River Derwent catchment was selected as a pilot study area for the scoping study as it includes a cascade of modelled sub-catchments which provide a range of hydrological characteristics that can be used to test the performance of different datasets and rainfall-runoff modelling tools. See Figure A2.4.

Figure A2.4: Derwent to Whatstandwell pilot study area



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Five lumped rainfall-runoff modelling tools tested in the study catchments are HYSIM, Catchmod, HBV, GR6j and PDM. In addition to these, the TETIS distributed model has also been explored to assess the performance of distributed modelling approach.

Comparison of model performance

The performance of all six models was assessed using the statistical measures outlined below. Calibration performance is a compromise based on these various measures. It is not possible to make a definitive classification of performance based on statistics alone. While the FDC provides a good overall estimate of the calibration performance it cannot be used in isolation without reference to the daily flow series. A common rule suggests the following broad aims for calibration:

- a mean flow percentage error of less than 5% (and ideally less than 1%); and,
- a NSE greater than 0.7 (and ideally greater than 0.8).

In order to assess the relative performance of the different datasets and models three statistical measures (volume error, Log-NSE and Log NSE FDC) which reflect different aspects of the fit were ranked for the assessment of models or datasets for both the calibration and validation periods. Average rankings could then be calculated for each test catchment. Log-NSE was used in the ranking calculation instead of NSE due to its weighting towards low flows which are more critical from a water resource perspective.

The average rank across the catchments and overall model performance ranking are summarised in Table A2.2.

Table A2.2: Overall model performance ranking

Model	HYSIM	HBV	PDM	Catchmod	GR6j	TETIS
Average score	2.0	2.4	3.1	2.5	**1.4**	4.4
Rank	2	3	5	4	**1**	6

This shows that from a performance perspective GR6j has the highest score. However, the comparison of the model results demonstrates that continued use of HYSIM would deliver comparable model statistics for most catchments. Adopting HBV as the third ranked model would also be acceptable. Adopting Catchmod or PDM was not recommended due to the weaker performance on some catchments.

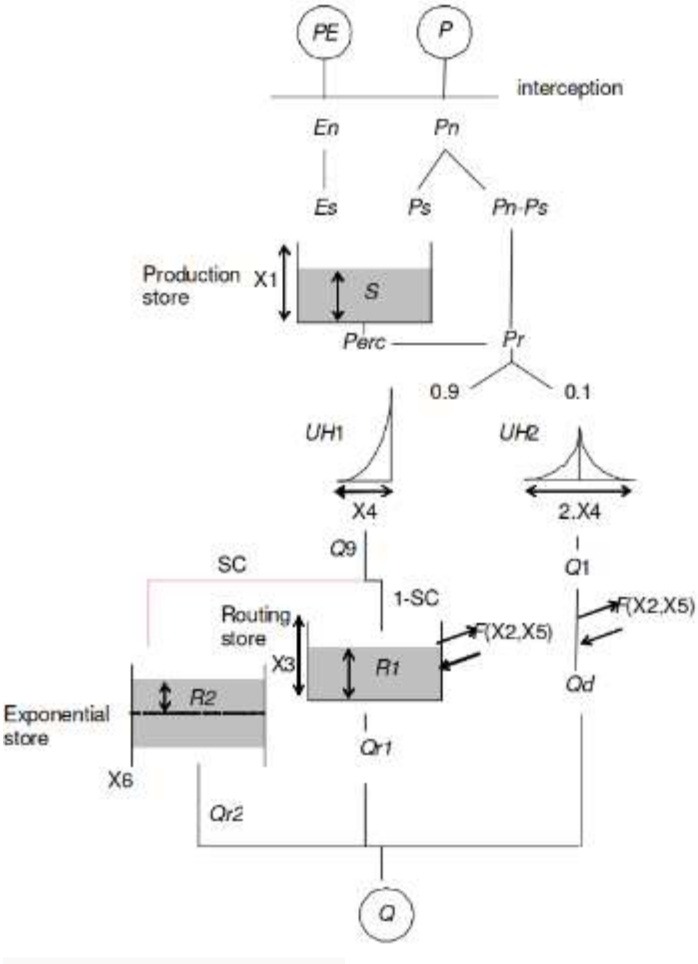
Practical considerations are as important as performance when considering the suitability of the different modelling packages tested. GR6j and HBV were both the quickest models to calibrate and run, followed by PDM then HYSIM. Catchmod was considered the most time-consuming lumped model to calibrate on account of the need to build up the model calibration in stages and slower run times. Both HYSIM and Catchmod take longer for each model to run and there is significant result post processing in order to derive all the required statistics and visualisations. All models except HYSIM are free to use and are already (or can be) coded in Python. The development of the TETIS model takes significantly longer than any of the lumped models but can then be used to estimate flows at multiple gauging stations or ungauged locations within the catchment. This might be needed when there are concerns on the validity of flow records or flow series must be obtained at an ungauged location. In light of all the practical and performance considerations, it was concluded that GR6j is the preferred model based on its performance, ease of calibration, open source code and ability to be coded in Python. Although HYSIM performed strongly, longevity concerns with the software, time taken for calibration, and a lack of ability to integrate the source code into Python led to the decision to switch rainfall-runoff model usage to GR6j. The scoping study results were presented to the Environment Agency (Midlands and National) and Natural Resources Wales in January and February 2020 as part of pre-consultation process prior to the main stage rainfall-runoff modelling.

GR6j modelling

The GR6j model was developed by Pushpalatha et al.(2011) as an improved version of GR4j model developed by Cemagre, Water Quality and Hydrology Research Unit. It is a daily lumped six-parameter rainfall-runoff model, belonging to the family of soil moisture accounting algorithms, and intended to provide a more parsimonious answer without losing accuracy with respect to more sophisticated models.

The model has three stores (see Figure A2.5), a production one, representing the soil package; a routing one, representing the delay in runoff reaching the outlet (interflow and baseflow); and an exponential store parallel to the routing store to differentiate between interflow and baseflow. Runoff can be generated either by exceeding the infiltration capacity of the soil, obtained as a function of its saturation, or by percolation from it, also derived from the soil moisture content. Total runoff is split into direct (10% of total) and routed (90% of total), the former simulating the quick response. Each runoff component is distributed through time-based unit hydrographs. A non-linear store routes the slow runoff component before joining the quick one.

Figure A2.5: GR6j model schematic



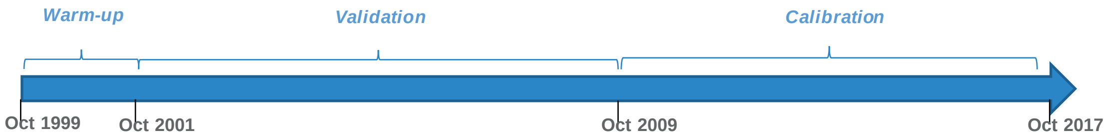
Source: Pushpalatha et al.2011

A groundwater exchange term F that acts on both flow components can simulate imports or exports of water with the underground (i.e. connections with deep aquifers or surrounding catchments). It is a function of the volume in the routing store with greater interchange when it is drained.

Calibration and Verification of the GR6J flows

The general approach is to adopt an 8-year calibration period based on the most recent period of records (October 2009 to September 2017) and an 8-year validation period (October 2001 to September 2009). A two-year warm up period was also used in the models (October 1999 to September 2001) (Figure A2.6).

Figure A2.6: Periods for calibration, validation and warm up



Calibration was undertaken mainly against naturalised flows, with the exception of some catchments in the Wye, Lower Severn, Lower Trent and Idle basins which have been calibrated against recorded flows. For some catchments naturalised series were converted to part-naturalised series in order to use upstream reservoir outflows as an input to the model (such as for the Elan Valley and Carsington). The models were calibrated using the following generalised approach:

1. The models were initially calibrated against the standard calibration period (10/2010-09/2018) unless a specific issue with flow data quality precluded use of this period;
2. A validation review on 10/2002-09/2010 was completed;
3. Consideration was given to switching the calibration period to 10/2002-09/2010 where the initial calibration resulted in issues in the validation period. Consideration was also given to a change in the optimisation approach, for example excluding the volume balance when high flows are unreliable or parameter ranges;
4. In the case of reservoir catchments with appropriate data, a reservoir simulation model was set up to simulate storage for comparison against recorded storage. The performance of this model was then reviewed alongside the flow charts and statistics.
5. Where data was available, long-term simulation checks were completed on the chosen model calibrations (section below about the long-term simulation checks provides more detail on this) with a particular focus on historical droughts;
6. Where results from the long-term checks were not satisfactory, alternative optimisation options were considered to improve key parts of the long-term simulations whilst recognising that the calibration and validation statistics are likely to deteriorate; and,
7. A final decision was made to select the most appropriate catchment parameters after weighing up all the checks and their relative importance for each catchment.

Adopting this approach to calibration and validation ensured consistency across the Severn Trent region, is in part due to the availability of naturalised records for the Trent (from 1999). It should also be emphasised that there is much greater confidence in the levels of artificial influence in the recent past due to more data compared to the 1980s and 1990s, and generally greater confidence in flow series in the recent past due to improvements in monitoring techniques. The 2002-2018 period includes the 2018 drought year which was notable in the region (e.g. for the Derwent reservoirs) but also key dry periods in 2003, 2006 and 2010-11.

The goodness of fit and adequacy of each simulation has been measured using the following criteria:

- Examination of the daily flow chart to confirm if the model matches the low flow periods, has a similar rate of recession, and matches summer and winter storm peaks. Not every feature can be replicated with a model, but this assessment provides an adequate representation of the hydrograph shape and how this might vary in key years or stages in the calibration period.

- Examination of the Flow Duration Curve (FDC) to help identify how good the fit is for lower flows and higher flows. Although the aim is to achieve a good fit over the whole record, the fit at lower flows is almost always most important for water resource assessments. The use of a log curve to display FDCs accentuates the lower part of the FDC allowing, at a glance, the goodness of the fit at low flows to be assessed.
- Comparison of the mean observed ($\overline{Q_o}$) and modelled ($\overline{Q_m}$) flows and calculation of a volume error:

$$Volume\ error = \frac{\overline{Q_m}}{\overline{Q_o}} \times 100\%$$

- The Nash-Sutcliffe Efficiency (NSE) coefficient, which is a normalised statistic that determines the relative magnitude of the model's residual variance compared with the reference data variance, has also been calculated and reported for the calibration and validation periods. The NSE is sometimes referred to as the Nash Sutcliffe correlation coefficient. The NSE is calculated by reference to the mean of observed flows ($\overline{Q_o}$) and the daily time series of observed (o) and modelled flows (m) as follows:

$$NSE = 1 - \frac{\sum(Q_m - Q_o)^2}{\sum(Q_m - \overline{Q_o})^2}$$

  An NSE value of 1 corresponds to a perfect match between observed flows and modelled flows.
- As a statistical measure, the NSE tends to be biased towards higher flows. An additional statistic has therefore been calculated which places more weight on the performance of the model at lower flows which are more critical from a water resources perspective. As such the log of the flows ($\ln(Q_o)$ and $\ln(Q_m)$) are substituted in the above NSE equation. This statistic is referred to as the Log-NSE.
- Furthermore, in order to statistically assess the relative fit of the FDC the above NSE equation has been calculated based on the log flow percentiles from Q1 to Q99 inclusive. This statistic is referred to as the Log-NSE FDC. Although comparisons of specific flow percentiles have been made (eg Q90) this statistic gives a broader measure of how good the fit is across the whole FDC.

In a change from the scoping study, the main stage rainfall-runoff modelling to calibrate and validate flow for all our catchments has adopted automatic calibration for GR6j in order to increase efficiency and ensure the optimum solution is found. Checks were undertaken on the scoping study catchments to ensure that the adopted automatic calibration outperforms the manual calibration originally undertaken as part of these studies. The automatic calibration used a global search algorithm called Shuffle Complex Evolution (SCE) which is a mixture of direct search and random methods (Duan et al. 1993). Genetic algorithms are designed to explore complex response surfaces in a more efficient manner than uniform random sampling methods. An advantage of using SCE is that it can reliably find the global optimum. The GR6j simulation model integrated with the automatic calibration process was able to search a set of parameter ranges with the aim of minimising the combined objective function.

The main emphasis in GR6J model calibration was achieving a close agreement between simulated and recorded flows in terms of the range of statistical methods described above. Whilst these provide a good overall estimate of the calibration the performance of the model can vary from year to year. We therefore include an element of uncertainty around the accuracy of the flow series in our target headroom analysis for our Water Resources Planning. Figure A2.7 shows an example of the flow duration curve produced for calibration and validation of each catchment area. Table A2.3 shows a more detailed example of the calibration statistics produced for each catchment area.

Figure A2.7: Example flow duration curve (Trent at Shardlow)

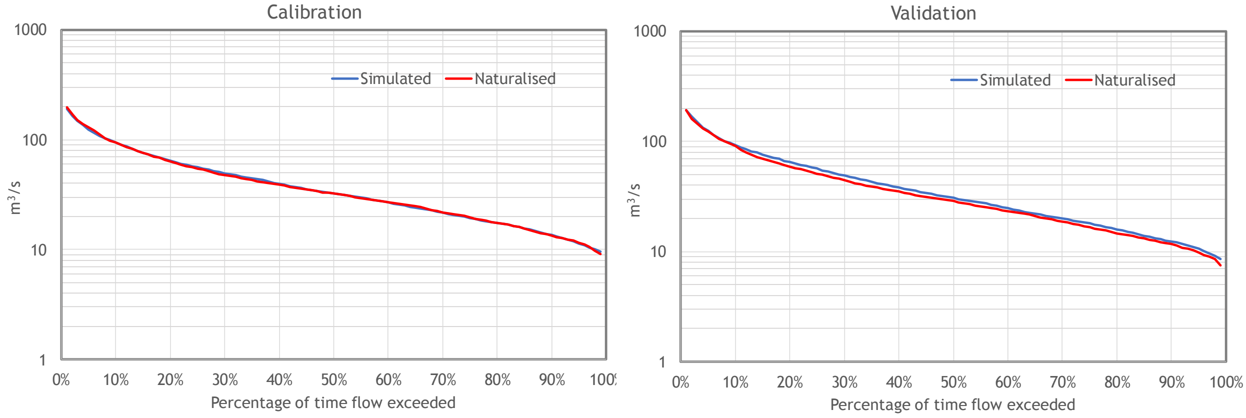


Table A2.3: Upper Severn model calibration results

Catchment	Reference flow series	Period	Mean flow (m^3/s)		Q90 (m^3/s)		Volume error (%)	NSE	Log-NSE	Log-NSE FDC
			Ref	Sim	Ref	Sim				
CL-RES Clywedog Reservoir	Naturalised	10/2010-09/2018	2.461	2.461	0.287	0.307	0.0%	0.703	0.630	0.984
		10/2002-09/2010	*2.276*	*2.341*	*0.177*	*0.250*	*2.9%*	*0.805*	*0.659*	*0.911*
SE-ABE Severn at Abermule	Naturalised	*10/2010-09/2018*	*15.584*	*14.977*	*2.191*	*1.249*	*-3.9%*	*0.885*	*0.753*	*0.914*
		10/2002-09/2010	14.265	14.265	1.126	0.966	0.0%	0.893	0.851	0.982
CO-CON Cownwy at Cownwy	Recorded	10/2010-09/2018	0.844	0.654	0.078	0.079	-22.6%	0.470	0.846	0.987
		10/2002-09/2010	*0.794*	*0.642*	*0.070*	*0.081*	*-19.1%*	*0.506*	*0.879*	*0.991*
VY-MAR Vyrnwy Reservoir	Naturalised	10/2010-09/2018	4.386	5.007	0.407	0.512	14.2%	0.671	0.760	0.952
		10/2002-09/2010	*4.264*	*4.932*	*0.271*	*0.488*	*15.7%*	*0.728*	*0.685*	*0.868*
VY-LLA Vyrnwy at Llanymynech	Naturalised	*10/2010-09/2018*	*27.524*	*22.400*	*3.819*	*2.445*	*-18.6%*	*0.866*	*0.828*	*0.917*
		10/2002-09/2010	22.431	22.431	2.703	2.704	0.0%	0.928	0.948	0.999
SE-MON Severn at Montford	Naturalised	10/2010-09/2018	45.567	45.567	5.857	5.692	0.0%	0.916	0.946	0.999
		10/2002-09/2010	*43.345*	*45.347*	*5.408*	*6.059*	*4.6%*	*0.904*	*0.942*	*0.991*
PE-YEA Perry at Yeaton	Recorded	*10/2010-09/2018*	*1.574*	*1.428*	*0.422*	*0.391*	*-9.3%*	*0.920*	*0.921*	*0.981*
		10/2002-09/2010	1.570	1.570	0.456	0.472	0.0%	0.897	0.932	0.997
TE-WAL Tern at Walcot	Recorded	*10/2010-09/2018*	*7.070*	*5.955*	*2.430*	*2.553*	*-15.8%*	*0.823*	*0.850*	*0.944*
		10/2002-09/2010	6.264	6.221	2.630	2.720	-0.7%	0.870	0.877	0.995
SE-BUI Severn at Buildwas	Naturalised	*10/2010-09/2018*	*60.937*	*58.127*	*10.135*	*9.889*	*-4.6%*	*0.916*	*0.950*	*0.998*
		10/2002-09/2010	60.132	58.415	10.540	10.526	-2.9%	0.911	0.956	0.998
WO-BUR Worfe at Burcote	Recorded	*10/2010-09/2018*	*1.298*	*1.133*	*0.473*	*0.369*	*-12.7%*	*0.836*	*0.744*	*0.875*
		10/2002-09/2010	1.087	1.087	0.421	0.430	0.0%	0.851	0.873	0.988
SE-BEW Severn at Bewdley	Naturalised	10/2010-09/2018	64.472	62.003	12.611	12.158	-3.8%	0.928	0.953	0.998
		10/2002-09/2010	*59.725*	*62.338*	*12.474*	*12.465*	*4.4.%*	*0.910*	*0.959*	*0.997*

(Table produced by Mott Macdonald, 2021)

Long-term verification

Assessing model performance outside of the formal calibration and validation periods is important in order to understand how the model performs in key historic drought years. Due to the above observations regarding changes in artificial influence and quality of records this comparison can be limited. However, where naturalised flow series exist, or where recorded flow series exist for predominantly natural catchments, the long-term simulations for the model have been compared against the available records to provide verification of the model performance in key drought years (e.g. 1975-1976, 1995-1996) and at key locations in the catchment.

This verification has been assessed through comparison of the flow charts and FDCs to confirm the suitability of the flow series; as part of this, consideration has been given to the reliability of the naturalised flow series and level of artificial influence in the catchment. Average flows have been compared though a more detailed quantitative assessment of performance has not been undertaken given the uncertainties with historic flow series and other potential changes between the periods.

Figure A2.8: Severn at Bewdley annual mean flows

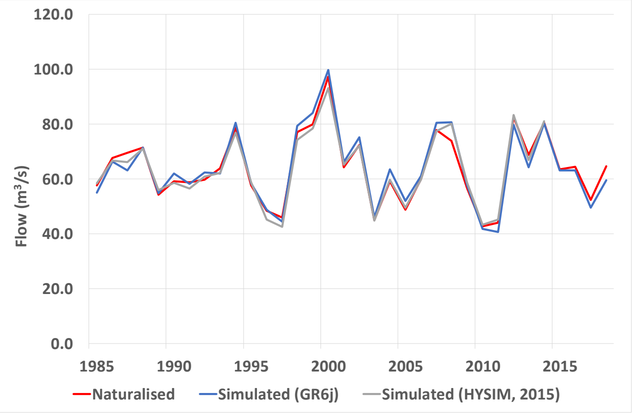


Figure A2.9: Severn at Bewdley FDC (1985-2018)

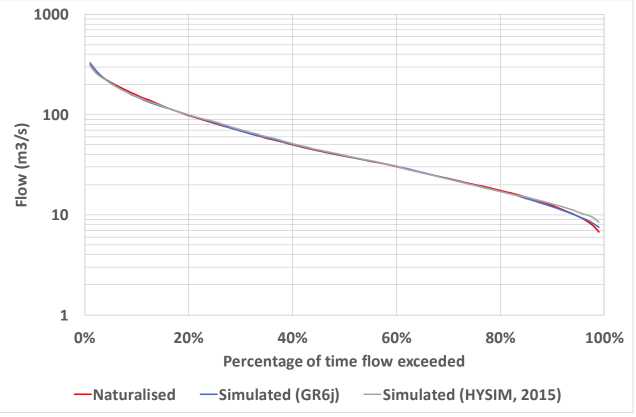
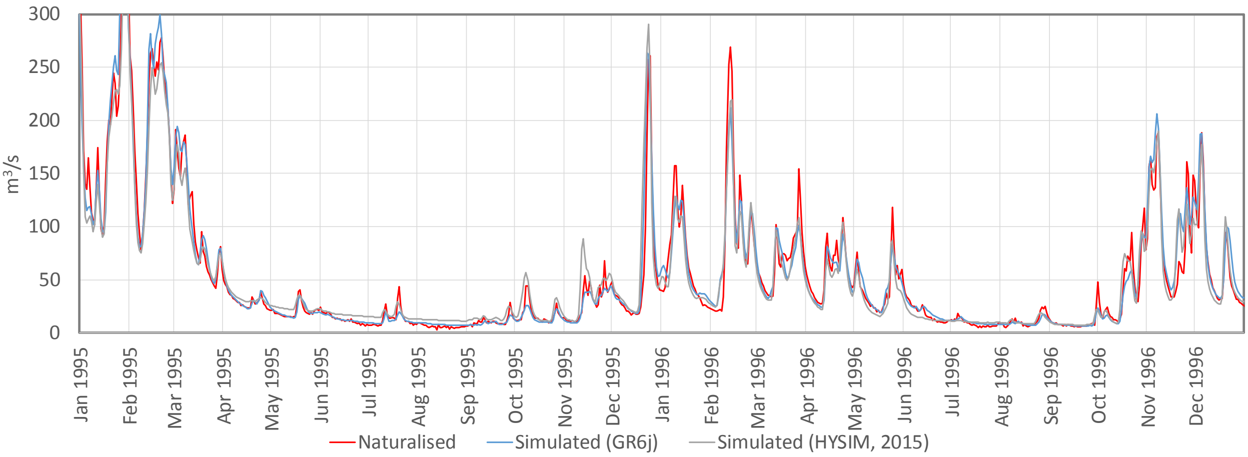


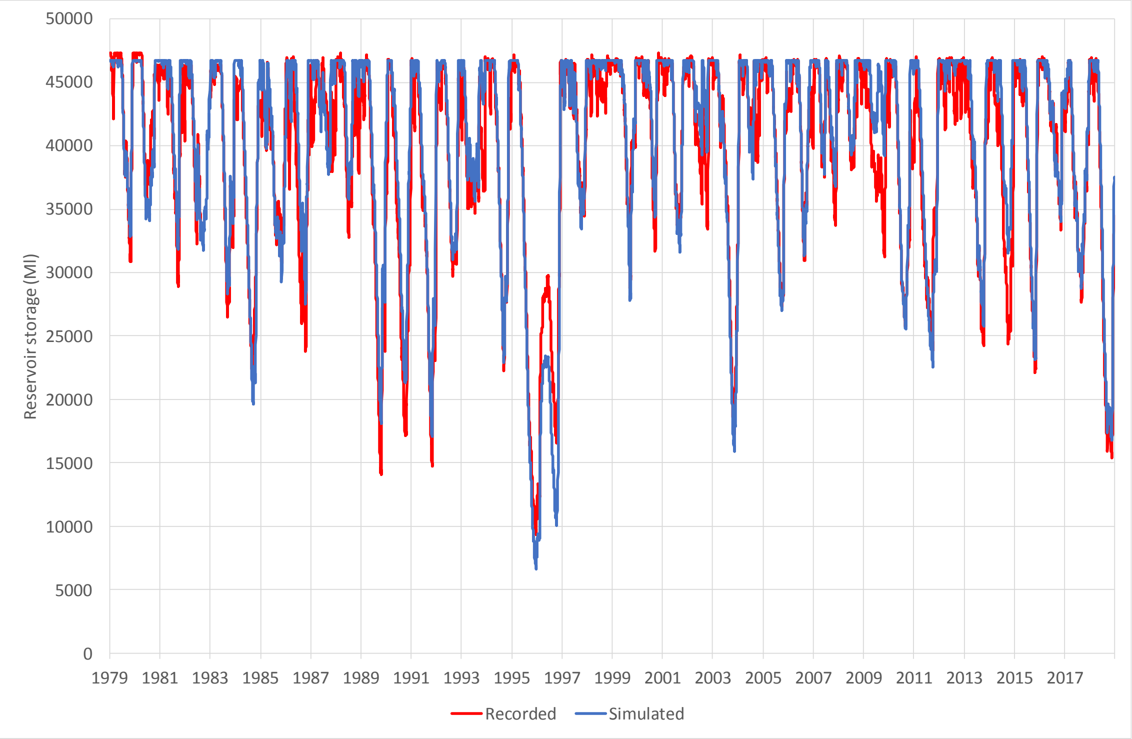
Figure A2.10 shows the historic flow series for the key drought year of 1995/96. In general, the fit is very close in low flow years, with improvements particularly in 1989, 1990 and 1995 compared to the HYSIM modelling used in WRMP19.

Figure A2.10: Severn at Bewdley flow series (1995-1996)



In addition, for selected reservoir catchments long-term simulation has been undertaken using a reservoir model that incorporates change in storage, abstraction and outflow data to simulate periods of drawdown and recovery to compare against observed records.

Figure A2.11: Derwent reservoirs simulation



Stochastic flow generation

The calibrated and validated GR6j models are used to generate stochastic flow series for water resources modelling. The stochastic flow generation is carried out using 400 daily time series (1950 to 1997) of rainfall and evaporation datasets that are generated with weather generator. The detailed methodology used for developing the stochastic dataset is outlined in the Regional Climate Data Tools report (Atkins 2020b). Details on rainfall site selection and rainfall time series generation for water resource west region are outlined in a separate technical note (Atkins 2020a). Rainfall datasets are generated for 47 rainfall stations and PET data are generated for all rainfall runoff modelling catchments across the SvE region.

GR6J simulated stochastic flows are used to derive flow duration curves (FDCs) for all catchments, with examples shown for Craig Goch Reservoir (R55007CRG) in the Wye and Rothley Brook at Rothley (C28056ROT) in the Soar (Figure A2.12 and Figure A2.13 respectively). The full flow range is shown on the left hand side on a log scale, with the lower flows shown in more detail on the right hand side. These FDCs show the spread of the 400 stochastic scenarios as well as curves representing the 10th, 50th and 90th percentiles of the stochastic range. The baseline historic FDC is also included for the equivalent 1950 to 1997 period. For both series the stochastic 50th percentile FDC corresponds reasonably well with the baseline FDC.

Figure A2.12: Derwent reservoirs simulation

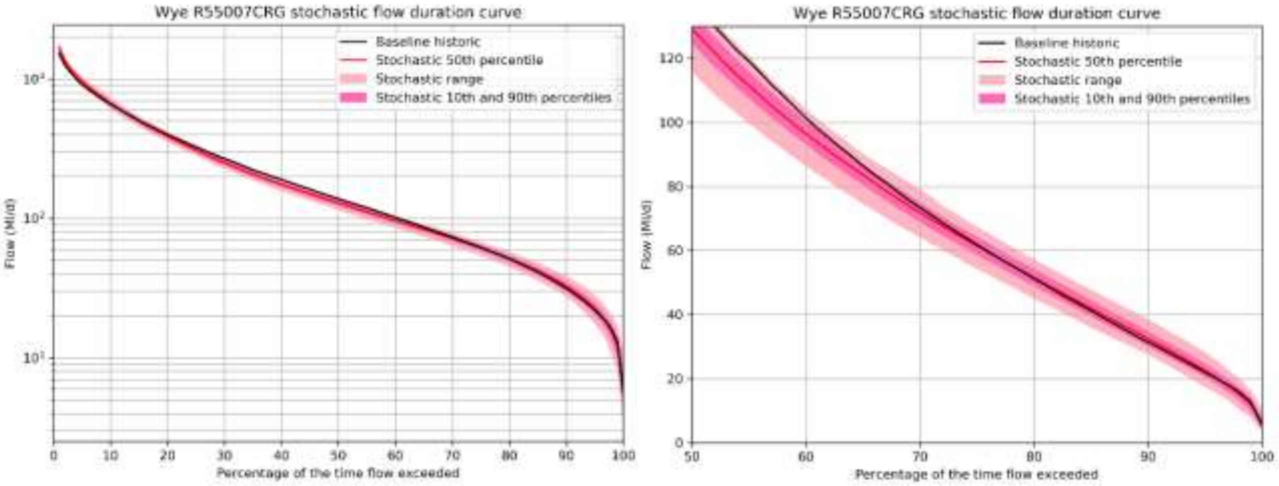
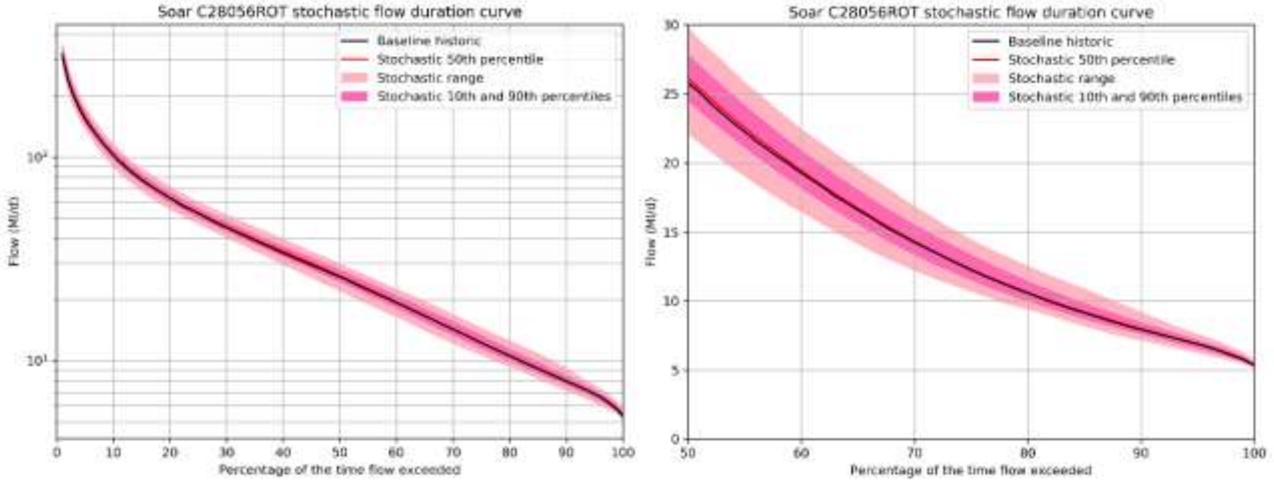


Figure A2.13: Derwent reservoirs simulation



Demand Centres and Demand Profiles

For our previous WRMP published in 2019 (WRMP19) we updated our demand centres where more detail has been added to the model. For this plan (WRMP24) we have kept demand centres consistent with our WRMP19 approach. The base level demands from 2006/07 financial year have been kept, but the monthly demand profiles allocated to the demand centres are updated based on 2018/19 financial year as this period included a more pronounced summer peak.

Surface Water Treatment Works Losses

For all of our zones with surface Water Treatment Works (WTWs), the process and treatment losses for these WTWs have been incorporated into the Aquator model. These have remained unchanged since our previous plan (WRMP19). This allows the model to take account of the process losses within the Deployable Output analysis. Table A2.4 shows the percentage process loss for each WTW that was input to out Aquator model.

Table A2.4: Modelled Surface Water Treatment Works Losses (excluding WTWs in Chester WRZ)

Water Treatment Works	Treatment works Losses (%)
Bamford	2
Campion Hills	8
Church Wilne	2
Cropston	3
Draycote	7
Frankley	1
Little Eaton	1
Melbourne	2
Mitcheldean	1
Mythe	3
Ogston	1
Shelton	7
Strensham	4
Tittesworth	8
Trimpley	1
Whitacre	2

Discussions with the Environment Agency (EA)

We have briefed the EA on our updated water resources model and new deployable output assessment at a number of meetings in 2020, 2021 and 2022. In these meetings we took the EA through the changes and improvements we have made to the Aquator model. This included the flow series update, model parameter review and our updated control curves. We have also discussed our updated groundwater baseline DO and our conjunctive use zone baseline DO.

We have also discussed with the EA our approaches to modelling climate change, extreme drought and how we have modelled the effect of the Water Framework Directive driven changes and Environmental Destination changes that are required in our system.

A2.4 Baseline Deployable Output

The WRMP24 supplementary note requires the estimation of a deployable output linked to a return period equivalent to 500 years for Level 4 restrictions (i.e. standpipes and rota cuts). The guidance states that the expected level of 1 in 500 resilience should be achieved as early as possible, or by 2039 at the latest. We plan to achieve 1 in 500 resilience across our systems by 2039 and 1 in 200 resilience will be met for the years up to 2039. The baseline deployable output (DO) for each zone based on the 1 in 200 and 1 in 500 resilience metric are presented in Tables A2.5 to A2.7. These are the 1 in 200 and 1 in 500 DO (linked to a return period equivalent to 500 years for Level 4 restrictions) provided by our current supply system that also complies with our current level of service (ensuring customers do not experience a Temporary Use Ban (TUB) more frequently than 3 times in 100 years). The baseline DOs do not include the potential impacts of future climate change or sustainability changes.

Groundwater Only Zones

For each of our groundwater only zones, the modelled zonal 1 in 200 and 1 in 500 year deployable outputs is equal to the sum of the individual source 1 in 200 and 1 in 500 deployable outputs as we have shown in Table A2.5.

Table A2.5: Deployable output of groundwater only zones

WRZ	WRMP24 1 in 200 DO (Ml/d)	WRMP24 1 in 500 DO (Ml/d)	Constraint
Bishops Castle	4.11	4.11	Groundwater Yield
Kinsall	5.00	5.00	Groundwater Yield
Mardy	3.50	3.50	Groundwater Yield
Ruyton	5.32	5.32	Groundwater Yield
Whitchurch & Wem	12.73	12.73	Groundwater Yield
Stafford	25.80	25.80	Groundwater Yield

Surface Water Only Zones

We do not currently have any water resource zones that are purely surface water fed. Our zones are either groundwater only or conjunctive use; where the surface water and groundwater sources in a zone are used together to give an improved overall deployable output.

We do however have one zone which is completely fed by an import from Anglian Water which is shown in Table A2.6. Our bulk supply agreement is for up to 18Ml/d, of which 6Ml/d is an import to the Strategic Grid zone.

Table A2.6: Deployable output of our surface water zone

WRZ	WRMP24 1 in 200 DO (Ml/d)	WRMP24 1 in 500 DO (Ml/d)	Constraint
Rutland	12	12	Bulk Supply Agreement

Conjunctive Use Zones

For each of our conjunctive use zones the modelled 1 in 500 deployable output of each source is based on the 1 in 500 deployable output of the whole zone, therefore we do not have any zones where the individual 1 in 500 deployable outputs shown in the WRMP tables do not aggregate to the water resource zone 1 in 500 deployable output which is shown in Table A2.7. Figure A2.14 shows an example of the modelled DO versus return period outputs for the conjunctive use zones where the Scottish DO methodology has been applied.

Figure A2.14: Modelled DO versus return period relationship

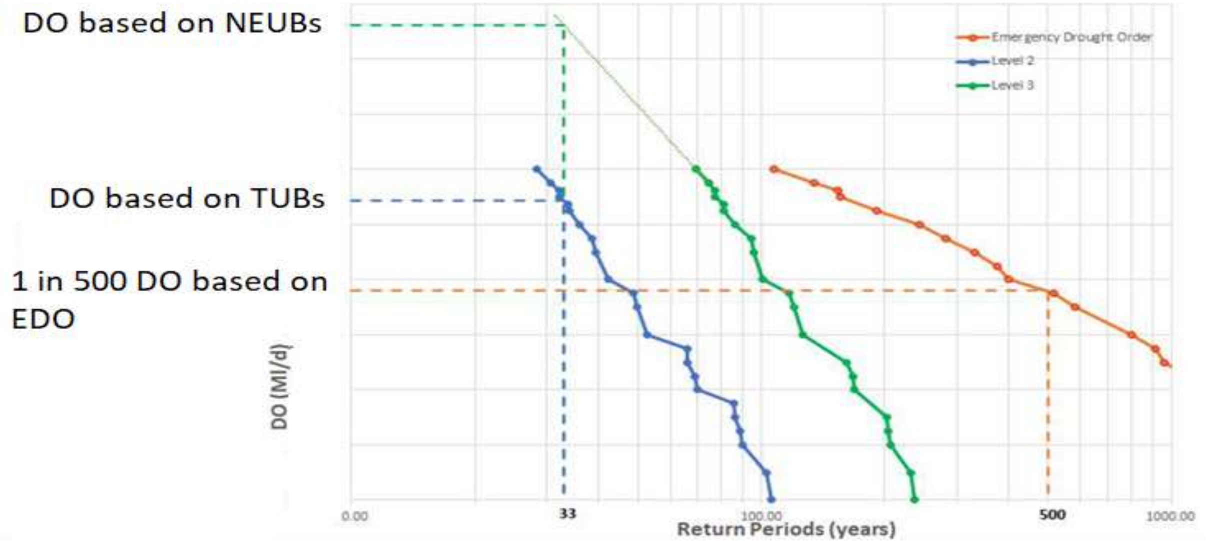


Table A2.7: Deployable output of our conjunctive use zones

WRZ	WRMP24 1 in 200 DO (Ml/d)	WRMP24 1 in 500 DO (Ml/d)	Constraint
Strategic Grid	1425.99	1377.40	Zonal Constraint. Surface and groundwater sources yields and licences constraints causing system failures during a set of 1 in 500 drought events.
Nottinghamshire	265.36	256.32	Zonal Constraint. Surface and groundwater sources yields and licences constraints causing system failures during a set of 1 in 500 drought events.
Newark	15.08	14.57	Zonal Constraint. Surface and groundwater sources yields and licences constraints causing system failures during a set of 1 in 500 drought events.
Shelton	138.00	138.00	Zonal constraint. Failure point is Shropshire; constraint is based on restricted groundwater yield in the zone.
Wolverhampton	66.37	65.95	Zonal Constraint. Constrained by available supply from River Severn.
Forest and Stroud	41.01	38.82	Zonal Constraint. Constraint based on groundwater yields and regulated river abstraction on River Wye.
North Staffordshire	141.00	140.27	Zonal Constraint. Surface water yield, groundwater and linkages constraints.
Chester	28.50	28.50	Zonal Constraint. Constraint based on groundwater yield and regulated river abstraction on River Dee.

A2.5 Deployable Output and Level of Service

Our level of service (LOS) of no more than three Temporary Use Bans (TUBs) in 100 years and not more than 3 Non-essential Use Bans (NEUBs) in 100 years is met in all of our water resource zones. This is described in more detail in Appendix A6. This LoS is set in our Aquator modelling as a requirement for our base deployable output (DO) assessment.

In our groundwater only zones, the sources of supply are all constrained by either abstraction licence or infrastructure.

- The Stafford water resource zone is supplied by five groundwater sources. The sources of supply are all constrained by infrastructure.
- The Bishops Castle water resource zone is supplied by two groundwater sources. The sources of supply are constrained by abstraction licence and infrastructure, respectively.
- The Mardy water resource zone is supplied by a single groundwater source. The source of supply is constrained by infrastructure.
- The Kinsall water resource zone is supplied by two groundwater sources. Individually, the sources of supply are constrained by abstraction licence and infrastructure, respectively. When abstracting

together the two sources of supply are further constrained by an overarching group abstraction licence.
- The Whitchurch and Wem water resource zone is supplied by three groundwater sources. Two of the sources of supply are constrained by abstraction licence. One of the sources of supply is currently out of supply, and has no deployable output attributed to it for this plan.
- The Ruyton water resource zone is supplied by a single groundwater source. The source of supply is constrained by abstraction licence.

A3 Impacts of Climate Change on Supply

A3.1 Overview of current approach

The Environment Agency's 2021 Water Resources Planning Guidelines (WRPG) requires companies to assess the risk and possible impact of climate change on the deployable output of their current and future sources of water. Environment Agency's 2021 climate change supplementary guidance states that the type of climate change analysis undertaken for a water resource zone should be:

- proportionate to the level of risk faced from climate change and/or the amount of planned investment; and,
- appropriate with respect to how existing assessment of climate change compares to projected change in a water resource zone based on UKCP18 projections.

We carried out a vulnerability assessment to identify which of our water resource zones (WRZs) are most sensitive to the potential impacts of climate change. This confirmed our findings from our WRMP 19 assessment, which demonstrated that our largest WRZs (the Strategic Grid and Nottinghamshire) were both vulnerable to potential changes in rainfall and temperature. With the exception of groundwater sources in the Forest and Stroud WRZ, the majority of groundwater sources were considered to be low vulnerability. However, in order to maintain spatial coherence across our WRZs (especially zones containing both surface water and groundwater sources) we have opted to apply Tier 3 approach to all zones, which involves analysis of the potential climate change impact on deployable output using the range of uncertainty across the UKCP18 products. This approach enabled us to assess impacts of climate change using the latest Met Office model (Regional Projections) and also explore the wider range of uncertainty based on evidence from other climate models (UKCP18 probabilistic projections).

Figure A3.1 shows the range of methodologies recommended in the Environment Agency's 2021 climate change supplementary guidance. The Tier 3, New climate change assessment using the full range of uncertainty with in UKCP18 approach, we applied is highlighted by the orange box.

Figure A3.1: Summary of climate change impacts assessment methods

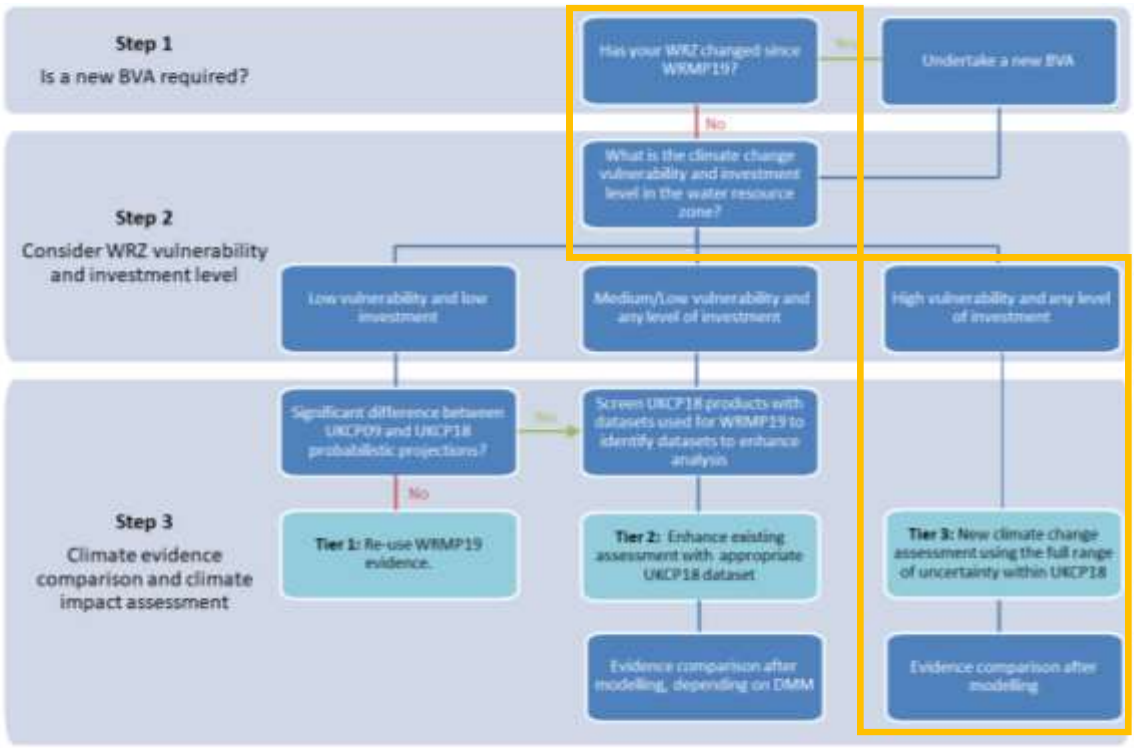
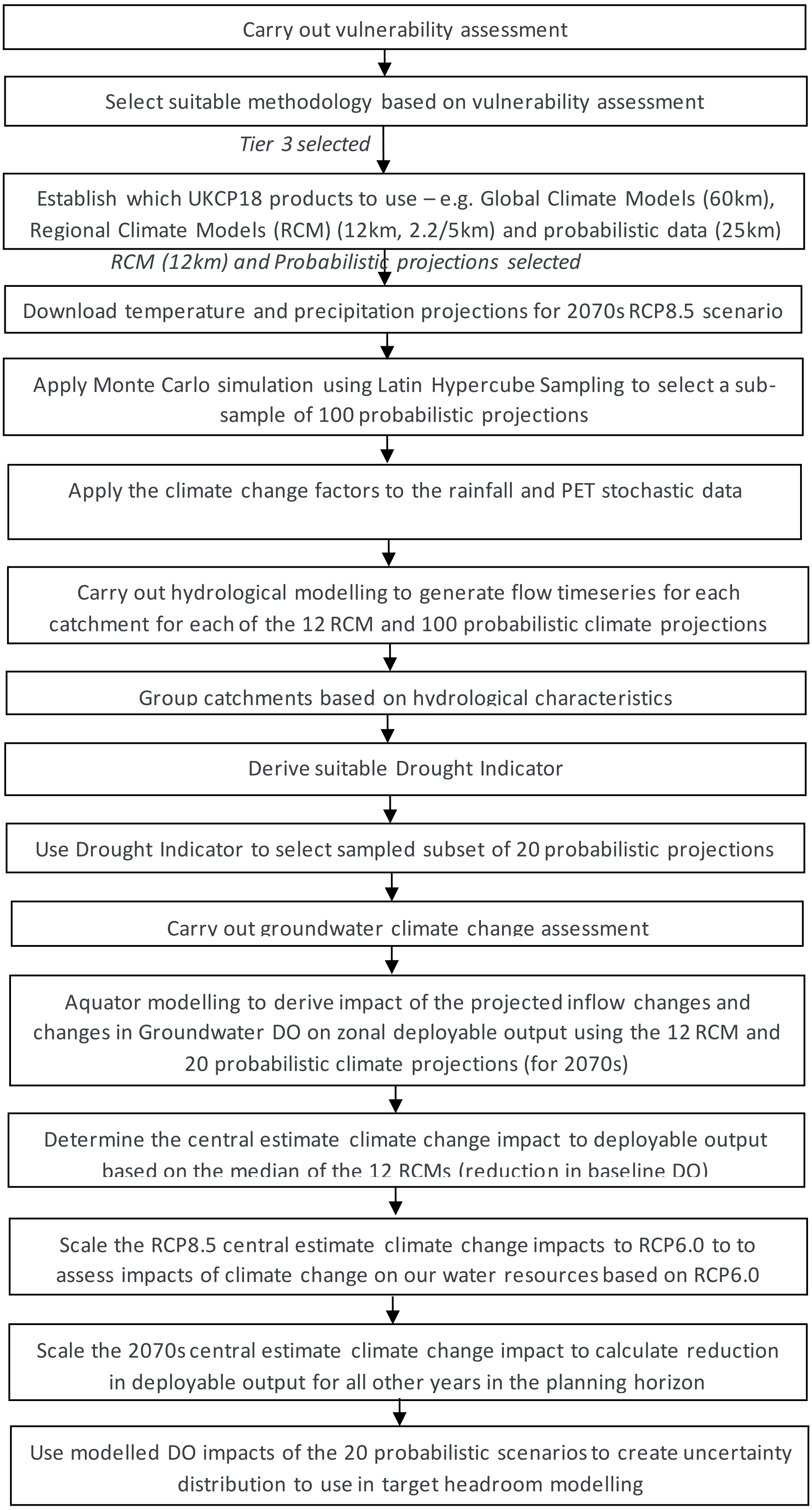


Figure A3.2 shows an overview of the full methodology we followed to assess impacts of climate change on deployable output in our water resource zones. A step by step description of our approach can be found in section A3.3. An overview of the impacts of climate change on our surface water and groundwater sources can be found in sections A3.4 and A3.5 respectively, and details of the impact on our water resource zone deployable output in section A3.6.

Figure A3.2: Overview of methodology followed to assess WRZ vulnerability to climate change



A3.2 Vulnerability Assessment

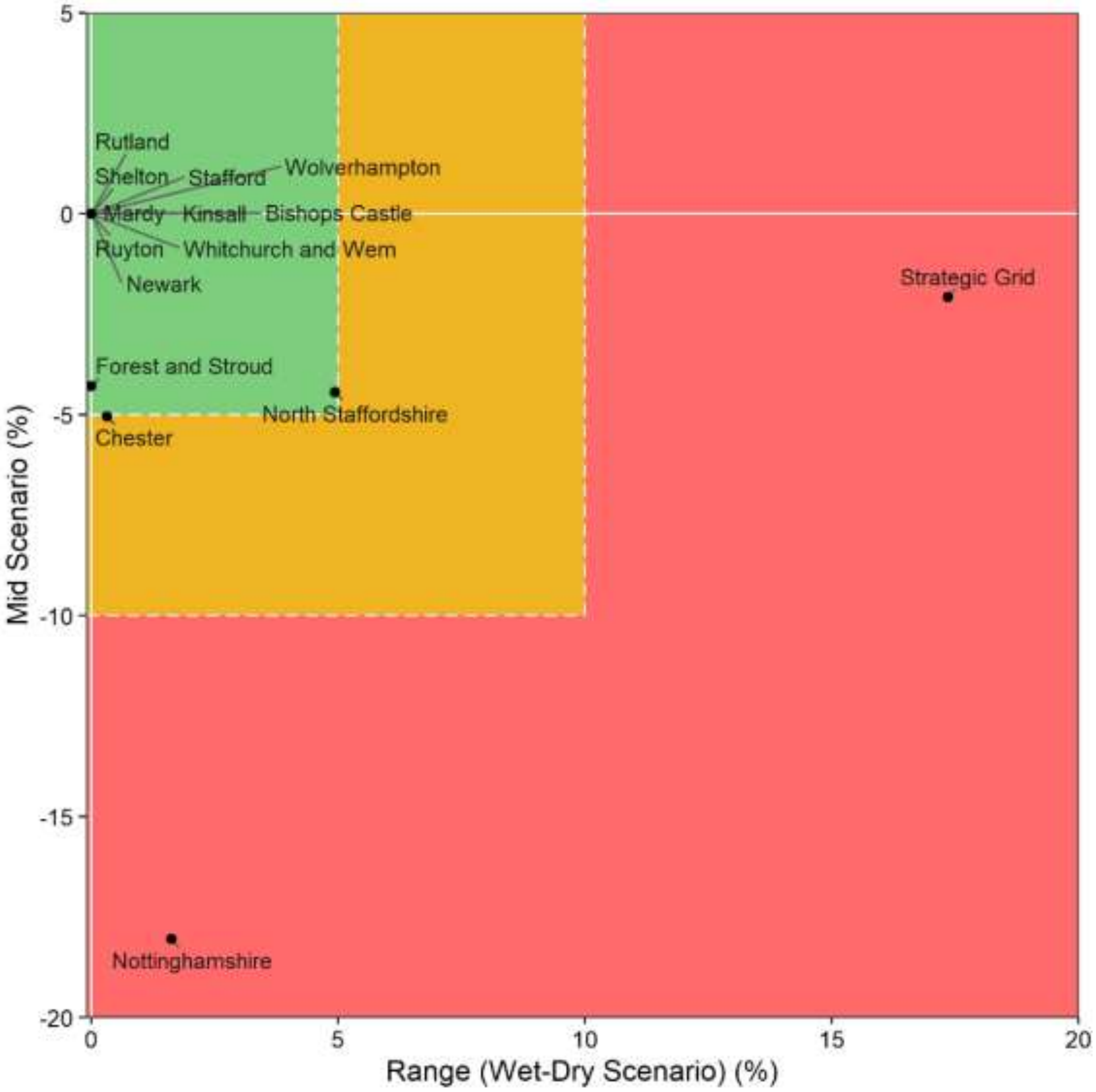
To decide which method to adopt, we carried out a vulnerability assessment for each of our water resource zones. By doing this, we were able to identify which zones are likely to be most sensitive to the effects of climate change and to determine whether our previous approach and assumptions are still applicable. Using our 2019 vulnerability assessment as a starting point, we have used a variety of sources of information to refresh and review the conclusions, including:

- Model outputs (deployable output modelling, modelled reservoir drawdown, supply- demand balance)
- Our abstraction licence documents and source information
- Our Drought Plan
- Our WRMP19

To quantify the vulnerability of our WRZs to the potential impacts of climate change we used our WRMP 19 climate change deployable output assessment. This modelling used our chosen method for WRMP19, which reduced the 10,000 UKCP09 projections to a sample of 20 by "smart sampling" using a drought indicator specific to our region. This sub-sample included 10 projections towards the "dry" end of the projection range and 10 projections which were equally spaced across the remaining range. For our WRMP 19 we carried out deployable output modelling for each of our conjunctive use WRZs (those zones which use a combination of impounding reservoirs, river abstractions and groundwater sources to supply our customers) using each of these 20 projections. The zones showing the biggest range of impacts were the Strategic Grid and Nottinghamshire.

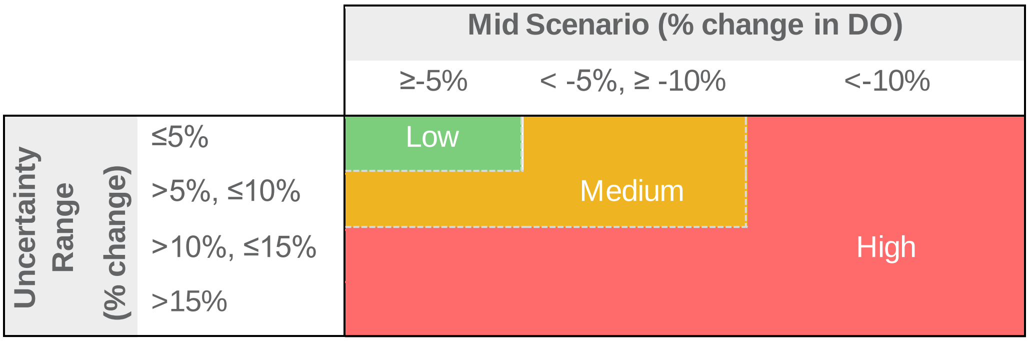
From the WRMP19 deployable output modelling results we generated a magnitude versus sensitivity plot, shown in Figure A3.3. This plot shows the percentage change in deployable output from the median or "mid" range scenario (rank 50 projection was used in WRMP19) against the range of uncertainty. The range of uncertainty is based on the difference between the "dry" rank 10 and "wet" rank 90 projections.

Figure A3.3: Magnitude versus Sensitivity plot for all of our water resource zones showing the climate change mid scenarios percentage change in deployable output (from the baseline) and the uncertainty range



Using the results from the magnitude versus sensitivity plot, we identified the vulnerability classification for each WRZ using the vulnerability scoring matrix shown in Table A3.1.

Table A3.1: Vulnerability scoring matrix



		Mid Scenario (% change in DO)		
		≥-5%	< -5%, ≥ -10%	<-10%
Uncertainty Range (% change)	≤5%	Low	Medium	High
	>5%, ≤10%			
	>10%, ≤15%			
	>15%			

The magnitude versus sensitivity plot and scoring matrix indicate that our two largest zones, the Strategic Grid and Nottinghamshire, are still both classified as “high” vulnerability. All our other conjunctive use zones are “low” vulnerability. A summary of WRZs vulnerability classification is shown in Table A3.2.

Table A3.2: Water Resource Zone vulnerability classification

WRZ Name	Vulnerability
Bishops Castle	Low
Forest & Stroud	Low
Chester	Low
Kinsall	Low
Mardy	Low
Newark	Low
North Staffordshire	Low
Nottinghamshire	High
Rutland	Low
Ruyton	Low
Shelton	Low
Stafford	Low
Strategic Grid	High
Whitchurch & Wem	Low
Wolverhampton	Low

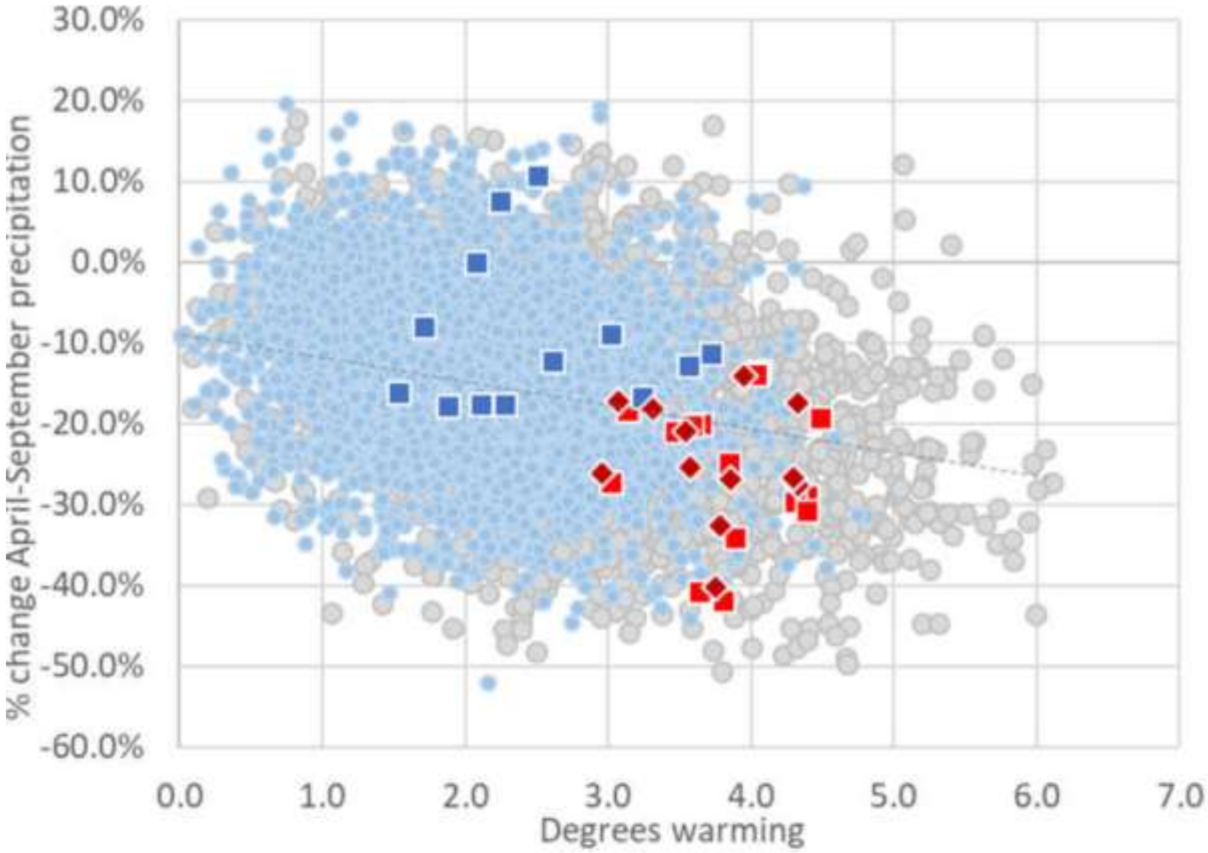
A3.3 Choice of Climate Change scenarios

Consistent with our WRMP19 we have adopted a “high” vulnerability approach for all 15 WRZs, including those classified as “low” vulnerability, to ensure consistency in our zonal deployable output modelling. The Strategic Grid zone covers a large area of the Severn Trent region and includes most of our strategic raw water reservoirs (the exception being Tittesworth reservoir, located in the North Staffordshire zone). The Strategic Grid zone is classified as being “high” vulnerability as the modelling produces a wide range of uncertainty - under very wet conditions, the deployable output could be higher than our baseline and under very dry conditions, deployable output could be much lower than baseline depending on the scenario used.

Nottinghamshire zone is mainly supplied by groundwater sources and also relies on large imports from some of the surface water sources in the Strategic Grid. Our modelling has shown that the surface water imports may be impacted by climate change, which has led to the Nottinghamshire zone being classified as “high” vulnerability based on previous WRMP19 climate change impact assessment. Groundwater sources in the Nottinghamshire zone are mainly constrained by infrastructure/licences and are not impacted by climate change as explained in section A3.5. Imports to Nottinghamshire zone from Strategic Grid are assumed to be maintained at existing levels under climate change scenarios and no climate change impact on DO is therefore attributed to Nottinghamshire zone in our WRMP24 climate change impact assessment. Few imports and exports exist between our other water resource zones, however, several of our zones have “shared resources”. For example, the Shelton, Wolverhampton and Strategic Grid zones are not physically connected but all abstract from the River Severn, taking water from different locations. Our largest abstractions from these shared resources are used to supply the Strategic Grid zone. Adopting different climate change assessment approaches for our “low” and “high” vulnerability zones when modelled together could result in climate change flow series which are not spatially coherent and could over, or under, estimate the impact of the changing climate.

The Environment Agency's Water Resource Planning Guidelines, 2021 and the climate change supplementary guidance outline how we can use the UKCP18 climate projections to estimate impacts of climate change on water resource zone's deployable output. The supplementary Guidance on Climate Change indicated that multiple sources of climate change evidence should be used, particularly UKCP18 Met Office climate models and probabilistic data. The UKCP18 projections provide Global Climate Models (60km), Regional Climate Models (12km), a high-resolution RCM (2.2/5km) and probabilistic data (25km) for scenario RCP8.5. Probabilistic data are also provided for scenarios RCP2.6, RCP4.5, RCP6.0 and A1B Medium Emissions. The UKCP probabilistic projections are generated based on the use of multiple variations of a specific climate model to simulate a wide range of different climate outcomes and are considered suitable to understand uncertainties in future risk assessment. Figure A3.4 below shows the comparison of different climate model data for England and Wales in the 2070s. (UKCP probabilistic A1B blue circles; RCP8.5 grey circles; CMIP5 blue squares; HadGEM red squares and RCM red diamonds).

Figure A3.4: Comparison of different climate model data for England and Wales in the 2070s. (UKCP probabilistic A1B blue circles; RCP8.5 grey circles; CMIP5 blue squares; HadGEM red squares and RCM red diamonds)



Source: Atkins climate change scaling report (2021)

All companies in Water Resources West (WRW) adopted common approaches to ensure that a consistent climate change approach is used across the region, particularly for strategic schemes, and in response to the Environment Agency (EA) supplementary guidance on climate change. It's been agreed at WRW level to include the RCMs and the probabilistic dataset in our climate change analysis. RCMs were considered to provide comparable climate change outputs across regions due to their better representation of spatial coherence of climate change and their use by most companies. Thus, median of RCM scenarios are used to inform central estimate climate change impact and probabilistic scenarios are used to assess and represent uncertainty range of climate change impacts in headroom. The RCM RCP8.5 data indicate warming of around 4°C (3.1 –4.3 °C) above the 1981-2000 baseline in England and Wales with wetter winters and drier summers. The EA climate change guideline does not specify which emission scenario to use in WRMP24/ regional planning. We carried out all climate change rainfall-runoff and water resources systems modelling using RCP8.5 scenarios with a view to include RCM scenarios (that are only available as RCP8.5 scenarios) in our climate change analysis. The use of RCP8.5 2070s scenarios in our analysis has also helped to understand the "business as usual" type scenario that demonstrates the impact of climate change most clearly, over and above natural variability and model uncertainties. It was also agreed at WRW level to use RCP6.0 impacts for the supply demand balance purpose in the planning tables. Thus, modelled climate change impacts based on RCP8.5 scenario are scaled down to impacts that reflect RCP6.0 scenario as explained in section A3.7.

Taking the above into consideration, the method we adopted is summarised below.

Step 1: Processing climate change projections

Following the release of the UKCP18 projections we commenced "Regional Climate Data" project to support water resources planning at regional and company level, which provided rainfall, average temperature and PET data for drought risk assessment and climate change modelling. This includes processing and bias-correction (BC) of UKCP18's 12km Regional Climate Models (RCM) for river basins, as well as climate change factors for UKCP18 Probabilistic projections and Global Climate models for England and Wales. This is summarised in Table A3.3.

Table A3.3: Climate change datasets used in WRMP24 climate change assessment

Data set	Rationale	Resolution
UKCP18 RCM bias-corrected factors	Climate change risk assessment. 12 bias corrected RCM RCP8.5. P, T and PET change factors to apply to stochastic data sets, to create stochastics *plus* climate change. Factors for the 2060-2080 period.	River basin
UKCP probabilistic	Climate change factors for P and T for RCP8.5 and A1B for the 2060-2080 period. To provide a broader context to the RCM data sets.	England and Wales

All climate change factors were provided on a monthly basis for both rainfall and temperature. The 12 bias corrected RCM projections have factors that are unique to each river basin and have been assigned to each model catchment based on spatial location. Probabilistic projections apply the same England and Wales factors to all catchment so that the same coherent data sets can be used in all regions.

Step 2: Sampling probabilistic projections

The UKCP18 dataset provides 3000 samples of probabilistic projections, which needed to be sampled down to 100 representative samples to be used in our climate change rainfall-runoff model simulations. The EA guidance acknowledges that companies may not be able to apply the whole 3000 scenarios for multiple RCPs. The following points are required to be considered when applying sampling methodologies:

- Select a sufficient number of samples to estimate the average impact and range of impacts
- Retain important multivariate correlations between changes in precipitation and temperature and changes from season to season or month to month
- Be based on relevant metrics for the specific water resources zones, for example some areas may require the best sample for winter rainfall and others for summer rainfall

We have used a simulator in @Risk, which fitted distributions to the 3000 UKCP18 probabilistic samples for 24 change variables and modelled the correlations between these variables. The simulator was then used to resample these distributions and produce 100 coherent sub-samples of the full data set. This used 3000 monthly Precipitation and Temperature change factors for 2060-79 to simulate a set of 100 scenarios, while retaining the correlation between Precipitation and Temperature changes for each month (a simulation with 24 dimensions). This method used a Monte Carlo simulation using Latin Hypercube Sampling rather than a strict selection procedure, but it provides a robust set of representative scenarios for RCP8.5 and 2060-79. Sampling performance statistics have shown that this method reproduces the average and range more reliably than the random sample that can be generated using the UKCP user interface. Probabilistic data along with two simulated sub-samples of 100 scenarios are presented in Figure A3.5. Statistical comparison of simulated UKCP change factors for precipitation percentage and degrees of warming for 2060-2079 are shown in Table A3.4.

Figure A3.5: Probabilistic data along with two simulated sub-samples of 100 scenarios

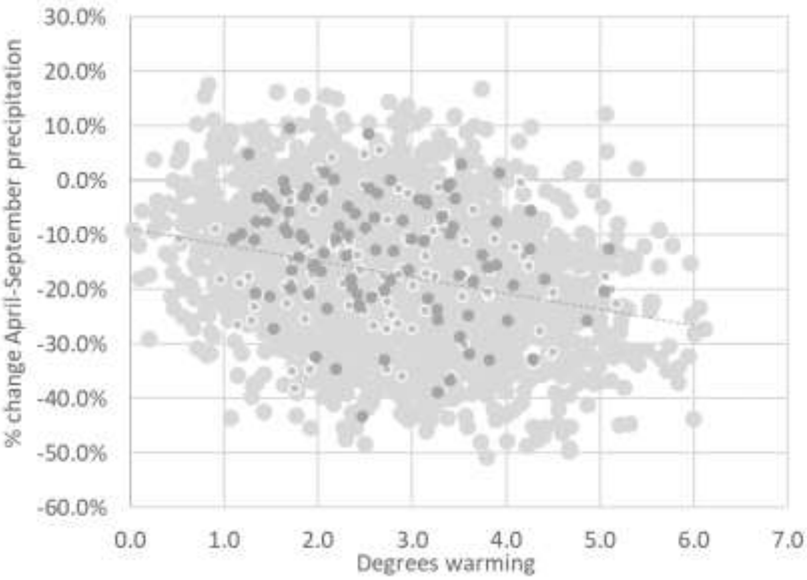


Table A3.4: Simulated UKCP change factors for precipitation percentage and degrees warming for 2060-2079

Summary statistics	RCP 8.5					A1B		
Annual average temperature rise °C	Probabilistic 3000	Random 100	LHS 100	RCM HadGEM3 n=12	GCM CMIP5 n=13	Probabilistic 3000	Random 100	LHS 100
Median warming	2.7	2.5	2.7	3.8	2.3	2.0	2.0	2.0
10th percentile	1.4	1.5	1.4	3.1	1.7	1.0	1.0	1.0
90th percentile	4.1	3.9	4.2	4.3	3.5	3.1	3.1	3.1
April-Sept rainfall change								
Median change	-17%	-12%	-17%	-26%	-12%	-13%	-13%	-13%
10th percentile	-32%	-27%	-28%	-32%	-18%	-27%	-26%	-27%
90th percentile	-2%	-1%	-2%	-17%	6%	0%	-1%	0%

Step 3: Apply climate change factors to stochastic rainfall and PET

The monthly climate change factors are applied to the rainfall and PET stochastic input data, including for the two year warm up period (1948 and 1949) that have been extracted from historical records. Example plots of the 12 monthly RCM climate change factors for the Avon basin for rainfall and PET are shown in Figure A3.6 and Figure A3.7 respectively.

Figure A3.6: RCM rainfall adjustment factors - Avon

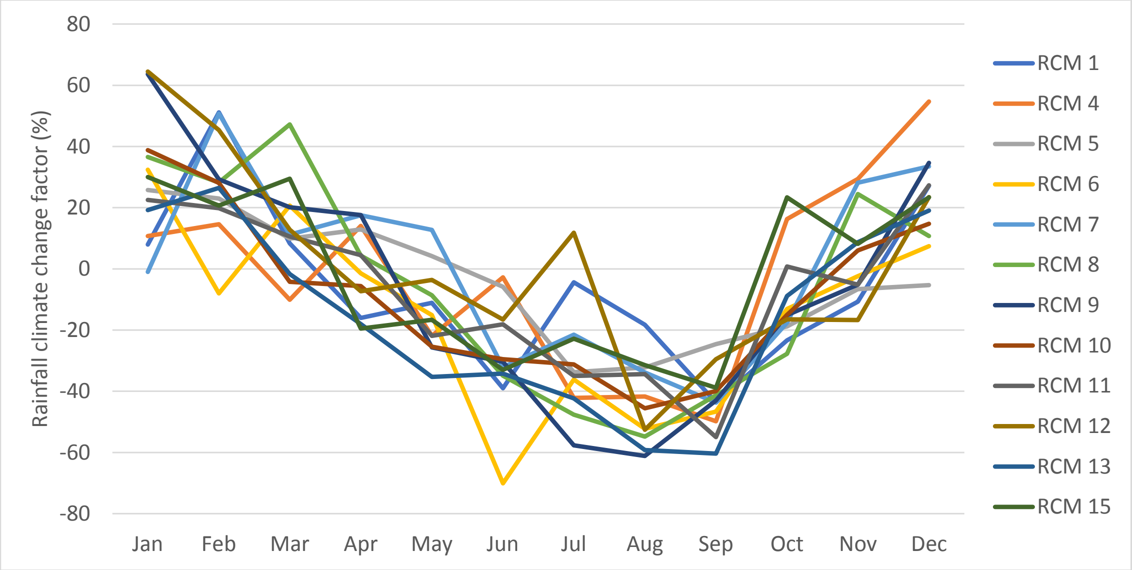
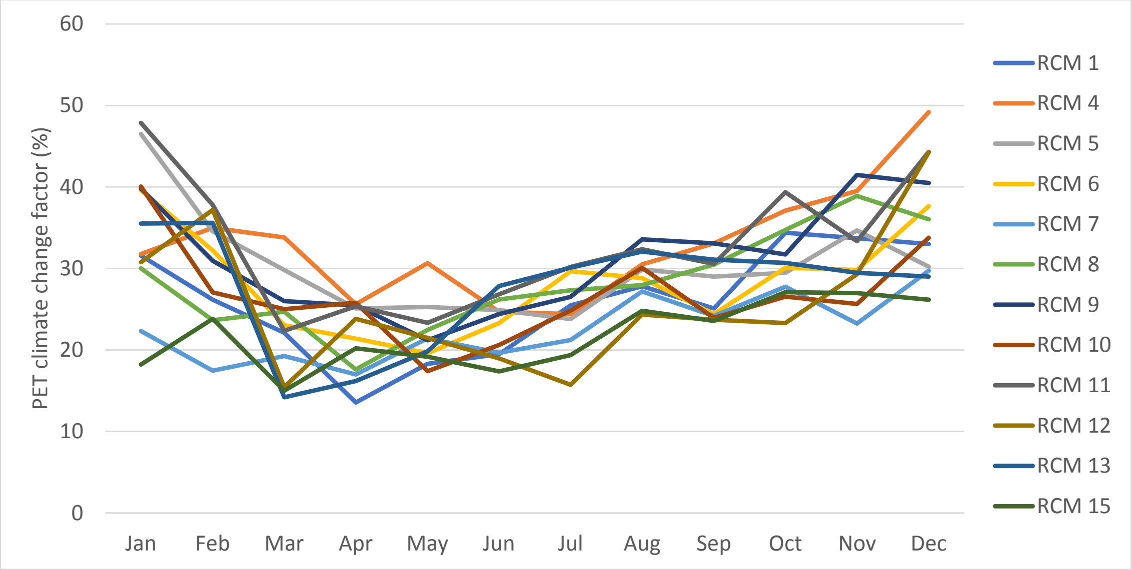


Figure A3.7: RCM PET adjustment factors - Avon



The spread of RCM climate change rainfall factors for the 2070s for the Avon indicate a reduction in summer rainfall with the majority of factors being negative between May and October and an increase in winter rainfall with the majority of factors being positive between December and March. There is significant variability between the different RCMs and from month to month, though the overall impact of each RCM will be very dependent on the monthly rainfall profiles for each catchment.

The spread of RCM PET climate change factors indicate greater percentage increases in PET in the winter and lowest in spring. However, in absolute terms PET remains low in the winter and significantly higher in the summer. As such the higher percentage PET increases in winter are unlikely to have as significant an impact as the percentage PET increases in the summer.

Step 4: Hydrological modelling
Rainfall-runoff model simulations were carried out using these perturbed datasets for 100 UKCP18 probabilistic scenarios and 12 RCM projections using 2070s factors (altogether 112 climate change scenarios). No other changes to the simulation model compared to the stochastic scenarios have been made. The GR6J

modelling generated 112 sets of climate change perturbed flow series for each of our Aquator catchments, which enabled us to estimate the impacts of climate change on natural flows.

Step 5: Grouping of catchments

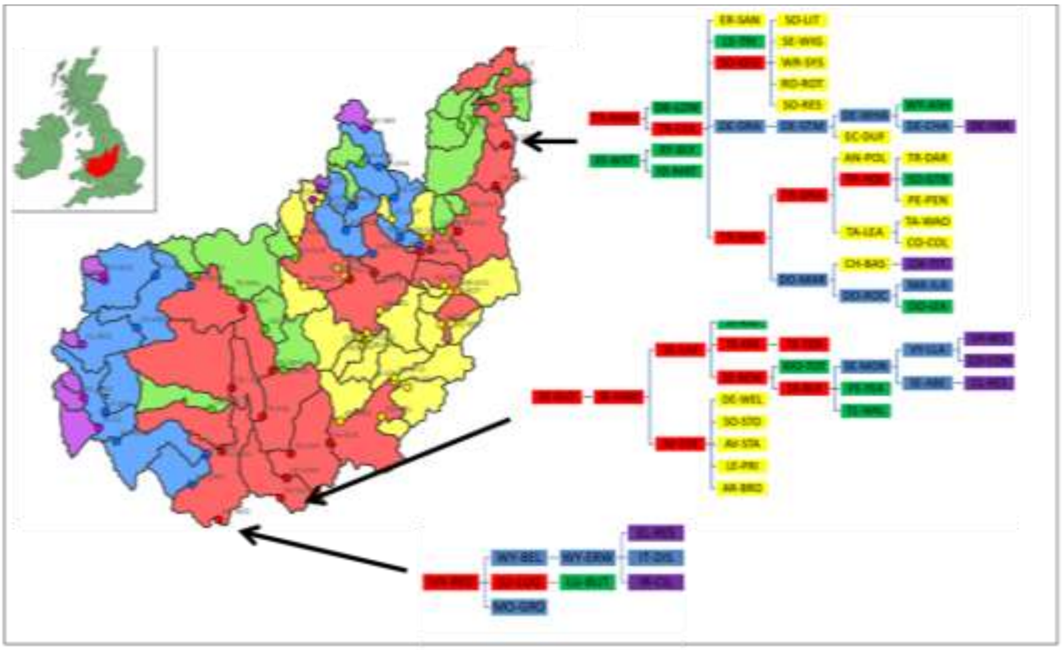
As previously discussed, our Aquator water resource model uses 19200 years of daily inflow data for 78 catchment points across the Severn, Trent and Wye catchments that are derived using 104 hydrological models (GR6J). The 100 probabilistic scenarios are required to be subsampled to 20 representative scenarios to enable us to cover the distribution across the full range of probabilistic scenarios using Aquator modelling. Grouping of catchments is required to be able to calculate drought indicators and carryout subsampling of the 20 representative probabilistic scenarios. In WRMP19, an analysis of several different catchment attributes, including topography, Base Flow Index and SAAR (Standard Annual Average Rainfall) were used to classify all the modelled catchments into five groups with similar hydrological characteristics and responses to climate. The catchment descriptions are shown in Table A3.5.

Table A3.5: Overview of the catchment groupings derived from hydrological analysis

Group	Minimum Area (Km²)	Maximum Area (Km²)	Minimum SAAR (mm)	Maximum SAAR (mm)	Minimum Base Flow Index	Maximum Base Flow Index	Number of models	Description
1	148	2027	936	1386	0.43	0.58	14	Larger intermediary catchments with generally higher rainfall
2	63	869	641	1165	0.59	0.79	13	Catchments with a high Base Flow Index reflecting a larger dominance of base flow
3	46	795	628	976	0.28	0.55	23	Smaller low lying catchments with lower rainfall
4	885	10443	654	1009	0.40	0.61	17	Large downstream, lowland catchments representing the main river reaches
5	10	246	926	1971	0.33	0.45	9	Small typically upland catchments with high rainfall and a flashy catchment response

Figure A3.8 shows the distribution of the hydrological models in the Severn Trent Region. The catchment types are indicated by the colouring as shown in Table A3.5.

Figure A3.8: Distribution of HYSIM hydrological models in the Severn, Trent and Wye basins



From these catchment groups, five representative "exemplar" rainfall runoff modelled catchments were chosen (one for each catchment group) based on the following criteria:

- Calibration method for the baseline flow series – for the exemplar modelled catchment it was preferable to use models which had been calibrated against naturalised flow data.
- Number of nested upstream models – for the exemplar catchment models this was zero as models nested downstream of another rainfall runoff model incorporate the hydrological response of both the upstream catchment(s) and the nested catchment, which could mask the hydrological response of the nested catchment.
- Proportional size of artificial influences – for the exemplar rainfall runoff catchment the proportion of artificial influences should be as small as possible so that only the impacts on the natural catchment flow are seen in the climate change modelling. Where artificial influences were included in the baseline flow series, the artificial influences were removed from the models for the climate change analysis and were added on again before being used in the Aquator modelling.
- Additional information collected during the derivation of the baseline flow series regarding the confidence in the model itself.

The Ithon at Disserth, Wye at Ashford, Wreake at Syston Mill, Teme at Tenbury and Elan Reservoirs were adopted as the five exemplar catchments in WRMP19. However it is now required to modify the exemplar catchments to make them more relevant from a supply perspective whilst maintaining different hydrological characteristics. As such it was decided to:

- Replace the Ithon at Disserth with the Dove at Marston
- Replace the Wreake at Syston Mill with the Rothley Brook at Rothley.

Thus, the five exemplar catchments adopted are:

- Dove at Marston
- Wye at Ashford
- Rothley Brook at Rothley
- Teme at Tenbury
- Elan Reservoirs

Step 6: Deriving a suitable Drought Indicator and sub-sampling the probabilistic scenarios
In order to reduce the number of projections in the assessment from the 100 which were sampled using Latin Hypercube based sampling, drought indicators are used to produce a targeted sample of 20 probabilistic projections. The 400 scenarios of stochastic baseline flow series for 1950-1997 are compared with each of the 100 probabilistic stochastic flow series for these five exemplar catchments using the following two drought indicators:

- Average annual flow (more relevant for catchments where winter storage is important); and,
- April to September average flows (more relevant for direct intakes).

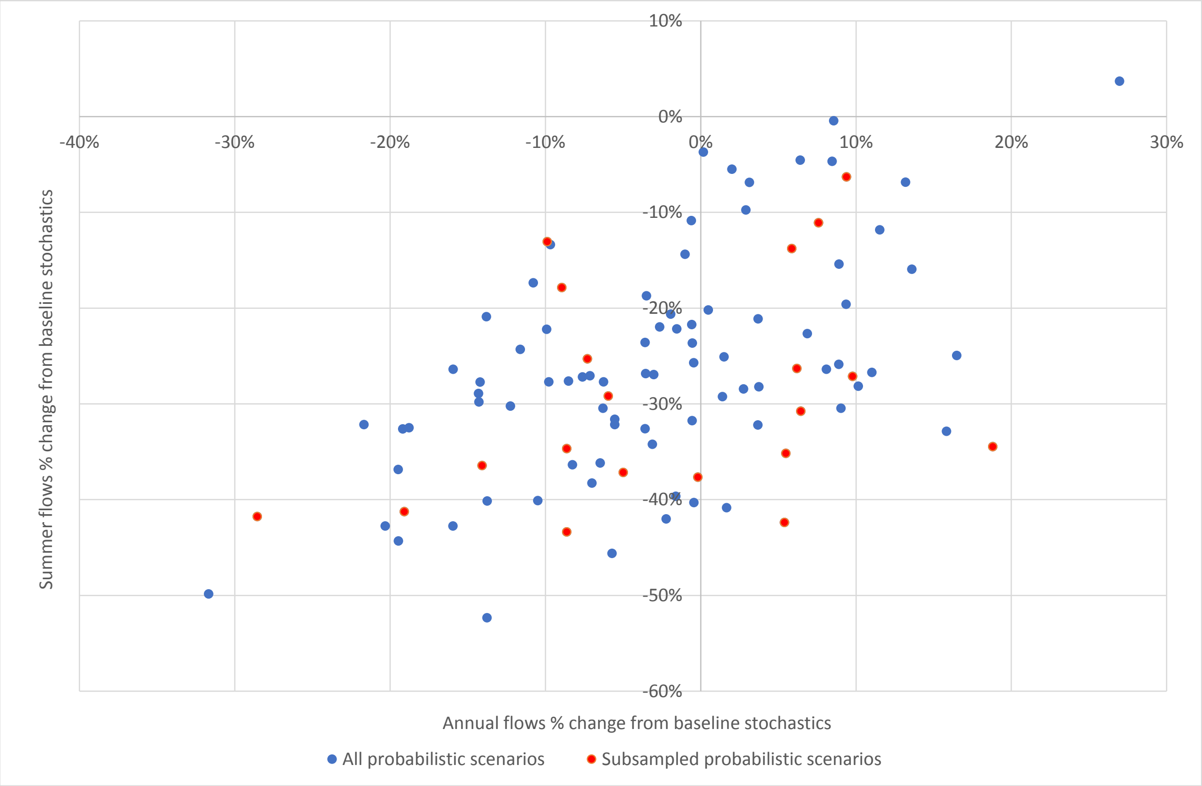
Percentage changes from the baseline stochastics were derived for the two drought indicators for each of the five exemplar catchments. An average change across the ten indicators was taken and then ranked to provide a combined drought indicator representing the whole SvE area. Every 5th ranking was taken with the addition of the 99th ranking to give a total of 20 scenarios for use in our water resources impact modelling. The final adopted probabilistic scenarios, their ranks and the percentage change in flow from the baseline stochastics are summarised in Table A3.6.

Table A3.6: Summary of subsampled probabilistic scenarios

Selected rank	Probabilistic Scenario ID	% Change in flow from baseline stochastics
5	77	2%
10	44	-2%
15	72	-4%
20	37	-8%
25	79	-9%
30	87	-10%
35	96	-11%
40	85	-12%
45	80	-13%
50	86	-15%
55	19	-16%
60	100	-18%
65	68	-18%
70	83	-19%
75	88	-21%
80	21	-22%
85	61	-25%
90	2	-26%
95	17	-30%
99	82	-35%

The average annual and summer change in flow compared to the baseline are plotted in Figure A3.9 for the full set of probabilistic scenarios (blue) and the 20 subsampled scenarios (red). This represents an average change across the five exemplar catchments.

Figure A3.9: Average annual and summer change in flow from the baseline (average for the five exemplar catchments)



From Figure A3.9 it can be seen that there is a general positive corelation between percentage changes from baseline for summer and annual flows, with greater relative decreases in summer flows compared to annual flows. Whilst annual flow changes tend to be negative there are a large number of positive changes, whereas virtually all summer flow changes are negative.

Step 7: Groundwater assessment

A groundwater assessment was completed using the 20 probabilistic scenarios identified in step 6 and the 12 RCM scenarios; this produced estimates of changes in groundwater level and DO for physical and flow constrained sources as explained in section A3.5. Licence constrained sources were assumed to be unchanged.

Step 8: Input of climate change data sets into Aquator

To enable us to model the combined impact of climate change on our inflow series and our groundwater sources in our conjunctive use water resource zones, we created a sequence set (to incorporate the climate change impacted inflow series) and a parameter set (to incorporate the climate change impacted groundwater sources) for each of our 32 climate change scenarios in our Aquator model, using the UKCP18 sample ID as the identifier.

We imported the climate change impacted flow series into our Aquator model, assigning them to the relevant catchment and the climate impacted constraint data for the affected groundwater components. For each climate change run we used the sequence set and parameter set with the same UKCP18 sample ID to ensure consistency between the datasets used. To ensure consistency with the baseline modelling, the climate change impacts were applied to the Aquator model which was used to derive our baseline DO. As discussed in section A2.3, a representative subset of the stochastic dataset (4800 years of data) is used for Scottish DO analysis of the climate change scenarios.

A3.4 Impact of Climate Change on our surface water sources

Under all 32 climate change scenarios modelled in Aquator, significant changes in monthly rainfall and temperature are seen to occur, both positive and negative. These changes in climate will have a knock-on effect to the flows in the water courses in our region. Impacts of climate change on our surface water sources is presented in this section for the two sets of climate change runs, the 12 Regional Climate Model (RCM) projections and 100 UKCP18 probabilistic scenarios using 2070s RCP8.5 factors. The same two catchments have been used as examples in this section (Craig Goch Reservoir (R55007CRG) in the Wye and Rothley Brook at Rothley (C28056ROT) in the Soar).

RCM climate change scenario results

Mean flows across the 400 stochastic scenarios for each of the 12 RCMs have been expressed as a percentage change compared to the baseline for each Aquator series. To give an approximate assessment of the overall impact across the Severn Trent region the percentage changes have been averaged across all Aquator series, as summarised in Table A3.7.

Table A3.7: Annual average change in flows as a percentage change from baseline across all Aquator series for RCM scenarios

RCM Scenario	Mean RCM 2070s % change from baseline for all Aquator series
RCM01	-25%
RCM04	-14%
RCM05	-27%
RCM06	-29%
RCM07	-4%
RCM08	-16%
RCM09	-13%
RCM10	-25%
RCM11	-19%
RCM12	-14%
RCM13	-27%
RCM15	-12%

This comparison with the stochastic baseline for 1950 to 1997 shows a range of -29% for RCM06 (worst-case) to -4% for RCM07 (best-case) for the 2070s. The median change across all 12 RCMs is -18%.

The RCM climate change results for each time series have also been presented spatially for the median RCM (Figure A3.10), the best-case RCM scenario (Figure A3.11) and the worst-case RCM scenario (Figure A3.12).

Figure A3.10: Median percentage change in annual flows from baseline for RCM 2070s RCP8.5 scenarios

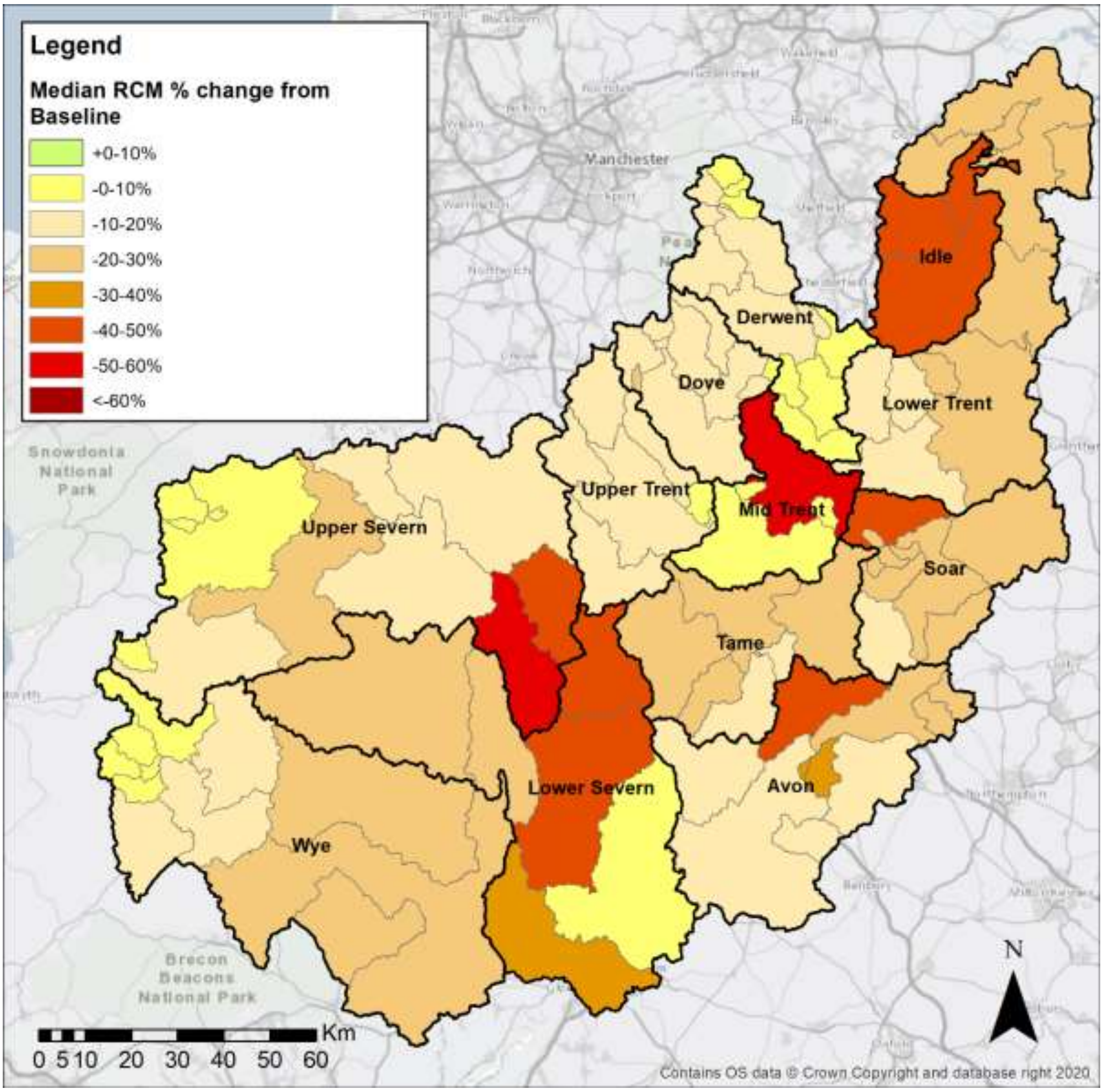


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Figure A3.11: Percentage change in annual flows from baseline for RCM07 2070s RCP8.5 scenario

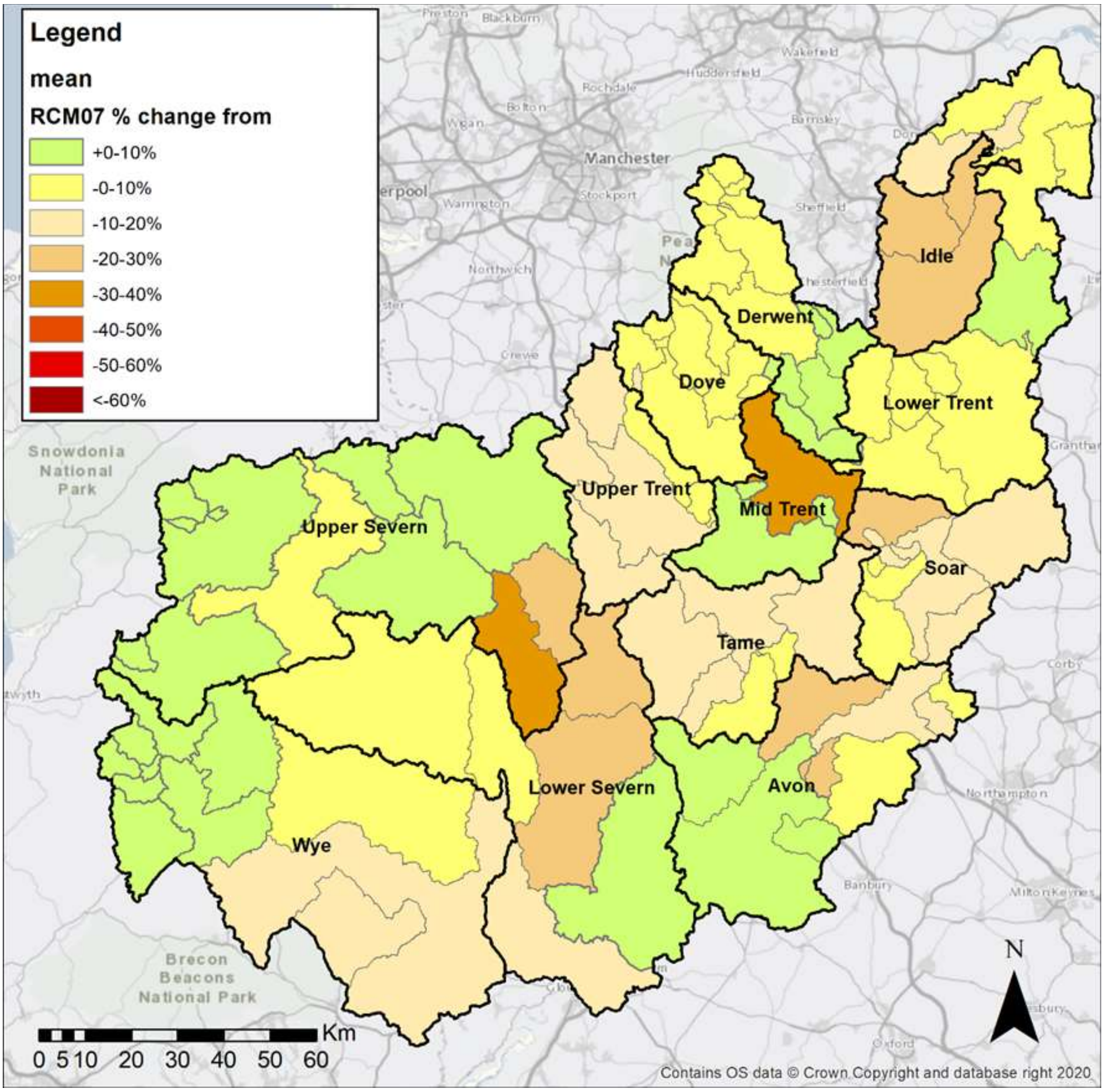

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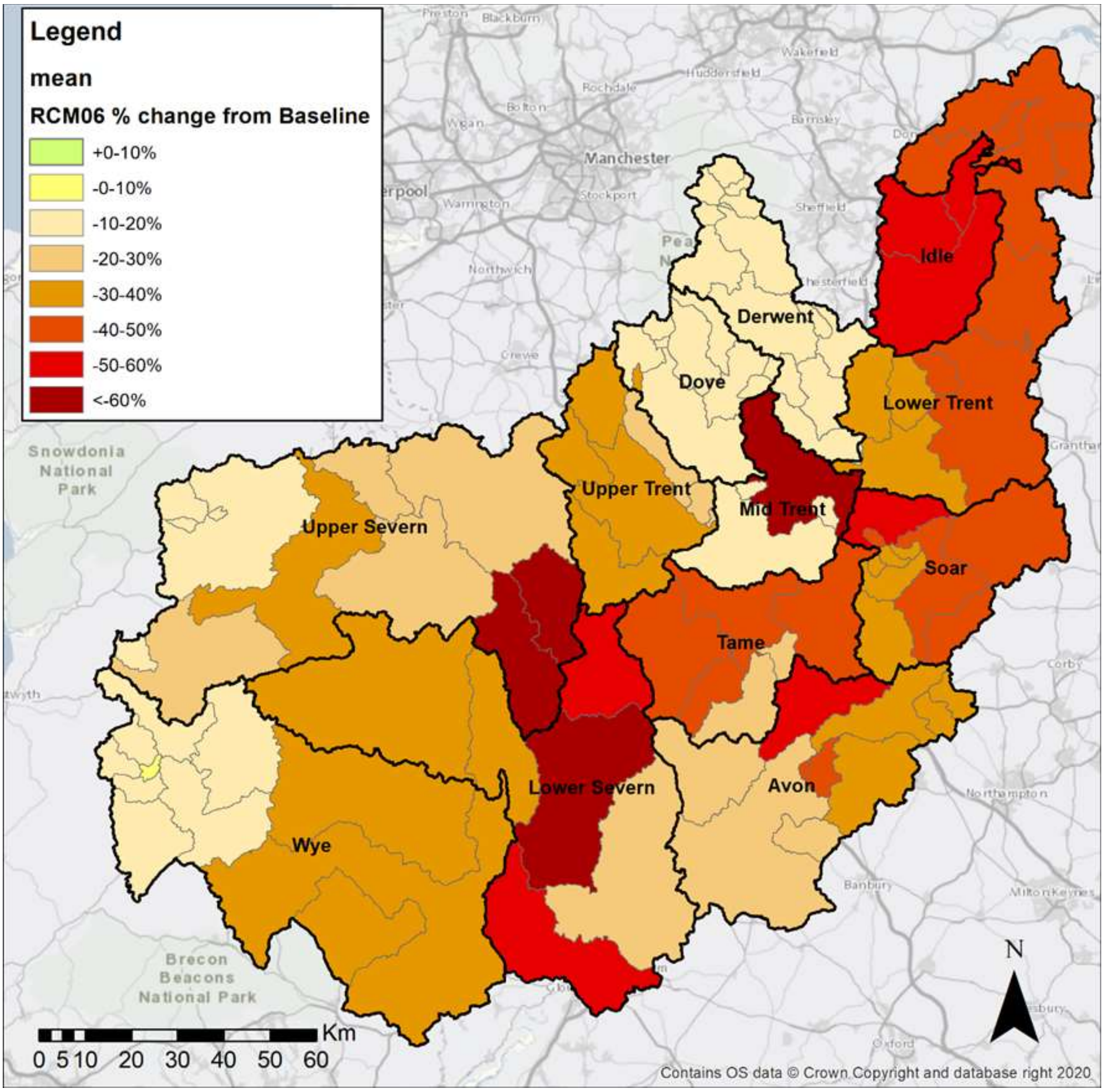
Figure A3.12: Percentage change in annual flows from baseline for RCM06 2070s RCP8.5 scenario



Whilst the scale of the impact varies between the worst-case and best-case RCMs as well as the median RCM, there is a general pattern of greater reductions in flow towards the east of the Severn Trent region.

Figure A3.13 and Figure A3.14 compare Flow Duration Curves (FDCs) of the 12 RCM climate change scenarios for the Craig Goch Reservoir (R55007CRG) in the Wye and Rothley Brook at Rothley (C28056ROT) in the Soar respectively. The baseline historic FDC is also included for the equivalent 1950 to 1997 period. Since the climate change scenarios are all based on applying factors to the stochastic datasets the flow duration curves presented below consider the median stochastic scenario when comparing between different RCMs and the baseline historic FDCs. Both example catchments, whilst showing different magnitudes of changes from the baseline, indicate a potential increase in higher flows for many RCMs and a reduction in mid to low flows across all RCM scenarios.

Figure A3.13: RCM 2070s FDC for Craig Goch Reservoir (R55007CRG)

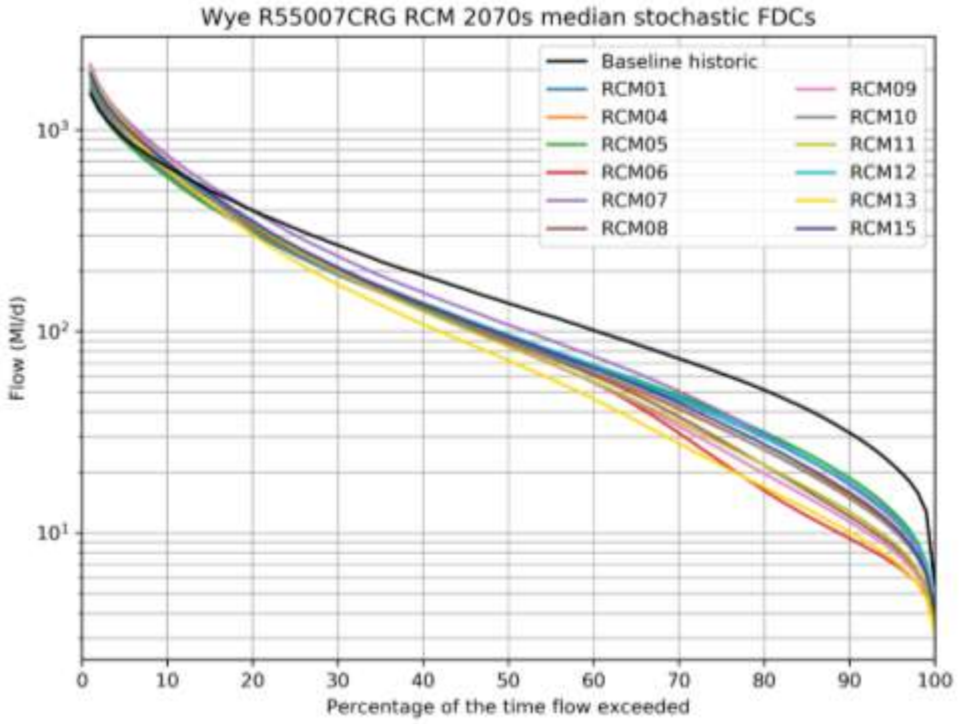
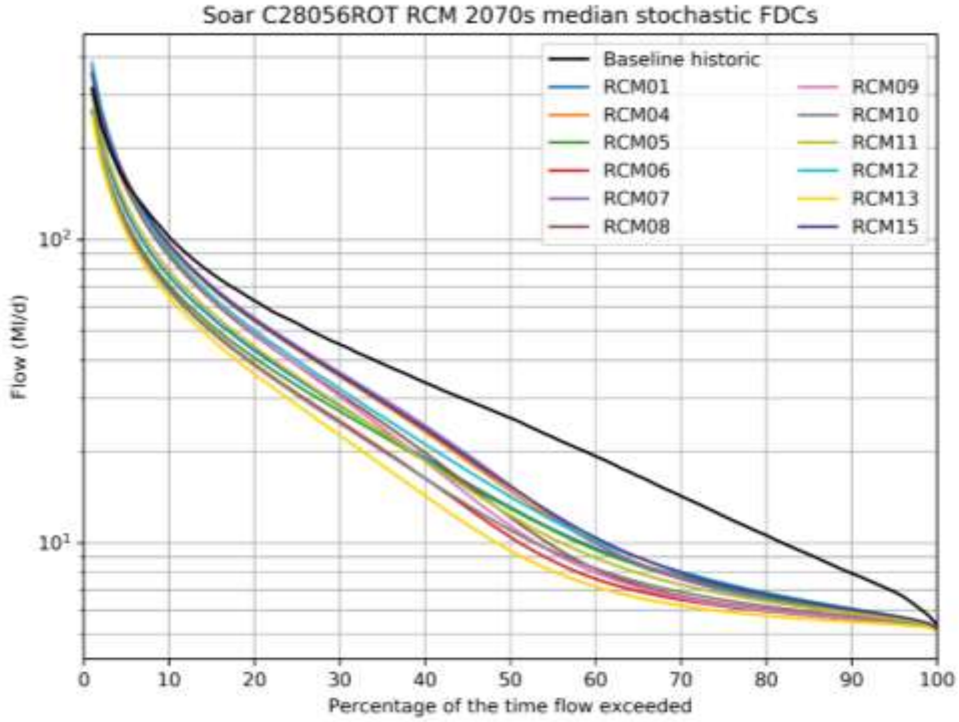


Figure A3.14: RCM 2070s FDC for Rothley Brook (C28056ROT)



Probabilistic climate change scenarios results

Flow duration curves (FDCs) have been derived for all catchments, with examples shown for Craig Goch Reservoir (R55007CRG) in the Wye and Rothley Brook at Rothley (C28056ROT) in the Soar in Figure A3.15 and Figure A3.16 respectively. Since the probabilistic scenarios are also based on applying factors to the stochastic datasets the following outputs consider the median stochastic scenario when comparing between different probabilistic scenarios. These FDCs in these figures show the spread of the 100 probabilistic scenarios as well as curves representing the 10th, 50th and 90th percentiles of the probabilistic range. The baseline historic FDC is also included for the equivalent 1950 to 1997 period.

Figure A3.15: Probabilistic 2070s FDC for Craig Goch Reservoir (R55007CRG)

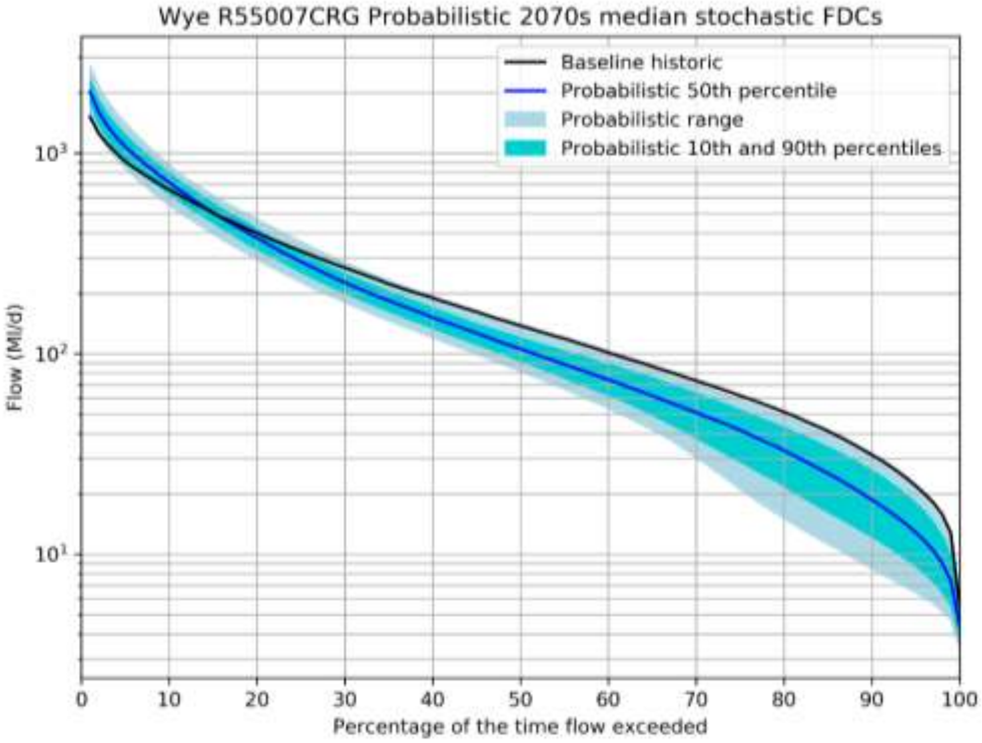
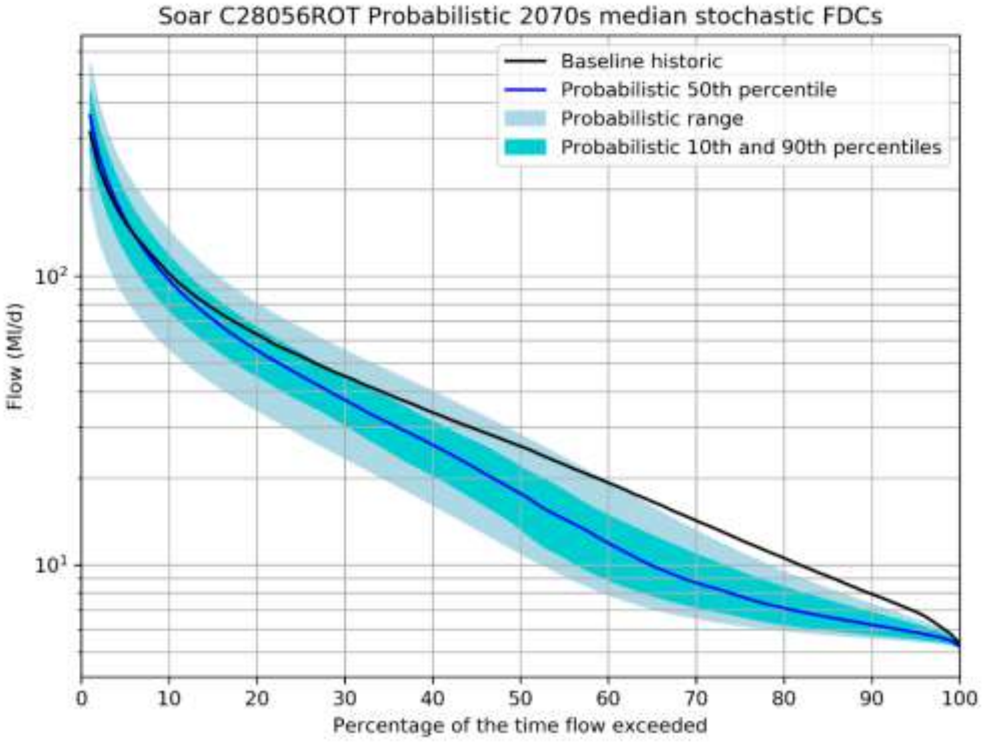


Figure A3.16: Probabilistic 2070s FDC for Rothley Brook (C28056ROT)



Similarly to the RCM climate change scenario results, the probabilistic scenario results show potential increases in high flow but decreases in mid to low flows. The 50th percentile probabilistic scenario is lower than the baseline scenario at approximately Q5 for the Rothley Brook series and Q15 for the Craig Goch Reservoir series.

A3.5 Impact of Climate Change on our groundwater sources

Approximately one third of our Deployable Output (DO) is abstracted from groundwater sources. The majority of our boreholes (c. 90%) abstract from the Sherwood Sandstone Group or other sandstone aquifers in the Midlands region, with a small percentage of sources taking water from minor aquifers, such as limestones and river gravel deposits.

Unlike most Chalk or limestone aquifers, the Midlands sandstones generally show only small annual changes in groundwater levels and are therefore considered to be resilient to drought conditions with DO being able to be maintained. This is because these sandstone aquifers have substantial storage within them, meaning they are generally insensitive to short term changes in recharge patterns (e.g. within year low rainfall/dry summer periods) and it can take longer for groundwater water levels to decline and affect DO. Therefore, it is acknowledged that groundwater storage can be depleted over time in response to, for example, multi-season events (e.g. dry summer/dry winter/dry summer sequence) or a longer term change in recharge patterns. These risks and the potential effects on DO need to be understood. This is of particular relevance for any groundwater sources that are known to potentially be affected by low groundwater levels more regularly or those where there are known groundwater level-controlled constraints that could affect their output, e.g. pump installation depths.

During the 2008 to early 2012 period, recharge to the Midlands aquifers was significantly depleted by lower than average rainfall and some of the lowest ever groundwater levels were recorded across the region. Despite this, groundwater level decline during this period was noted to be only a few metres across the majority of groundwater sources, providing evidence that the sources are robust to these types of events, when compared to other low-storage aquifer systems across the UK which may be more susceptible. However, the effects on our limestone and river gravel sources are likely to be more significant as these aquifers generally have less storage and are potentially more susceptible to changes in climate and associated recharge patterns.

The following sections document the steps we have followed to assess the risk of DO reductions from groundwater sources in the SvE region. The results are reported at Company level for all Water Resource Zones (WRZ). The detail behind the assessments, at the individual WRZ level, is contained in a separate technical report. The DO figures as quoted are average deployable output (ADO) values[3]. Peak Deployable Output (PDO) values, that being the amount of water available over a peak demand period, e.g. peak week/peak month) have also been calculated, but are not presented here.

Sources constrained by groundwater levels/flows

The WRMP24 water resources planning guidance[4] requires water companies to be resilient to a 1 in 500 year drought. As previously described, whilst the output of the majority of SvE's groundwater sources are not believed to be affected, some sources are understood to be level constrained and therefore less likely to be

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[3] The average deployable output (ADO) is that amount of water available from a source/treatment works or a group of sources/treatment works over a year

[4] Environment Agency, 2020, Water resources planning guideline supplementary guidance – 1 in 500

resilient to groundwater level fluctuations caused by droughts and climate change. Understanding the effects of climate change on these sources was assessed by the following steps.

Identification of groundwater sources

STWL has previously completed an assessment to identify the sources that are considered to be sensitive to groundwater level changes. The assessment used the Source Performance Diagrams (SPDs) that form part of the baseline deployable output assessment to identify sources that are either groundwater level constrained under operational conditions or had less than 5 metres of groundwater level available under drought conditions. The output from this earlier screening exercise was used as the basis for determining which sources should be regarded as level dependent sources for the WRMP24 assessment.

In total, 27 sources (22 boreholes and five spring sources) were regarded as being (or at risk of becoming) groundwater level dependent and therefore formed the focus of this current investigation.

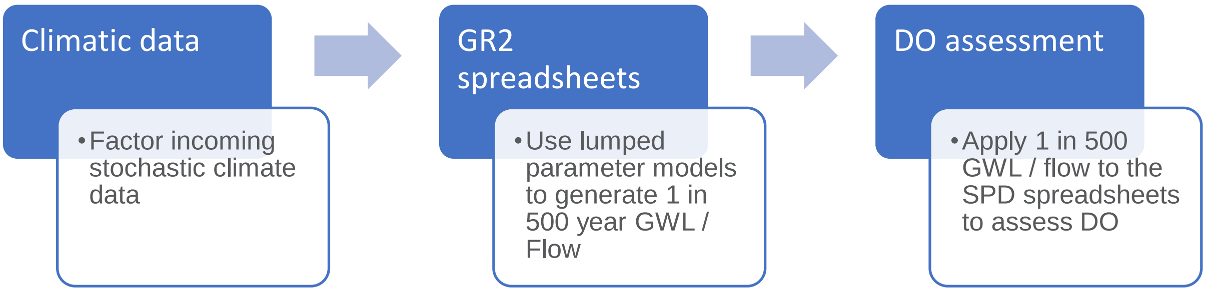
1 in 500 year assessment – methodology

There are three stages within the methodology:

1. **Analysis of climate data**: Stochastic rainfall and potential evapotranspiration (PE) datasets have been scaled to be representative at the sources under consideration.
2. **Estimation of minimum groundwater levels and flows**: Factored climatic data have been applied to source *'GR2' spreadsheets*, i.e. lumped parameter spreadsheet models and frequency analysis conducted on the output to estimate 1 in 500 year annual minimum groundwater levels or spring flows.
3. **Revised DO assessment**: These 1 in 500 year annual groundwater levels or spring flows have then been used to recalculate the SPD curves and determine the source DO under these revised conditions.

An overview of the methodology applied to assess the DO under a 1 in 500 year drought condition is shown in Figure A3.17.

Figure A3.17 - Overview of level dependent assessment methodology



Further detail on each step is set out in the following sections.

Analysis of climate data

The regional water resource planning groups have generated stochastic rainfall and potential evapotranspiration (PET) datasets for use by the water companies in WRMP24. The Water Resources West (WRW) stochastic dataset were utilised to encompass STWL's full operational area; referred to hereafter as WRW-STWL. The stochastic data comprise of 48 years x 400 series, giving a total of 19200 years' worth of data.

The stochastic climatic sequences were generated for relatively large geographical areas. These data have been derived from historical data for regional rainfall gauges (and spatially distributed using Thiessen polygons) and PET datasets. In contrast, the GR2 spreadsheets, which were originally developed in previous WRMP cycles and represent groundwater levels or surface water flows at key locations, have been calibrated using local climatic data. Ideally, the GR2 spreadsheets would have been recalibrated using the historical datasets underlying the stochastic data. This would enable the stochastic data to be applied directly within the GR2 spreadsheets. However, recalibration of lumped parameter models can be time consuming and with a GR2 spreadsheet for each source, this approach was considered to not be practical and instead stochastic datasets were factored to make them appropriate for use in the GR2 spreadsheets.

To derive these factors, the historical datasets underlying the stochastic data were correlated with the historical data stored in the GR2 spreadsheets. These relationships were then applied to the stochastic data to generate stochastic rainfall and PET datasets applicable to each of the 27 GR2 spreadsheets.

Estimation of minimum groundwater levels and flows

The full 19,200-year factored stochastic climatic data have been applied to the 27 individual GR2 lumped parameter model spreadsheets, which output modelled monthly groundwater levels and/or spring flows for their representative location. Frequency analysis was undertaken using these outputs to determine groundwater level and surface water flow, as appropriate, under different drought severities. Frequency analysis was undertaken to determine annual minima for use in the DO assessment groundwater levels and/or spring flows.

This methodology is different to that from WRMP19, where recharge return periods were calculated from a hindcast-extended observed record. In WRMP19, the accumulated rainfall – PET (P-PET), starting in October each year, was calculated for 18, 30 and 60 month periods. The accumulated P-PET time series were then statistically analysed using extreme value analysis to generate P-PET values equivalent to a 1 in 200 and 1 in 500 year return period. For each catchment, the stochastic climatic datasets were then analysed to identify years that were equivalent to these accumulated P-PET return periods. These stochastic sequences were then stitched to the end of the historical period and run through the GR2 spreadsheet.

It is felt that the new methodology is more transparent and makes best use of the stochastic record. However, it is noted that this may introduce a discrepancy in how frequency analysis is conducted between the groundwater and surface water components.

The result of this second part of the methodology was a set of modelled groundwater levels for both the 1 in 200 and 1 in 500 year return periods for the annual minima for DO values for the level dependent groundwater sources and the equivalent minimum flows for the spring sources.

Revised DO assessment

The modelled groundwater levels and flows from Stage 2 were combined with the operational SPD spreadsheets, used for the baseline deployable output assessments, to generate new DO values for each of the sources and springs under the different return periods. The process for each is described below.

Borehole sources

The DO assessment for borehole sources relates groundwater levels to abstraction rates in order to determine the reliable source output available for representative pumping durations during a design drought. The DO represents the resource available during the period of lowest resource availability.

Available data, such as operational and pumping test data, are used to establish the relationship between groundwater levels and abstraction for each source. The operational DO is then calculated based on the intersection of the analytical or bounding curve with operational level or capacity constraints such as pump depth or licence limits. To determine DO for droughts of different severities, the operational rest water level (RWL) origin of the operational curve is downshifted to reflect the anticipated rest water level of the drought considered and the new intersection calculated. The following steps are applied:

Scaling of groundwater levels between GR2 and SPD

As noted above, no scaling factor has previously been generated between the GR2 spreadsheets, which theoretically represent a nearby non abstraction influenced observation boreholes, and the SPD RWL, to reflect the difference in groundwater behaviour between the two geographical and hydrogeological settings. Instead, the GR2 GWL drought adjustment is assumed to be directly transferable to the SPD RWL as a 1:1 relationship.

Rest water level downshift

The 1 in 500 year groundwater levels have been generated from the GR2 spreadsheets in the form of metres Above Ordnance Datum (mAOD). However, the SPD spreadsheets use the units meters (above datum, usually referring to headplate or top of dip tube). It is therefore necessary to relate the 1 in 500 year water level to the RWL recorded within the SPD sheet. This has been achieved by downshifting the SPD RWL by the difference between GR2 modelled historical water level on the same date and the 1 in 500 year level as set out in the equation below. This approach is different to previous WRMPs where the average impact between scenarios was taken forward.

$$Downshift\ (m) = SPD\ RWL_{on\ date\ x} - (GR2\ historical_{on\ date\ x} - GR2\ 1\ in\ 500\ year)$$

The resultant 1 in 500 year groundwater level in metres above datum is compared to the both the original SPD RWL and the “drought” SPD RWL. The latter is an SvE estimate of drought impact of unspecified severity, typically based on conceptual understanding of the site.

Relationship between groundwater level and abstraction

As noted above, the SPD spreadsheets encapsulate the relationship between groundwater levels and abstraction rates in the form of a curve. These have typically been derived from step test analysis data, or where data are incomplete, straight line relationships have been described to define a relationship between groundwater levels and abstraction rates.

Operational constraints

The operational constraints have been taken from the SPD curves. These may be either level dependent or abstraction/flow related. The most DO constraining (horizontal) level constraints are typically either the pump depth or deepest advisable pumping water level (DAPWL). The most constraining abstraction/flow (vertical) constraints include licence limits, treatment works or pump capacities and water quality issues. These constraints are given at a source level rather than individual borehole.

Calculation of DO value

The DO values have been calculated based on intersection of the downshifted curve with the most significant source constraint. Since some of the abstraction constraints are recorded at the source level rather than individual borehole, the assessment first determines the potential DO of the individual boreholes assuming they are level constrained and sums the potential DO for the source, taking account assumed source operations. The potential DO is then compared with the most constraining abstraction/flow constraint and the lower of the two taken as the source DO.

Spring sources

Spring sources are considered slightly differently to borehole sources as it is not always possible to generate a relationship between groundwater level and spring flow. As a result, only abstraction/flow related constraints are typically used within the DO assessment. In addition to the typical constraints of e.g. licence or infrastructure, the minimum total spring monthly output is used to assess the DO. When considering a 1 in 500 year event, it may be assumed that the minimum monthly and weekly spring flows will be reduced from historically recorded.

The minimum SPD flow has been reduced based on the percentage reduction between the GR2 modelled historical flow on the date of the minimum spring flow and the 1 in 500 flow.

Results for 1 in 500 year assessment for level/flow constrained sources

The results of the 1 in 500 year DO assessment for level dependent and spring sources are summarised in Table A3.8. The 1 in 200 year DO has also been calculated by the same method and stated for comparison. These are the changes to the total DO across all Water Resource Zones for the 27 sources under consideration. However, the potential DO reduction calculated is built up from a sub-set of seven sources; two boreholes and five springs (S), these are described in Table A3.9.

Table A3.8 - DO results summary for Level / Flow constrained sources

	Operational DO (Ml/d)	1 in 200 yr DO (Ml/d)	1 in 500 yr DO (Ml/d)	1 in 500 yr DO reduction in Operational DO (Ml/d)	1 in 500 yr DO reduction in 1 in 200 yr DO (Ml/d)
ADO	75.49	69.89	69.50	5.99	0.39

Table A3.9 – Sources that contribute to overall DO reduction

Source Name	Water Resource Zone	Operational ADO	Difference between Operational and 1 in 500 ADO (Ml/d)
Blacklake	North Staffordshire	3.33	0.37
Campion Terrace	Strategic Grid	2.3	0.67
Bigwell (S)	Forest and Stroud	1.04	0.41
Chalford (S)	Forest and Stroud	6.05	3.20
Coombe (S)	Strategic Grid	0.46	0.23
Lydbrook (S)	Forest and Stroud	1.14	0.67
Mill End (S)	Strategic Grid	0.70	0.45
TOTAL			**5.99**

Climate Change Assessment - methodology

The impact of climate change on DO has been assessed using the 1 in 500 year DO as the baseline (see Section 2.2) and a suite of UKCP18 scenarios. The assessment has considered the same 27 'level dependent' sources (borehole and spring sources) identified as being (or at risk of being) level dependent.

Climatic scenario application in DO assessment

The climate change factors have been applied to perturb the GR2 stochastic PET and rainfall datasets. The GR2 models have then been run for each climate change scenario, frequency analysis undertaken and the DO determined, following the methodology set out in Section 2.2. The results are presented compared to the baseline 1 in 500 year DO.

This methodology differs from WRMP19. For WRMP19 the baseline was taken to be the 'drought corrected' operational DO although the drought severity is not quantified in terms of return period. The average difference in head (for level dependent sources) or flow during the selected drought year (for spring sources) between the historical and perturbed climate sequences was calculated, and then used to determine the potential change in DO for each source.

It is believed the current method provides more transparency, clearly linking the assessment to a drought severity and using the absolute climate change impact rather than average to assess the worst-case prediction.

Level dependent sources – Climate change DO results

The results of the climate change DO assessment are summarised in Table A3.10 in comparison to the 1 in 500 year baseline. The minimum and maximum DO reduction climate change scenarios are presented along with a 'central' climate change scenario which was stipulated by SvE as the mean of RCM scenarios 8 and 9. The following points are noted:

In general, the DO impact of climate change on a 1 in 500 year baseline (as described in Table A3.8) is relatively small at borehole sources, with greatest impacts predicted at spring sources

Table A3.10 - DO climate change results summary

	DO total (Ml/d)	DO reduction (Ml/d)
1 in 500 year baseline (from Table A3.8)	69.50	-
RCM Scenarios		
Min CC DO	69.13	0.36
Max CC DO	66.98	2.51
Central CC DO (mean of RCM Sc8 & Sc9)	68.94	0.56
Probabilistic Scenarios		
Min CC DO	70.11	-0.62
Max CC DO	63.24	6.26

Sources not constrained by groundwater levels/flow

In addition to the 27 level dependent sources assessed above, SvE has a further c.120 groundwater sources that were either deemed to be non-level dependent based on SvE's screening. This section considers the impact of a 1 in 500 year event and climate change on these other additional sources.

GR2 spreadsheets are not available to enable non-level dependent sources to be assessed in the same way as level dependent sources. The original screening exercise was completed as part of WRMP09 and then carried forward to WRMP14. A comparison between the WRMP14 and WRMP24 source DO values was undertaken to identify how the DO has changed. Three categories of sources were identified:

- those where the reported DO has decreased;
- those where the DO had stayed constant; and
- those where the DO has increased.

Based on this and considering the outcomes from the assessment of the borehole level dependent sources, high level consideration has been given first to the likelihood of non-level dependent sources becoming hydrogeologically constrained, and second to the likely implications on DO.

Decrease in DO from WRMP14

The DO values have decreased at 53 sources. For these sources the reduction is most likely to be related to a capacity/flow constraint (e.g. operational pump capacity or water quality threshold) and so water level headroom is likely to have increased rather than decreased, and therefore they are unlikely to have become level dependent.

No change to DO from WRMP14

The DO has not changed for 29 sources. These sources are therefore expected to have at least 5m of headroom based on the initial screening criteria applied. However, the average groundwater level downshift applied to the level dependent borehole sources was greater than 5 m at 5.4 m during a 1 in 500 year event.

The downshifts applied translate to an average 1.3% reduction in DO during a 1 in 500 year event and up to 3.9% when drought was combined with climate change, see Table A3.11.

Table A3.11 - Impact summary of level dependent borehole sources

	GWL reduction (m)			DO (Ml/d)	DO reduction (Ml/d)			
	Mean	Min	Max	Total	Mean	Mean (%)	Min	Max
				ADO				
Operational	-	-	-	79.60	-	-	-	-
1 in 500 year	5.41	1.26	13.85	78.56	0.05	1.3%	0.00	0.67
Climate change - RCM	1.49	0.00	5.46	77.33	0.06	1.6%	0.00	0.64
Climate change - probabilistic	2.12	0.00	6.36	75.52	0.14	3.9%	0.00	1.19

Increase in DO from WRMP14

Since WRMP14, the DO has increased at 37 non-level dependent sources. Therefore, the groundwater level headroom at these sources is likely to have been reduced, with the risk that some may have become level dependent. The SPDs for these sources have been reviewed and the groundwater level headroom calculated. The assessment identified four borehole sources plus two spring sources for ADO where the water level headroom was less than 7.5 m (the average downshift incorporating both a 1 in 500 year event and worst climate change scenario for DO[5] i.e. 5.41 + 2.12 m from Table A3.11):

Results

The DO estimates for non-level dependent sources are presented in Table A3.12. These estimates are derived from a simple high level assessment, applying average impacts observed from the level dependent sources to

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[5] The equivalent downshift for PDO is 7.2 m and so, adopting a precautionary approach, the larger ADO downshift was applied as the required water level headroom threshold when considering potential impacts on ADO and PDO.

those non-level dependent sources deemed to be most at risk of becoming level dependent based on professional judgement; the assessment doesn't necessarily consider source-specific details and is therefore considered to be precautionary with the resulting impact on overall DO being relatively small.

Table A3.12 Non level dependent sources - ADO results

	No. of sources	ADO in 2025 (Ml/d)	1 in 500 yr		1 in 500 yr + climate change	
			Potential ADO reduction (Ml/d)	Revised ADO (Ml/d)	Potential ADO reduction (Ml/d)	Revised ADO (Ml/d)
Sources with decrease in ADO since WRMP14	53	273.0	0	273.0	0	273.0
Sources with no change in ADO since WRMP14	29	159.6	2.1	157.5	8.16	151.4
Sources with increase in ADO since WRMP14	37	237.3	6.3	231.0	8.22	229.1
Total	**119**	**669.9**	**8.3 (1.24%)**	**661.6**	**16.4 (2.45%)**	**653.5**

Summary of DO changes for all sources

The combined DO assessment for level/flow constrained and non-level/flow constrained sources is presented in Table A3.13 below.

Table A3.13 Overall summary of ADO on WRZ level

WRZ	Operational ADO (Ml/d)	1 in 500-yr		1 in 500-yr + max climate change		1 in 500-yr + ‘central’climate change	
		1 in 500-yr ADO (Ml/d)	1 in 500-yr ADO reduction from operational ADO (Ml/d)	Max climate change ADO (Ml/d)	Maximum climate change ADO reduction from 1 in 500-yr ADO (Ml/d)	Central climate change ADO (Ml/d)	Central climate change reduction from 1 in 500-yr ADO (Ml/d)
Bishops Castle	4.11	4.11	0.00	3.80	0.30	4.11	0.00
Chester	1.40	1.40	0.00	1.40	0.00	1.40	0.00
Forest and Stroud	22.60	18.24	4.36	16.68	1.56	17.49	0.75
Kinsall	5.80	5.73	0.07	5.48	0.26	5.48	0.26
Mardy	3.50	3.50	0.00	3.50	0.00	3.50	0.00
Newark	4.00	4.00	0.00	4.00	0.00	4.00	0.00
North Staffs	149.61	148.79	0.82	143.47	5.33	146.94	1.85
Nottinghamshire	205.76	205.30	0.46	203.48	1.82	203.48	1.82
Ruyton	5.32	5.32	0.00	5.32	0.00	5.32	0.00
Shelton	122.68	122.30	0.38	120.78	1.51	120.78	1.51
Stafford	26.24	25.79	0.45	25.71	0.09	25.78	0.01
Strategic Grid	146.28	138.26	8.02	129.16	9.10	130.19	8.07
Whitchurch & Wem	12.73	12.63	0.10	10.29	2.34	10.29	2.34
Wolverhampton	32.18	31.95	0.23	31.06	0.89	31.06	0.89
Total ADO	**742.21**	**727.32**	**14.89**	**704.12**	**23.2**	**709.82**	**17.51**

A3.6 Modelling the impact of Climate Change on Deployable Output

The climate change modelling was largely a repeat of the modelling and post processing procedures discussed in the stochastic modelling for a range of climate change scenarios. The model simulations were made for 20 UKCP18 probabilistic scenarios and 12 Regional Climate Model (RCM) projections using the 2060-2079 factors (altogether 32 climate change scenarios). The need to assess high number of scenarios in climate change modelling required selecting a subset of the stochastic inflow data in our model to enable a more practically feasible and accurate assessment of the climate change scenarios. As discussed previously in section A2.2, a quarter (2 batches) of the inflow time series (climate change combined with stochastic time series) were used for climate change modelling. The extent of computational resources and processing time required for each climate change scenarios’ Scottish DO analysis and post-processing time were thus reduced, which enabled us to cover modelling and analyses of all of the 32 scenarios.

We have modelled the impact of climate change on our surface water and groundwater sources in our conjunctive use WRZs using our Aquator model. Modelling of each climate change scenario provides us with estimates of deployable output for the year 2070s RCP8.5. We applied the climate change impacted flow series to our existing model, to establish what the potential impacts would be on water resources zone's deployable output.

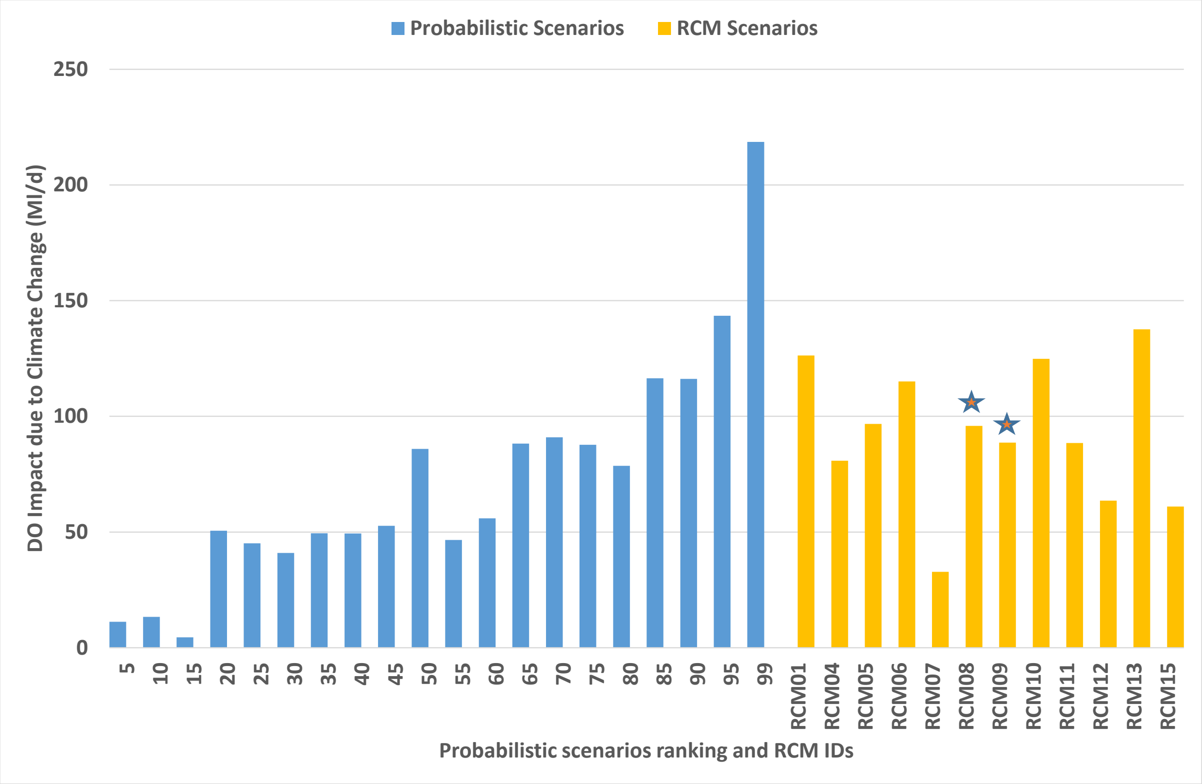
As discussed in section A3.3 (step 6), we were able to reduce the 100 UKCP18 probabilistic projections, based on a drought indicator to a targeted sample of 20. This targeted sample includes projections that are equally spaced across the whole probabilistic range. Each of the targeted samples are used to inform uncertainty around central estimate climate change impact in headroom. A normal distribution is fitted to the modelled climate change DO impacts from these twenty probabilistic samples as discussed in Appendix C, and thus the weighting used to inform uncertainty in headroom is based on normal distribution.

The current guidance on how to apply the climate change methodologies does not include any recommendations for how water companies should derive a suitable "central estimate" for use in the supply / demand balance calculations. Similarly, there is no best practice guidance on how to appropriately deal with the wide range of uncertainties presented by the multiple scenarios. The 12 RCM projections we modelled are generated based on a dynamical downscaling method that embeds regional features within coarse-resolution global climate models (GCMs), which are widely considered as the most complex and precise models for understanding climate systems and predicting climate change. In addition, RCMs provide comparable climate change outputs across regions due to their better representation of spatial coherence of climate change. Thus, we decided to use the DO impacts from the median of the 12 RCM scenarios as central estimate climate change impact, which was also agreed at WRW level. We believe this better represents a physically plausible hydrological scenario and is more representative of what could happen to our region. We have assessed the range of uncertainty around this central estimate using our target headroom model. We have also used a range of these 32 UKCP18 climate projections to produce individual climate change impacted scenarios in our Decision Making Upgrade (DMU) model. By doing this we are able to consider the impacts of each of the climate change scenarios and remove uncertainty around climate change from target headroom. Further details about this assessment can be found in Appendix E.

The full range of the modelled impact of the climate change scenarios on our deployable output in 2070s under RCP6.0 scenario are shown in Figure A3.18 and Figure A3.19. As our vulnerability assessment indicated, the greatest impacts of climate change are seen in the Strategic Grid water resource zone. Groundwater sources in Nottinghamshire zone are mainly constrained by infrastructure/licences and are not impacted by climate change (see section A3.5), and thus no climate change impact on DO is attributed to our Nottinghamshire zone in our WRMP24 climate change impact assessment as discussed in section A3.3. Our modelling showed there was no impact on the deployable output of the Shelton, Wolverhampton and Newark WRZs under any of the 32 climate projections modelled. Shelton and Wolverhampton WRZs are supplied by a combination of a river abstraction and groundwater sources, whilst Newark WRZ is supplied by groundwater sources and groundwater derived imports, both of which are highly resilient to the potential impacts of climate change.

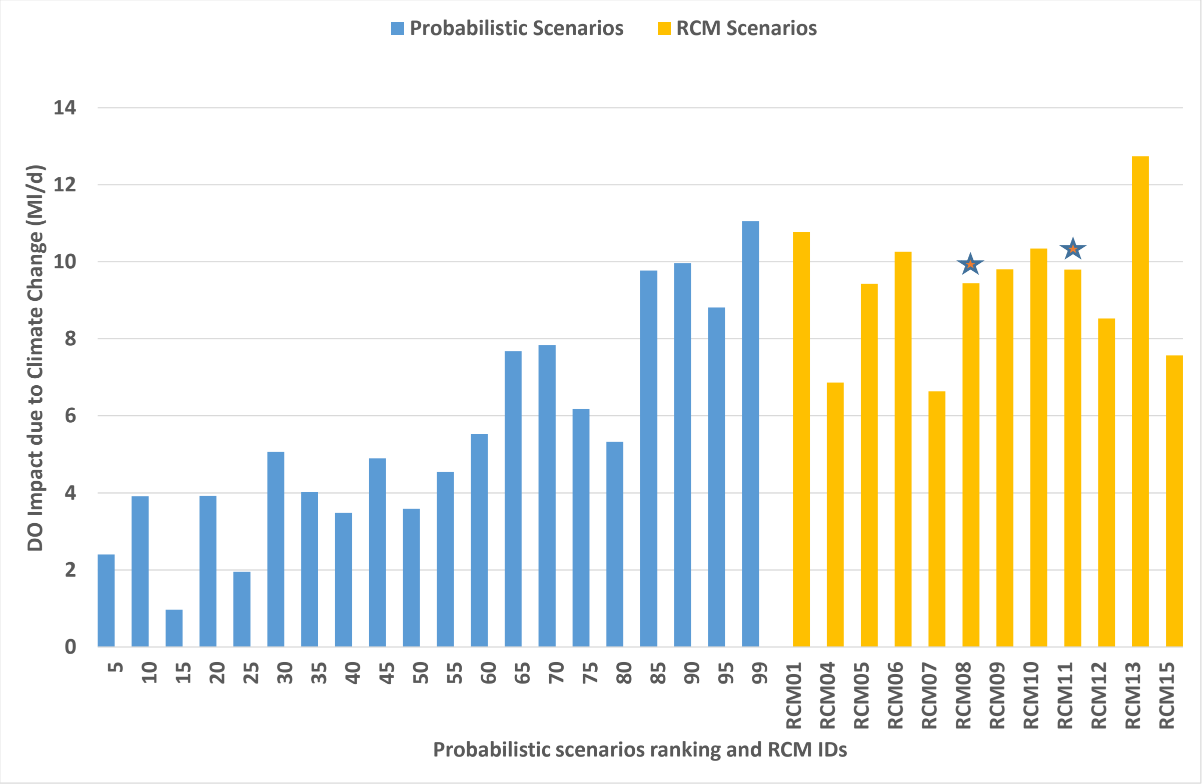
The Strategic Grid and North Staffordshire WRZs are the most affected by the potential impacts the changing climate may have on our surface water sources as both zones are directly affected by either reduced river flows or reservoir drawdowns. Varying levels of climate change impact is observed in both zones across the 32 modelled scenarios. Forest and Stroud WRZ's DO is affected by a small amount of climate change impact that is caused mainly due to future yield reductions in groundwater sources in the zone. Our source assessment has shown that few of our groundwater sources are vulnerable to potential future changes in climate and where groundwater sources are vulnerable the resultant change in source yield is likely to be relatively small. As a result, all our groundwater only zones are not affected by impacts of climate change with the exception of Bishops and Castle WRZ, which has a small amount of climate change impact. A detailed description of how we have tested and used the range of uncertainty around climate change is provided in Appendix C2.

Figure A3.18: Strategic Grid zonal impacts of climate change using the 32 modelled scenarios RCP6.0



★ Median RCM scenarios

Figure A3.19: North Staffordshire zonal impacts of climate change using the 32 modelled scenarios RCP6.0



★ Median RCM scenarios

A3.7 Scaling climate change impacts across emissions scenarios

We decided to assess impacts of climate change on our water resources based on RCP6.0 emission scenario, which is widely considered as approximately equivalent scenario to the SRES A1B emissions scenario that was used in WRMP19. This has also been agreed at WRW level and all companies in WRW are consistent in using the RCP6.0 emission scenario. Thus, modelled climate change impacts based on RCP8.5 scenario need to be scaled down to impacts that reflect RCP6.0 emission level. In the absence of comprehensive hydrological and systems modelling of different RCPs, temperature-based scaling methods are adopted to estimate potential climate change impacts from RCP8.5 to RCP6.0. Atkin's climate data tools scaling project has produced temperature based linear equations (y = m . x + c) that relates monthly temperatures of RCM RCP8.5 scenarios with monthly temperatures of probabilistic RCP6.0 50th percentile scenario for each region. Scaling factors for UKCP basins are provided in table A3.14 to scale down impacts estimated based on RCP8.5 scenarios down to RCP6.0. We used the scaling factor derived for the Severn River Basin as the majority of our strategic water resource sources are located within or near this basin. Thus, median of RCP8.5 RCM DO impacts in 2070s are scaled down by 49% for use as central estimate climate change impact. A relationship between warming levels at RCP8.5 and RCP6.0 levels for the probabilistic scenarios at 50th percentile are also derived and applied on all the 20 modelled probabilistic scenarios to scale down modelled DO impacts for use in target headroom.

Table A3.14: Impact scaling factors for scaling the range of possible impacts across the UKCP18 probabilistic projections

	Warming oC3	Prob.	GCM	Probabilistic				GCM
UKCP River Basin	**RCP 8.5 bc (3.7°C)**	**RCP 2.6 (1.3°C)**	**RCP 2.6 (1.7°C)**	**RCP 4.5 (1.8°C)**	**RCP6.0 (1.9°C)**	**A1b (2°C)**	**RCP8.5 (2.3 °C)**	**RCP8.5 (2.7°C)**
Anglian	3.9	34%	47%	47%	48%	52%	70%	89%
Dee	3.6	34%	46%	47%	49%	53%	71%	90%
Humber	3.7	34%	47%	47%	49%	52%	70%	89%
Northumbria	3.5	34%	46%	48%	49%	53%	71%	90%
NW England	3.6	34%	46%	47%	49%	53%	71%	90%
SE England	4.0	34%	47%	47%	48%	52%	70%	89%
Severn	3.8	34%	47%	47%	49%	52%	70%	89%
SW England	3.7	34%	47%	47%	49%	53%	70%	89%
Thames	4.0	34%	47%	47%	48%	52%	69%	89%
W Wales	3.5	34%	46%	48%	49%	53%	71%	90%
Median	**3.7**	**34%**	**46%**	**48%**	**49%**	**53%**	**71%**	**90%**

A3.8 Scaling the impacts of climate change through time

The Environment Agency Supplementary Guidance on Climate Change provides a linear scaling equation to scale the impacts of climate change from 1990 to 2100. This method is based on the assumption that observed rising temperatures have already translated to observed impacts or there is an elevated level of risk in terms of water resource availability. The guidance mentions that companies may depart from using this method, particularly if impacts of climate change are going to drive significant level of investment and if they can present a rationale for alternative approaches. Atkins climate data tools scaling project report showed that changes in temperature over time in UKCP18 climate modelling products are non-linear and typically follow an upward curve. Moreover, hydrological impacts are anticipated to emerge later in the planning horizon and few companies have yet observed statistically significant changes in river flows and Deployable Outputs. Atkin's climate data tools scaling project has provided an alternative universal scaling equation, which scales the impacts of climate change from 1990 to 2100 based on impacts modelling for the 2070s (the latest period available for RCM data). This scaling method uses a power relationship rather than linear relationship, which has a marginally lower impact at the beginning of the planning period and higher impact after 2070.
Figure A3.20 below shows power curves fitted to the median of UKCP18 annual average warming for a range of different products. Figure A3.21 shows curves fitted to dimensionless rate of impact between 1990 and 2100 for all scenarios and temporal scaling based on EA's straight line method and power relationship method.

Figure A3.20: Curves fitted to the median of UKCP18 annual average warming using the power relationship

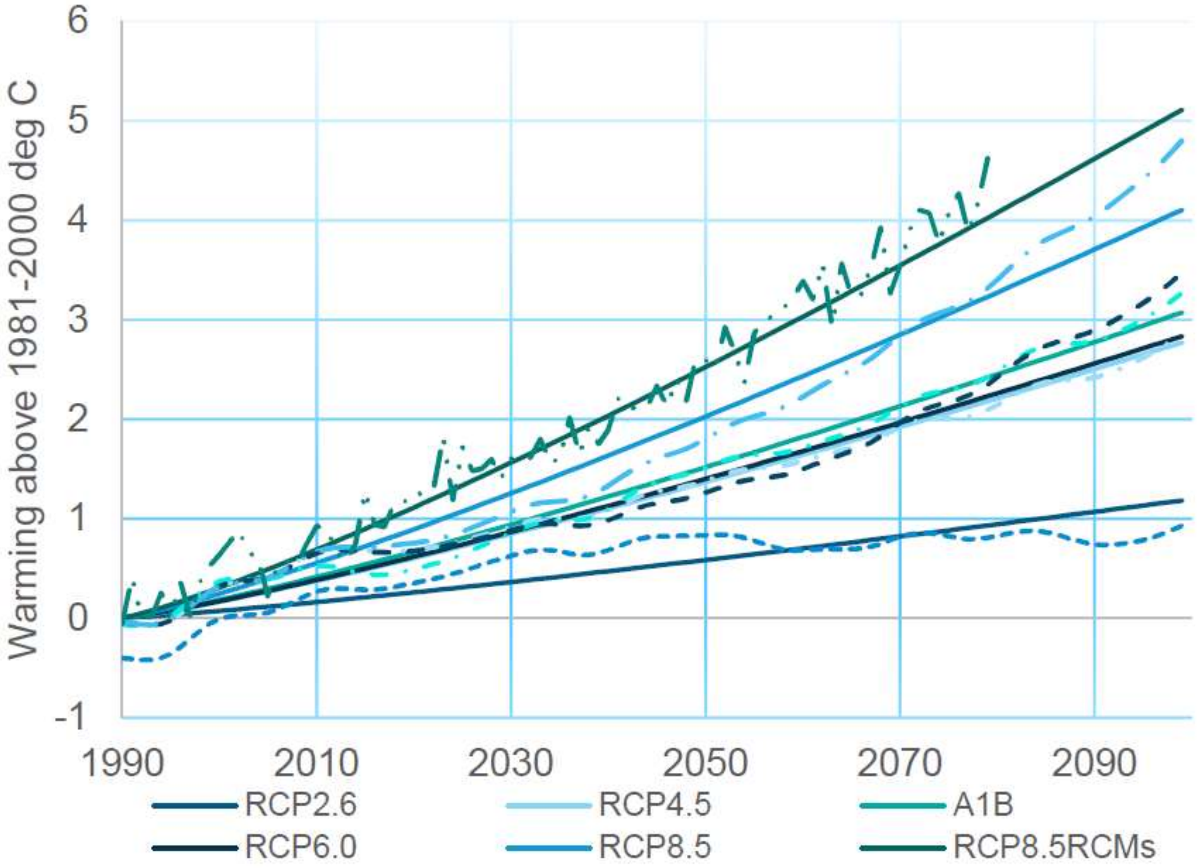
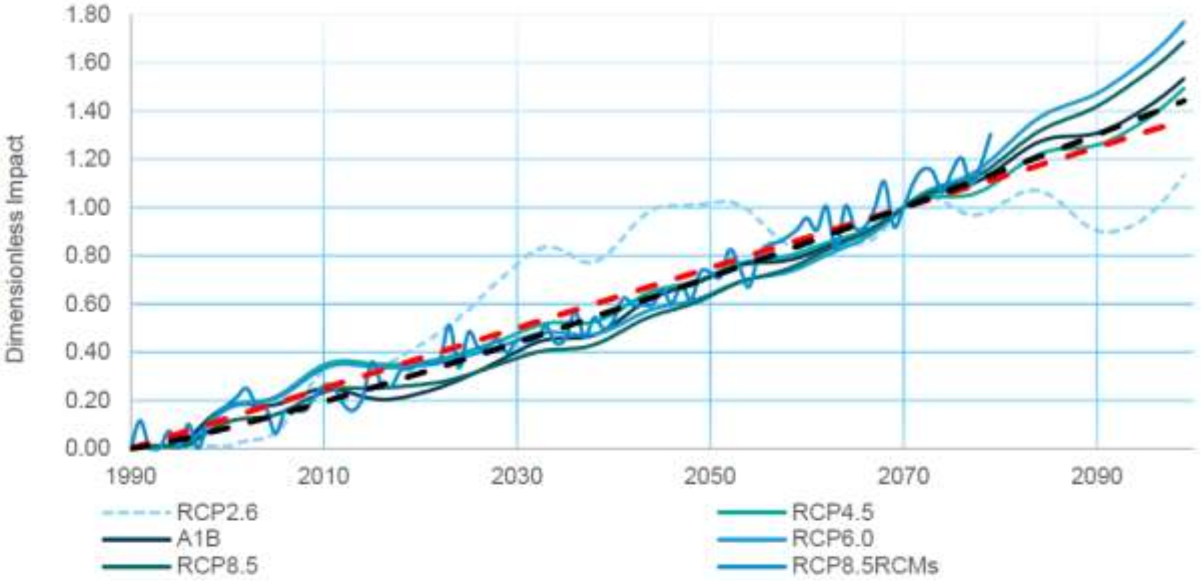


Figure A3.21: Curves fitted to dimensionless rate of impact based on EA's straight line method and power relationship method



As shown in Figure A3.20 and Figure A3.21, rates of warming and temperature related impacts follow typically non-linear projection. Thus, the following power relationship equation is derived based on the assessment of the rates of warming in UKCP18 climate models:

$$Time\ Scale\ Factor = a\ (Year - 1990)^{b}$$

Where a is 0.0056 and b is 1.1835. This has been shown to fit all RCPs well, with the exception of RCP2.6 as the rate of warming levels off at the end of the century (Atkins). These parameters were based on fitted equations to the normalised modelled warming in 2070, which were then averaged and the power was optimised to ensure that the result in 2070 was 1 or 100%. We have used this power relationship based scaling approach (as recommended by Atkin's project) to scale down impacts through time from 2070s to the start of planning period.

A4 Outage

Our water supply planning projections include an assessment of the likelihood of source outages occurring in our supply system. The Water resources planning guideline supplementary guidance – Outage from the Environment Agency and Natural Resources Wales (2020, p. 1) defines an outage as a "**temporary short-term loss in deployable output**". Outage can be planned, where the outage is foreseen and pre-planned, or unplanned, where the outage is caused by an unforeseen or unavoidable event. It can result in either partially reduced output of a source or complete closure. Outages include events which affect the "Water Available For Use" (WAFU), by restricting our ability to supply our customers and also events which do not affect the WAFU but pose a potential risk to supply and can last for longer than 3 months. However, careful consideration needs to be given to events lasting longer than 3 months as it may be more suitable to reflect these restrictions/closures as part of the source deployable output if the loss of output is not recoverable. In accordance with the EA and NRW Water Resource Planning Guideline supplementary guidance (2020) we have considered our outage allowance outside of our target headroom assessment and ensured that we have not double-counted outage.

In 2007 we implemented a new company reporting system for recording planned and unplanned outages occurring at our major surface water treatment works and we started using this data for our outage assessment in 2008. Once this recording process was fully established as business as usual at our surface water treatment works, we increased coverage to capture outage events at our groundwater sources later in 2008. We have used this database to inform our latest assessment of future outage risk. The database records the following information:

- The source(s) that is affected,
- The cause of the outage (quality issue, process maintenance etc.),
- Whether the outage was planned or unplanned,
- Whether the source was fully offline or partially restricted,
- The duration of the event,
- How much of the capacity of the source could not be deployed as a result of the outage.

We have used the recorded data in our assessment where available. We now have approximately 12 years of historic outage data for our surface water sources and groundwater sources. In line with our outage assessment for WRMP14 and WRMP19, we have considered both planned and unplanned events in our analysis.

As with our assessment of outage in recent previous plans (WRMP14 and WRMP19), we have not included any “extreme” events in the outage assessment. These are rare, unpredictable events which cannot reasonably be foreseen but when they occur would result in a major disruption to supplies, such as the failure of one of our aqueducts. The nature of these kinds of extreme events means that they are outside of our normal day to day water resources management. These “extreme” events are dealt with separately as part of our emergency planning and supply resilience investment programme.

A4.1 Our modelling approach

We have used a risk-based approach which follows the best practice principles set out in the UKWIR report *Outage Allowances for water resources planning* (UKWIR, 1995). This method uses Monte-Carlo analysis to assess the “allowable” outage (the probability distribution of the combined risks of the legitimate planned and unplanned outages occurring), with the output of the analysis enabling us to adopt a suitable level of risk.

The outage allowance modelling approach described in this section is applied to all of our water resource zones except for Chester. Chester was part of Dee Valley Water therefore we do not have as long records of observed outage as for our other zones, therefore we have supplemented observed outage by performing an assessment of potential outage and including these events.

Our outage models allow us to use a “bottom up” approach which utilises the operational outage data and information collated in our database for individual sources in each water resource zone. This is the same approach that was used for WRMP19. We believe the use of site-specific outage records results in a more appropriate assessment of future outage risk. Our outage allowance models use data which is processed in our specially developed “Event Tracker” tool to generate the outage events and consolidate them into suitable distributions which are required to perform the Monte Carlo simulations in the outage allowance models. The outage allowance model uses triangular distributions for assessing the magnitude and duration of outage risks and a Poisson distribution for event frequency.

Our outage allowance models have been developed with a user interface which enables a thorough audit trail to be maintained. The user interface captures key pieces of information, including a full set of input data and output data for the model run.

Due to the interconnectivity of our supply network, outages at the majority of our sources do not impact on our ability to supply our customers. In most cases other sources in our network are able to increase output to make up any potential shortfall caused by the partial restriction or full shutdown of other sources on our "grid". For operational purposes the daily records of outages at our surface water sources record how much of the maximum sustainable treatment capacity is available (and unavailable) due to planned and unplanned restrictions and shutdowns. The outage allowance model has an additional function built in, which allows us to assess the impact of the outage in two ways:

- The outage is included in the model as a proportion of the full source deployable output.
- The outage event is only recognised by the model if the severity of the event exceeds the buffer between the source deployable output and the maximum capacity of the source. Furthermore, when an outage event does exceed this buffer, its calculated magnitude takes this buffer into account. As a result, outage severity for a source is reduced when calculated against capacity (unless deployable output is equal to maximum capacity, in which case it will be equal).

We have used the second option in our modelling. In most cases, the deployable output of our sources is constrained by a factor other than the maximum treatment capacity of the treatment works, such as licence or infrastructure. Applying the outage impact to the full source deployable output in the modelling would result in a higher Outage Allowance. Adopting the second option enables us to assess the impact the outage events would have on our dry year deployable output.

The following is a summary of the approach used to select which issues are to be included in the outage assessment:

- If an actual event has been identified by the Event Tracker then it has been included in the outage assessment unless it was an operational choice such as 'preserving raw storage' or 'works control'.
- Generic pump or valve issues have been included for groundwater sources where events have not been observed in this category or their magnitude is lower than the generic issue.
- Any outage event that was removed during the WRMP14 and WRMP19 process was also removed for our dWRMP24 outage assessment as the issues had been resolved.
- Only 'legitimate' events have been included in the outage assessment. These events were identified through internal stakeholder consultation.
- Following the UKWIR 1995 guidance, any outage event that lasted longer than 90 days either needed to be removed (as this counts as a long term loss of deployable output) or treated with caution. We decided to cap the duration to 90 days as the updated deployable output assessment has taken these into account.

A4.2 Planned outages

We have an ongoing programme of planned maintenance and capital enhancement activities at our water production sites in order to maintain the long-term serviceability of our assets. To minimise the loss of output from maintenance activities we schedule work to be carried out in a way that limits risks to customers' supplies. As previously discussed, since 2008 we have maintained a database to record all planned and unplanned outages at our sources. We also have a record of actual planned outages going back to 2005. Our databases record the cause, the duration and the impact of the planned outage events. The records have been examined and the loss of output in each month has been identified.

Analysis of the records from our surface water treatment works indicates that output restrictions are often due to the prolonged partial or complete closure of a works for a major refurbishment. Planned maintenance is avoided at peak demand periods and this is reflected in very low numbers of planned outages between June and August. Outages due to repair and maintenance activities will only affect average deployable outputs and are not expected to influence our ability to supply our customers during peak demand periods. Furthermore, where possible, planned maintenance is planned so that works may be brought back into production at short notice if required.

For our groundwater sources, we have used actual data of the impacts of planned maintenance of our boreholes wherever it is available. Most of our water resource zone assessments include an element of planned outage due to process maintenance and capital improvement.

A4.3 Unplanned outages

The UKWIR (1995, p. 4) methodology defines an unplanned outage as being "an outage caused by an unforeseen or unavoidable legitimate outage event affecting any part of the sourceworks and which occurs with sufficient regularity that the probability of occurrence and severity of effect may be predicted from previous events or perceived risk". Their definitive list of unplanned events are:

- Pollution of source
- Turbidity
- Nitrate
- Algae
- Power failure
- System failure.

Surface Water Sources

The risk of unplanned outages has been assessed by examining the operational records in our outage database of the unplanned events that actually caused a loss of available output from our water treatment works. A summary of the key types of issues included in the assessment of unplanned outage events is given below:

- Burst / leak on the site (leading to a system failure)
- Electrical issues on site (leading to a system failure or caused by power failure)
- Mechanical issues on site (leading to a system failure)
- Pump / valve issues on site (leading to a system failure)
- Quality issues (including pollution of source, turbidity problems, algae issues).

Groundwater sources

The main unplanned outage issues for groundwater sources are pump failures and power failures. There are also issues of flooding at some sources and occasional periodic quality problems, principally turbidity after heavy rain. Where unplanned outages have occurred and have been recorded on our groundwater outage database, we have used actual recorded data to inform the outage assessment. The types of issues included in the assessment are summarised below:

- Burst / leak on the site (leading to a system failure)
- Electrical issues on site (leading to a system failure or caused by power failure)
- Flooding on site (leading to a system failure)
- Mechanical issues on site (leading to a system failure)
- Pump / valve issues on site (leading to a system failure)
- Quality issues (including pollution of source, turbidity problems).

Although our detailed site outage record for groundwater sources extends back to 2008, several of our sources have not been affected by outage events during this time. Therefore, for groundwater sources we have included allowances for pump / valve issues with the following distribution: frequency of 0.4 events per source per year; and a duration average of three days, between a minimum and maximum of one and five days respectively.

A4.4 Annual average outage allowances to 2085

The output from the probabilistic analysis of outage risks we have undertaken is summarised in Table A4.1. The table shows the likelihood of different outage quantities occurring in the year. For example, in the North Staffordshire zone our assessment shows that there is a 60% certainty (40% risk) that in any given year, up to 1.26 Ml/d will be lost due to outage, and a 90% certainty (10% risk) that up to 5.23 Ml/d will be lost due to outage.

Table A4.1: Range of outage allowances at different levels of risk

WRZ Name	DO (Ml/d)	Outage (Ml/d)				
		60% (40% risk)	70% (30% risk)	80% (20% risk)	90% (10% risk)	100% (0% risk)
Bishops Castle	4.09	0.00	0.00	0.01	0.04	4.89
Chester	27.21	0.02	0.02	0.02	0.03	0.07
Forest & Stroud	40.90	0.62	0.79	1.03	1.57	15.09
Kinsall	5.00	0.04	0.08	0.19	5.00	5.00
Mardy	3.50	0.02	0.05	0.11	2.88	2.88
Newark	14.40	0.00	0.00	0.47	11.31	15.50
North Staffordshire	136.14	1.26	1.98	3.02	5.23	79.09
Nottinghamshire	253.38	0.66	1.38	5.77	34.56	216.74
Rutland	0.00	0.00	0.00	0.00	0.00	0.00
Ruyton	5.32	0.04	0.09	0.22	5.30	5.30
Shelton	138.00	0.83	1.25	1.93	3.87	33.72
Stafford	25.80	0.00	0.04	0.15	0.64	11.60
Strategic Grid	1329.61	36.83	51.96	76.17	118.73	619.31
Whitchurch & Wem	12.73	0.00	0.00	0.04	0.14	2.30
Wolverhampton	30.00	0.00	0.28	1.21	3.23	30.23

As Nottinghamshire is supplied by imports from some of the water treatment works (WTW) in the Strategic Grid we carried out sensitivity testing to see whether the outage allowance for these WTWs could be proportioned across the two water resource zones. We modelled each of our major WTWs separately to enable us to calculate the proportion of outage from each water treatment works that could be attributed to the Strategic Grid and Nottinghamshire zones depending on the proportion of their output that supplies customers in each of those zones. We decided not to use the proportioned figures in the outage assessment as it artificially skewed the outage allowance for Nottinghamshire WRZ. In the event of an outage it would be an operational choice about how supply is provided – supply to Nottinghamshire WRZ would be maintained and other sources would be used to make up any shortfall in the Strategic Grid WRZ.

For some of our groundwater only zones, including Bishops Castle, Kinsall, Mardy, Newark (groundwater with imports from the Nottinghamshire zone), Ruyton and Whitchurch and Wem, few outage events have been recorded in part because these zones are highly resilient so rarely go out of supply. To this effect we have maintained the same assumptions that are consistent with WRMP19. The outage allowance for these zones has therefore remained constant from WRMP19.

We have not included any outage allowance for Rutland as this water resource zone is supplied by a bulk supply and we assume that supplies will be maintained in accordance with our bulk supply agreement.

As shown in Table A4.1 there is a large difference between the 80th percentile outage value and the 90th and 100th percentile outage values for many WRZs, but the difference between the 80th percentile and the 60th and 70th percentile values is relatively small. This is due to the probabilistic methodology; when selecting a percentile closer to the tails of the distribution the change for each percentile change is typically greater than the same percentile change closer to the centre of the distribution. In some of the smaller zones, such as Kinsall, Mardy, Newark and Ruyton, adopting a lower level of risk would increase the Outage Allowance significantly, with a large proportion of the zonal deployable output being lost to outage. Consistent with WRMP19 we have therefore used the 80th percentile values of the cumulative frequency distribution of outage probabilities in our water resources planning. Table A4.2 shows the outage allowances we have adopted with the percentage of the zonal deployable output that is affected.

Table A4.2: Summary of outage allowances adopted for dWRMP24

WRZ Name	Outage Allowance (Ml/d)	Percentage of Deployable Output (%)
Bishops Castle	0.01	0.24
Chester	0.02	0.09
Forest & Stroud	1.03	2.51
Kinsall	0.19	3.73
Mardy	0.11	3.25
Newark	0.47	3.24
North Staffordshire	3.02	2.22
Nottinghamshire	5.77	2.28
Rutland	0.00	0.00
Ruyton	0.22	4.09
Shelton	1.93	1.40
Stafford	0.15	0.58
Strategic Grid	76.17	5.73
Whitchurch & Wem	0.04	0.31
Wolverhampton	1.21	4.03

Overall, the outage allowance is low as a percentage of total DO at both a company level and at the individual zone level, being a maximum of 5.73% of DO in the Strategic Grid zone and being less than 3% in 9 of the 15 zones. At a company level, the outage allowance is 4.46% of our total DO.

The allowances vary widely between our WRZs, according to the nature of the sources and the degree of supply integration of the zones. The allowances are greatest in the Strategic Grid WRZ, which makes up approximately 85% of the company's whole vulnerability total under the 80th percentile. As with WRMP19, we are adopting the 80th percentile outage allowance across the whole of our planning period.

A4.5 Components of Outage Allowance

For the final plan, the overall outage risk will be broken down into categories so that their relative contribution can be estimated. The outage categories are quality, process maintenance, burst/leak, capital improvement, electrical, and pumps/valves. This will be achieved by running the outage model multiple times with only issues from a single category enabled and other issues excluded each time. The proportional contribution of each category of outage issue will be used to estimate the proportion of the total outage for each WRZ that is attributable to each category. It should be noted that because a probabilistic model is used, the results from this analysis should be regarded as indicative rather than definitive.

A4.6 Reducing future outage risks

At the time of writing our draft WRMP, our wider PR24 investment plans are not fully formed. Our PR24 investment plans will likely include a programme of capital maintenance, resilience and water quality improvement work which will improve the condition of our assets, making treatment processes more reliable and lowering the risk of their failure. The PR24 capital maintenance programme will prevent future asset deterioration, while our planned asset enhancements should increase the reliability of treatment processes and reduce the risk of asset failures. As a result, some of the unplanned outages included in the draft WRMP probability distribution-based outage model are likely to be resolved through these investments across future AMPs. Therefore, we will update the outage allowance for the Strategic Grid based on investment plans in each AMP. This will enable us to account for the reduction in the outage allowance due to the improved asset conditions.

For planning purposes we assume that planned outages associated with delivering maintenance and investment plans in future AMPs are likely to be statistically similar to historical planned outages in current and previous AMPs. Thus, the statistical method we have used to estimate planned outages due to maintenance works in future AMPs based on historical (observed) planned outages is a reasonable approach using auditable data and assumptions.

A5 Imports and Exports

We operate a number of raw and treated transfers and bulk supplies between the water resource zones within our region, as well as externally to and from third parties. For the purposes of our plan, we only report on imports and exports that are of strategic importance. We use a threshold of 1 Ml/d to determine whether an import or export classes as strategic, meaning that we do not consider transfers of less than this magnitude as being strategic. We are aware that transferring raw water from catchment to catchment could cause the spread of invasive non-native species (INNS). We have described our assessment of this risk in Appendix D.

As we have described in section A1, our region is divided into 15 separate WRZs and these closely align with the WRZ definition set out in the Water Resources Planning Guideline (WRPG). As a result, our 15 WRZs are broadly self-contained with limited connectivity across borders. The internal transfers that remain are described in the following sections.

A5.1 Internal transfers

In our water resources deployable output (DO) modelling, our Aquator model optimises the use of internal transfers based on least cost and resource state. In our WRMP tables, our internal transfers are included within the calculation of the water available for use (WAFU) in each zone, either through:

- our DO modelling in which case the transfer is only included in our planning table as “for information”;
- or for a small number of transfers, as a non-modelled transfer, in which case the transfer is included as part of the calculation in the WRMP Tables.

When we calculate DO for our WRZs we ensure that the import to a receiving WRZ is consistent with the export from the donor WRZ.

Note that as these transfers do not have abstraction licence constraints the annual total that we can transfer is theoretically 365 times the daily maximum shown in the table. As requested in the current WRPG we can confirm that the water quality of all of these transfers is treated water quality. We use the word treated to describe water that is fully treated and complies with all of our Drinking Water Inspectorate (DWI) quality obligations. None of these transfers cause adverse impacts on the water quality of the receiving area. Table A5.1 shows the utilisation during our 1 in 500 return demand model run and capacity of these transfers, rounded to the nearest Megalitre per day (Ml/d). Note that none of these transfers are bi- directional, so they can only be operated in one direction:

Table A5.1: Inter zonal transfers modelled within baseline deployable output

Name of transfer	Exporting WRZ	Importing WRZ	Average 1 in 500 utilisation (Ml/d)	Maximum capacity (Ml/d)
Derwent Valley Aqueduct (DVA) to Nottinghamshire (Notts)	Grid	Notts	14	28
DVA to Strelley (Notts)	Grid	Notts	6	43
Church Wilne to Notts	Grid	Notts	70	84
Higham to North Notts	Grid	Notts	9	23
Mythe to Mitcheldean	Grid	Forest & Stroud	0 Note 1	0 Note 1
Notts to Chesterfield	Notts	Strategic Grid	5	10
Mitcheldean to S. Gloucestershire	Forest & Stroud	Strategic Grid	0	10 Note 2
Caunton and Ompton to Newark	Notts	Newark	10	16
Oxton CG transfer to Newark CG	Notts	Newark	4	5

Note 1: We did not include this transfer in our base DO modelling but we have assumed a transfer of 10 Ml/d in our WRP tables.
Note 2: We only use this link in emergencies and 10 Ml/d is our estimated maximum capacity

For simplicity in the tables we assume that these values remain constant across the planning period, though for these internal transfers the flows could increase (to the maximum capacity) or decrease as the need to optimise across the zones arises.

A5.2 External strategic transfers

We have assumed in our base DO modelling that the external bulk supplies operate in line with the relevant agreement. Note that four of the six transfers described in Table A5.2 are of treated water quality. We use the word treated to describe water that is fully treated and complies with all of our, or the neighbouring company's, Drinking Water Inspectorate (DWI) quality obligations. One of the other transfers (the export to Yorkshire water) is raw, untreated water directly supplied from our Derwent Valley reservoirs. The raw water quality of this transfer will vary depending on the time of year and prevailing hydrological conditions. The import from Dŵr Cymru Welsh Water's Elan Valley reservoirs is partially treated before it enters the Elan Valley Aqueduct (EVA). This initial treatment occurs at our Elan water treatment works (WTW) and includes lime dosing and rapid gravity filtering but the water undergoes full treatment when it reaches our Frankley WTW. None of these transfers cause adverse impacts on the receiving area water quality.

Table A5.2 shows average utilisation of these transfers in our baseline 1 in 500 DO model run, rounded to the nearest Ml/d. Note that none of these transfers are bi- directional.

Table A5.2: External strategic transfers, modelled utilisation, maximum capacity and limiting factors

Neighbouring Company	Location	Average Aquator 1 in 500 simulation (Ml/d)	Max transfer capacity (Ml/d)	Total annual volume available (Ml/yr)	Limiting factors
Export to Yorkshire Water Services	Derwent Valley reservoirs (Strategic Grid WRZ)	57	Up to 68 Ml/d of untreated or raw water	21,535 (as specified in abstraction licence)	Terms of the agreement. Also quantity reduces as storage in the Derwent Valley reservoirs reduces
Wing import from Anglian Water	Split between our Strategic Grid and Rutland WRZs	NA Note 1	Up to 18 Ml/d of treated water	365x18 = 6,570	Terms of the agreement
Export to Dŵr Cymru Welsh Water (DCWW)	From our Forest and Stroud WRZ	9	We provide DCWW with up to 9 Ml/d of treated water.	365x9 = 3,285	Terms of agreement - Volume is supported by regulation releases from the Elan Valley. This is not usually variable in a drought.
Import from Dŵr Cymru Welsh Water	To our Strategic Grid WRZ from the Elan Valley reservoirs	282	Currently 320 Ml/d of partially treated water	365x320 = 116,800	Terms of the agreement (including reservoir control rules) and hydraulic capacity of EVA
Hampton Loade import from South Staffordshire Water (SSW)	River Severn to our Wolver-hampton WRZ	41 Note 4	peak day of 48 Ml/d of treated water.	24,911	Terms of agreement and associated abstraction licences and section 20 agreements
Import from South Staffordshire Water (SSW)	Brindley Bank To our Stafford WRZ	1.4 Note 2	Estimated at 5 Ml/d of treated water.	365x5 = 1,825	Terms of agreement: Higher import volumes more likely in higher demand periods
Import from Hafren Dyfrdwy (HD) Wrexham WRZ	To our Chester WRZ	2.08 Note 3	metered data, which is also used to update the bulk supply agreement	At least 2.08 x 365 = 1,095	See note in text below regarding imports and

					exports with HD.
Import from Hafren Dyfrdwy (HD) Llanfyllin WRZ	To our Shelton WRZ	0.15[Note 3]	metered data, which is also used to update the bulk supply agreement	At least 0.15 x 365 = 1,095	See note in text below regarding imports and exports with HD.
Import from Hafren Dyfrdwy (HD) Llandinam and Llanwrin WRZ	To our Shelton WRZ	0.85 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 0.85 x 365 = 1,095	See note in text below regarding imports and exports with HD.
Import from Hafren Dyfrdwy (HD) Llandinam and Llanwrin WRZ	To our Bishops Castle WRZ	<0.1 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least <0.1 x 365 = <36.5	See note in text below regarding imports and exports with HD.
Export to Hafren Dyfrdwy (HD) Saltney WRZ	From our Chester WRZ	4.73 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 4.73 x 365 = 1,460	See note in text below regarding imports and exports with HD
Export to Hafren Dyfrdwy (HD) Llanfyllin WRZ	From Shelton WRZ	7.24 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 7.24 x 365 = 2,555	See note in text below regarding imports and exports with HD
Export to Hafren Dyfrdwy (HD) Llanfyllin WRZ	From Mardy WRZ	0.02 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 0.02 x 365 = 2,555	See note in text below regarding imports and exports with HD
Export to Hafren Dyfrdwy (HD) Wrexham WRZ	From Mardy WRZ	0.04 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 0.04 x 365 = 2,555	See note in text below regarding imports and exports with HD
Export to Hafren Dyfrdwy (HD) Llandinam and Llanwrin WRZ	From Shelton WRZ	0.26 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least 0.26 x 365 = 2,555	See note in text below regarding imports and exports with HD
Export to Hafren Dyfrdwy (HD) Llandinam and Llanwrin WRZ	From Bishops Castle WRZ	<0.1 [Note 3]	metered data, which is also used to update the bulk supply agreement	At least <0.1 x 365 = <36.5	See note in text below regarding imports and exports with HD

Note 1: In our planning we have factored in a reducing profile is available as shared by Anglian Water we assume that up to 12 Ml/d of this import can supply the Rutland WRZ and the remaining upto 6 Ml/d enters our Strategic Grid WRZ.
Note 2: We do not model this within Aquator.
Note 3: Since we published out WRMP19 we have installed metering across these bulk supplies, reviewed the metered data and used it to update the bulk supply agreement.
Note 4: Aquator uses less than the full bulk agreement amount on average, but 41Ml/d is the most constraining amount during river regulatiom.

We have contacted the relevant companies to share the assumptions that we have made and to check that there are no significant inconsistencies. The following text explains how we manage our external transfers in normal years and under dry year/ drought year scenarios:

Bulk Supply arrangements and the calculation of imports and exports with Hafren Dyfrdw (HD)

We have bulk supply agreements in place for a number of transfers between Hafren Dyfrdwy and Severn Trent, which are summarised in Table A5.2. Although some of these are less than the 1Ml/d threshold, we have reported all transfers between us for completeness. Since we published out WRMP19 we have installed metering across these bulk supplies, reviewed the metered data and used it to update the bulk supply agreement. The new metered data revealed that the Wrexham to Chester export was approximately 1Ml/d lower than calculated at WRMP19. This is reflected in our WRMP tables.

Bulk supply arrangements with Yorkshire Water

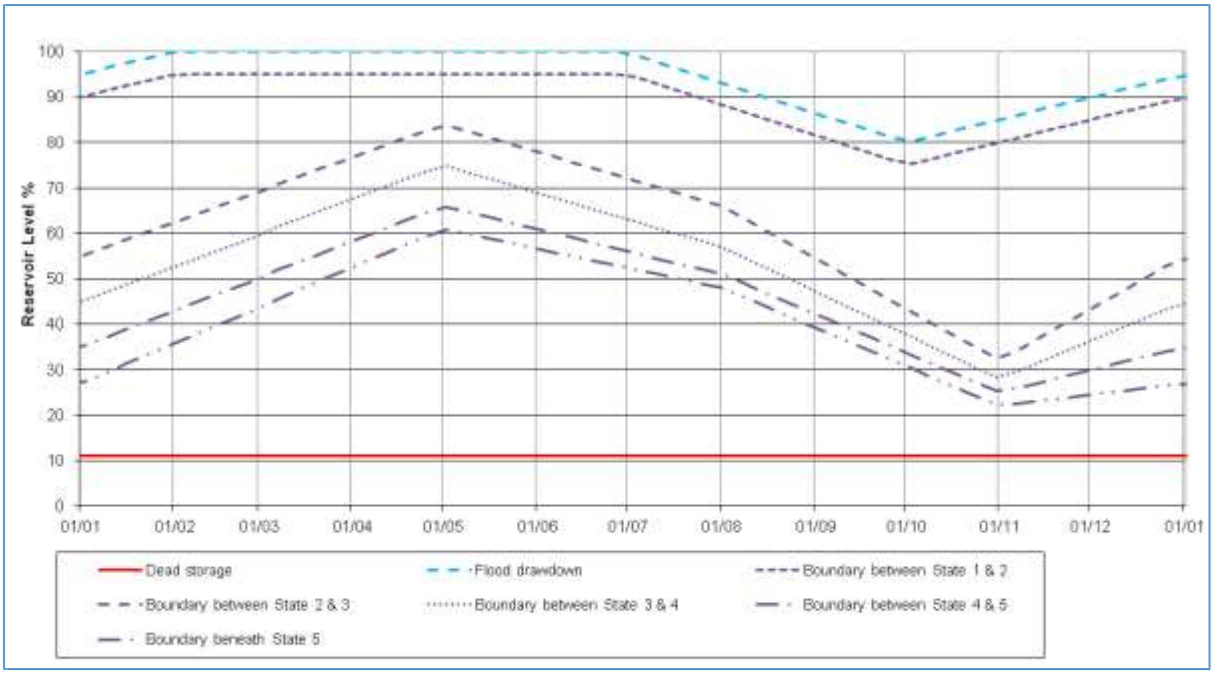
The normal operation of this bulk supply is governed by an agreement signed by both companies in 1989. The minimum supply rate between Severn Trent and Yorkshire Water Services (YWS) is 35Ml/d unless storage falls below state 5 on the reservoir control curve. In ‘normal’ conditions we operate to the terms of this agreement and so does YWS. There are minor differences between our modelled bulk export and YWS' modelled import. This is because we both use different models and our systems are very different. However, we account for this uncertainty within the S6 (accuracy of supply side data) element of our headroom.

Bulk supply arrangements with Yorkshire Water during drought

There is provision in the agreement to modify these rules and this has occurred many times. One example of such flexibility was during the 1995-96 drought. In events like droughts, extremely high customer demand or major outages in our region we approach Yorkshire Water and ask if we can make changes to the entitlements of one or other company.

We understand that the response we receive to these approaches will depend on the water resources position in Yorkshire. For example, during the drought of 2010-12 we explored with Yorkshire Water the possibility of them reducing their take. However, the hydrological conditions changed dramatically and meant that there was no longer a need to change the bulk supply arrangements. During the very hot weather / high demand period in the summer of 2018, we agreed with Yorkshire water to alter our agreement for a number of weeks to allow us both to increase our take to enable us to continue to supply our customers. Later in the year we both “paid back” this extra take as per the conditions of the agreement. Figure A5.1 shows the control lines that help to guide how we work with Yorkshire Water to operate this system.

Figure A5.1: Control lines for Derwent Valley bulk transfer to Yorkshire Water



The decision on whether to impose restrictions in Yorkshire Water's supply area is triggered by their resources and not our water resources situation. The opposite is also true: if Yorkshire Water has imposed restrictions but we have not, we will make our decision based upon our wider water resources situation. However, in scenarios of this sort we will work closely with Yorkshire Water, and all other stakeholders, to minimise the impact of a drought on customers and the environment.

Ultimately the decision on whether to impose customer restrictions lies with each company and depends on their own water resources position. This applies not only to us and Yorkshire Water but also to our interaction with all neighbouring companies.

Bulk supply arrangements with Anglian Water

We have a bulk supply agreement with Anglian Water, which provides up to 18 Ml/d from their Wing WTW into the rural areas of the former county of Rutland. Supplies from this import is split between our Rutland zone and Strategic Grid zone. We have split values based on full supply amounts in our supply demand balances and WRMP tables.

Bulk supply arrangements with Anglian Water during drought

This bulk supply does not automatically vary with any drought management measures, and the agreement does not stipulate that we will reflect any drought management measures that Anglian Water have to impose on its customers that are fed from their Wing WTW system. Nevertheless, in such circumstances, we will liaise closely with Anglian Water to minimise the impact on our customers whilst supporting Anglian Water's efforts to maintain supplies from the Wing WTW system.

We are confident that the legal agreement we have in place means Anglian Water will continue to maintain this supply during design droughts. By consulting with Anglian Water we have demonstrated that they can meet their obligations. However, as is the case with our own system, (see sections A10 and A11 on LoS and Drought) there will always be some extremely unlikely, but very severe, drought scenarios when it may be impossible for Anglian Water to maintain supply.

Bulk supply arrangements with Dŵr Cymru Welsh Water (DCWW)

We provide a bulk supply of up to 9 Ml/d to DCWW from our treatment works at Mitcheldean. In addition, we receive a bulk supply from the DCWW reservoirs in the Elan Valley. The quantities of this supply and how it may vary throughout the year are dictated by the abstraction licences of the associated water sources. For example, the transfer from the Elan Valley reservoirs is controlled by licence rule curves. If reservoir storage is below the lower licence rule curve it reduces the licensed maximum transfer along the Elan Valley Aqueduct (EVA) as well as affecting the required compensation flow.

Bulk supply arrangements with Welsh Water during drought

We are confident that the Elan Valley reservoirs will continue to maintain this supply during design droughts. By including this reservoir group in our Aquator model we have demonstrated that there is sufficient water available, even during 1 in 200 year drought scenarios, so that DCWW can meet its bulk supply obligations. Our Aquator model's maximum capacity (see Table A5.2) is based on the current (and end of AMP7) hydraulic capacity. We are aware that DCWW has to make the more precautionary assumption that we take our 'fully licensed" entitlement from the Elan Valley reservoirs. This is an approach that was discussed and agreed as part of the Habitats Directive (HD) review of consents (RoC) modelling group.

This group involved the Environment Agency, Natural Resources Wales, DCWW and other interested organisations. As the fully licensed quantities are higher than those that we presented in Table A5.2 the approach taken between ourselves and DCWW could be underestimating the available water in the River Wye during dry conditions. We are sharing flow data and assumptions and modelling each other's scenarios to quantify the amount of water that may be available whilst the EVA capacity remains at its existing maximum capacity.

Bulk supply arrangements with South Staffordshire Water (SSW)

We receive a bulk supply of treated water from SSW to supply the Wolverhampton area. We often refer to this as our Hampton Loade import. In a severe drought we would review with SSW and the Environment Agency the way we apportion our respective shares of the joint abstraction licence on the River Severn. This licence allows for the transfer of the overall quantity between SSW and us. If we were to consider the resource allocation during a drought, we would review our respective positions with regard to the availability of other resources and the prevailing demands in this part of our region. If necessary, we would allocate the balance between SSW's and our abstraction points accordingly. This agreed arrangement has existed for over 25 years and has worked satisfactorily throughout this time.

We also receive a smaller supply of treated water from SSW to support our Staffordshire WRZ. We usually refer to this supply as the Brindley Bank import. In recent years, this bulk import supplied an average of 1.4 Ml/d.

Bulk supply arrangements with South Staffs Water during drought

We are confident that the Hampton Lode supply will continue to be maintained during our design drought. By including this source, the treatment plant and SSW distribution system within our Aquator model we have demonstrated that there is sufficient water available so that SSW can meet its bulk supply obligations.

Our estimate for the peak capacity of our Brindley Bank import is 5 Ml/d. We are confident that the legal agreement we have in place means SSW will continue to maintain this supply during design droughts. By consulting with SSW we have demonstrated that they can meet their obligations. However, as is the case with our own system, there will always be some extremely unlikely, but very severe, scenarios when it may be impossible for SSW to maintain supply.

The annual River Severn Regulation meetings with organisations such as SSW, the Environment Agency and the Canal and River Trust, provide a forum for collaborative management of water resources on the River Severn. In addition, we work with SSW to align our Aquator modelling assumptions and we work with SSW, United Utilities, Environment Agency, Natural Resource Wales, Natural England, Bristol Water, Thames Water, Dŵr Cymru Welsh Water, the Canal and River Trust and Defra as part of the River Severn working group. This group formed during 2017 and its purpose is to coordinate strategic water resources planning matters related to the River Severn. Another area where we are working together with SSW is in relation to the potential for us to apply for a drought permit at Trimpley.

We assume that the values for all of the bulk transfers remain constant in each of the 25 years of the planning period.

A5.3 Maximum transfer capacity and factors which limit this capacity

Internal transfers

We earlier described the maximum transfer capacity and the limiting factors for our internal transfers in Table A5.1. The limiting factors for these transfers are the maximum capacities of the pipelines. The maximum capacities shown in Table A5.1 are those we use in our Aquator modelling as model parameters. These maximum values are either hydraulic capacities or where the flow is limited by operational factors such as water quality and discolouration risks.

External strategic transfers

The maximum transfer capacity and the limiting factors for our external transfers are described in Table A5.2. We note that in most cases the relevant infrastructure will be sized so that it does not allow significantly more than the agreed quantity of the bulk transfer.

How we manage our transfers in a dry year scenario

For our internal transfers our DAT (drought action team) makes decisions about intra and inter-zonal transfers. This decision making process is described in more detail in our drought plan. We have described above how we manage our external strategic transfers in a dry year scenario.

Reliability of transfers involving neighbouring companies

We have described above the assumptions we make in relation to the reliability of these inter-company transfers in a drought. We have also provided a high level description of the nature of these transfers and any limiting factors. We have not provided further details in the WRMP as these are commercially confidential agreements between the two companies. There have been no occasions since the WRMP09 when the requested import or export quantities were not provided.

A6 Levels of service and consistency with our drought plan

Levels of service are a contract between a water company and its customers, setting out the standard of service that customers can expect to receive. Our WRMP sets out our recommended strategy for maintaining the minimum standard of service that our customers can expect for restrictions on water use.

If we ever had to restrict our customers' use of water we would either impose a temporary use ban (TUB) or, in a more severe drought, we could apply to Government for a drought order to restrict wider use through a non-essential use ban (NEUB). A TUB is roughly equivalent to what we would have called a hosepipe ban prior to the change to the legislation / regulation in 2010.

Based on the analyses carried for our supply forecast and drought resilience we consider that our current annual average risk of drought restrictions of 3% will not change across the planning period. This annual average risk value has been calculated based on the frequency of Temporary Use Bans (TUBs) and Non-Essential Use Bans (NEUBs) water use restriction that we used in our calculation of deployable output in our Aquator water resources model. NEUBs are also known as Ordinary Drought Orders. We have not changed our stated levels of service for customer restrictions since our previous WRMP in 2019. Our levels of service in response to drought is shown in Table A6.1.

Table A6.1 Company Level of Service and Annual Average Risk of Drought Restrictions for each AMP from 2020 to 2045

Drought Restriction	Our levels of services	2020-25	2025-30	2030-35	2035-40	2040-45
Temporary Water Use Ban	3 in 100 years (3% annual risk)	3%	3%	3%	3%	3%
Ordinary Drought Orders (Non-Essential Use Restrictions)	3 in 100 years (3% annual risk)	3%	3%	3%	3%	3%
Emergency Drought Orders	1 in 500 years (0.2% annual risk)	0.2%	0.2%	0.2%	0.2%	0.2%

Further information on our drought resilience work can be found in Section A7. We have also ensured alignment of these figures with our current Drought Plan.

To put our current levels of service in context, we have not restricted our customers' use of water since the 1995-96 drought. The period since 1996 includes the twelve month period to February 2012 which was the driest in the Midlands region since records began in 1910 (as demonstrated by the Environment Agency's Water Situation Report dated February 2012). The summer months in 2018 and 2022 have also been very dry in our region. Despite these extremely dry periods we were able to manage our water resources without recourse to customer restrictions. Although we have not needed to implement restrictions on use for two decades and we managed without rota cuts / standpipes in the 1975-76 drought, we are not complacent about drought resilience.

We still consider emergency measures such as rota cuts or standpipes are unacceptable and we will do everything we can to avoid them. However we accept that we may have to resort to them in the unlikely event that we experience a drought more severe than the 1 in 500 year droughts we have modelled. We describe our drought modelling in Section A2.

Although we provide a higher level of service than most companies, we do this at the lowest possible cost to our customers. If we planned on the basis that we will never impose restrictions even during times of drought, it would not be economically or environmentally feasible to meet unrestrained consumer demand in all possible circumstances. If we planned never to restrict the use of water, our customers' bills would have to be higher. Conversely there are potential savings if we planned to restrict customers more frequently. We have taken on board the outcomes from our customer engagement when preparing our plan as described in Section A6.3. We believe that our balanced approach to our level of service presents the most acceptable and best value plan for our customers.

Consistency with our drought plan

Every 5 years we produce both a WRMP and a drought plan. A drought plan is a plan that guides our operational response to a drought during a five year period. It is not a costed investment plan. A WRMP is more strategic and looks much further ahead (a minimum of 25 years). Our WRMP is part of our PR24 plan and shows activities that we intend to do (such as reducing leakage or increasing levels of metering) that require funding via the Ofwat Periodic Review 2024 (PR24) process.

We have used our stated level of services in the modelling we have carried out for both our WRMP and for our drought plan. This means that our stated and modelled frequency of service restrictions is consistent between our WRMP and our drought plan.

Additionally, our stated levels of service are consistent with those we have quoted in our previous publications, such as our previous WRMP in 2019 and the drought plan we published in 2022 to cover the period 2022-2027. In our drought plan we explain how we respond when drought indicators, such as strategic reservoir storage, enter different drought trigger zones. We use our drought plan to help our decision making during a drought. Our water resource model (Aquator), our drought trigger zones and our assumptions in relation to demand reductions are consistent between our WRMP, the associated tables and our drought plan. Section A2 and A7 provide more information on the drought resilience work we have carried out to produce our WRMP24 plans.

Consistency with the EA and NRW drought plans

When preparing our draft drought plan and this WRMP we have considered and referred to the Environment Agency's 2016 National Drought Framework. We have also referred to the EA area drought plan and/or Natural Resources Wales drought plans as appropriate and where available. We can confirm that there is consistency between the EA/NRW drought plans that we have reviewed and our own plans.

Do our levels of service change over time?

All water resources modelling to predict baseline deployable output, sustainability reductions, climate change, drought resilience and supply option DO benefits have been carried out using a 3 in 100-year frequency of TUBs and NEUBs and 1 in 500 frequency of EDO. If there is a supply-demand deficit in any WRZ we have reported the timing and magnitude of it (in Ml/d) in our baseline WRMP tables. In our final planning scenario we show how any supply-demand deficits forecast will be resolved through our preferred programme of supply-side and demand-side options. Therefore, we assume that with the implementation of these options, the actual level of service will match the planned level of service over the planning horizon. In summary, we plan to maintain the level of service we currently provide to our customers along with the 1 in 500 EDO LoS and not make any changes to it. Over the 25-year planning period (2025 - 2050), this equates to a 75% risk of implementing TUBs/NEUBs and 5% risk of implementing EDO water use restrictions.

Our approach to groundwater drought

We have considered the resilience of our groundwater sources to long term droughts in particular multiple year droughts. As part of our climate change investigations, we assessed the impacts of multiple year droughts on the deployable output from our groundwater source water production sites. This study concluded that a small number of our borehole sources would be impacted by a prolonged multiple year drought, however only peak deployable output would be affected.

A6.1 Customer views on our levels of service

During the preparation of our WRMP24 we considered it necessary to review and consider the applicability of previous customer engagement that we carried out during development of our previous WRMP 19. This established that when preparing WRMP24, we reviewed the evidence held about customer support for different levels of service.

In summary, notable outputs from our customer engagement process for WRMP 24 included:

- We carried out willingness to pay research and also produced an online ‘sliders’ game that allowed visitors to our website to see the impact of competing priorities on total water and wastewater bills.
- Evidence from our customer survey in 2012 suggests that customers may not have been clear about the options that we proposed.
- During the PR14 and WRMP14 customer engagement activities, our customers supported a frequency of water usage restrictions of once every 38 years.
- At that time, the frequency of water usage restriction accepted by our customers was not significantly different to our level of service standard (usage restrictions occurring not more than once every 33 years). We subsequently did not change our level of service standard in our PR14 Business Plan.
- During the customer research we did not make a distinction between temporary use bans (TUBs) and non-essential use bans (NEUBs). We believed that this helped to avoid confusion.

During development of our WRMP 2024, we carried out further customer engagement as described in Appendix H. When we gathered customer views on levels of service for WRMP 24, we improved our approach by carrying out different phases of work:

- **Willingness to Pay (WTP) work**
  This is similar to the work we carried out for WRMP19.
- **Immersive research**
  This has many advantages over the other approaches as it means we can ‘immerse’ selected customers in more detail so that they are properly informed before we ask them for their views on these (often technical and complex) issues. This work also allows customers to consider competing priorities. Figure A6.1 is an extract from the immersive research that we carried out into the topic of drought and levels of service.

Figure A6.1: Extract from immersive research

To obtain their informed feedback, we showed participants information on STW's plans for when long periods of dry weather put water sources under stress...

Our customer engagement for WRMP19 found that customer awareness of our supply / demand challenge is very low. According to our customer tracker only 7% of customers think that we won't have enough water in 10 years' time and 10% in 20 years' time. The inference being that severe drought is not something that customers anticipate will affect the UK.

Since drought is not something customers consciously consider, we used deliberative research to discuss and understand our customer's informed views (in line with our strategic research framework). We used a drought 'story board' to help customers imagine the development of a drought situation over time, with progressively more serious customer impact as outlined in Figure A6.1.

Our customer engagement established that the occurrence of a drought would be seen as exceptional and outside of the water company's control. Climate change and changing weather patterns give rise to some concern that droughts could become more common in the UK, and a feeling that this would have a negative impact on the water service. While 'hosepipe bans' were mentioned spontaneously, these are generally seen as quite common and linked to 'hot summers' and not 'droughts', which as a term is interpreted as an extreme scenario that is unlikely to occur. In the engagement quiz about Severn Trent that we ran on Tap Chat, and in our deliberative research, we found that most respondents mistakenly believed that there had been a hosepipe ban in the region since 1996. In our research we find that Severn Trent customers are often confused about when restrictions to supply have last been imposed in the region, when in reality the last formal hose pipe ban was in 1995/96. For example, 25% of household (HH) customers told us they had experienced a restriction in the past 3 years, and only 41% had never experienced one. Customers could be confusing a formal temporary use ban with direct messaging (e.g. via SMS) asking them to use less water for a few days during a heat wave to alleviate peak demand. 33% of our Tap Chat members remember getting a message from Severn Trent asking them to use less water in the past 2 years, and 11% say that they remember a hosepipe ban.

The summarised results of this work and how our customers felt about different drought restrictions are:

- **Drought restriction level 1: Encouraging customers to use less water**
  They would feel little impact from level 1 (i.e. being encouraged to use less water), and therefore find the current frequency (once every one to two years) acceptable.
- **Drought restriction level 2: Temporary Use Bans (TUBs)**
  Temporary Use Bans (TUBs) are considered acceptable in principle; customers describe them as a pragmatic approach in such circumstances, provided that we can demonstrate we are taking additional steps to limit own water loss. Some customers believed that they had experienced a TUB recently and were surprised to learn that it has been more than 20 years since one has been implemented in our region. Many customers noted that the likely impact on them from a Temporary Use Ban was minimal. Due to the perceived minimal impact of temporary use ban (TUB) restrictions, the expected frequency (once every 33 years) is mostly seen as acceptable.
- **Drought restriction level 3: Non-Essential Use Bans (NEUBs)**
  Most customers in our engagement did not consider Non-Essential Use Bans (NEUBs) to have direct impact on them, but they did worry about the impact of such restrictions to businesses.
- **Drought restriction level 4: Emergency Drought Order**
  Participants recognised that requiring the use of standpipes would only occur due to severe and exceptional weather conditions. Therefore they regard our response in those circumstances as proportionate to the seriousness of the situation. However, they are clear that support would need to be put in place for vulnerable customers. The described predicted frequency of 'never (once every 500 years)' for these events is seen as acceptable by most customers. There was no willingness to accept a lower level of service in exchange for a bill reduction. Information on levels of drought

resilience for other companies was discussed in the session and not found to influence our customers' view.

Overall, our deliberative research found little support for further investment for the purposes of reducing the risk of requiring TUBs from the current level. Likewise there was no support to reduce the risk of requiring standpipes. Our willingness to pay research also showed that reducing the risk of needing to use standpipes is a very low priority for customers. As part of our valuation research programme we did a survey which we have called the budget game. In the budget game we interviewed customers using a large 'board game' to present them with different service levels (a current level and two improvement options). Each improvement option was costed in terms of a potential bill impact. Customers were able to select their preferred plan using tokens. The total 'cost' of the plan was then calculated and customers had the option of reviewing their choices. Using this approach we found that only 10% of customers selected an improved level of service for standpipe usage.

We think that this useful and in depth customer insight work has shown that the current levels of service we provide and those that we plan for in our drought plan and WRMP are in line with customer views and expectations.

As suggested in the 2022 Water Resource Planning Guidelines (WRPGs), we considered using the United Kingdom Water Industry Research (UKWIR) risk based planning report directly in our customer research in relation to drought resilience. We did not think that this work was suitable for the WTP phase of our work but we have adapted elements of it to assist with our immersive research.

When carrying out our PR19 WTP work we focused our research on emergency drought measures such as rota cuts and standpipes. We expected customers to have stronger views on these than they did on TUB or NEUB frequency. The WTP research showed that our customers were willing to pay £3.8m to halve the risk of standpipes. This may sound like a large amount of money but it was actually smaller than the WTP values for some of the other improvements we asked customers about. We will not make any decisions about the level of service that we offer our customers without clear evidence. Table A6.2 shows the modelled frequency of different restrictions:

Table A6.2: Modelled frequency of restrictions on customers' use

Restriction	Modelled LoS frequency[Note1]	Company stated LoS frequency
Temporary use ban (TUB)	1.19% (Not more than 1 in 84 years)	3% (Not more than 3 in 100 years)
Non-essential use ban (NEUB)	0.68% (Not more than 1 in 147 years)	3% (Not more than 3 in 100 years)
Emergency Drought Orders	0.25% (Not more than 1 in 400 years)	0.2% (Nor more than 1 in 500 years 2039 onwards) 0.5% (Not more than 1 in 200 years until 2039)

Note1 – This is modelled LoS at the start of the planning period. Modelled LoS for individual years over the planning period are better than the company stated LoS for each restrictions as shown in the data table (Table 2F).

We are aware that there are challenges involved in helping customers to better understand the likelihood of extreme drought events. We have reproduced the table produced as part of the UKWIR work on the topic of resilience metrics and included this as Table A6.3. It provides an illustrative example of different ways in which companies can describe drought. It does not apply to Severn Trent but we have included it here to show that we are looking at different ways of communicating drought risk.

Table A6.3 Illustrative example of different approach to describe drought severities

Drought Severity Band	Qualitative description: What are the chances of this happening to me in the next 25 years?
1	Just under 50/50
2	Some chance
3	Small chance
4	Unlikely
5	Highly unlikely
6	Implausible

A6.2 Critical droughts within our 100 year hydrological record

Our historical deployable output (DO) modelling of the 100 year period from 1919 to 2018 shows that the two most critical droughts in our region in terms of causing TUBs or NEUBs are those that include the years 1976 and 1984. Our water resource modelling shows that these are the droughts when we would have needed to impose customer restrictions. Our modelling also shows that reservoirs such as the Derwent Valley reservoir group and Tittesworth reservoir cross the TUB and NEUB triggers but they do so outside of ‘summer’ period in which we would impose restrictions. These ‘winter’ crossings at Tittesworth and Derwent occur in the 1933-34 and the 1995-96 droughts. Figures A6.2 and A6.3 show both a ‘winter’ and ‘summer’ crossing of the trigger level 2.

Figure A6.2: Tittesworth reservoir modelled baseline DO storage entering drought trigger level 2 in the 1995-96 ‘winter’

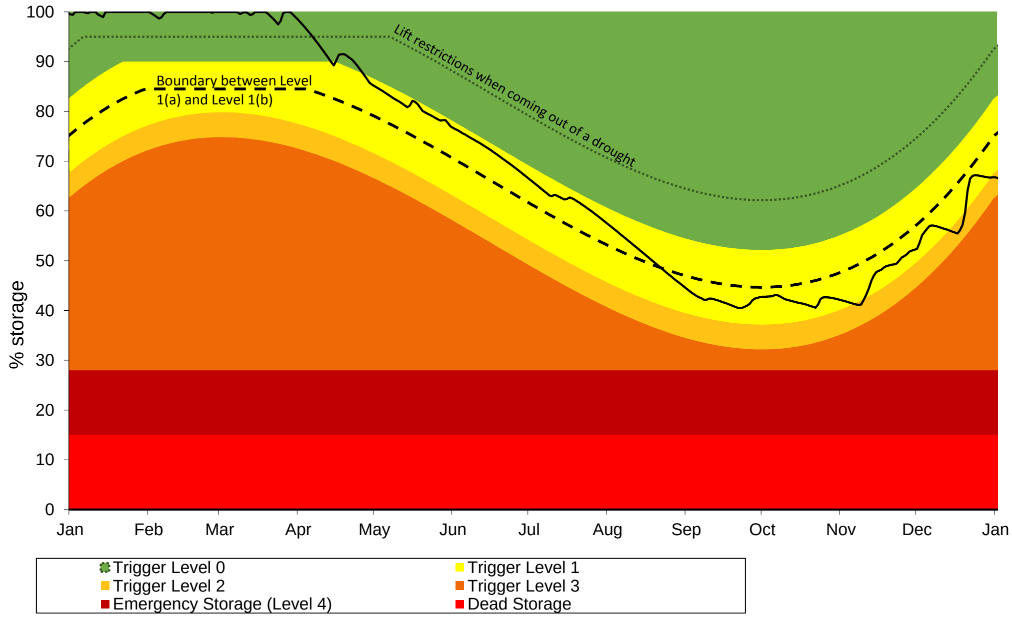
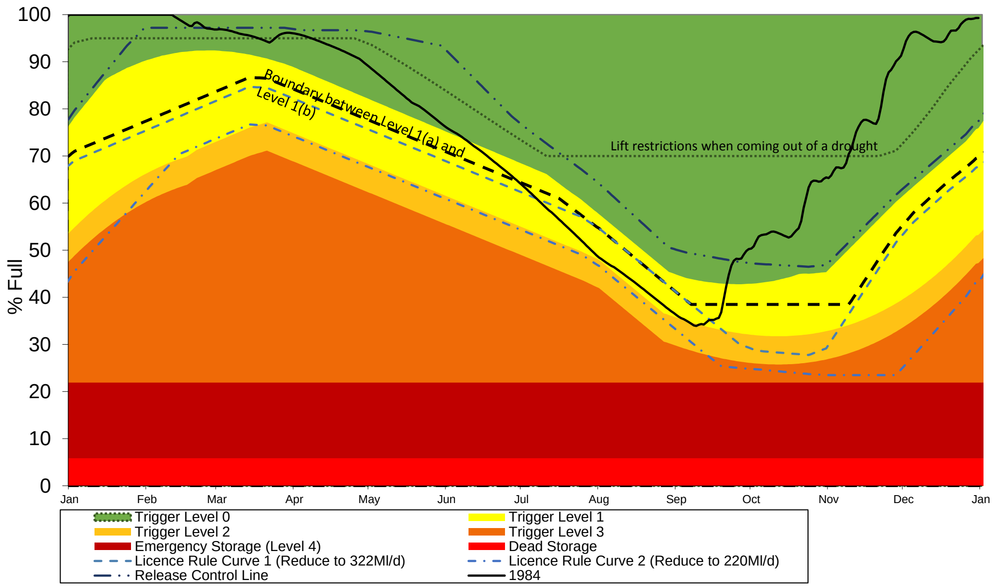


Figure A6.3: Elan Valley reservoir modelled baseline DO storage entering drought trigger level 2 in the 1984 'summer'



A7 Drought Resilience

A7.1 Testing our plan with challenging droughts

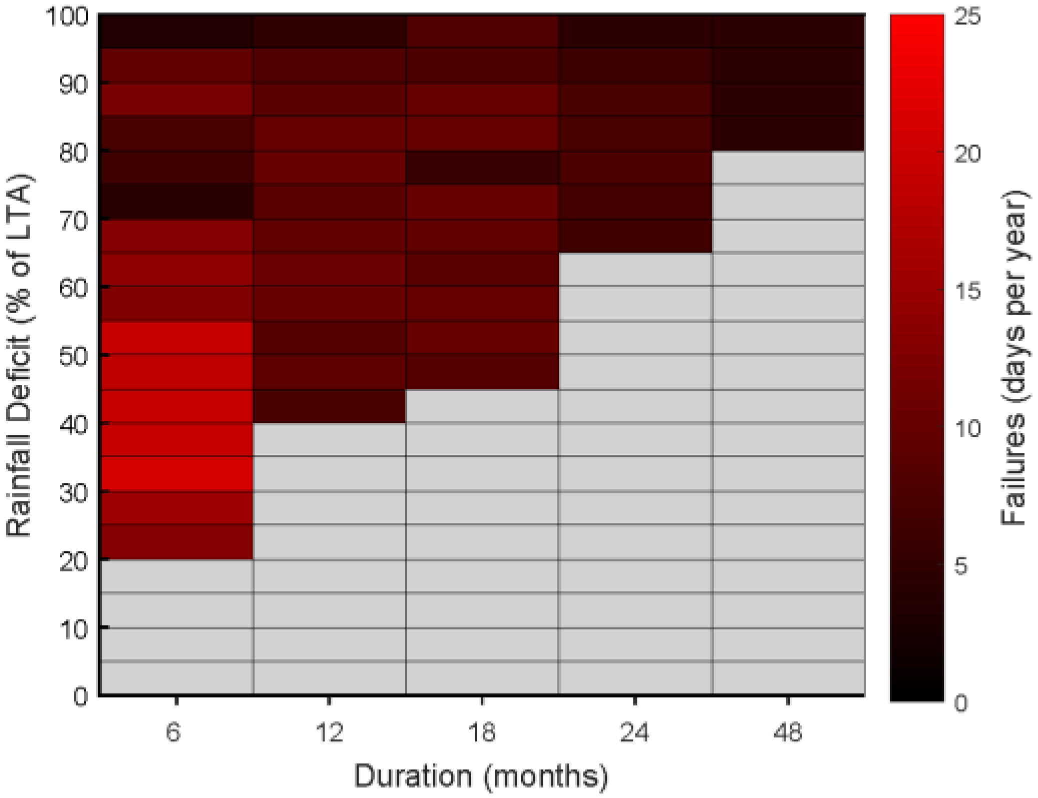
We have made a step change in terms of improving our understanding of drought resilience for our WRMP24 when compared to previous WRMPs. As discussed in sections A2 and A3, in developing this plan we have used a system response technique to assess the resilience of our system using the stochastic dataset, which enabled us to investigate how our water resource system copes with a variety of droughts including a range of severities and durations. The WRMP guidelines states that water companies should use a system response assessment approach to estimate deployable output based on the 1 in 500 resilience metric, which requires supplies to be available with a 0.2% annual chance of failure caused by drought. In addition to applying system response method to understand performance of our water supply systems, we have used outputs from the stochastics modelling to produce drought response surfaces.

Drought response surfaces

The WRMP24 supplementary guidance on Stochastics suggests the presentation of stochastic dataset using Drought Response Surfaces (DRS) based on the techniques described in the Drought Vulnerability Framework report (UKWIR, 2017). Detailed modelling and analysis of our WRZ systems is analysed using the system response approach as discussed in section A2 and the DRS are presented in this section with a view to illustrate how our water resource systems vulnerability varies according to drought duration and severity. The UKWIR Drought Vulnerability Framework approach is applied to show the impact on customers of droughts with different durations and different rainfall deficits (severities). A rainfall deficit is a way of saying how much drier a drought is compared with average conditions. For example, if a certain six month period has half as much rainfall than average we would refer to this as a 50% of long term average (LTA) rainfall deficit; Figure A7.1 illustrates this. Each box represents a different drought scenario. For example, the box in the bottom right represents the exceedingly unlikely scenario in which there is only 5% of rainfall for 48 months (4-years). By contrast the box in the top left is the much more likely scenario of having 95% of average rainfall for six months.

In Figure A7.1 below colour coding is used to present the 'number of days' failure metric. Statistically implausible deficit/ duration combinations are greyed out on the response surface. The boxes shaded from dark to red indicate the number of days that emergency drought order restrictions might be implemented under each drought scenario. Rainfall data for a range of catchments across our conjunctive use water resource zones have been used when calculating rainfall deficits. As the drought response surfaces approach requires Aquator modelling, we did not use it for the groundwater only WRZs. These other WRZs are more drought resilient (see later section on drought risk composition).

Figure A7.1: Drought Response Surface for all conjunctive use WRZs



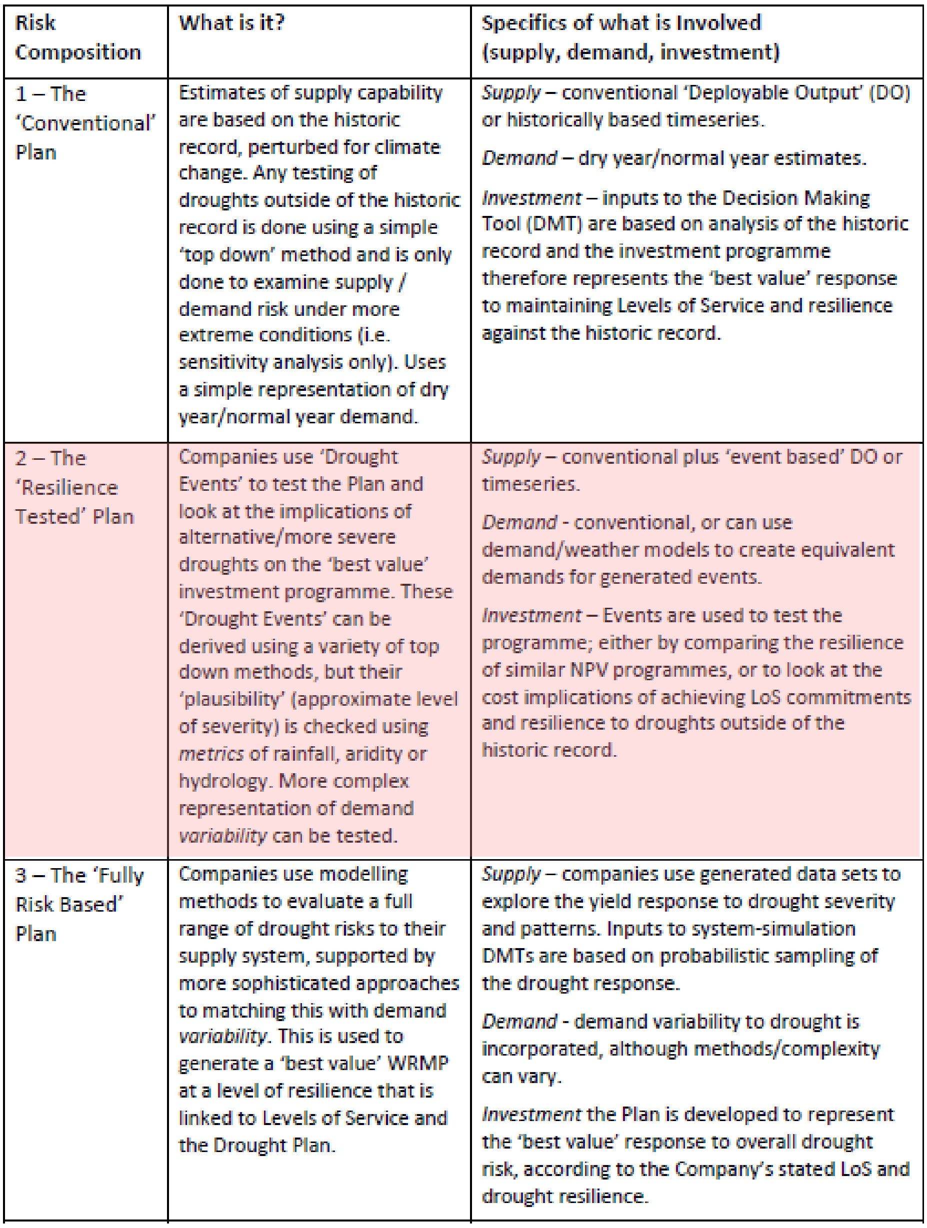
As described in our drought plan, drought management actions in our conjunctive WRZs would be implemented based on storage levels in our strategic reservoirs. Thus, we have developed DRS for the conjunctive WRZs based on storage levels in our strategic reservoirs dropping into dead storage or demand centre failures, which are both used to estimate number of days of failures as described in the drought vulnerability framework. Our Aquator model along with stochastically generated weather data for the surface water catchments are used to produce the DRS for the conjunctive WRZs. DRS are created for droughts ending in a pre-specified month, which is aligned to the most likely system failure point. For reservoir storage based system this is considered as the end of the drawdown period. Based on analysis of the stochastic model results, DRS were created for droughts ending in September as shown in Figure A7.1. We used this process to create scenarios for a range of representative catchments across our conjunctive use WRZs. Periods of demand centre failures and strategic reservoirs hitting dead water level resulted from the stochastic modelling are mapped across the scenarios produced from the stochastic dataset. We then plotted the results of this onto a grid using a range of colours to represent the impacts.

Risk composition

We have developed our drought resilience work using the Risk Based Planning: Guidance (UKWIR, 2016) methodology as suggested by the water resources planning guideline. A key component of this guidance is the need to state our risk composition. This composition, shown in Figure A.7.1, indicates how we have incorporated drought resilience into our WRMP analysis.

Table A7.1: Our risk composition- "Resilience Tested" Plan

Table Source: WRMP 2019 Methods – Risk Based Planning: Guidance (UKWIR, 2016)



Risk Composition	What is it?	Specifics of what is Involved (supply, demand, investment)
1 – The 'Conventional' Plan	Estimates of supply capability are based on the historic record, perturbed for climate change. Any testing of droughts outside of the historic record is done using a simple 'top down' method and is only done to examine supply / demand risk under more extreme conditions (i.e. sensitivity analysis only). Uses a simple representation of dry year/normal year demand.	*Supply* – conventional 'Deployable Output' (DO) or historically based timeseries. *Demand* – dry year/normal year estimates. *Investment* – inputs to the Decision Making Tool (DMT) are based on analysis of the historic record and the investment programme therefore represents the 'best value' response to maintaining Levels of Service and resilience against the historic record.
2 – The 'Resilience Tested' Plan	Companies use 'Drought Events' to test the Plan and look at the implications of alternative/more severe droughts on the 'best value' investment programme. These 'Drought Events' can be derived using a variety of top down methods, but their 'plausibility' (approximate level of severity) is checked using *metrics* of rainfall, aridity or hydrology. More complex representation of demand *variability* can be tested.	*Supply* – conventional plus 'event based' DO or timeseries. *Demand* - conventional, or can use demand/weather models to create equivalent demands for generated events. *Investment* – Events are used to test the programme; either by comparing the resilience of similar NPV programmes, or to look at the cost implications of achieving LoS commitments and resilience to droughts outside of the historic record.
3 – The 'Fully Risk Based' Plan	Companies use modelling methods to evaluate a full range of drought risks to their supply system, supported by more sophisticated approaches to matching this with demand *variability*. This is used to generate a 'best value' WRMP at a level of resilience that is linked to Levels of Service and the Drought Plan.	*Supply* – companies use generated data sets to explore the yield response to drought severity and patterns. Inputs to system-simulation DMTs are based on probabilistic sampling of the drought response. *Demand* - demand variability to drought is incorporated, although methods/complexity can vary. *Investment* the Plan is developed to represent the 'best value' response to overall drought risk, according to the Company's stated LoS and drought resilience.

We consider that our plan is at least at risk composition 2, as it is a “resilience tested” plan (see Table A7.1). In our baseline supply forecast we have used stochastics datasets to explore our WRZ’s system response to drought severity and patterns. Stochastic drought events combined with climate change impacts are thus used to test our plan and examine the implications of more severe droughts on our investment programme through our Decision Making Upgrade (DMU) analysis. This choice of risk composition reflects the complexity needed as part of our wider decision making approaches (see Appendix F for more information).

We used the stochastic drought analysis outlined above to investigate drought resilience across all of our conjunctive use WRZs (Strategic Grid, Nottinghamshire, Forest and Stroud, North Staffordshire, Shelton and Wolverhampton, Chester) and some of our groundwater only zones (Newark, Stafford, Bishops Castle and Mardy). We consider that the zones outlined above have a “resilience tested” risk composition. We did not carry out the stochastic drought assessment across the remaining groundwater only WRZs (Whitchurch and Wem , Ruyton, and Kinsall) and they are therefore risk composition 1 - “conventional plan” see Table A7.2. These WRZs were not included in the stochastic drought assessment as these zones have low vulnerability to drought. The deployable outputs in these zones are not typically constrained by water level but by other constraints, such as pump depth, due to the nature of the sandstone aquifers. This follows the same approach as our climate change assessment in these groundwater only zones. The WRZs not included in this assessment account for a very small percentage (approximately 2%) of our overall company level DO.

Table A7.2: Risk composition used for each WRZ

WRZ	Risk composition	Comment
Strategic Grid	Composition 2 - “resilience tested”	Conjunctive use WRZ
North Staffs	Composition 2	Conjunctive use WRZ
Chester	Composition 2	Conjunctive use WRZ
Forest and Stroud	Composition 2	Conjunctive use WRZ
Shelton	Composition 2	Conjunctive use WRZ
Wolverhampton	Composition 2	Conjunctive use WRZ
Nottinghamshire	Composition 2	Conjunctive use WRZ
Newark	Composition 2	Groundwater only WRZ – we assessed that these could be vulnerable to drought
Stafford	Composition 2	As above
Bishops Castle	Composition 2	As above
Mardy	Composition 2	As above
Whitchurch and Wem	Composition 1- “conventional plan”	Groundwater only WRZ – we assessed this WRZ as having low drought vulnerability
Ruyton	Composition 1	As above
Kinsall	Composition 1	As above
Rutland	n/a	Entirely supplied by bulk import – see section A7

Drought interventions and their impact

Table 6 of the WRMP data tables provides a link between the WRMP and Drought Plan. Within Table 6 we report a range of deployable output benefits from drought management actions based on our drought resilience modelling. We based these DO benefit numbers on a number of model runs of stochastic drought scenarios with various levels of return periods. We report DO benefit values for three conditions; (1) DO benefit under drought severity of 1 in 500 (0.2% chance of occurrence in any given year); (2) DO benefit under drought severity of 1 in 200 (0.5% chance of occurrence in any given year); (3) DO benefit under worst historic drought scenarios. We have run our model with and without drought management actions such as demand saving restrictions (TUBs and NEUBs) and drought permit/order interventions e.g. measures taken during a drought to increase water abstractions above permitted limits. Modelling DO under these varying conditions allows us to understand and quantify the benefit of demand saving measures and drought permit/ order interventions under a range of drought conditions. We outlined all of the drought interventions/ actions we consider in our 2022 Drought Plan.

Our baseline supply forecast does not include demand saving drought actions, drought permits or drought order interventions. Reference can be made to our Drought Plan for more detail on our drought trigger zones and the associated drought management actions. For example, our Drought Plan contains some options that involve reversal of flow along a bi-directional link. Where we model these links as bi-directional in Aquator, this option is built into our base DO. Another example of drought management actions being part of our baseline DO are actions that involve ‘maximise source X’. Operationally, during wet or average years we may choose not to use a certain source if we have other, possibly cheaper, sources of water but in a drought we would use it if our drought action team decide we need it. Our Aquator modelling represents this scenario by using low cost sources first but, when resources become scarcer, it over rides the financial considerations and uses sources based on their availability instead of their cost.

As stated above we quantify the impacts of demand interventions (such as TUBs and NEUBs) as well as drought permits and drought orders in Table 6 of the WRMP tables. Table 7.3 below shows the estimated yield benefits from the supply side drought management actions that are not part of our base DO and are not TUBs, NEUBs, drought permits or drought orders:

Table A7.3: Estimated yield from supply side drought interventions

WRZ	Drought Measure / source	Estimated peak yield Ml/d	Estimated average yield Ml/d	Comment
North Staffs	None	n/a	n/a	n/a
Strategic Grid	Witcombe	8.7	1.4	We assume this is licence constrained but we would undertake flow gauging and/ or a hydrological yield assessment if we were going to use it.
Strategic Grid	Linacre	9.1	6.8	As above
Strategic Grid	Monkdale	2	1.5	As above
Strategic Grid	Stanley Moor	2.2	0.5	As above
Strategic Grid	Norton emergency	n/a	0.7	As above and in addition, we cannot split out a daily/ peak max for the emergency part of this licence as much of the overall daily total of 24 Ml/d is used BAU for public supply. The real constraint to this emergency supply is the 5-year maximum.
Strategic Grid	Beechtree Lane emergency	18.0	0.9	We assume licence constrained but we would undertake flow gauging and/ or a hydrological yield assessment if we were seriously thinking of using it.
Strategic Grid	Blackbrook	14.5	6	We calculated a dry year hydrological yield of 6 Ml/d by using Q70 inflows, 10 % unusable storage, compensation flow of 0.136 Ml/d and a critical period of 18 months (548 days). We also used the minimum cumulative 548 day inflows and that also gave a 'yield' of 6 Ml/d so this adds to the reliability of the Q70 estimate.
Nottinghamshire	None	n/a	n/a	Covered by the Strategic Grid East actions that affect the Grid to Notts transfer
All of the other WRZs	None	n/a	n/a	n/a

We note that there are other drought management actions such as ‘raise awareness internally’ or ‘speak to the Environment Agency or neighbouring companies’ that are important actions but do not necessarily bring direct yield benefits. We give more detail on all of the drought management actions in our Drought Plan.

A7.2 Drought Resilience Statement

We have planned our system based on the new 1 in 500 resilience standard, which makes sure that exceptional demand restrictions such as Emergency Drought Orders are not required due to drought more than once every 500 years on average. The guidance states that the expected level of 1 in 500 resilience should be achieved as early as possible, or by 2039 at the latest. We plan to achieve 1 in 500 resilience across our systems by 2039 and 1 in 200 resilience will be met for the years up to 2039. The baseline deployable output (DO) for each zone based on the 1 in 200 and 1 in 500 resilience metric are presented in section A2. This means our system is resilient with a 0.5% annual chance of stand pipes and rota cut implementation until 2039 and 0.2% annual chance of these restrictions after 2039. We are confident that our plans represent a good balance between cost, environment and resilience to severe droughts.

A8 Protecting drinking water quality

On 12th September 2017, the Drinking Water Inspectorate (DWI) issued supplementary guidance to water companies relating to long term planning. The guidance included the following requirements:

"3.1 We would draw to your attention to two specific requests for information contained within the guidance note on long term planning for the quality of drinking water supplies:

a. A statement from the Board Level Contact for each company that the company's draft Water Resources Management Plan (WRMP) takes account of all statutory drinking water quality obligations, and plans to meet all drinking water quality legislation. This statement should be sent to the Inspectorate when the company's final draft WRMP is submitted to Ministers for approval, and it will inform any advice that the Inspectorate may subsequently provide to Ministers that is relevant to their decision (para 4.3.10); and

b. To provide assurance that risk assessments for drinking water quality include a long term view. Each company is requested to prepare and submit to the Inspectorate, a concise statement that sets out significant new future risk mitigation measures that a company considers it will need to provide for by the end of May 2018. New measures are those that are beyond routine provisions for current risk mitigation for all of a company's supplies from source to tap…"

In order for us to maintain our position as an authorised holder of a water supply licence, Severn Trent continually works to meet all regulatory requirements set out under:

- Water Industry Act;
- Drinking Water Directive;
- Water Supply (Water Quality) Regulations 2016, and;
- All other regulatory framework requirements.

This includes reporting to and liaison with the DWI.

Of utmost importance to us is ensuring the water we supply from both our own and imported sources (transfers) is wholesome for all our customers. We check water quality meets drinking water standards by collecting around 500,000 tests each year, analysed for all relevant water quality parameters. These tests are taken from source to tap, including from works, reservoirs and customer taps across all our water supply zones. We also sample imported sources of water. We consistently achieve a pass rate of over 99.9% with a result last year (2017/18) of 99.96% compliance. We also ensure that any breaches of water quality and associated regulations are investigated and reported to DWI accordingly.

We have a planned sampling and testing programme (our Annual Sampling Plan) to ensure we comply with the number, frequency and location of our samples and analysis for each water quality parameter as specified by the regulations. We determine the samples and analysis required based on the volume of water supplied (at reservoirs or works) or population served (at water supply zones) as required and in accordance with the regulations. We update our Annual Sampling Plan each year and monitor our adherence to it.

All surface water and groundwater sources in our region each have a catchment risk assessment. These cover all Drinking Water Protected Areas (DWPAs). Risk assessments are undertaken for all contaminants based on a source, pathway and target model as part of our Drinking Water Safety Planning Process. The risk assessments were first undertaken in 2008. We continue to review our risk assessments in line with our Drinking Water Safety Planning (DWSP) Framework which is managed by our DWSP Team. To date we have produced 16 surface water catchment risk assessments and in the region of 180 groundwater risk assessments.

The following Sections explain how we have incorporated the need to fulfil water quality obligations into the process of developing our long term plan that is described in this Water Resources Management Plan. In summary, protecting drinking water quality affects our supply projections and on the scope and design of any new water supply investment option that we include in our WRMP:

- Our water supply modelling includes an assessment of future raw water quality, and our plan explains what measures we propose to take to prevent any deterioration. We then build drinking water quality requirements into the decision making process, and;
- Our water supply investment optioneering explicitly takes drinking water quality obligations into account when designing and costing the scope of the potential solutions.

A8.1 Impacts on deployable output

Appendix A2 explains the detailed pumping, treatment and distribution components that we take into account in our water resources Deployable Output (DO) modelling. We consider current water quality constraints in our modelling of surface water and groundwater DO, and we take a view on how they might change in the future.

In our assessment of surface water source DO using our Aquator model, we have sought to incorporate potential raw water quality influences at sources with a known risk. An example of this is our approach to modelling our Eathorpe abstraction on the River Leam where we have represented the effect of not being able to abstract for approximately 15 days a year between September and December due to metaldehyde pollution risk. The need to suspend abstraction during higher risk periods then becomes a constraint on our modelled DO.

In our assessment of groundwater DO, the dry year average and peak source yield of each of our operational sources are included in our Aquator model as either an individual source or a group of sources. Source output constraints include the abstraction licence daily, annual or multi-year conditions as well as the need to maintain water quality blending requirements in multi-source locations.

For our groundwater DO projections we include a review of nitrate concentrations and trends, and the consequent impact on source output up to 2045. A series of nitrate blend scenarios were evaluated to determine the impact that rising nitrate concentrations would have on source DO over this period without interventions.

In our target headroom assessment, we have made an allowance for the risk of gradual pollution, where worsening water quality will affect the ability of the source to maintain the current DO. We have based this assessment on the list of groundwater sources identified through our Drinking Water Safety Plans as being at risk of deteriorating water quality. Through an initial screening assessment, these sources were then investigated further in order to determine what, if any, impact the deteriorating water quality would have upon the source DO. If there was no risk of DO being affected, or the source fulfilled one or more of the criteria below, the sources were excluded from the headroom risk assessment.

- There is no reference to water quality problems by area managers or in Severn Trent’s lists of sources at risk or in the Water Framework Directive Article 7 list of pollution risks;
- The source is no longer in use and is not contributing to DO;
- The issue presented an outage risk rather than a loss of DO.

We have also assessed the uncertainties around the loss of DO due to increasing trends in groundwater nitrate concentrations. Many of our groundwater sources have rising nitrate concentrations, which prompted a review of all groundwater nitrate trends to be undertaken in 2016. The results of this investigation were then used to indicate which blends or individual sources would be at risk of breaching the Prescribed Concentration Value (PCV) by 2045. Where a risk has been identified a blend calculator was constructed and a high resolution study into the potential impacts and mitigations was carried out.

Our analysis suggests that several blends and individual groundwater sources could be severely impacted by rising nitrate concentrations before 2045. An estimate of these potential impacts to DO has been made using projections of existing trends for all groundwater sources at potential risk of exceeding the PCV of 50 mg/l. The outputs of this study have been incorporated with our wider evaluation of our projected future supply / demand balance.

A8.2 Catchment Management to protect drinking water quality

Catchment management is an important part of our strategic planning 'toolkit', but it cannot solve all of the current and future water challenges and it needs to be targeted in the right places at the right time for maximum benefit. It is also widely acknowledged that it can take significantly longer to achieve the desired outcomes than using traditional engineering solutions. Sustaining these outcomes is likely to require continuing effort over numerous AMPs and the use of significant financial and practical resources. Consideration of the resource, time and risk to achieve the desired outcomes is necessary when considering where to apply this approach.

Our drinking water 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 on raw water quality deterioration. This will be achieved through collaboration with Environment Agency (EA), Drinking Water Inspectorate (DWI) 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 DWSPs and reduce carbon usage.

Over the last three AMPs our catchment management programme has been both ambitious (covering the whole of our region) and pioneering (one of the first such programmes in the country). Through our programme we undertake catchment investigations and schemes in both surface water and groundwater catchments. This programme of catchment management activities has allowed us to manage water quality risks in a sustainable and cost beneficial manner in accordance with regulatory requirements in Article 7 of the Water Framework Directive and Water Supply (Water Quality) Regulations.

Our catchment management activities include investigations and catchment schemes. Investigations consider the potential for reducing pollution loading in drinking water sources in our region through catchment management. This work is typically undertaken as part of the Environment Agency's National Environment Programme (NEP). Outputs are fed into cost benefit assessments to consider the wider benefits and justification for proposing catchment management activities and other remedial actions. This supports our business planning process and helps to derive and prioritise a programme of interventions that we will carry out in the next AMP period. Catchment schemes are the delivery of programmes of catchment management activity on the ground. They involve the deployment of tools and staff to engage with landowners and stakeholders in order to proactively manage water quality risk in our catchments.

The evolution of catchment management at Severn Trent

During AMP5, we successfully delivered one of the largest programmes of catchment management investigations in the industry. Our AMP5 catchment schemes were delivered through partnership agreements, for example the Leam Strategic Partnership and partnership working with the Rivers Trust in the Tittesworth catchment. Our AMP5 investigations provided a justification for the development of 27 AMP6 catchment schemes.

AMP6 saw the delivery of these 27 catchment schemes through a team of Severn Trent and Severn Trent funded partnership agricultural advisors. Farmers in these 27 'priority catchments' were offered a range of advice, training, monitoring, events and grants in accordance with the water quality issues in that catchment. The success of these schemes was tracked in terms of 'engagement' and increased awareness of WQ issues amongst farmers in our priority catchments. This reflected our understanding that engagement and understanding would be the precursor of land management changes and infrastructure improvement.

In preparation for AMP7, a further 3 surface water and 10 groundwater investigations were undertaken through the WINEP process during AMP6. A 3 stage process, alike to that followed in AMP5, was utilised to investigate the potential of catchment management to manage pesticide (SW) and nitrate (GW) issues in these catchments. These investigations concluded that all 3 SW catchments and 4 of the GW catchments would benefit from a catchment scheme in AMP7.

In AMP7 Severn Trent are delivering its biggest catchment programme to date, supported by an expanded team of 22 agricultural advisors and 7 catchment scientists. In recognition of the long term nature of catchment management and an ongoing commitment to working with farmers, we have continued to fund and develop the 27 catchment schemes from AMP5 and AMP6. A further 7 schemes have been rolled out in accordance with our AMP6 NEP investigations recommendations. On top of this, an additional 5 groundwater sites were identified as having issues with crypto and likely to benefit from a AMP7 catchment scheme. A further 5 catchments, previously grouped, were named as individual catchments to ensure their specific priorities could be addressed. This brought our AMP7 total to 44 catchment schemes. The location of these catchments can be found in A8.1. Building on the engagement focus of work in AMP6, the success of AMP7 schemes is tracked in terms of pollutant load reductions which are impacted by the implementation of land management changes and on farm infrastructure improvement.

Nine groundwater sites have been the focus of NEP investigations in AMP7 with 5 recommended as new schemes for AMP8 and further 2 still in discussion with the Environment Agency. Figure A8.2 shows the location of these catchment investigations.

Our plan for AMP7 and beyond includes the continuation of our current 44 catchment schemes plus 5/7 new schemes that were recommended through our AMP7 NEP investigations. The proposed catchment schemes will help protect our current sources from water quality risks, ensure no deterioration, help improve the resilience of our assets, and generate wider environmental benefits. We are currently in the process of identifying potential new GW and SW investigations for AMP8.

Figure A8.3 provides a summary of how catchment management at Severn Trent has developed since AMP5.

Figure A8.1: Map showing locations of catchment schemes in AMP7

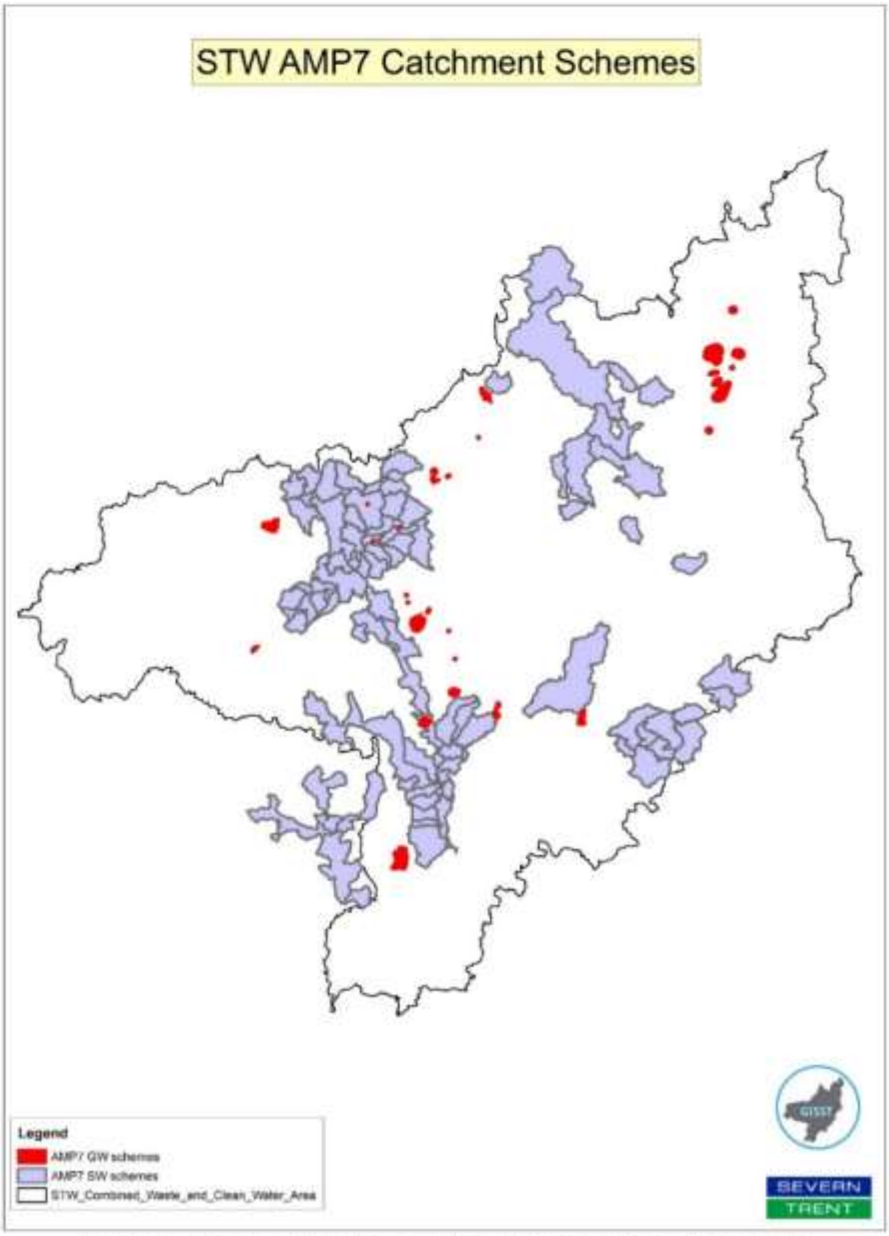


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Figure A8.2: Map showing locations of WINEP catchment investigations in AMP7

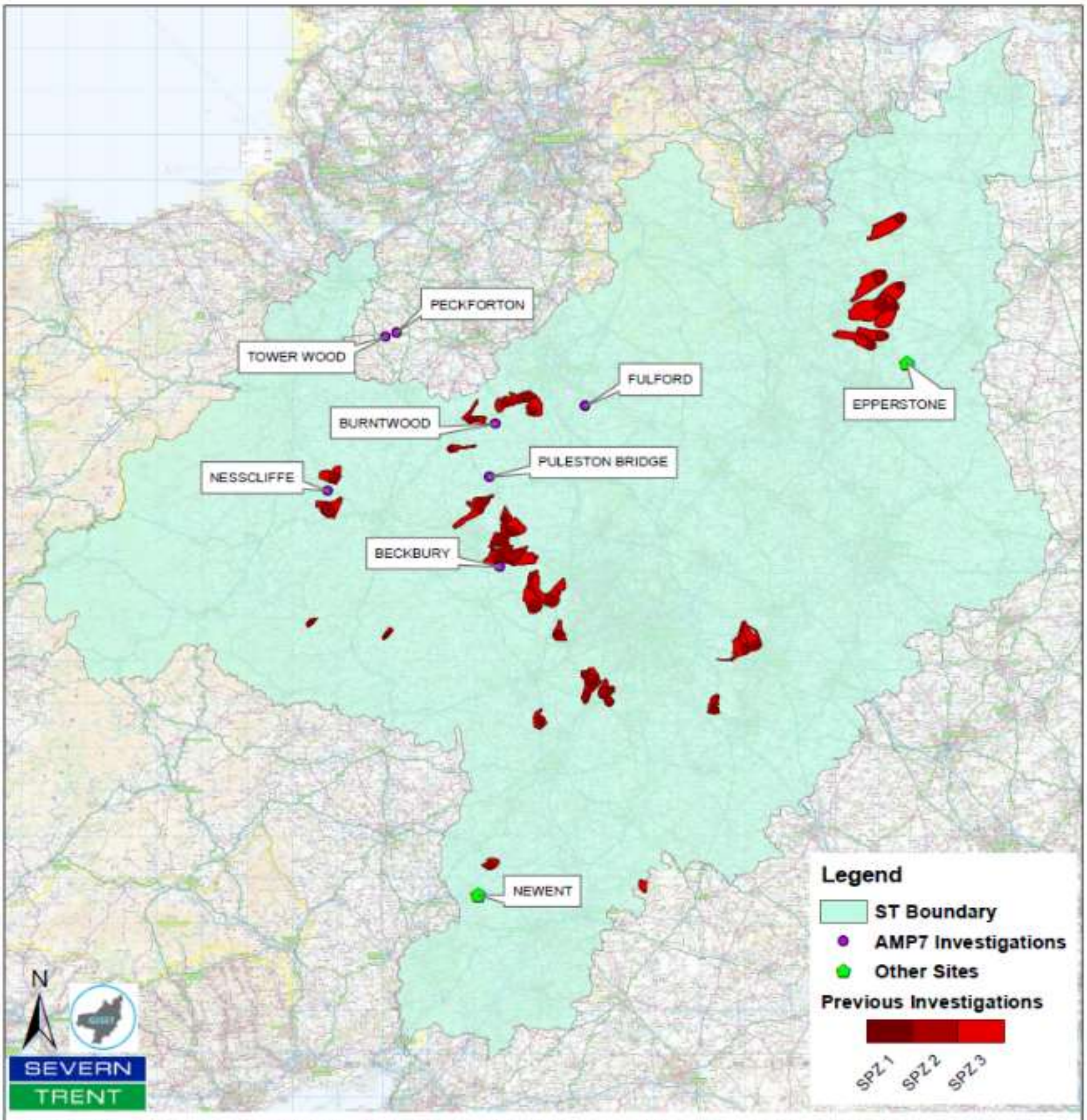
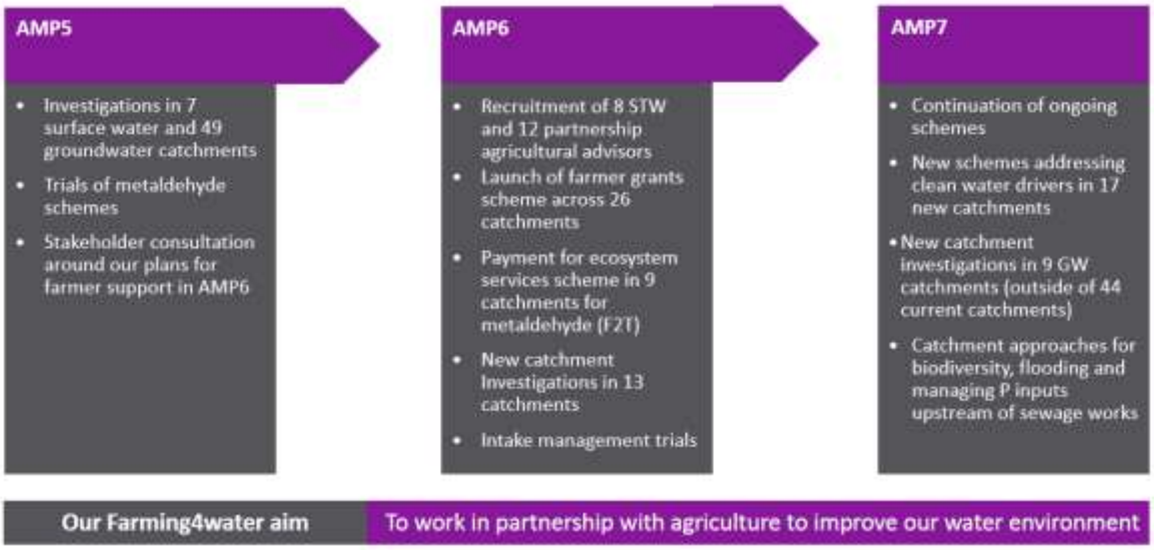


Figure A8.3: Evolution of catchment management at Severn Trent



AMP5

- Investigations in 7 surface water and 49 groundwater catchments
- Trials of metaldehyde schemes
- Stakeholder consultation around our plans for farmer support in AMP6

AMP6

- Recruitment of 8 STW and 12 partnership agricultural advisors
- Launch of farmer grants scheme across 26 catchments
- Payment for ecosystem services scheme in 9 catchments for metaldehyde (F2T)
- New catchment Investigations in 13 catchments
- Intake management trials

AMP7

- Continuation of ongoing schemes
- New schemes addressing clean water drivers in 17 new catchments
- New catchment investigations in 9 GW catchments (outside of 44 current catchments)
- Catchment approaches for biodiversity, flooding and managing P inputs upstream of sewage works

Our Farming4water aim To work in partnership with agriculture to improve our water environment

Our approach to catchment management

Our approach to catchment management activities has been formulated across many AMP periods. In AMP5 we made significant improvements in our catchment risk assessment processes. We have been able to verify the identified catchment risks through catchment walkovers, land use mapping and water quality data coupled with flow travel times. During AMP6 we built on these processes further to incorporate Research & Development (R&D) work that we carried out to improve our pesticide risk modelling (CatchIS) for groundwater catchments. This included enabling the potential to run the modelling software with a greater resolution (field scale through the use of our remote sensing data) into our business as usual procedures. Outputs from the Drinking Water Safety Plan (DWSP), coupled with water quality trending have also been used to help identify future water quality risks which need to be investigated or mitigated in future AMPs. In AMP7 improved availability of farmer data, partnerships with farm business consultancies, universities and charities are helping us gain better agricultural insight, offer the right schemes for farmers at the right time and develop our knowledge of emerging pollutants.

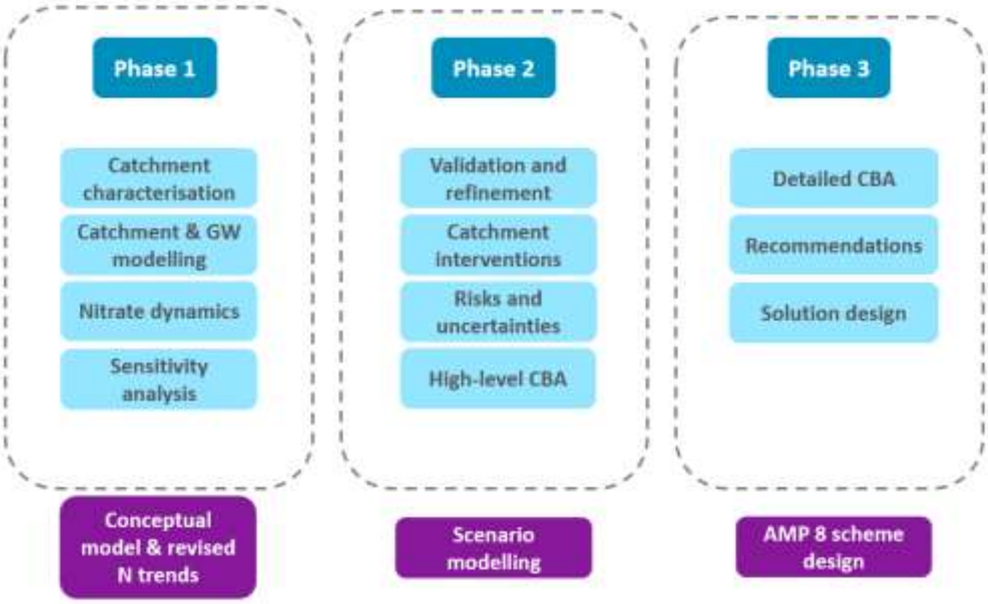
During AMP7 we have also expanded our approach to catchment management for wastewater assets in a series of pilot catchments. In these rural headwater catchments, the wastewater assets are receiving incoming phosphorus permits, or tighter phosphorous permits which are at the limits of what is technically achievable, and/or which are cost prohibitive. We are working in these catchments, as part of the national Environment Agency trial, to reduce the phosphorus within the catchment at source rather than upgrade the works. This approach removes between 20-100% more phosphorus than what is required from the permit, and so has material water quality benefits, as well as reducing our reliance on carbon and chemical heavy treatment options and improving the wider environment and resilience of those catchments.

Catchment investigations and schemes, whether for potable water supply or wastewater permit offsetting, provide cost beneficial solutions to water quality risks, addressing issues at source rather than relying on unsustainable and expensive end of pipe solutions. Article 7 of the Water Framework Directive requires water companies to move away from treatment options, utilising catchment approaches as the first and preferred option where possible. Minimising risks to water quality through proactive catchment management provides resilience in the face of uncertain future climates and growth, and with pressure to reduce abstraction in some areas, there is even greater need to protect the quality of our remaining sources.

WINEP catchment Investigations

As part of our WFD Article 7 obligations and through liaison with the Environment Agency, each AMP we are tasked with developing a list of National Environment Programme (NEP) sites for which we are obligated to undertake investigations or deliver catchment schemes in the following AMP. Surface water investigations tend to be based on operational issues. Groundwater investigation sites are identified through a screening approach considering a range of environmental and operational targets. We have adopted a phased approach to the investigation as summarised in Figure A8.4. This approach was agreed in advance with the Environment Agency, with the development of signed measure specification forms.

Figure A8.4: Phased approach to catchment investigation



A similar range of activities is undertaken for each catchment investigation. However groundwater catchments receive greater focus on building a conceptual understanding of the groundwater system and interactions with pollutant sources. For surface water catchments, we focus on understanding the existing activities amongst stakeholders that can influence management of water in the catchment. Catchment investigations enable us to prioritise activity on high risk fields / sub-catchments to ensure catchment interventions are delivered in the most influential parts of the catchment. The key deliverables of each catchment investigation are:

- The identification of potential sources of pollution and pathways to the source.
- A catchment model, either simple source apportionment or if the investigation requires more detailed scenario modelling.
- The identification of possible mitigation measures, including the evaluation of potential treatment options.
- A wider benefits assessment and cost benefit analysis.
- A catchment plan to be undertaken in the following AMP.

A large number of our current catchment schemes seek to address multiple water quality parameters, covering issues such as multiple pesticides, cryptosporidium, nitrate, colour/sediment and metaldehyde. In AMP7 and beyond our catchment approach has been extended to include biodiversity, flooding and managing phosphorus inputs upstream of wastewater treatment works.

In order to further protect drinking water from pollution and the need for more treatment at our water treatment works (WTWs) the Environment Agency have designated Safeguard Zones (SGZs). These zones are areas where land use is causing pollution of the raw water. Action is targeted in these zones to address pollution so that extra treatment of raw water can be avoided. SGZs are a joint initiative between the EA, water companies and other key stakeholders in a catchment and are one of the main tools for delivering the drinking water protection objectives of the WFD. All SW catchments currently involved in catchments schemes and the majority of groundwater catchments linked to schemes are designated as SGZs, requiring us to undertake catchments schemes and deliver mitigation measures upstream of our WTWs.

Our offer to farmers

Our experience from trials in AMP5 and subsequent roll out to eligible farmers in AMP6 has enabled us to continually evolve our offering to farmers. STEPS continues to represent our biggest investment, available to farmers in all of our priority catchments. In pesticide catchments with metaldehyde issues, an outcome-based scheme known as Farm 2 Tap has rewarded improvements in water quality.

Recognising the challenges and uncertainty affecting farmers due to the development of ELMs, reduction in the Basic Payment Scheme, market conditions and input prices we have continued to develop and improve our STEPS offer to farmers. To ensure effective investment of STEPS funding, we have bolstered our specialist on farm advice (SOFA) offering whereby ST funded specialist contractors provide on farm advice and follow up report with recommendations focusing on specific priority issues and investment opportunities e.g. pesticide wash down handling area. To adapt the challenges of continuing farmer engagement during the Covid-19 pandemic, we have introduced webinar-based support, specifically our Swap Your Nozzles campaign.

To align with developments and partnerships in the wider business around biodiversity, river water quality improvements (Severn Trent’s River Pledges and Get River Positive campaign), the Commonwealth Games, sustainability and the increasing relevance and profile of regenerative farming, AMP7 has seen the addition of Agreena to our farmer offer, providing access to the voluntary carbon trading market, and Trees for Water. Both Agreena and Tress for Water are available throughout the ST region. Additionally, we are working to create 2 bathing rivers within our region; the Teme (Shropshire) and Leam (Warwickshire). This programme, awarded under the Green Recovery and linked to our River Pledges and Get River Positive campaign, aims to reduce faecal inputs to the rivers such that they are suitable for swimming and other riverine activities. Further details of all schemes can be found below and summary of 4 key schemes shown in Figure A8.5.

Figure A8.5: Summary of 4 components of our farmer offer in AMP7

All catchments (Biosolids)

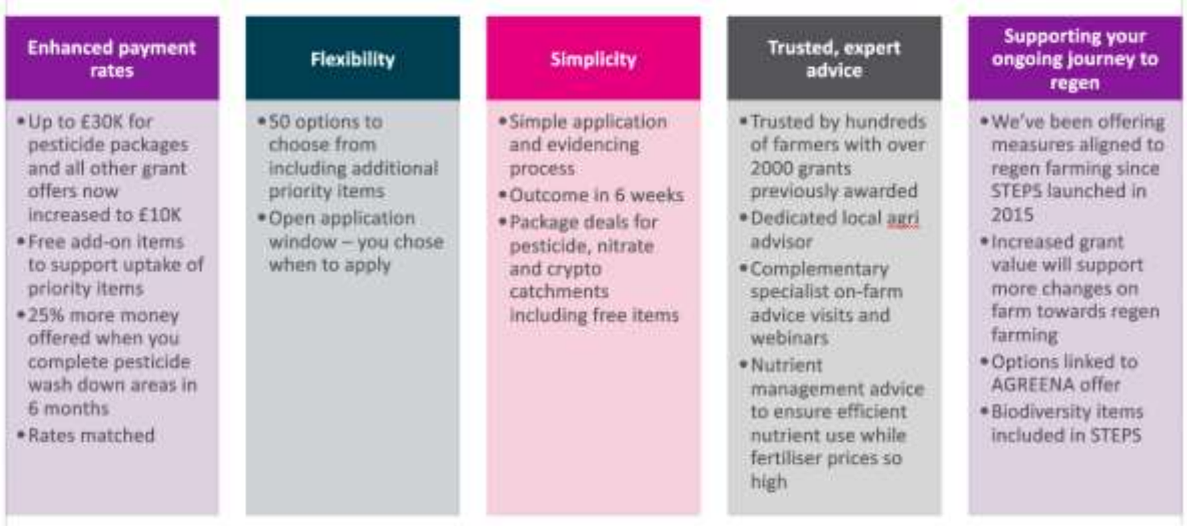
Priority catchments (Agri Advisers)

Enhanced STEPs	Specialist on-farm advice	Agreena	Trees for Water
An improved and enhanced range of options	Free farm visits by experts to advise farmers on how they can best move to more sustainable farming practices	Carbon credits for adopting regenerative farming practices	Riparian buffer and agroforestry tree offer

STEPS (Severn Trent Environmental Protection Scheme)
STEPS is a competitive grant scheme available to farmers in all our priority catchments. Under our STEPS scheme we offer grants to farmers to undertake works to reduce diffuse pollution, through improved infrastructure and changes to land management. Each catchment has several priority items most likely to be funded, linked to the WQ issue in the catchment. Farmers also have the option to apply for farmer innovation and biodiversity options (with a WQ benefit).

STEPS is in its 8th year with over 2500 grants awarded to date. Figure A8.6 highlights the changes which have been made for 2022, the key ones being the introduction of 'packages' to incentivise delivery of priority items, uplifted rates to match increased input / material prices and an open application window to increases opportunities to discuss schemes with farmers and allow farmers to apply at a time that suits them.

Figure A8.6: Summary of changes made to STEPS in 2022



Enhanced payment rates	Flexibility	Simplicity	Trusted, expert advice	Supporting your ongoing journey to regen
• Up to £30K for pesticide packages and all other grant offers now increased to £10K • Free add-on items to support uptake of priority items • 25% more money offered when you complete pesticide wash down areas in 6 months • Rates matched	• 50 options to choose from including additional priority items • Open application window – you chose when to apply	• Simple application and evidencing process • Outcome in 6 weeks • Package deals for pesticide, nitrate and crypto catchments including free items	• Trusted by hundreds of farmers with over 2000 grants previously awarded • Dedicated local agri advisor • Complementary specialist on-farm advice visits and webinars • Nutrient management advice to ensure efficient nutrient use while fertiliser prices so high	• We've been offering measures aligned to regen farming since STEPS launched in 2015 • Increased grant value will support more changes on farm towards regen farming • Options linked to AGREENA offer • Biodiversity items included in STEPS

Payment for Ecosystem Services – Farm to Tap

Our Farm to Tap scheme, previously known as Farmers as Producers of Clean Water (FaPCW), is an outcome driven scheme rewarding farmers for a reduction in metaldehyde concentrations in their local catchment. The scheme commenced in September 2016 and has been run annually until 2021 focusing on September and December -the highest risk metaldehyde period. This scheme pays farmers for producing clean run-off from their land and therefore contributing to improvements in drinking water quality within their local sub-catchments. Farmer payments are based on water quality data from fortnightly sampling. The scheme encompasses the principles of PES (Paid Ecosystem Services) with the overall aim of changing farmer behaviour and promoting ownership of the river(s) within their catchments. The approach helps drive long lasting behavioural change and sustainable improvements in water quality.

The scheme provided landowners with information on what activities can help reduce metaldehyde losses (Figure A8.7). However, it did not stipulate that they must undertake these activities, but instead it allows the farmer to choose management options that suit their farm business. Farmers received up to £8/ha for improvements or no deterioration in downstream water quality. All participants were required to complete a survey at the end of each year detailing what mitigation actions have been taken to help reduce metaldehyde losses during the monitoring period.

Figure A8.7: Farm to Tap practices to reduce Metaldehyde losses in water

Over the 5 years of the scheme we had a maximum annual sign up of 814 farmers covering over 42000ha. The most popular changes farmer made were the switch to ferric phosphate instead of metaldehyde, rolling seedbeds to reduce slug activity, creating enlarged buffers around fields and using information about weather, drainflow and slug numbers to ensure metaldehyde use was as targeted as possible.

Future Farm 2 Tap

At the end of March 2022 metaldehyde was withdrawn from outdoor use in the UK to protect wildlife and the environment. With metaldehyde no longer in legal outdoor use, 2021 was the last year we ran Farm 2 Tap for metaldehyde. However, 5 years of the scheme has shown us that the Farm 2 Tap concept is an effective one, both for engagement and water quality benefit. We are therefore trialling a propyzamide Farm 2 Tap scheme in winter 2022/23 in the River Bourne and Blythe catchments. Fortnightly sampling will be supplemented by intensive rainfall event monitoring via autosamplers. We are currently gaining insight from farmers local to the pilot to help identify management changes farmers could adopt to reduce propyzamide losses from their land. This catchment was chosen due to elevated levels in the catchment and because the catchment hosted our first F2T scheme trial remains receptive to engaging with us on trial work.

Swap Your Nozzles

During the Covid-19 pandemic the Severn Trent catchment team hosted several webinars to enable continued engagement and development of our catchment schemes. The webinars were aimed at pesticide users (farmers and contractors) and covered topics including best practice spraying, environmental considerations, nozzle types, legislation, and LERAPs. Those who attended the webinars were subsequently given the opportunity to apply for low drift nozzles to further reduce the risk of pesticide losses. The webinars received great feedback and another 2 rounds were run in 2021 and 2022. A total of 196 farmers took part in the scheme covering over 33,000 ha

Specialist on farm advice – SOFA

Building on an industry first partnership with Natural England's Farm Advice Framework (FAF), we are continuing to help farmers identify opportunities for improvement on their farm and target planned investment through specialist on farm advice visits. Farmers receive a one-to-one farm visit from a specialist contractor followed up by a report and recommendations.

Visit types available to farmers include:

- Nutrient action plans
- Soil management assessments
- Soil / slurry / manure sampling
- Whole farm / farmyard plans
- Water management plans
- Pesticide washdown / biofilter / biobed facility design visits
- Precision equipment and farm machinery
- Wetland system / pond management plans

To date 735 farm reports were provided to farmers with a large proportion supporting the application and delivery of a related STEPS grant.

In addition to these measures, since 2014 we have also funded a pesticide amnesty to reduce the amount of unwanted pesticides within catchments. To date a total of 16 tonnes of pesticides have been removed from our catchments. However in light of EA guidance brought to the attention of water companies in 2021, ST are no longer funding pesticide amnesties due to the additional responsibilities placed on water companies acting as the waste 'broker' in these arrangements. We will continue to advise farmers to dispose of chemicals in the appropriate manner and direct them to their local EA officer for further guidance.

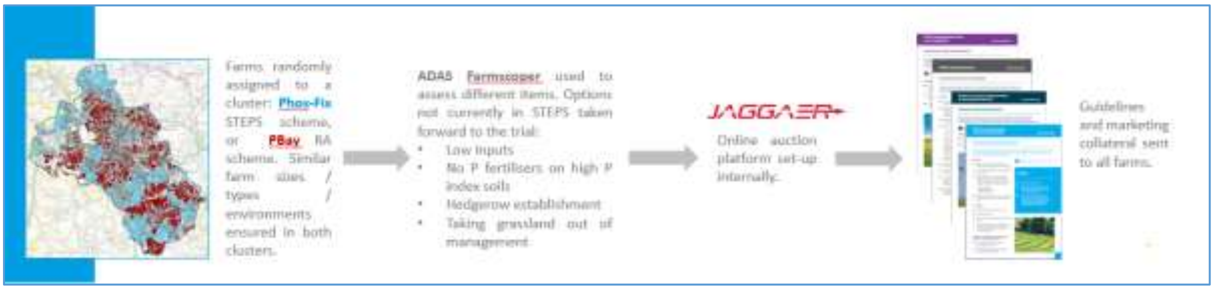
Alongside our training, visits and advice activities, we also strongly advocate Farming Rules for Water. We have a number of Agricultural Advisors that provide advice and guidance on legislative requirements when carrying out farm visits. Our schemes are voluntary and are designed to enable farmers to go above and beyond good agricultural practice rather than specifically to meet regulatory requirements. Where there is evidence that voluntary measures are insufficient to meet these requirements and all voluntary measures have been exhausted then we will liaise with the appropriate Regulators.

Reverse auctions

From 2018-2021 we have been testing reverse auctions as an alternative method to deliver water quality improvements with the agricultural sector, with a focus on delivering phosphorus improvements. Reverse auctions are inherently set up to be outcomes led, in that they pay the farmer £ per kg of reduction (in this case phosphorus), rather than an ‘outputs’ focussed approach, like that of our STEPS scheme, which pays a fixed cost based on the catchment intervention measure being undertaken. Figure A8.8 provides a summary of the steps undertaken to deliver this scheme.

The reverse auction trial has only been available in 2 catchments to date; the Wye (Derbyshire) and Dove (Derbyshire), with farmers offered a suite of measures to reduce the amount of phosphorus being input and/or lost from their farmlands. The trial tested the reverse auction concept, as well as the measures available to reduce phosphorus at source. Through this programme, 27 farmers were taken through to completion, signing up 634 ha of land, saving over 475 kg of phosphorus. Going forward, we will be using reverse auctions and other outcomes focussed approaches to sit alongside our existing STEPS scheme to deliver water quality benefits.

Figure A8.8: Reverse auction process



Farms randomly assigned to a cluster: Phos-Fix STEPS scheme, or PBay RA scheme. Similar farm sizes / types / environments ensured in both clusters.

ADAS Farmscoper used to assess different items. Options not currently in STEPS taken forward to the trial:
- Low inputs
- No P fertilisers on high P index soils
- Hedgerow establishment
- Taking grassland out of management

Online auction platform set-up internally.

Guidelines and marketing collateral sent to all farms.

Bathing rivers

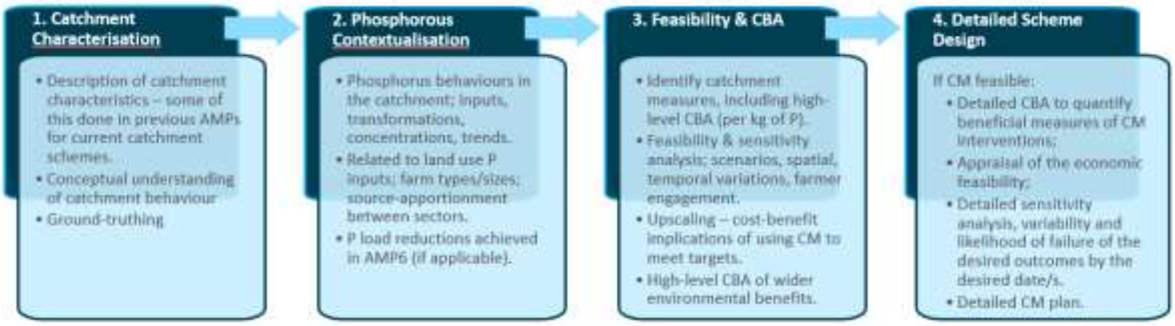
The bathing river programme is a relatively new area of work which began in 2021. With funding through the Green Recovery, the programme aims to create bathing river quality rivers in the Teme and Leam catchments, suitable for aquatic recreation activities, such as swimming and kayaking. Activities include river quality monitoring and predictive app development, CSO improvements and monitor installation, improving riverine access, and engaging with the agricultural sector.

The farmer engagement workstream of the programme involves engaging with the agricultural sector to reduce faecal inputs to the rivers by improving their livestock animal health, and through improvement of biosecurity measures on farm. This is delivered through webinar-based training, antigen testing of a range of faecal diseases, and the undertaking of animal health plans for high-risk farms or those who have had positive test results. The programme is expected to engage with over 1000 farmers in the 2 catchments over a 2-year period.

Catchment Nutrient Balancing (CNB)

During AMP7 we have started to expand our offering to manage wastewater assets in addition to water treatment assets. Catchment Nutrient Balancing (CNB) is the method through which this is achieved and involves working upstream of our wastewater assets to reduce phosphorus inputs at source with the agricultural sector, such that we are not required to upgrade the wastewater treatment works. This is a new concept, and as such is subject to a national trial being led by the Environment Agency. We are one of 3 water companies allowed to test CNB and are doing so in 3 catchments (2 in Shropshire, 1 in Worcestershire). To reduce the risk proposed by nature-based solutions to deliver a permit, we are required to remove at least 20% more phosphorus than is required by the permit in the catchment. Figure A8.9 provides a summary of the work done through our involvement in the CNB trial.

Figure A8.9: Catchment Nutrient Balance process



1. Catchment Characterisation

- Description of catchment characteristics – some of this done in previous AMPs for current catchment schemes.
- Conceptual understanding of catchment behaviour
- Ground-truthing

2. Phosphorous Contextualisation

- Phosphorus behaviours in the catchment; inputs, transformations, concentrations, trends.
- Related to land use P inputs; farm types/sizes; source-apportionment between sectors.
- P load reductions achieved in AMP6 (if applicable).

3. Feasibility & CBA

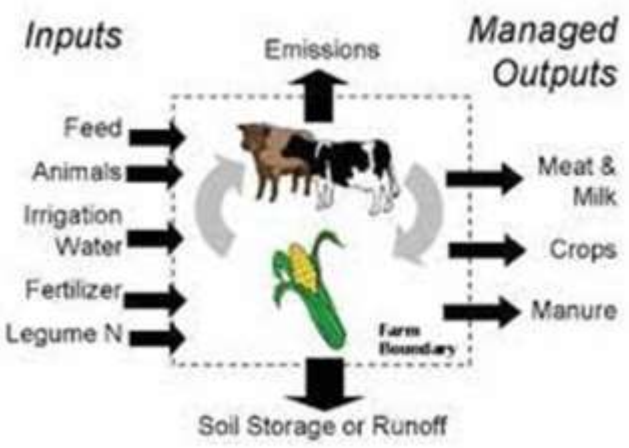
- Identify catchment measures, including high-level CBA (per kg of P).
- Feasibility & sensitivity analysis; scenarios, spatial, temporal variations, farmer engagement.
- Upscaling – cost-benefit implications of using CM to meet targets.
- High-level CBA of wider environmental benefits.

4. Detailed Scheme Design

If CM feasible:
- Detailed CBA to quantify beneficial measures of CM interventions;
- Appraisal of the economic feasibility;
- Detailed sensitivity analysis, variability and likelihood of failure of the desired outcomes by the desired date/s.
- Detailed CM plan.

The CNB programme will be delivered by our in-house agricultural advisors utilising catchment interventions and nature-based solutions, off the back of undertaking farm gate nutrient budgets. Farm gate nutrient budgets are an area of R&D for us and involve undertaking a phosphorus mass balance assessment of all of the farms in the catchments, to identify the inputs and outputs of phosphorus on the farm, as well as that which is retained by the farm environment and therefore has the potential to be lost to the watercourses – see Fig A8.10. This approach allows us to move towards outcomes, through payment of phosphorus load reductions on a £ per kg of P reduction basis. This reduction will offset our wastewater permit, as well as deliver real water quality benefits to the rivers in the catchments, as well as the wider environmental benefits of the work to the locale such as carbon reduction, biodiversity improvements and air purification. Utilising CNB and farm gate nutrient budgets is expected to form a larger part of our catchment management approach going forward into AMP8 and beyond.

Figure A8.10: Whole farm mass balance for CNB



Successes to Date

Over the last 8 years (when ST catchment management progressed from trials to catchment wide schemes), much has been achieved across our catchments – a summary can be found in figure A8.11. Our Catchment Team has engaged with 2678 farmers across 44 catchments. We have received over 2500 applications for funding towards on farm improvement works under our STEPS grants and sign-ups for our metaldehyde schemes have topped out at 814 farms covering an area of over 42,000 hectares. 33,000 hectares of land benefited from our swap your nozzles campaign and 735 specialist on farm advice visits have been delivered.

Figure A8.11 - A summary of successes from Severn Trent's catchment schemes

2678 farmers engaged with over 44 catchments	**16 tonnes** of unwanted pesticides safely disposed of through pesticide amnesties	**33,000ha** Involved in our Swap Your Nozzle campaign
42,000ha Max. Annual sign up to Farm to Tap (Metaldehyde Scheme)	**>2500** 'STEPS' grant applications received to address local WQ issues	**735 SOFA visits** delivered

Our catchment schemes have also resulted in:

- A 63% reduction in metaldehyde exceedances of PCV at our Water Treatment Works (WTWs) with no WTW failing for metaldehyde in the final year of the scheme
- A 50% reduction in pesticide peaks at Tittesworth WTW, avoiding the need for the installation of a Granular Activated Carbon (GAC) plant to treat water for pesticides.
- The cancellation of planned capital investment (plus ongoing opex) in a nitrate removal plants at groundwater sources. This was achieved through better understanding of agricultural practices in the area and a partnership approach with local landowners about changing practices.

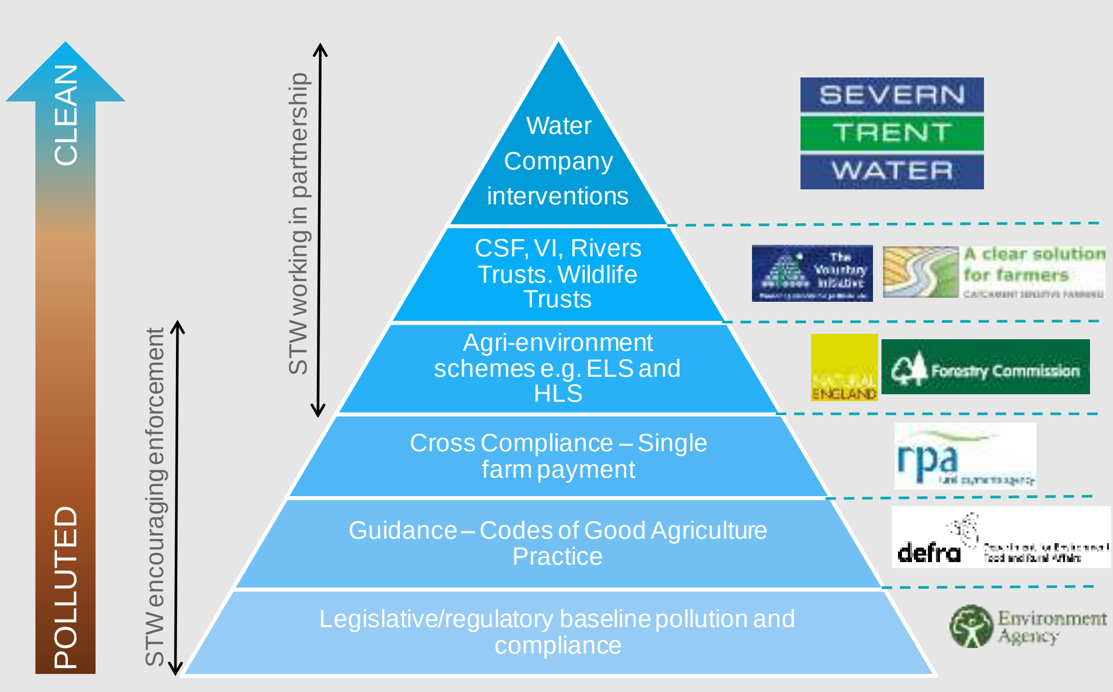
Furthermore, cost benefit and wider environmental benefit assessment has identified that spending £1 on catchment management can results in £2-£20 savings in treatment costs and £4 of wider environmental benefits.

Stakeholder Engagement

Stakeholder engagement is essential for the implementation of a catchment management strategy. However, advice only catchment management work has shown that in some catchments, stakeholder engagement, good agricultural practice and advice alone will not bring about sufficient water quality improvements. In these priority catchments or high risk areas, enhanced and targeted catchment measures are needed to meet drinking water standards (DWS) or target water quality concentrations. It is in these areas where we see water company intervention as being key to managing catchment risk and where we place our catchment schemes in our tiered approach to catchment management activities as shown in Figure A8.12.

Our partnerships with River Trusts, Wildlife Trusts and other organisations that have complementary objectives for our catchments (such as Wye & Usk Foundation, Trent Rivers Trust, Severn Rivers Trust, Catchment Sensitive Farming, Derbyshire Wildlife Trust, Shropshire Wildlife Trust, Worcestershire Wildlife Trust, Warwickshire Wildlife Trust and Nottinghamshire Wildlife Trust) are key to helping us deliver our catchment ambitions. This is most notably through the provision of 'partnership agricultural advisors', funded by Severn Trent but employed by our partners who adopt a very similar role to our in-house advisors. We fully recognise and appreciate the cost effective, reliable and extensive and local expertise these partnerships bring to our current catchment programme. We will also aim to further utilise our partnerships with Wildlife and Rivers Trusts along with Catchment Based Approach (CaBA) groups to explore large integrated catchment management approaches.

Figure A8.12: Tiered approach to catchment management initiatives and stakeholder engagement



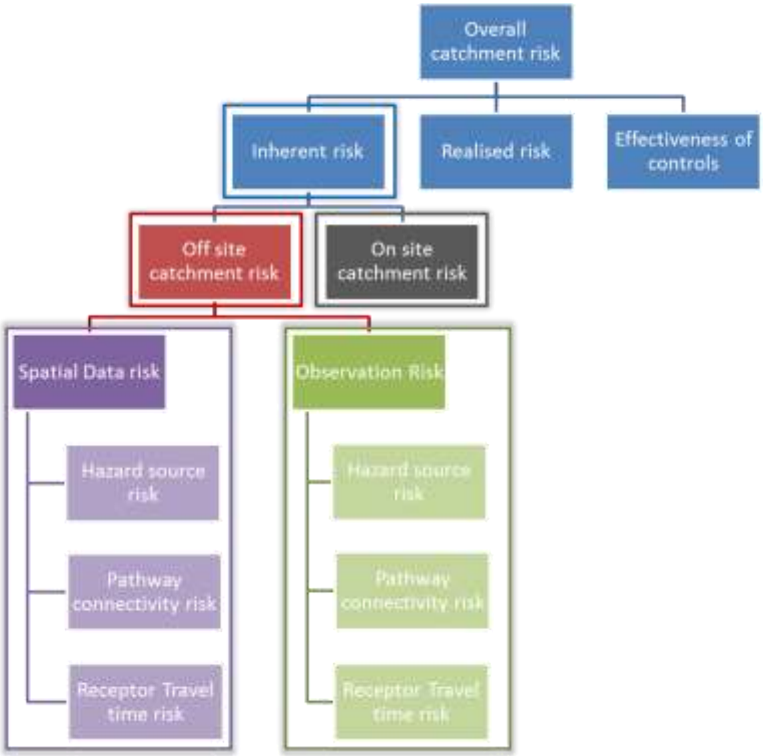
We need to be clear both internally and externally about the principles of catchment management in these areas. To this end, we have established high level principles for engagement which will underpin activities and communication in this area.

Drinking Water Safety Plans – Catchment Risk Assessment

Complementing Severn Trent's catchment management schemes is a programme of catchment risk assessment, feeding into our Reg 27 requirements to carry out a risk assessment for each treatment works (including the water source and catchment) and the connected supply system. An overall catchment risk is derived from an inherent risk, realised risk (water quality data) and an effectiveness of control as shown in figure A8.13. On-site and off-site risks both feed into the inherent risk. Inherent risks are determined by both spatial data risk (a theorised risk from spatial data sets) and an observation risk identified from extensive catchment walkovers.

There is a close link between our catchment schemes and catchment risk assessments. Agricultural advisors support the identification of off site 'observation risk' with their local knowledge, while data used to quantify spatial data risk has often formed part of our catchment investigations, helping to identify priority sub-catchments for example. In AMP7 the two workstream were more formally linked with load reductions from catchment interventions being modelled to quantify progress towards catchment load reduction targets. Load reduction targets are then linked to improvements in effectiveness of control.

Figure A8.13: Components of overall catchment risk



A8.3 Our future catchment management schemes

Our future plan includes continuation of the current 44 catchments, plus the 5 new groundwater catchments recommended through our AMP7 NEP investigations. We will also be continuing with the 3 new catchment nutrient balancing schemes for managing phosphorus upstream of our wastewater treatment assets, and our 2 bathing river catchments. Additionally, many of our existing catchments will have additional water quality drivers, which will add to our focus and activity going forwards. These catchment schemes will help protect our current sources from water quality risks, ensure no deterioration of the water body and help towards improving the resilience of our assets.

The scope of our future catchment management activities includes moving to an outcomes approach instead of outputs. Activities to enable this include:

- Farm gate nutrient budgets
- Reverse auctions
- Farm to Tap
- STEPS (Severn Trent Environmental Protection Scheme)
- Advice and training
- Greater partnership working – to include external partners as well as a better joined up approach internally

We also envisage that natural capital accounting and environmental credit trading will form a larger part of our activities going forward.

We will follow these principles:

- We will use scientific evidence and/or expert opinion to support the need for any cost beneficial changes in catchment management.

- We will work with stakeholders (including farmers and landowners) to bring about catchment management improvements voluntarily.
- We will use local expertise and insight to deliver our schemes efficiently through partnerships with Rivers Trusts, Wildlife Trust and other organisations with complementary objectives for our catchments.
- We will seek to facilitate management changes in the source catchment areas by bringing together interested parties and/or external funding streams into the catchment area to improve resource protection.
- Where farmers are asked to go above and beyond good agricultural practice we may part fund improvements or offer incentives to farmers to encourage changes in practices.
- We expect farmers to meet good agricultural practice through existing legislation, regulation and guidance. Where farmers do not adhere to the Code of Good Agricultural Practice (COGAP) through voluntary means we will look to the Environment Agency to enforce good practice.
- We will actively seek to have catchment areas designated as Safeguard Zones to promote voluntary activity.
- We will only resort to regulatory tools such as Water Protection Zones as a last option.
- We will seek to influence regional and national research needs, policy and delivery mechanisms where we identify gaps through our catchment engagement and R&D work.

A8.4 Water quality and new supply-side options

For our WRMP we have identified 119 different feasible options for increasing deployable output. These options include increasing water treatment works outputs, further optimising treatment works processes and increasing our strategic distribution capabilities. Further information on how we derived our feasible options is provided in Appendix D. The individual components of each solution has been considered in terms of:

- The source of raw water abstraction.
- The treatment works and treatment processes.
- The means of distributing the treated water.
- The distribution service reservoirs impacted by the new source.

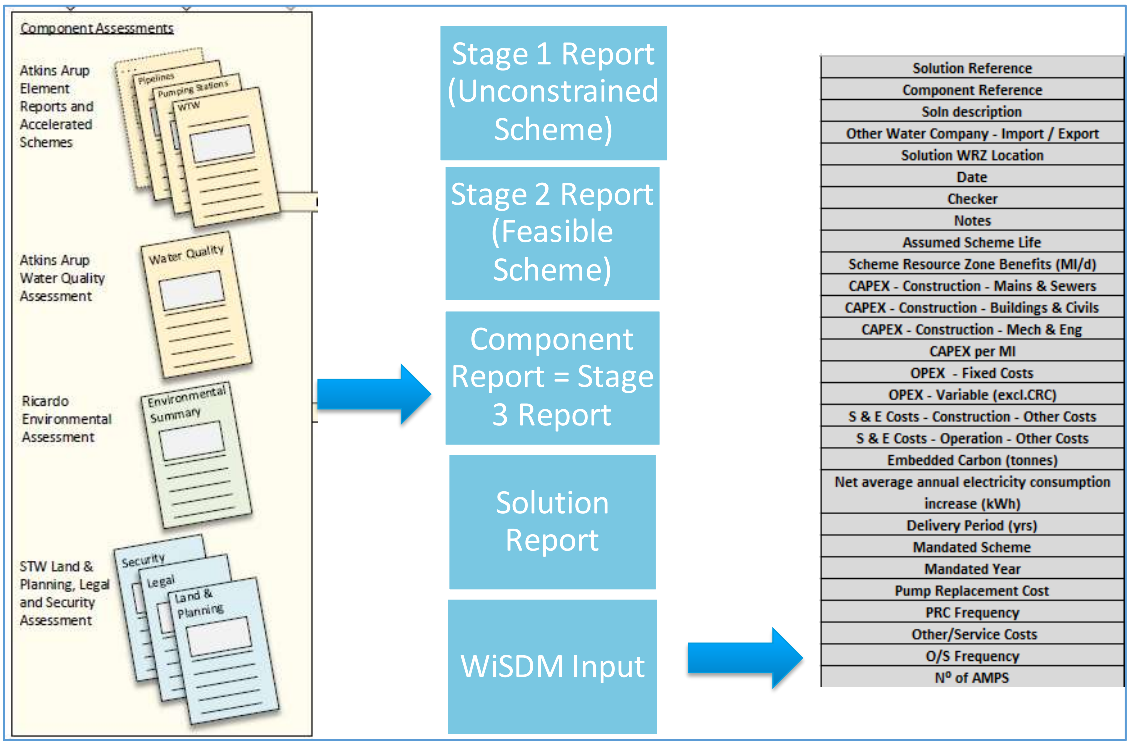
The design and scope of each option has been assessed using a ‘bottom up’ approach, and water quality is explicitly one of the elements we have considered when developing our supply-side options. Figure A8.14 outlines the option development process and shows how water quality considerations were integrated into the assessment alongside other factors such as environmental impact and planning requirements.

We followed an option screening process to refine our list of potential options and to screen out any options that would not be considered feasible. Technical expert screening workshops were held to:

- Appraise each option.
- Understand whether any identified constraints could be resolved.
- Assess any wider opportunities or potential benefits offered by each option.
- Remove any unfeasible options from further subsequent development stages.

This screening process is described in greater detail in Appendix D.

Figure A8.14: Assessing water supply options



Qualitative assessment was followed up (where applicable) with quantitative assessment. Where necessary, this technical expert screening included consultation with our water treatment process design and engineering team for water quality and treatment specific considerations. As a summary, our screening considered the generic questions shown in Table A8.1:

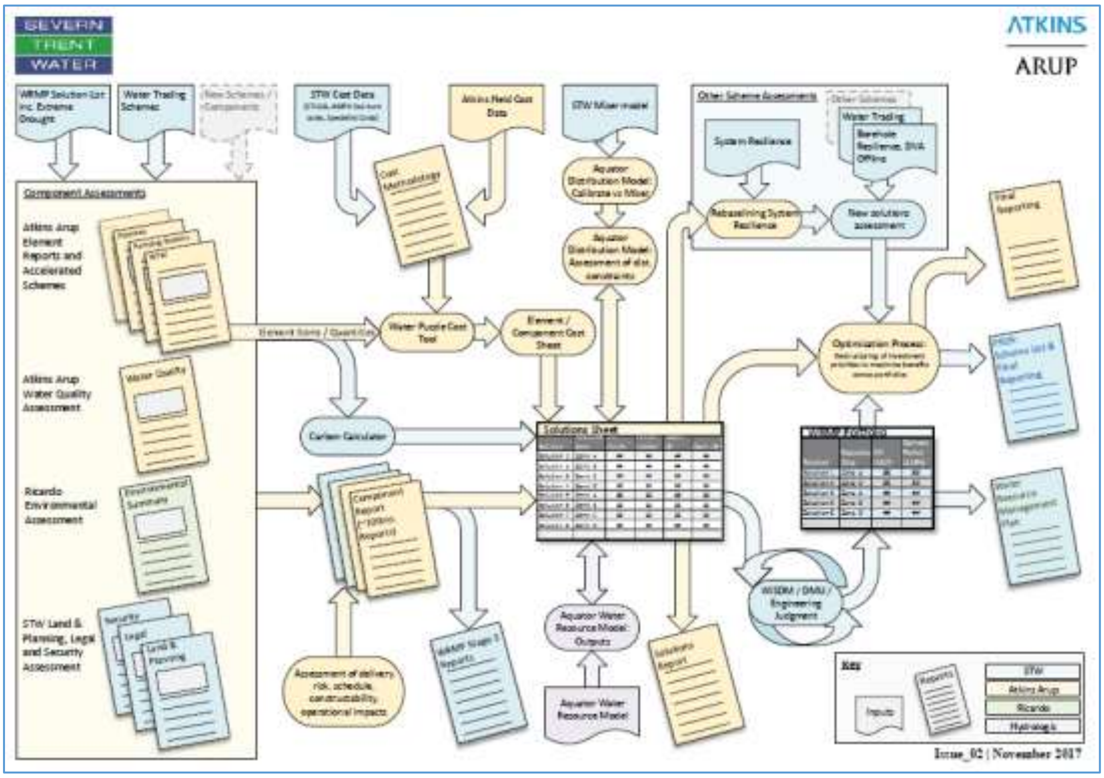
Table A8.1 Option screening considerations – Water Quality Factors

Item	Screening Considerations
Raw water provision and treatment	- Can we abstract any additional raw water required without environmental damage and, if required, what are the mitigation measures?
	- What is the quality of the raw water and is additional treatment required? - Do we need new / upsized or additional (under new DWI regs) treatment works? - If new treatment is required, is there physical space on existing sites for treatment or do we need to purchase land and establish a new site?
	- Can a range of deployable output values be specified for different circumstances?
Distributing water to our customers	- If the option involves increasing capacity of an existing site, do we need to upsize our assets?
	- Does the distribution network have the capacity for the extra water? - Do we need to improve/upgrade our existing assets or do we need new ones (for example additional pipelines or pumping stations)?
	- Does the distribution system rely on a current water quality blend and how would the new supply impact on that? What could we do to mitigate blending / quality impacts?
	- Do we know if there are any other interventions that are being delivered in AMP6 or being proposed for AMP7 implementation that may impact on the option? This is to avoid abortive spend or duplication of work/cost.

Item	Screening Considerations
For option specific considerations, we explored the following questions.	New groundwater source - Where will this be located and what is the Catchment Abstraction Management Strategy (CAMS) status of the source? - What are the Water Framework Directive implications – both for groundwater and surface water bodies? - Will the new source be near any Water Dependant Terrestrial sites or Sites of Special Scientific Interest (SSSIs) or Special Areas of Conservation (SACs)? - Do we own the land already? - At what depth should the borehole be drilled? What aquifer is it sourcing from? How many boreholes are required? - What is the theoretical yield of the site? - What is the predicted water quality of the new water source? Do we need treatment at the site? - How will the new source be connected to our network? Existing groundwater source - What is the condition of the existing asset? Is it near or reaching the end of its asset life within the 25 year planning period? - Will we need to incorporate the costs for borehole rehabilitation and/or re-drill to ensure operation across the entire planning period? Has the expected rehabilitation technique been attempted before? - Are there any known issues with water quality? Can raw water from the source be treated using the existing assets or with conventional treatment methods?

These different screening elements have formed an important element of our overall WRMP supply-side options appraisal process. The overall process is summarised in Figure A8.15 and described in more detail in Appendix E.

Figure A8.15: The WRMP options development and appraisal process



A9 Critical period

In addition to reporting the supply demand balance under a dry year annual average scenario, the water resources planning guideline also requires that we assess the need for a dry year critical period scenario in our plan for each WRZ. This is to ensure that we understand when peak demands could put strain on our system. Therefore, we have completed an updated assessment (since our 2019 plan) and reviewed whether a critical period scenario could affect each WRZ by looking at both the peak demand and supply components.

Critical period demand

Critical period factors (peak week and peak month) have been estimated for each WRZ using demand management area (DMA) daily consumption data for 2018/19 (April 2018 to March 2019). These daily data were mapped to our WRZs for household and non-household consumption and then peak week rolling and peak month rolling profiles were derived for each dataset.

Consumption data for each profile (household and non-household separately) were normalised using Met Office normalisation factors. We next calculated ratios of rolling peak week to average normalised weekly consumption, and rolling peak month factors to average normalised monthly demand for each WRZ. The output was a set of peak week and peak month factors for household consumption and non-household consumption, as shown in Table A9.1.

Table A9.1: Critical period demand factors per water resource zone

WRZ	Critical Period	Household peak factor (2018)	Non-household peak factor (2018)
Bishops Castle	Peak week	1.21	1.19
Chester	Peak month	1.17	1.33
Forest and Stroud	Peak month	1.29	1.09
Kinsall	Peak week	1.22	1.09
Mardy	Peak week	1.36	1.11
Newark	Peak week	1.28	1.09
North Staffs	DYAA	n/a	n/a
Nottinghamshire	DYAA	n/a	n/a
Rutland	Peak week	1.33	1.08
Ruyton	Peak week	1.48	1.08
Shelton	Peak month	1.19	1.09
Stafford	Peak month	1.22	1.10
Strategic Grid	DYAA	n/a	n/a
Whitchurch and Wem	Peak week	1.29	1.13
Wolverhampton	Peak month	1.19	1.12

The selection of either a peak week or peak month factor was determined using the same methodology used through AMP6 for the Security of Supply Index (SOSI) analysis and is described below.

Critical period supply

Two methods have been completed:

- For zones with the potential for peak week critical period, the assessment has been based on the individual groundwater peak DO assessments for each groundwater source as described in section

A2.1. The effects of climate change on these peak DO values (as described in section A3) were applied.

- For zones with the potential for peak month critical period, the available peak month DO has been assessed using outputs from the Aquator water resources model. The annual average DO for each zone was increased by the maximum monthly demand used in each year of the model run. This was calculated by combining the demand/demand factors for all demand centres in a water resource zone and finding the peak supply that was therefore required in the zone for that month from all sources combined. This gives the maximum monthly supply available based on the modelled outputs. Figure A9.2 shows critical period assessment framework.

For the Forest and Stroud WRZ, which is constrained by a combination of the river source and spring sources in the zone, we have also looked at how often the river source is likely to be constrained at its lowest abstraction level. As discussed in section A2, based on outputs from stochastic modelling our plan aims to achieve the 1 in 500 EDO (1 in 200 till 2039) resilience level in this zone, while our existing 3 in 100 temporary use/ non-essential use bans level of service are met. Figure A9.1 shows a schematic of a conjunctive river and groundwater abstraction zone.

Figure A9.1: A conjunctive river and groundwater abstraction zone

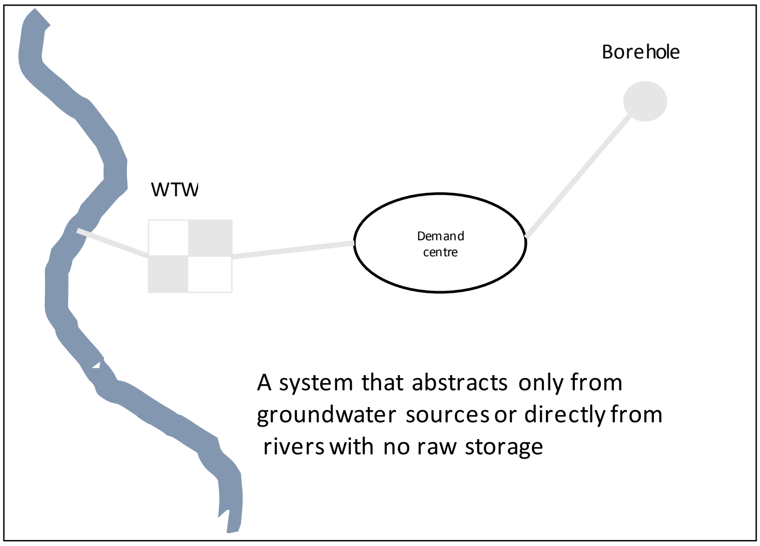
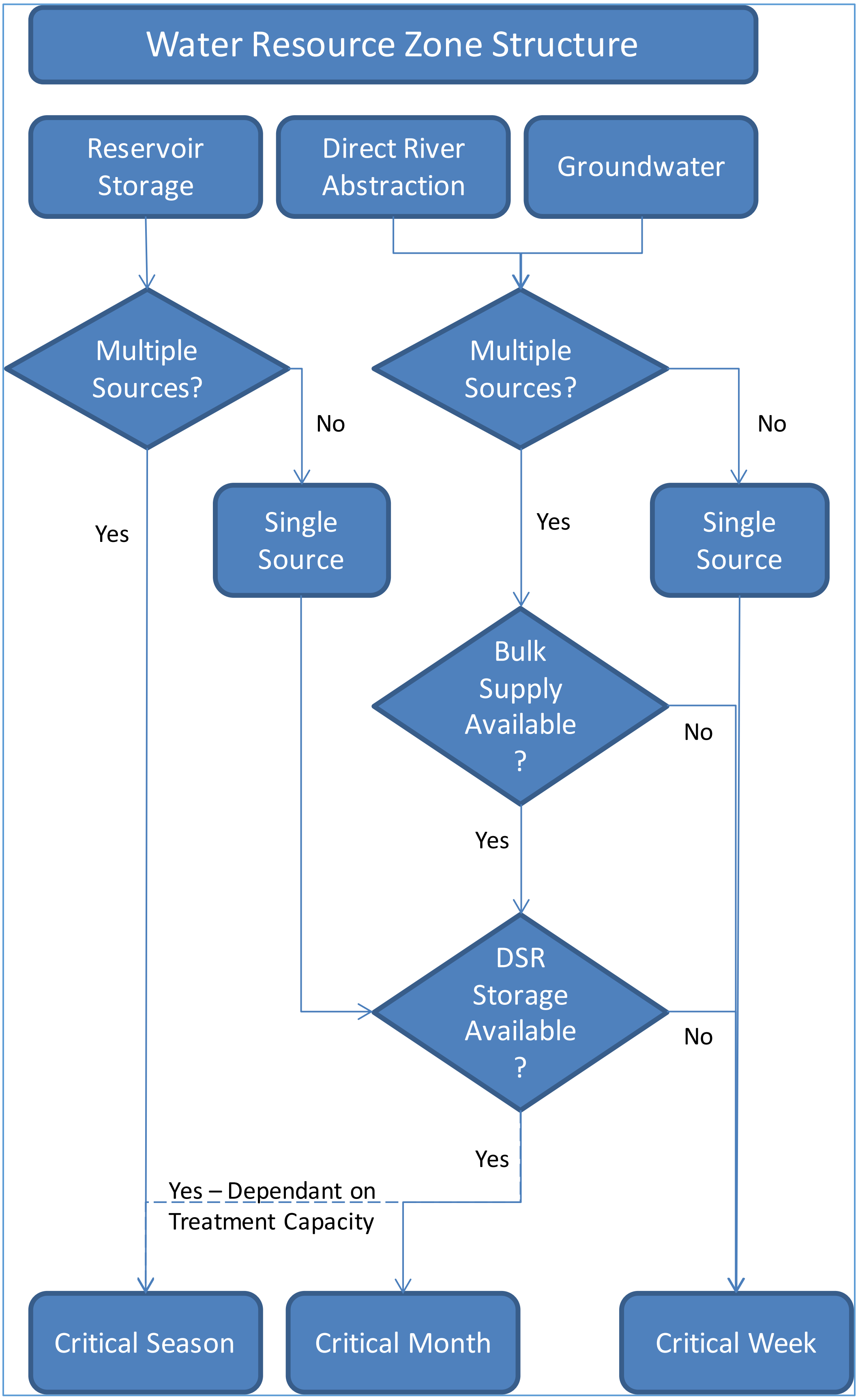


Figure A9.2: Critical period assessment framework



Critical Period supply demand assessment

The conclusions are that:

- A critical period, peak week scenario is relevant for our water resource zones that are entirely supplied from groundwater sources because these zones are not affected by reservoir storage levels or fluctuations in available river flows. The peak deployable output limiting factors are abstraction licence or the physical treatment, pumping or distribution capacity.
- A critical period, peak month scenario is relevant for zones which are supplied conjunctively from groundwater and river sources. The peak deployable output limiting factors are abstraction licence or physical treatment, pumping or distribution capacity combined with available river flows.
- A critical period scenario is not relevant to our zones supplied from raw water storage reservoirs.
- We are not predicting any critical period deficits and therefore we have not produced a separate set of WRMP critical period data tables.