Appendix A - How much water do we have available?

A1 Our Water Resource Zones - Redacted

A2 Calculating Deployable Output - Redacted

A3 Impacts of Climate Change on Supply

A3.1 Overview of current approach

The EA's 2017 Water Resources Planning Guidelines (WRPG) require companies to assess the risk and possible impact of climate change on the deployable output of their current and future sources of water. Companies can use their 2014 Water Resources Management Plan (WRMP14) assessment of climate change, or a method outlined in:

- Environment Agency (2013) Climate change approaches in water resources planning – Overview of new methods
- Environment Agency (2017) Estimating impacts of climate change on water supply

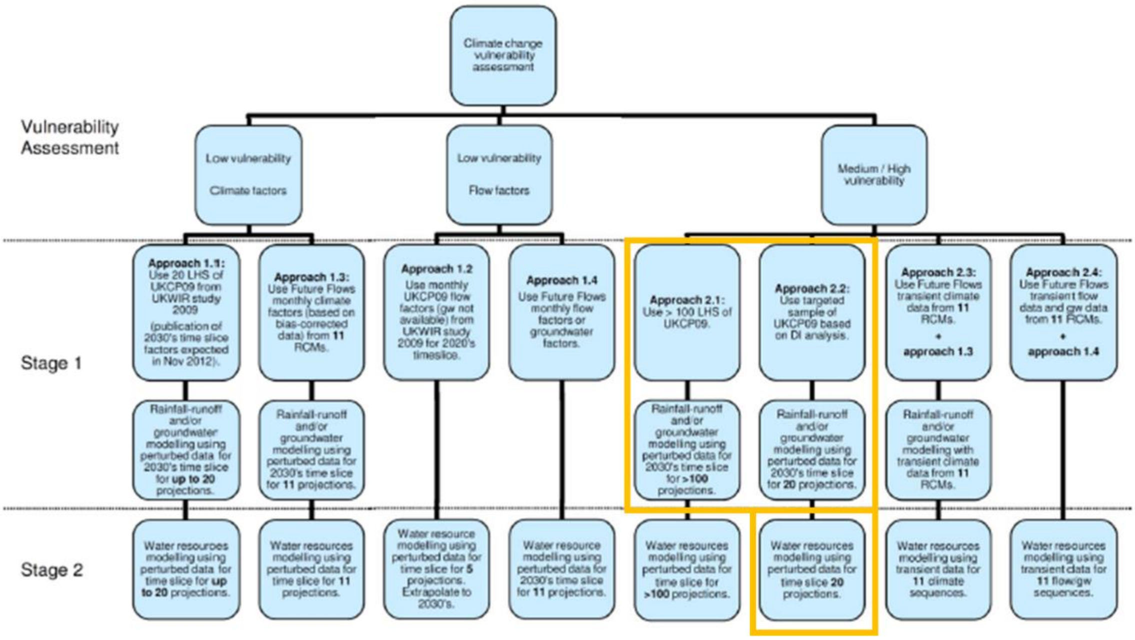
We carried out a vulnerability assessment to identify which of our water resource zones (WRZ) are most sensitive to the potential impacts of climate change. This confirmed our findings from our WRMP14 assessment, which demonstrated that our largest WRZs, the Strategic Grid and Nottinghamshire, were both 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 a "high" vulnerability method to all zones to assess the potential impacts on deployable output. This approach uses the UKCP09 projections (medium emission scenario) directly.

Figure A3.1 shows the range of methodologies recommended in the Environment Agency's WRPG, which was published in 2012. The approach we applied is highlighted by the orange box:

- Approach 2.1 was used to derive 100 Latin Hypercube Samples from the full UKCP09 scenarios
- Approach 2.2 was then used to derive a sub-sample of 20 scenarios using a Drought Indicator derived specifically for the sources in our region.

A full explanation of our reasons for choosing this method can be found in Appendix A3.2 of our WRMP14.

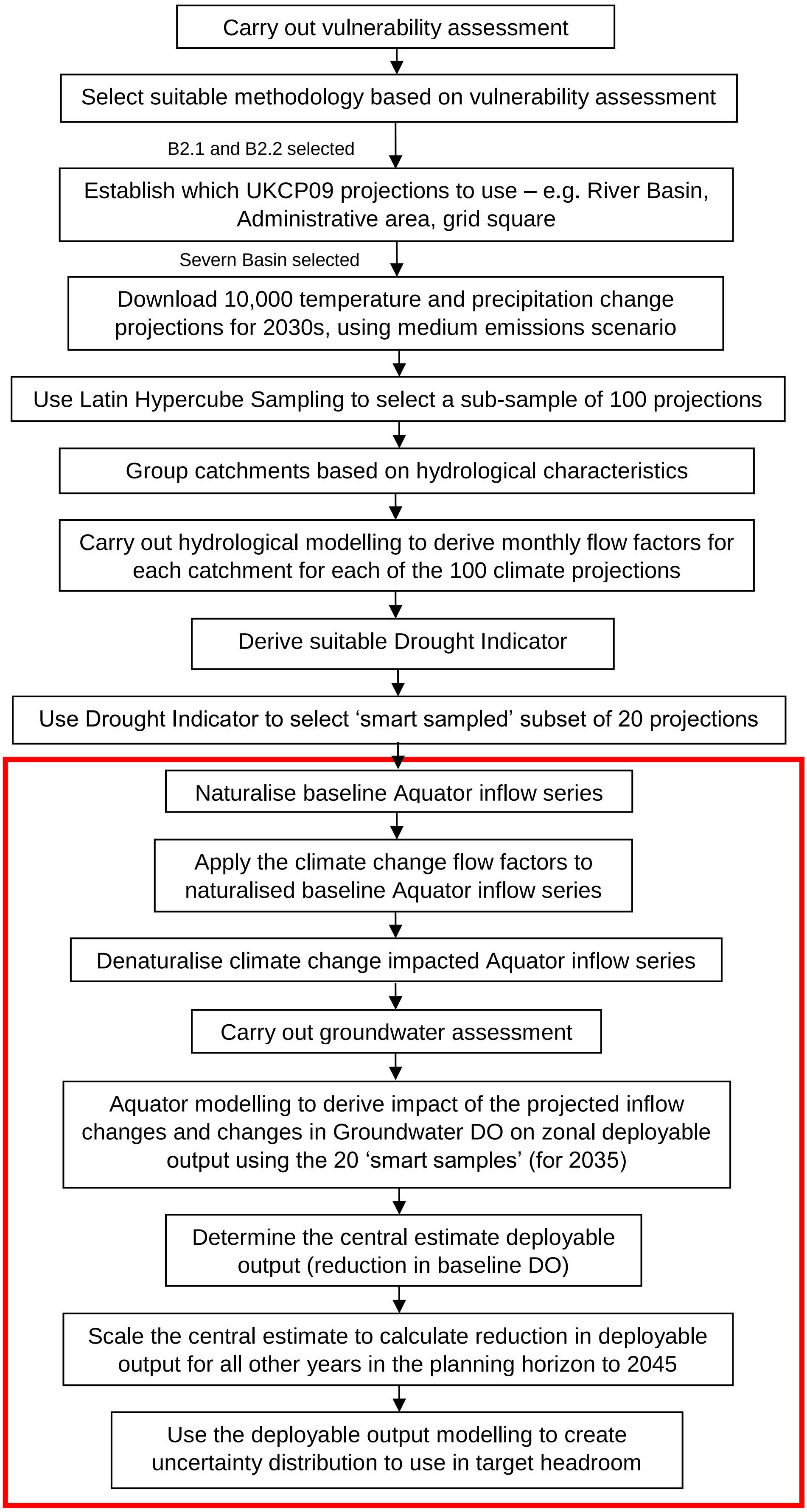
Figure A3.1: Summary of climate change impacts assessment methods



For consistency with our previous plan we have used the same methodology to form our current assessment, using the UKCP09 2030s time slice (2020-2049) to inform our baseline plan. We have also carried out an assessment using the 2080s time slice (2070–2099), which we are using to test the robustness of our long term plan.

Figure A3.2 shows an overview of the full methodology we followed for WRMP14. The red box indicates the steps taken for our current assessment. 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. Our assessment of the impacts of the 2080s climate change scenarios can be found in section A3.7.

Figure A3.2: Overview of methodology followed



A3.2 Vulnerability Assessment: Surface water

Vulnerability Assessment: Surface water

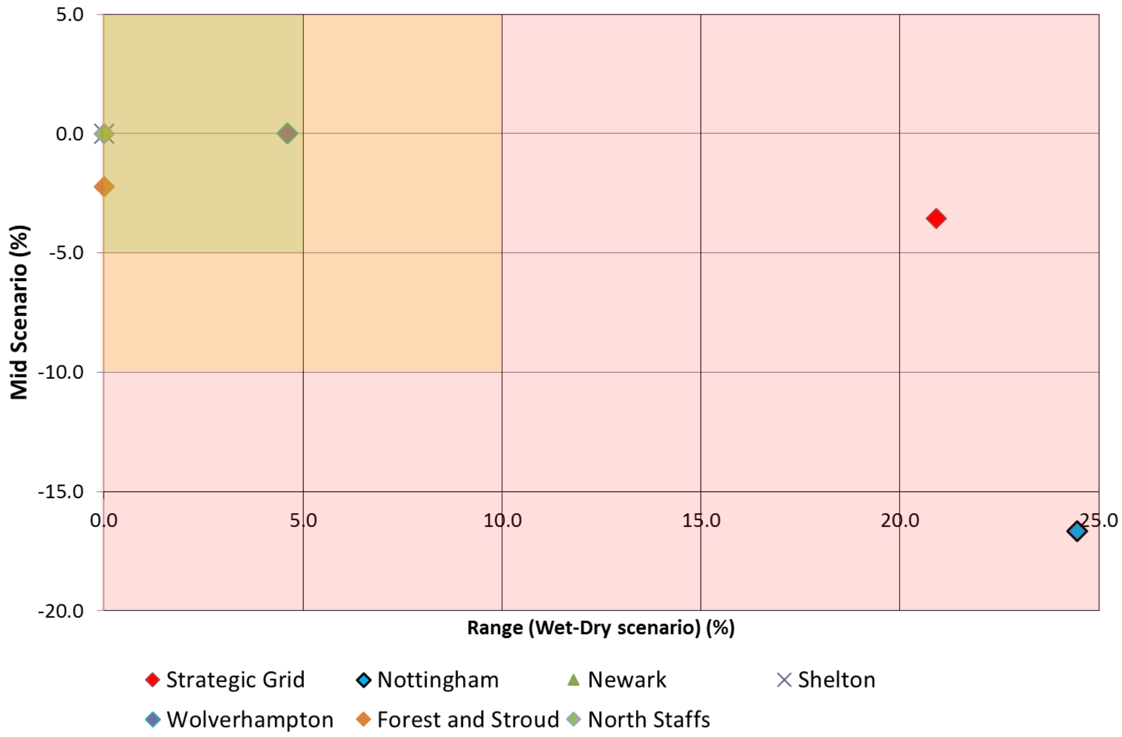
In order to decide which method to adopt, we carried out a vulnerability assessment for each of our water resource zones. By doing this, we were able to identify which zones are likely to be most sensitive to the effects of climate change and to determine whether our previous approach and assumptions are still applicable. Using our 2014 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 WRMP14
- Our climate change adaptation report “Future Proofing”, which was published in 2015.

To quantify the vulnerability of our WRZs to the potential impacts of climate change we used our WRMP14 climate change deployable output assessment. This modelling used our chosen method, B2.2 (shown in Figure A3.1) 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 WRMP14 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 WRMP14 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) 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 our conjunctive use 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

Uncertainty range (% change wet to dry)	Mid scenario (% change in deployable output)		
	<-5%	>-5%	>-10%
<5%	Low	Medium	High
6 to 10%	Medium	Medium	High
11 to 15%	High	High	High
>15%	High	High	High

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.

Vulnerability assessment: Groundwater

Our groundwater vulnerability analysis considered three methods of selecting which groundwater sources to include in the assessment of impacts on groundwater deployable output (DO) due to climate change:

- Option 1: Only consider the sources identified as flow or level constrained (i.e. where the DO defined for the source is limited by the flows or level at the abstraction point). These sources comprise approximately 15% of our groundwater sources. Under this assessment, only the sources that were initially screened as vulnerable to level or flow changes would be assessed for climate change;

- Option 2: Consider the sources identified as flow or level constrained and those in the areas of the West Midlands, Bromsgrove and East Midlands and Yorkshire Sandstone groundwater model, that comprise a number of licence constrained sources. Under this assessment the sources that were initially screened as vulnerable to level or flow changes would be assessed. Also, under this assessment the regional groundwater models would be utilised to predict recharge changes to the groundwater units under the various climate change scenarios. This assessment would proportionally reduce the deployable output of any licence constrained sources in the modelled units by the predicted recharge changes to the unit;

- Option 3: All groundwater sources, including infrastructure and licence constrained sources. Under this assessment the sources that were initially screened as vulnerable to level or flow changes would be assessed. The sources that were licence constrained and fell within the regional groundwater models would be assessed (as Option 2) and sources that were licence constrained and fell outside of the groundwater models would be assessed by applying a company-wide change to recharge and proportionally reducing the deployable output by the predicted recharge (and licence) derived changes to the unit;

We were able to use outputs of the historical WRMP09 and recent WRMP14 assessments and modelling work to undertake the initial groundwater vulnerability assessment. Both the WRMP09 and WRMP14 work showed limited impact on flow or level constrained sources. For our assessment, we therefore selected groundwater sources based on Option 1.

Vulnerability assessment: Water Resource Zone Vulnerability Classification

The vulnerability assessment for our conjunctive use and groundwater only zones followed the methodology described in the EA’s WRPG (2012). For each zone we have produced a table containing the information required, as per Table 3.0 of the WRPG. Table A3.2 shows the vulnerability classification for each water resource zone.

Table A3.2: Water Resource Zone vulnerability classification

Water Resource Zone	Vulnerability
Bishops Castle	Low
Forest & Stroud	Low/Medium
Kinsall	Low
Llandinam & Llanwrin	Low
Mardy	Low
Newark	Low
North Staffordshire	Low

Water Resource Zone	Vulnerability
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

As discussed in section A2, we have continued to review and update our Aquator model since the publication of our WRMP14. To take into account changes to our water supply system (for example known changes in water treatment works capacities) and our improved inflow series we have opted to re-model the sub-set of 20 climate projections for the 2030s time slice rather than use the climate change assessment directly from our previous plan. We have carried out additional analysis using UKCP09 projections for the 2080s (2070-2099) time slice, taking into consideration the methods outlined in “Environment Agency (2017) Estimating impacts of climate change on water supply”.

Consistent with our WRMP14 we have adopted a “high” vulnerability approach for all 15 WRZs, including those classified as “low” or “medium” 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 (with the exception of Tittesworth reservoir which is located in the North Staffordshire WRZ). 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. Although the Nottinghamshire zone is supplied by a number of groundwater sources, it also relies on 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. 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.

Taking all this into consideration, we have used the UKCP09 projections method. The method adopted is summarised below. Steps 1 to 4 were carried out for our WRMP14 so did not need to be repeated as the assumptions and processes remain unchanged.

Step 1: Selecting the climate change projections – Severn Basin

The UKCP09 projections are available at different resolutions – at River Basin level, Administration District level and individual 25km grid square level. An analysis of the different projection sets available for our region showed that the UKCP09 climate projections from different aggregate areas across our region all provide similar climate change impacts.

The River Severn is an important source of supply for the Strategic Grid, Shelton and Wolverhampton water resource zones. The Severn River Basin area covers the headwaters and a large stretch of the River Severn and is also close in proximity to the headwaters of the River Trent. It was therefore deemed to be a valid approach to apply the Severn River Basin projection set across the whole of our region, ensuring consistency in the modelling approach. The UKCP09 Severn River Basin Medium Emissions projections for the 2030s were used for our assessment, with a sub-set of 100 projections being selected using Latin Hypercube Sampling (LHS) for use in the hydrological modelling.

Step 2: Grouping of catchments

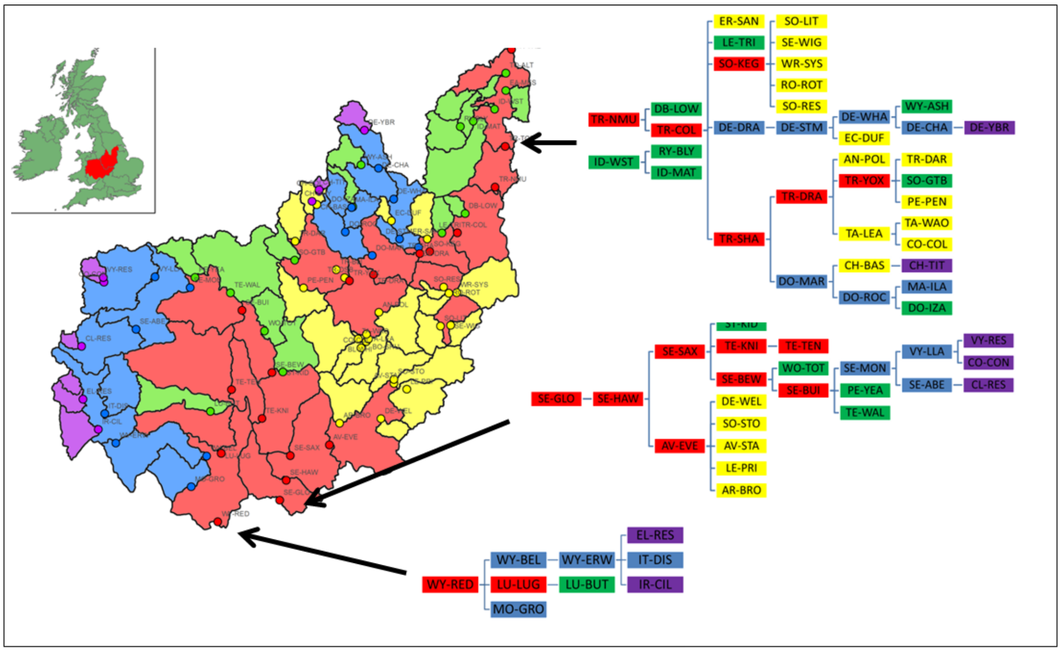
In our Aquator water resource model we use 95 years of daily inflow data for 78 catchment points across the Severn, Trent and Wye catchments. This inflow data series is derived using 81 hydrological models (HYSIM), with the outputs of these HYSIM models being grouped together and adjusted for artificial influences, such as spray irrigation and sewage effluent discharges, to allow them to be used in our Aquator model. An analysis of several different catchment attributes, including topography, Base Flow Index and SAAR (Standard Annual Average Rainfall) allowed us to classify all the HYSIM modelled catchments into five groups with similar hydrological characteristics and responses to climate. The catchment descriptions are shown in Table A3.3.

Table A3.3: 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 A3.4 shows the distribution of the HYSIM hydrological models in the Severn Trent Region. The catchment types are indicated by the colouring as shown in Table A3.3.

Figure A3.4: Distribution of HYSIM hydrological models in the Severn, Trent and Wye basins



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

- Calibration method for the baseline flow series – for the exemplar HYSIM catchment models it was preferable to use models which had been calibrated against naturalised flow data

- Number of nested upstream models – for the exemplar HYSIM catchment models this was zero as models nested downstream of another HYSIM 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 HYSIM 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 five exemplar catchments are:
  - Ithon at Disserth
  - Wye at Ashford
  - Wreak at Syston Mill
  - Teme at Tenbury
  - Elan Reservoirs

__Step 3: Hydrological modelling__

The five catchments were modelled in HYSIM using the 100 UKCP09 projections which had been selected from the 10,000 UKCP09 sample set in stage 1 of our approach. This HYSIM modelling generated 100 sets of climate change perturbed flow series for each of the five catchments. These flow series were then used to derive monthly flow factors for each catchment for each climate scenario. This enabled us to estimate the impacts of climate change on natural flows.

Step 4: Deriving a suitable Drought Indicator

In order to reduce the number of projections in the assessment from the 100 which were sampled using Latin Hypercube Sampling, a drought indicator was used to produce a targeted sample of 20 climate projections. The drought indicator analysis identified the climatic drivers for historic droughts in our region. We considered a number of different potential drought indicators, such as aridity indices specific to key strategic reservoirs and changes in flow. We used mean April to September flow change as our “Drought Indicator” as this was based on robust hydrological modelling and used information on the climate sensitive period gathered from the aridity index analysis.

The flow factors from step 3 were reviewed and the Drought Indicator was used to identify a split sample of 20 scenarios for use in our water resources impact modelling. The split sample provided 20 scenarios covering the full range of expected climate change impacts, but with 10 of these scenarios focussing on the drier end of the range.

Step 5: Flow naturalisation of baseline Aquator inflow series and application of climate change flow factors

As previously discussed, our Aquator inflow series is derived using the outputs of 81 HYSIM catchment models, which are grouped together to form the 78 catchments used in our Aquator model and adjusted for any in-catchment artificial influences, such as agricultural abstractions. In creating the climate change impacted inflow series, the artificial influences were removed from each catchment before the climate change factors generated in step 3 were applied to the HYSIM flows for the 20 scenarios selected in step 4. This ensured that only the natural flows were being impacted by climate change.

The catchment groupings were used to decide which factors were used for which catchment. This created 20 climate change impacted naturalised flow series for us to use in our Aquator modelling.

Step 6: Denaturalisation of climate change impacted Aquator inflow series

Once the relevant flow factors had been applied to the naturalised inflow series, the artificial influences were put back in to the flow series and the HYSIM flows were combined into the Aquator catchments so that they could then be used in our Aquator model.

Step 7: Groundwater assessment

A groundwater assessment was completed using the 20 scenarios identified in step 4; 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 20 climate change scenarios in our Aquator model, using the UKCP09 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 UKCP09 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. The same period of record was used in both our baseline and climate change assessments (1920 to 2014).

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

Under all 20 of our sub-sampled climate change projections, 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. The annual average change in flows for our five catchment groupings is shown in Table A3.4. Monthly variations within these annual averages range from an increase in flows in some catchments of 28% (compared to the current baseline flows), to a decrease in flows of 31%.

Table A3.4: Annual average change in flows as a percentage change from current baseline flows

Rank	UKCP09 ID	Annual Change in flows (%)				
		Catchment Group 1	Catchment Group 2	Catchment Group 3	Catchment Group 4	Catchment Group 5
1	8632	-13%	-19%	-31%	-21%	-13%
2	9855	-9%	-14%	-24%	-13%	-10%
3	3111	-11%	-16%	-28%	-16%	-12%
4	6108	-3%	-8%	-17%	-7%	-3%
5	1090	-9%	-14%	-26%	-15%	-10%
6	2203	-8%	-12%	-20%	-12%	-8%
7	1345	-14%	-20%	-31%	-24%	-13%
8	8282	0%	-5%	-14%	-3%	-2%
9	6461	0%	-4%	-10%	-1%	-1%
10	684	-12%	-17%	-27%	-20%	-11%
15	2726	-5%	-10%	-19%	-11%	-5%
20	9701	-4%	-8%	-15%	-6%	-5%
30	3521	6%	1%	-6%	5%	5%
40	281	-5%	-9%	-19%	-9%	-5%
50	3903	-5%	-9%	-17%	-12%	-4%
60	2745	6%	3%	-3%	5%	5%
70	3306	-10%	-12%	-19%	-17%	-7%
80	9623	4%	2%	-1%	3%	4%
90	1467	21%	21%	23%	28%	19%
95	8764	4%	4%	3%	3%	4%

Across all of the catchment groupings there is a general seasonal cycle of summer decreases and small winter increases which reflects the overall pattern of rainfall changes from UKCP09. However, there are a number of different responses to the changing climate between the five catchment groupings which are important to note:

- Catchment groupings 1 and 5 represent higher rainfall regions, catchment 1 being large intermediary catchments with higher rainfall and catchment 5 being small, typically upland catchments with high rainfall and a flashy catchment response. Both of these groups show a similar response to climate change, with very large reductions in flows during the summer months and larger increases in flows in the winter.

- Catchment grouping 3 represents small catchments in lower rainfall areas. The flow factors show more prolonged decreases across the summer months and fewer increases in flows during the winter months.

- Catchment grouping 2 which represents catchments with a higher Base Flow Index, have a much smaller range of flow changes compared with the other groupings. The largest flow reductions occur in September and October, which is later in the year compared to the other groupings.

- Group 4 represents the largest downstream catchments. The flow factors for this grouping have more prolonged summer decreases but are smaller in magnitude than those seen in group 3. The maximum flow decreases occur later in the year, in September and October, reflecting the delayed response due to the larger catchment area.

A3.5 Impact of Climate Change on our groundwater sources

Approximately 34% of our DO is abstracted from groundwater sources. Of our operational groundwater sources, the majority (~88%) abstract from Sherwood Sandstone or sandstone aquifers in the Midlands region, with a small percentage of sources taking water from limestone and river gravels.

The sandstone aquifers have substantive storage; meaning they are generally not sensitive to short term changes in climate. Unlike most chalk or limestone aquifers, the Midlands sandstones generally show only small annual responses in water level due to extreme wet or dry conditions and are generally considered to be resilient to drought conditions. In severe drought it takes several years for water levels to fall in the sandstone aquifers. During the 2008 to early 2012 period, recharge to the Midlands aquifers was significantly depleted by low average rainfall over this period, and some of the lowest ever groundwater levels were recorded across the region. Despite this, at our sources, groundwater level decline during this period was only of the order of <5m. In summary, this means that the impact of climate change is likely to be limited on our sandstone resources in comparison to other aquifer units across the UK.

Possible climatic impacts 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.

The process for calculating the change in Deployable Output (DO) for groundwater sources due to climate change has been calculated by taking the UKCP09 projections and assessing the impacts according the GR2 methodology as originally described in the UKWIR2006 guidance. This involved:

1. assessing the sensitivity of pumped sources to water level changes resulting from any changes in recharge;

2. for all zones, use of representative synthesized hydrographs (calibrated to observed data) at sources to determine the change in recharge to the aquifer under the various UCKP09 projections, and using the GR2 methodology to determine the modelled range of water level change for each site;

3. converting the modelled water level change into a range of DO changes using the Source Performance Diagrams;

4. the assessment of likely changes in summer flows at our spring sources as a result of changes in recharge in these catchments.

For WRMP14 we had planned to use the EA's regional groundwater models to assess groundwater response to climate change driven changes to recharge in our region, under Options 2 and 3 of the vulnerability assessment. This analysis could potentially determine the likely scale of any future licence reductions needed to mitigate effects of climate change on the environment and to prevent mining of groundwater where sources were currently licence constrained.

In WRMP14, we explored this potential approach with the EA, but it was determined that it would not be appropriate for us to make assumptions about climate change driven abstraction licence changes. We did not pursue assessment under Option 2 and 3 of the vulnerability assessment, and we have followed the same approach for dWRMP18. As such, the risks around climate change driven potential licence changes is not included in dWRMP18. The impacts of climate change on our groundwater sources are therefore limited to those sources vulnerable to short term changes in water levels or flow.

Initial Screening

For our groundwater sources, an initial review of individual groundwater source sensitivity to groundwater level change was conducted as a preliminary screening exercise to the overall vulnerability assessment. This screening assessment utilised the source specific Source Performance Diagrams, as illustrated in Figure A3.5, to determine what the current constraint to abstraction was at the source. This can be broken down into five main constituents:

1. Licence constrained – the source can abstract up to licence
2. Infrastructure constrained – the source is constrained by infrastructure (usually pump capacity, which is set slightly below the licence in order to prevent breach of licence)
3. Level constrained – the source is constrained by a specific level in the borehole below which groundwater levels should not be taken in order to preserve pumping equipment (pump depth), water quality (adits or Deepest Advisable Pumped Water Level (DAPWL)), aquifer resource (DAPWL), borehole integrity (borehole casing, DAPWL, adits) etc. These are site specific and may vary source to source
4. Flow constrained – the source is constrained by gravity fed flows into the site. This is applicable to spring sources
5. Water Quality constrained – the source may not be able to abstract above a certain rate in order to preserve water quality

This review highlighted the following number of sources falling into each constraint category as shown in Table A3.5.

Table A3.5: Number of groundwater sources in each constraint category by WRZ

Water Resource Zone	Licence	Infrastructure	Level	Flow	WQ
Bishops Castle	1	1	0	0	0
Forest & Stroud	3	0	0	3	0
Kinsall	2[1]	0	0	0	0
Llandinam & Llanwrin	1	1	0	0	0
Mardy	1	0	0	0	0
North Staffordshire	15[2]	10	2	0	3
Stafford	0	5	0	0	0
Newark	2[3]	0	0	0	0
Nottinghamshire	14[4]	6	0	0	2
Ruyton	1	0	0	0	0
Shelton	12[5]	7	0	0	0
Strategic Grid	12[6]	19	0	3	2
Whitchurch & Wem	2	0	0	0	1
Wolverhampton	1	1	1	0	1

[1] Two constrained by overarching Group Licence (within Group Licence constrained, at source specific level: one licence and one infrastructure constraint)
[2] Seven constrained by overarching Group Licence (within Group Licence constrained, at source specific level: three licence, three infrastructure and one WQ constraints)
[3] Two constrained by overarching Group Licence (within Group Licence constrained, at source specific level: one licence and one infrastructure constraint)
[4] Eleven constrained by overarching Group Licence (within Group Licence constrained, at source specific level: four licence, six infrastructure and one WQ constraints)
[5] Five constrained by overarching Group Licence (within Group Licence constrained, at source specific level: two licence, two infrastructure, one WQ constraint)
[6] Five constrained by overarching Group Licence (within Group Licence constrained, at source specific level: four infrastructure and one water quality constraints)

The initial screening assessment utilised the SPDs to determine the operational profile of the source in drought conditions and consider how far this drought curve sat above a source specific groundwater level constraint (i.e. borehole pump depth, DAPWL etc.).

In the example presented in Figure A3.5, the source is constrained by pump capacity at ~15.7Ml/d in both average years (red curve) and drought years (black curve), and when operating at this constraint in drought conditions, there is approximately 12m of groundwater level "headroom" before water levels would start to be constrained by a level constraint (in this instance DAPWL), rather than the pump capacity.

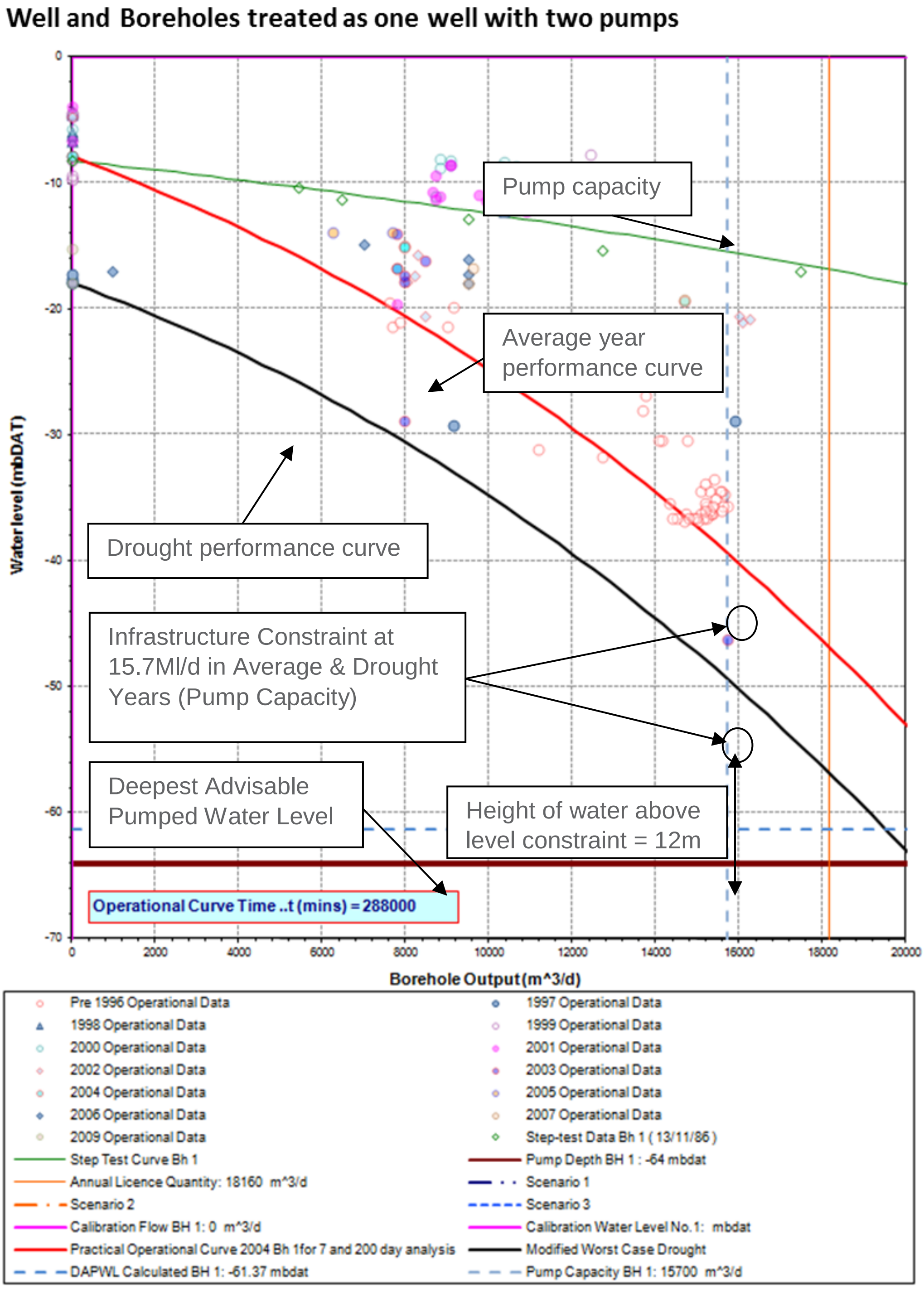
From the initial screening assessment, it was considered that sources that are currently level constrained in drought conditions and sources that are constrained by gravity fed flows (spring sources) should be taken forward for climate change assessment. Fourteen sources were initially highlighted and these sources were considered to be vulnerable to climate change (some of these sources were later found to be constrained by Water Quality (WQ) constraints, so are not shown under the Flow column in Table A3.5).

Furthermore, it was considered that sources that had less than 5m of groundwater level "headroom" between the intersect of the drought performance curve and an infrastructure constraint, and a level constraint, should be taken forward for climate change assessment as these were considered to be potentially vulnerable to climate change. Eight sources were initially highlighted.

Sources that had greater than 5m of groundwater level "headroom", or were currently licence or water quality constrained were considered to be at low vulnerability to climate change and were not assessed.

In addition to the initial screening, a series of interviews were conducted with our Operational staff which indicated an additional twelve sources which may be potentially sensitive to dry weather conditions. These sources were considered as potentially vulnerable to climate change and were taken forward for climate change assessment; even though assessment of the SPDs suggested that they were likely to have low vulnerability to climate change. The inclusion of these additional assessments is considered to be conservative.

Figure A3.5: Source Performance Diagram and example initial source vulnerability screening. Note there is 12m of water level "headroom" in drought conditions, before the constraint on the source would change from an infrastructure constraint (pump capacity) to a level constraint (DAPWL). In this instance the initial screening is low vulnerability to climate change.



Head Dependent Changes in DO (Pumped Sources)

The majority of our groundwater abstractions are from deep boreholes in the Sherwood Sandstone. As there is significant storage in this aquifer, water level changes due to recharge variation are usually buffered and can take several years or decades to have any significant effect. In addition, due to the depth of many of our boreholes, there would usually be space to lower the pumps in the borehole and maintain the same output if regional water levels dropped significantly.

However, for certain sources, a change in recharge could produce a significant borehole water level change within the planning horizon (i.e. the next 25 years), where:

1. the aquifer has low storage (e.g. fissured limestone) and responds rapidly to recharge;

2. the pumping water level is already close to the base of the borehole;

3. there is some inflow feature particular to that source that would cause a rapid loss of yield if water levels dropped beyond a certain level (e.g. an adit or a fissure zone); or

4. the source is an aquifer of very limited vertical or horizontal extent with limited capacity to buffer recharge variation

The screening exercise identified approximately 23 sources that might fall into one or more of the above categories. These were then considered in detail using the UKWIR06 methodology to predict the likely change in water level and thus DO for each of the UKCP09 scenarios. Of the 23 sources, only eight were determined to have climate change impacts after detailed assessment. These are shown in Table A3.6 below.

Table A3.6: Head dependant groundwater source impact

WRZ	Source	Range of Changes in DO (Ml/d) using 20 smart sampled UKCP09 scenarios	
		Min	Max
Bishops Castle	Oakley Farm	-0.18	0.27
North Staffordshire	Draycott Cross	-0.89	0.74
	Blacklake	-0.46	0.49
Nottinghamshire	Clipstone Forest	-1.26	-0.06
Stafford	Shugborough	-0.11	0.08
Strategic Grid	Meriden Shafts	-0.26	-0.10
	Campion Well[1]	-0.48	0.51
	Ladyflatte[1]	-0.63	0.61

[1] For the Campion well and Ladyflatte sources, the estimates were made on the basis of changes in annual recharge. This is because of the nature of the sources it is not appropriate to apply a conventional GR2 assessment.

The results indicate that Bishops Castle was the only groundwater only zone predicted to have head (level) dependant deployable output impacts resulting from the modelled climate change scenarios. The result from this, and the predicted impacts on groundwater sources in conjunctive use zones, as presented additionally above, were then input into our Aquator model.

Head-Dependent Changes in DO (Gravity-Fed Sources)

We have nine abstraction sources fed by springs or drainage tunnels. As these are gravity-fed and in fracture-flow aquifers, they are likely be more sensitive to groundwater level changes than our other sources. The effects on the Site D source have been considered as part of the surface water climate change assessment.

Changes to flows in these sources were predicted using the UKWIR06 methodology. This applies the selected climate change projections to actual or synthesized flows from the sources, and the outputs are reported for the average yearly minima and the drought year minima (based on lowest observed year recharge data). Any special conditions at those sites that constrain reported DO (e.g. minimum observed flow, licence condition or infrastructure constraint), are noted. Of the ten gravity fed spring sources, six were determined to have climate change impacts after detailed assessment. These are shown in Table A3.7, below.

Table A3.7: Head dependant gravity-fed spring source impact

WRZ	Source	Range of Changes in DO (Ml/d) using 20 smart sampled UKCP09 scenarios	
		Min	Max
Forest & Stroud	Bigwell	-0.26	0.16
	Chalford	-1.87	1.09
	Lydbrook	-0.19	0.36
Strategic Grid	Coombe	-0.18	0.10
	Millend	-0.23	0.14
	Site D[1]	Perturbed flow series provided for assessment within Aquator	

[1] Assessed as part of the surface water climate change assessment

Gravity fed springs sources at Postlip, Pinnock and Charlton Abbots springs were assessed as not impacted by climate change as they are disused.

The results indicate that none of our groundwater only zones are predicted to have head (gravity fed) dependant deployable output impacts resulting from the modelled climate change scenarios. The predicted impacts on spring sources in conjunctive use zones, as presented above, were then input into our Aquator model.

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

As previously discussed, 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 scenario provides us with estimates of deployable output for the year 2035. We applied the climate change perturbed flow series to our existing model, to establish what the potential impacts could be if the system and reservoir control curves remain unchanged.

By adopting method B2.2 we were able to reduce the 100 UKCP09 projections selected using Latin Hypercube Sampling for method B2.1, based on a drought indicator to a targeted sample of 20. This targeted sample included 10 projections towards the “dry” end of the projection range and 10 projections which were equally spaced across the remaining range.

Each of the targeted samples was given a “weighting” to estimate the probability of this projection occurring. The weight describes the relative probability of each projection in the sub-sample of 20 with respect to the original 100. Including 10 samples towards the “dry” end of the projection range means we could be including some “outliers” in our assessment, i.e. extreme changes in climate which have a low probability of occurring. By applying the weighting we were able to assign a low probability to these outcomes, but are still able to consider the full range of potential impacts in our overall assessment.

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. Nor is there any best practice guidance on how to appropriately deal with the wide range of uncertainties presented by the multiple scenarios. We have therefore tested the impacts of adopting different “central estimates” of future climate change impacted supplies, along with different approaches to capturing the range of uncertainty around this estimate.

One option is to derive a “weighted average” impact on deployable output from the full range of scenarios. This uses a statistical calculation taking into account the weightings assigned to each scenario and the change the scenario causes to deployable output. Alternatively we could choose to use the outputs of a particular high-weighted scenario, such as the rank 50 which is also the median of the 100 Latin Hypercube Sample.

There are mathematical reasons for adopting a weighted average approach, because it includes the full range of scenarios, including all drier scenarios and any potential “outliers”. However, by applying a weighted average approach we would be unable to relate the implications back to any one UKCP09 climate change scenario or modelled hydrological dataset. Therefore to maintain transparency in our impact assessments, we prefer to base our modelling on the outputs from the specific UKCP09 climate change scenarios, each of which have probability weightings attached to them.

Consistent with our WRMP14 our preference is to use the values from the median model output (rank 50) scenario from the Latin Hypercube Sample as our central estimate of climate change impacts in our baseline plan. 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 each of the 20 UKCP09 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 – which are all equally likely – 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 2035 are shown in Figure A3.6 to Figure A3.10. As our vulnerability assessment indicated, the greatest impacts of climate change are seen in the Strategic Grid and Nottinghamshire water resource zones. Our modelling showed there was no impact on the deployable output of the Wolverhampton and Newark WRZs under any of the 20 climate projections modelled. Wolverhampton is fed by a combination of a river abstraction and groundwater, whilst Newark is fed by groundwater and groundwater imports, both of which are highly resilient to the potential impacts of climate change.

Both the Strategic Grid and Nottinghamshire zones are most affected by the potential impacts the changing climate may have on our surface water sources – the Strategic Grid is affected directly by reduced river flows and reservoir refill, which in turn reduces the availability of water in the Strategic Grid zone to export to the Nottinghamshire 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. The groundwater sources in the Nottinghamshire zone are largely resilient to climate change.

Figure A3.6: Strategic Grid zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

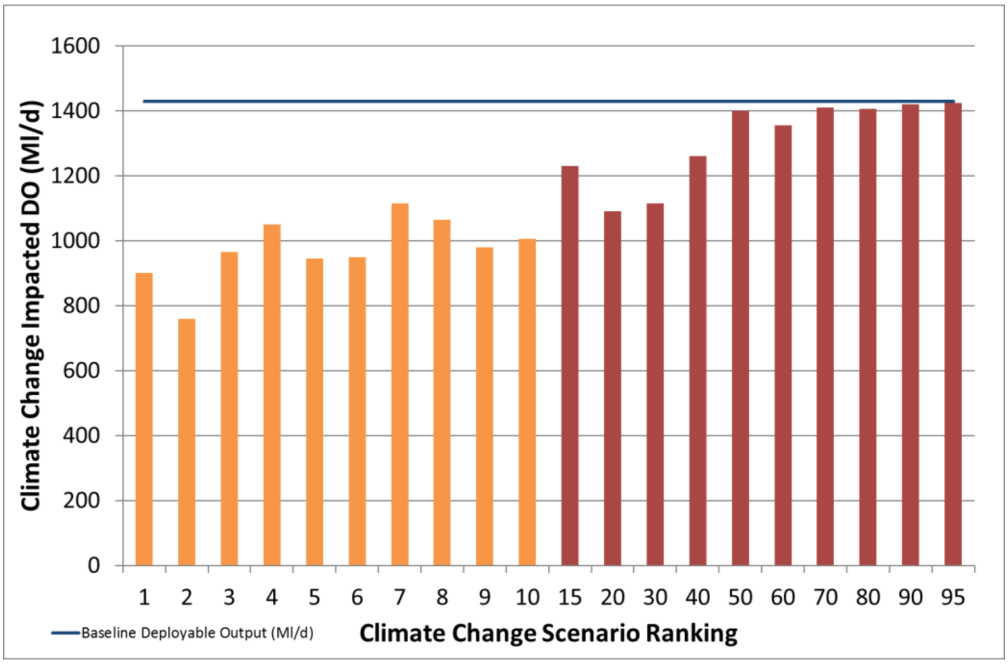


Figure A3.7: Nottinghamshire zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

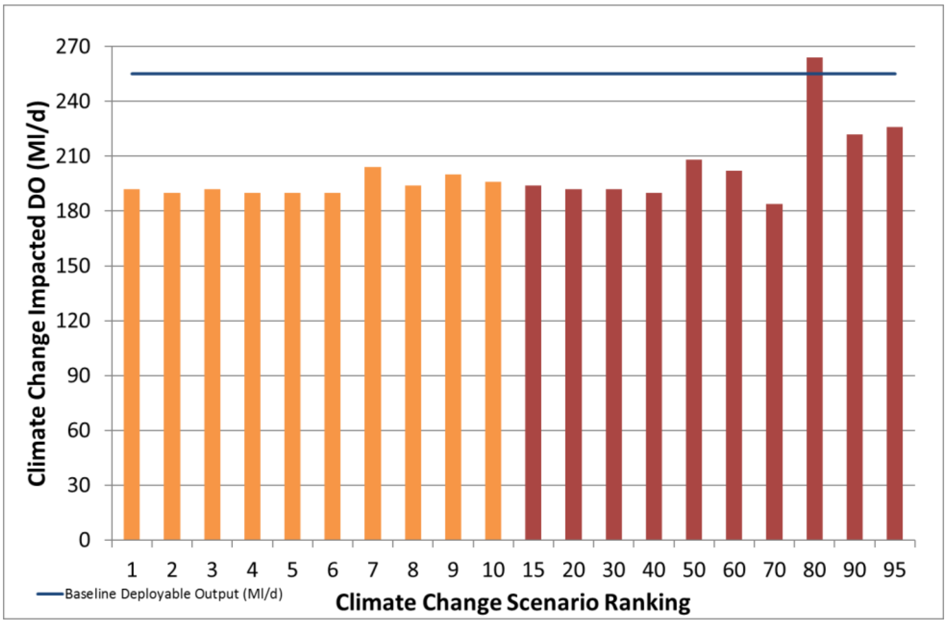


Figure A3.8: Shelton zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

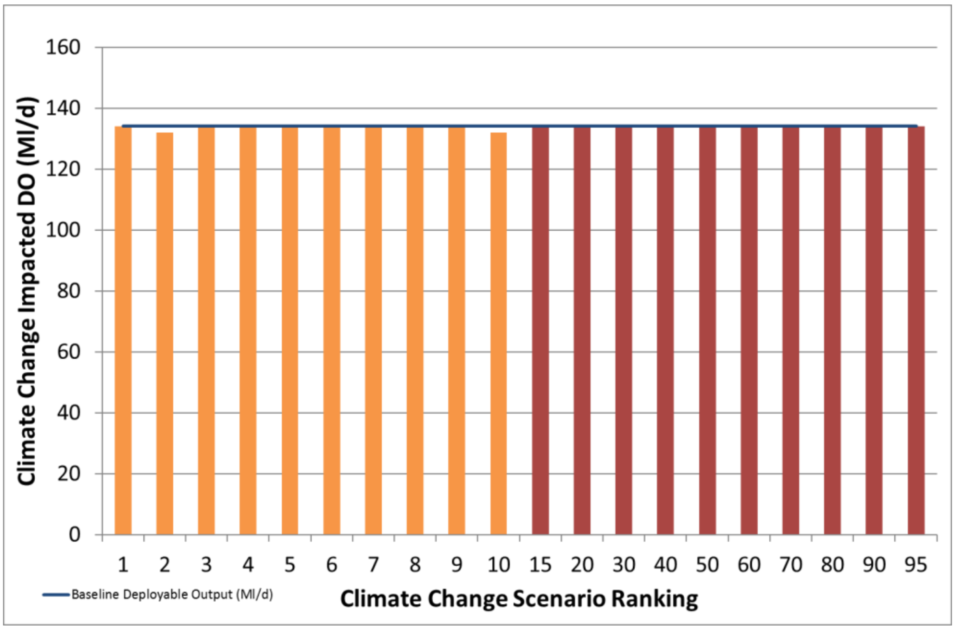


Figure A3.9: Forest and Stroud zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

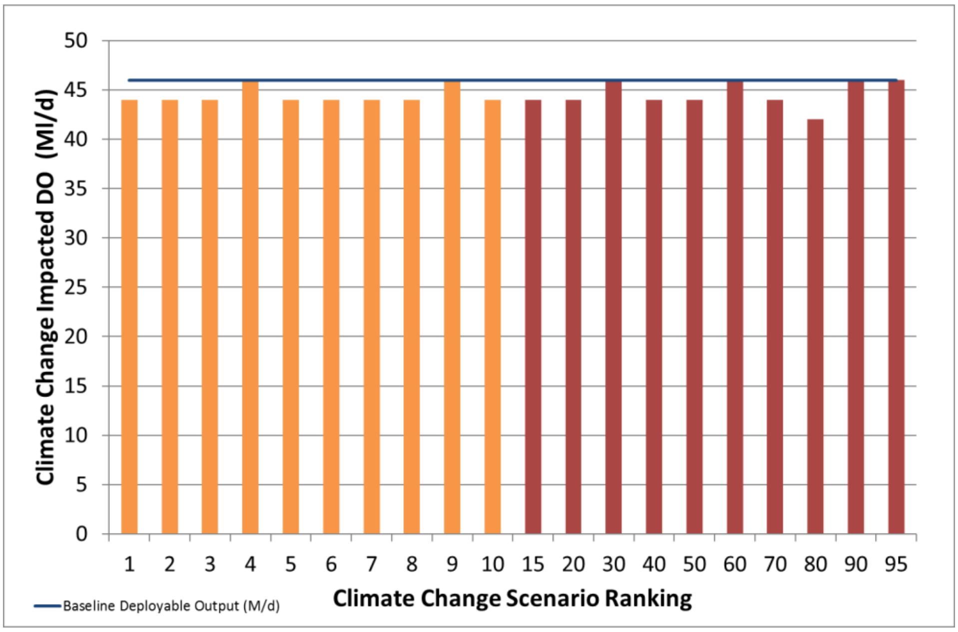
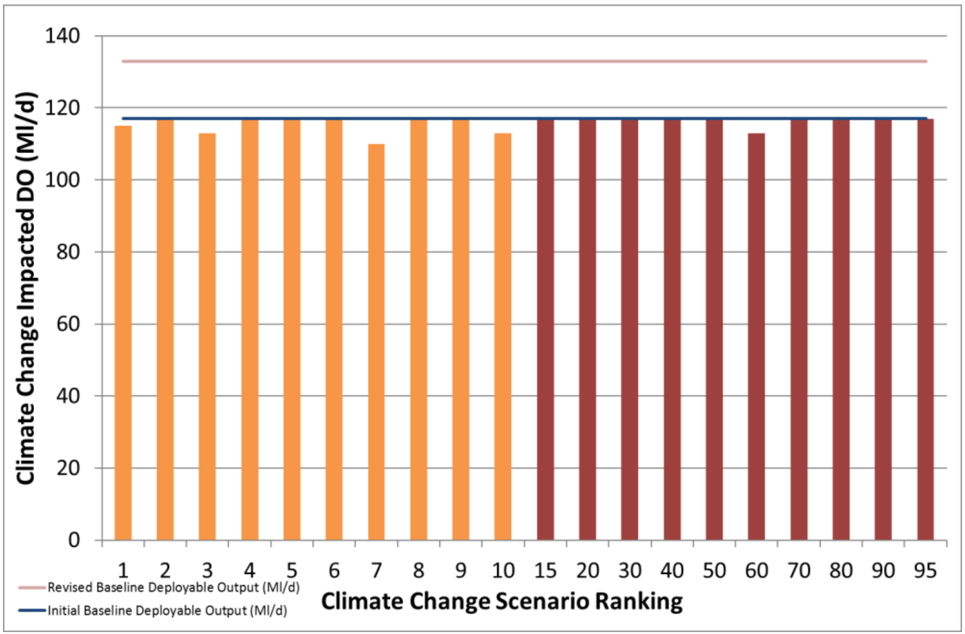


Figure A3.10: North Staffordshire zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios



The climate change modelling was carried out prior to the revision of baseline deployable output for North Staffordshire. The impacts for this zone were seen to be minimal. We will test the impacts of climate change in North Staffordshire for the final WRMP by repeating the climate change modelling using the revised baseline model.

A detailed description of how we have tested and used the range of uncertainty around climate change can be found in Appendix C2.

A3.7 Impact of 2080s climate change projections on deployable output

Our climate change assessment also includes the use of UKCP09 projections for the 2080s time slice following the guidance in "Environment Agency (2017) Estimating impacts of climate change on water supply". This analysis used the same 20 climate change projections identified in Step 4 of section A3.3 for the 2030s time slice. These projections were used to investigate DO impacts following the same approach explained in Steps 5 to 9 of section A3.3 for our conjunctive use WRZs and sections A3.5 for our groundwater only WRZs. As with our 2030 assessment the greatest impacts are observed in our Nottinghamshire and Strategic Grid WRZs. Results of this assessment will be used to test the long-term robustness of our plan.

A3.8 Scaling the impacts of climate change to 2045

Before scaling the modelled impacts of climate change we first needed to establish whether any impacts are currently being experienced in our existing river flows and other sources. To investigate whether any climate change signal is currently detectable in our river flows we carried out a series of statistical tests for trend detection. For each of the identified five catchment groups (our "exemplar" catchments described in Step 2 of section A3.3) a single river flow dataset was analysed. In order to fully capture any trend we used data from our extended historic record for the period 1884-2014. The results of this analysis (shown in Table A3.8) indicate that there is no observed trend for three of the five catchment groups and the two catchment groups with an observed trend both detect an increase in river flows over the 131-year analysis period.

Table A3.8: Catchment group trend detection summary

Catchment Group	Trend Observed?
1	Yes - Increasing ↑
2	No
3	Yes - Increasing ↑
4	No
5	No

This trend analysis supports finding of academic studies such as Hannaford (2015) which have found that there is currently no strong evidence of anthropogenic warming influences on river flows in the UK. These findings are also supported by the Living with Environmental Change (LWEC) Water Climate Impacts Report Card 2016; this document summarises the findings of a variety of research papers investigating climate change impacts on water.

We have also analysed the impact of extending our baseline Aquator inflow series which previously covered 1920 to 2010, by 4 years to 2014. The extended flow series captures the 2010-2012 period, which was for much of the UK was classed as a drought. The inclusion of this period caused no change to our deployable output. Although 2011 was very dry for most of our region (2nd or 3rd driest for most sub-catchments) for the catchments where the bulk of water is taken (Elan & Derwent) it was only the 29th and 16th driest year respectively.

We have therefore assumed no reduction in DO has occurred due to climate change in our scaling calculations, so have zero DO reductions in our base year 2016/17 in accordance with the scaling method described in the EA's Water Resources Planning Guidelines (2012).

In order to estimate the impact of climate change for each year of the planning period from the base year up to 2045, we scale the DO change using two sets of equations. These equations enable us to interpolate and extrapolate the 2035 DO estimates to produce a smooth time series which we can then include in our supply demand balance calculations. Consistent with our 2014 WRMP we have used the scaling equations described in the EA's Water Resources Planning Guidelines (2012) but with a revised base year to reflect the fact we have experienced no loss of DO to date.

We have applied these equations to our central estimate for each water resource zone.
Equation 1 is used to extrapolate from 2030/31 onwards. In the equation "Year" is the year of interest.

$$\text{Scale factor} = \frac{\text{Year} - 1975}{2035 - 1975} \qquad \textit{Equation 1}$$

Equation 2 is used to avoid a step change in 2016/17 between baseline deployable output and the underlying trend. It interpolates linearly between 2016/17 and 2029/30 (inclusive).

$$\text{Scale factor} = \frac{\text{Year} - 2016}{2031 - 2016} \qquad \textit{Equation 2}$$

References

Hannaford, J., 2015. Climate-driven changes in UK river flow: A review of the evidence. Progress in Physical Geography, 39(1), pp. 29-48.

LWEC, 2016. NERC Living with Environmental Change Report Card 2016: Water. Accessed at http://www.nerc.ac.uk/research/partnerships/ride/lwec/report-cards/water/

UKWIR, 1995. A Methodology for the Determination of Outputs of Groundwater Sources. UKWIR Technical Report 95/WR/01/2.

UKWIR, 2000. A Unified Methodology for the Determination of Deployable Output from Water Sources. UKWIR Technical Report 00/WR/18/2.

UKWIR, 2012. Water Resource Planning Tools 2012. UKWIR WR27 Technical Report 12/WR/27/6.

A4 Restoring Sustainable Abstraction (RSA)

Some of our existing water abstractions may be having a detrimental effect on the environment, particularly during dry weather periods when river flows are low. Throughout AMP6 we are investigating the impacts of those abstractions identified by the EA as possibly causing harm to the environment. Through our investigation work we are gathering site specific evidence of the extent of damage being caused, and whether our activities are the main cause, or just part of the problem.

Where our abstractions are identified through investigation to be the cause of the problem, we need to find and implement solutions. These solutions might include revoking or reducing our abstraction licences at the affected sites and possibly finding an alternative source of supply. Sustainability reductions to licences may be required to protect international or national designated conservation sites (Habitats Directive, Sites of Special Scientific Interest or Biodiversity 2020 sites), to protect locally important sites or to deliver Water Framework Directive (WFD) objectives.

In preparing our draft WRMP, we are working with the EA to find workable solutions ranging from local environmental mitigation measures to finding alternative strategic sources of supply. We are current assessing a range of potential options (Options Appraisal), with the aim of agreeing a solution with the EA for implementation in AMP7. For our dWRMP18 we have used scenario modelling in our supply / demand analysis to assist with managing the uncertainty around the solutions.

In March 2017 the EA issued phase 1 of their Water Industry National Environmental Programme (WINEP) which included the list of the sources where sustainability changes to abstraction licences may be required. The list includes:

- The current sources under investigation in AMP6, as the investigations are still underway the final amount of sustainability reduction has not been identified at this stage. Some of the sources listed may be removed from future versions of WINEP if the results of the investigation into the impact shows that we are not the main cause of the problem; and
- The Battlefield Brook and Upper Worfe sources where licence reductions were agreed with the EA in AMP5, but will not be implemented until AMP7.

We have incorporated these sustainability reductions in our baseline deployable output forecast.

A second notification was issued by the EA in Phase 2 of the WINEP in September 2017. Two additional implementation schemes were listed: Blacklake Plantation (fish passage); and Tittesworth (fish passage). These schemes were listed with status of ‘Indicative (Amber)’ and ‘Certain (Green)’ respectively, with the additional comment that they will be reviewed by EA prior to WINEP3. Given the timing of the notification of these schemes we have been unable to model the potential impact on DO or include them in our scenario modelling for the draft WRMP.

The final formal notification of the sustainability changes required by the EA will be issued in Phase 3 of the WINEP in March 2018 and will include the final results of our AMP6 investigations and the solutions developed through our appraisal of the options.

Potential Sustainability Changes

The sources requiring abstraction licence sustainability changes are listed in Table A3.4.1. We have modelled three restoring sustainable abstraction scenarios for these surface and ground water sources. The values used in these scenarios were based on the findings from our AMP6 investigations to date and our judgment of the potential range of the reduction that may be required at each of the sources we are investigating:

- A lower scenario which assumed a licence change that reduces the current source deployable output to a low range sustainability reduction by 2025. This equates to a 13Ml/d reduction (includes surface water).
- A middle scenario which assumed a licence change that reduces the current source deployable output by a high estimation of sustainability reduction by 2025. This equates to a 40Ml/d reduction (includes surface water).
- A high scenario which assumed a licence change that reduces the source deployable output to recent actual volumes minus a high-range sustainability reduction by 2025. This equates to a 65Ml/d reduction (69Ml/d if Cropston Reservoir sustainability reduction is included).

Table A4.1 below outlines the sources where sustainability reductions or other solutions may be required. This list is based on our AMP6 investigation sites and those sites listed as implementation in the March 2017 Phase 1 WINEP provided by the EA.

Table A4.1: List of potential sustainability changes for groundwater (site list based on AMP6 RSA investigations and measure and status taken from WINEP1- March 2017)

Site	Measure	Status of Measure*
Batchley Brook	Sustainability Change	Unconfirmed (Red)
Rudyard	Sustainability Change	Unconfirmed (Red)
Coventry Coal Measures (River Sowe)	Sustainability Change	Unconfirmed (Red)
Coventry Coal Measures (River Sherbourne)	Sustainability Change	Unconfirmed (Red)
Lower Worfe -Stratford Brook	Sustainability Change	Unconfirmed (Red)
Lower Worfe - Albrighton Brook	Sustainability Change	Unconfirmed (Red)
Lower Worfe - River Worfe	Sustainability Change	Unconfirmed (Red)
Cinderford Brook	Sustainability Change	Unconfirmed (Red)
Spadesbourne Brook	Sustainability Change	Unconfirmed (Red)
Aldford Brook	Sustainability Change	Unconfirmed (Red)
River Strine (multiple waterbodies)	Sustainability Change	Unconfirmed (Red)
Dover Beck and Oxton Dumble	Sustainability Change	Unconfirmed (Red)
Rainworth Water	Sustainability Change	Unconfirmed (Red)
Bevercotes Beck	Sustainability Change	Unconfirmed (Red)
River Maun	Sustainability Change	Unconfirmed (Red)
Vicar Water	Sustainability Change/ Adaptive Management	Unconfirmed (Red)
Battlefield Brook	Sustainability Change	Certain (Green)
Upper Worfe -Burlington Bk	Sustainability Change	Certain (Green)
Upper Worfe-Neachley Bk	Sustainability Change	Certain (Green)

Hartlebury Common SSSI	Adaptive Management	Unconfirmed (Red)
Puxton and Stourvale SSSI	Adaptive Management	Unconfirmed (Red)

*the status of measure in WINEP1 is red as investigation/impact assessments where not complete when WINEP1 was released.

The site specific RSA licence reductions that we have assumed in the draft WRMP are shown in table A4.2. These reductions reflect our best available assessment of the likely required reductions and the timetable over which we will make them. One important underlying assumption is that when making abstraction licence changes, we will use an 'up front permitting' approach during AMP7 which allows us to agree changes that do not come into effect until AMP8. Using this approach means we will be able to make these changes without putting AMP7 security of supply at risk.

Table A4.2: Site by site Restoring Sustainable Abstraction groundwater licence reductions included in the 2018 draft WRMP

WRZs	Sources	WINEP CATEGORY (July)	Average DO (Ml/d)	Recent Actual (15 yr RA for PT SST sites, 6 yr for all others 2009-15)	Max sustainability reduction from RA (AMP6 RSA Investigations)
Forest of Stroud	Buckshaft	Mitigation and Prevention	6.00	3.57	2.00
Notts	Clipstone Forest	Adaptation	8.00	6.92	4.00
Notts	Amen Corner	Adaptation	8.00	6.68	1.00
Notts	Far Baulker	Adaptation	9.00	5.36	2.50
Notts	Markham Clinton	Adaptation	19.00	17.76	4.00
Notts	Boughton	Adaptation	14.00	9.96	4.00
Notts	Ompton	Adaptation	28.50	23.54	8.00
North Staff	Poolend	Mitigation and Prevention	10.00	5.10	2.00
North Staff	Peckforton	Mitigation and Prevention	2.33	2.86	3.00
Strategic Grid	Astley	Investigation & OA	7.86	7.44	0.50
Strategic Grid	Meriden shafts	Mitigation and Prevention	7.20	6.09	3.30
Strategic Grid	Watery Lane	Mitigation and Prevention	0.00	1.70	3.00
Strategic Grid	Mount Nod	Mitigation and Prevention	2.70	2.70	1.00
Strategic Grid	Brockhill	Adaptation	7.95	5.67	1.50
Shelton	Cosford	Mitigation and Prevention	9.16	8.05	1.00
Shelton	Hilton	Adaptation	12.79	11.40	2.00

Table A4.3: List of potential sustainability changes for surface water (site list based on AMP6 RSA investigations and measure and status taken from WINEP1- March 2017)

Site	Measure	Status of Measure*
Carsington Reservoir (Henmore Brook)	Sustainability Change	Unconfirmed (Red)
River Dove at Egginton	Sustainability Change	Unconfirmed (Red)
Tittesworth Res (R. Churnet)	Sustainability Change	Unconfirmed (Red)
River Blythe (pumped offtake)	Fish Passage	Indicative (Amber)
Stanford Reservoir	Sustainability Change	Unconfirmed (Red)
Quorn Brook (Cropston and Swithland Resrs)	Adaptive Management	Unconfirmed (Red)
River Ashop[1]	Sustainability Change	Unconfirmed (Red)
River Noe[1]	Sustainability Change	Unconfirmed (Red)
Charnwood reservoirs RSA (Cropston, Swithland and Blackbrook)	Sustainability Change	Unconfirmed (Red)

*the status of measure in WINEP1 is red as investigation/impact assessments where not complete when WINEP1 was released.

We have where possible incorporated these potential surface water abstraction licence changes into our Aquator model to allow us to demonstrate the impact on water resource zone deployable output of the low, medium and high scenarios. This translates into the zonal DO reductions shown in the table below.

The overall impacts on deployable output in our water resource zones that will be affected by the RSA changes is illustrated in Table A4.4 and discussed in the sections below.

Table A4.4: Deployable output impacts of combined RSA changes

Water Resource Zone Name	Base DO (Ml/d)	Reduction in DO per zone resulting from each of the RSA Scenarios		
		Low (Ml/d)	Medium (Ml/d)	High (Ml/d)
Strategic Grid Zone	1429	2	10	25
Forest and Stroud zone	46	0	0	2
Shelton zone	134	1	2	13
North Staffs zone	117	0	19	19
Nottinghamshire zone	255	10	25	34

[1] Not included as implementation in WINEP 1 were listed as no deterioration, but included as Implementation in draft WINEP2.

A5 Achieving Water Framework Directive objectives

A5.1 Future Changes to Deployable Output

Under the Water Framework Directive (WFD) we have an obligation to prevent the deterioration of the quantitative and qualitative status of a waterbody. Deterioration of the quantitative status of a waterbody could arise if our abstractions increase in the future due to growth. If this occurred, we would be taking more water out of the environment. Taking action to prevent deterioration now will prevent us from having to repair damaged waterbodies in the future, which would be more expensive. Our abstractions need to be more sustainable and we need to achieve this without compromising the supply of water to our customers.

The Environment Agency (EA) undertook a risk assessment of the likelihood of our abstractions causing deterioration as part of the 2nd cycle of river basin management plans (RBMPs) released in 2015. This risk assessment was based on the consequence of our licences being used at their full capacity. In October 2016, the EA indicated that their initial assessment could have a significant impact on our security of supply and would drive unnecessary investment. Following this statement, the EA issued a second assessment, which is risk-based and considered to be more representative of the actual risk of deterioration. The trigger to assess whether deterioration would occur was set by using a future predicted scenario based on PR14 WRMP planned growth figures. These figures were used in combination with the Environmental Flow Indicator (EFI) as a means to undertake a nation-wide screening of ecological impact related to a future deterioration risk. The EFI, which is a hydrological indicator, is the EA's best available, nationally consistent indicator of the impact of abstraction on flow and ecology.

Waterbodies, and consequently abstractions from those waterbodies, were grouped into categories, depending on where the planned growth falls against the EFI. A planned increase in abstraction may not pose a deterioration risk if flow is currently above the EFI and is likely to remain above the EFI with the planned growth in abstraction. The EA grouped waterbodies in the following categories:

- Waterbodies suffering from seriously damaging abstractions (Category 1)
- Waterbodies where deterioration is likely to occur by 2027 (Category 2)
- Waterbodies where deterioration is likely to occur by 2040 (Category 3)
- Waterbodies where deterioration will not occur by 2040 (Category 4)

We wanted to improve our understanding of the risk associated with taking more water from water bodies that may be subject to deterioration. We took the EA's work a step further as we wanted to further explore the potential impacts on water supply to our customers. Our first step was to undertake our own growth assessment, and use this to understand where growth may occur.

In 2016, we obtained the most recent Local Authority (LA) house hold (HH) year by year growth figures and we mapped these to our Water Quality Zones (WQZs). We then mapped WQZs to the individual sources supplying these WQZs. We added HH growth figures for the period 2015-2027 and 2027-2040 to the household numbers for 2015 to determine the total number of households in 2027 and 2040 respectively. Then, we multiplied the number of HHs in each period by the current average household occupancy rate to estimate the total potential population growth in each WQZ. We converted the population to a volume of additional demand for water for each period using our current estimate of per-capita water consumption. We then used these demand growth projections to determine which sources of water would need to increase future output. We classified sources that had planned abstraction growth by 2027 as Category 2 sites while we classified those that had planned abstraction growth by 2040 as Category 3 sites. We shared our assessment in advance of the EA releasing their 1st Water Industry National Environment Programme (WINEP 1) in March 2017.

Since 2016, Local Authority HH growth figures have been updated by some Councils and these have been incorporated into our draft WRMP modelling. We will need to update the growth assessment before WINEP 3 is released and will incorporate this update into our final WRMP. Changes to growth figures may lead to having to re-categorise some of our sources. We will communicate these changes to the Environment Agency and these will be incorporated into WINEP 3.

WINEP 1 listed a total of 134 abstraction sources (123 groundwater and 11 surface water) that were situated in either Category 1 or Category 2 water bodies. The groundwater sources alone were putting approximately 160 Ml/d of our deployable output at risk. A no deterioration investigation driver was set against 88% of the sources. We considered this large AMP7 investigation programme to be too big to manage for us and for the EA. We required a more manageable approach that brought other lines of evidence into the assessment.

We need to put plans in place to manage the risk of deterioration and restore waterbodies where deterioration has already occurred because of our abstractions. This and the need for a more manageable AMP7 investigation programme has led us to take a no-regrets approach that has been incorporated into our methodology. We shared this methodology with the EA in advance of the EA releasing WINEP 2 at the end of September 2017.

We have a long history of environmental investigations, which started in AMP2. Most of the 134 sources on WINEP 1 were investigated in past AMP cycles and we hold significant amounts of data and tools that we have developed over the years. Our no-regrets approach is based on the idea that we have a good understanding of the risks surrounding no deterioration for all those sources that have been investigated in the past under our National Environment Programmes (NEP). For all the others, we will have to undertake environmental investigations so that we better understand the risk around no deterioration.

We have categorised all of the sources listed on WINEP 1 using the categories listed below and have used these to inform our future approach for managing the risk of waterbody deterioration. We used this categorisation to inform what we thought the NEP driver should be and shared this with the Environment Agency. The Environment Agency have considered our recommendations and incorporated these in WINEP 2 where relevant.

Our categories are as follows:
Sources that require an adaptation approach: these are sources where we understand that deterioration will occur if we increase our abstractions. In WINEP 2, these sources have a No Deterioration implementation driver where action is required. They are shown with either green or amber certainty. There are also multiple drivers (WFD no deterioration, restoring sustainable abstractions, resilience, catchment wide water quality issues, etc.), often within the same WRZ. We want to take action now to prevent future deterioration and we realise that strategic solutions will deliver more holistic approaches for resolving the complex nature of the problems in these areas as opposed to a multitude of local solutions. Such strategic solutions are likely to require several AMP cycles for delivery and alternative solutions will be required to prevent deterioration in the interim. We realise that there may be a need to invoke WFD Article 4.7[2] however, at this stage, we believe that this will not be necessary as our interim measures should prevent deterioration from occurring. We will aim to focus on catchment and partnership measures as alternative interim measures while the strategic solutions are being delivered. We believe that this is a more cost effective way of delivering solutions across the short, medium and

[2] Article 4(7) of the WFD sets out the conditions for derogation in the event of new modifications to the physical characteristics of a body of surface water, alterations to the groundwater levels within a groundwater body or new sustainable human development activities

long term. We will apply for licence changes by 2025 and have accounted for a consequent loss of deployable output in our WRMP by 2030 in our central best estimate for each source in this category.

Sources that require prevention/mitigation: here too we believe we understand the risk of deterioration but we believe we can manage the risk through a series of actions that will prevent deterioration occurring.

Measures such as local flow support, hydromorphology measures to improve environmental resilience, catchment and partnership solutions, localised demand management will help us mitigate against the risk of deterioration. Other measures such as enhanced source abstraction management controls through better Instrumentation Control and Automation (ICA) and telemetry and new distribution links to more sustainable sources of water will help us prevent the risk of deterioration. We would seek to use an adaptive management approach where possible but we realise that future sustainability reductions may be required at some point. Due to the lack detailed feasibility assessments, we have accounted for some of this uncertainty in our WRMP by running different scenarios with high, medium or low WFD scenarios. We have assumed that we may lose up to 50% of the difference between our current deployable output (DO) and our recent actual (RA) abstractions. This is driven by the fact that, although we will take action to prevent deterioration, we may still need to request five or ten year rolling average licences by 2025 for many of our groundwater sources. Ultimately, this would lead to a net reduction of our average licence over the five – ten year period. We have therefore accounted for a consequent loss of deployable output in our WRMP by 2030 in our central best estimate for each source in this category.

Sources that require investigations and options appraisal in AMP7: these are sources where we have no environmental data and therefore do not fully understand the risk of deterioration. We believe that we will need to collect data and undertake further assessments to improve our understanding of the risks. We would be promoting sources within this category for no deterioration investigations in AMP7. Here too we have to manage uncertainty and have reflected this uncertainty in our WRMP central best estimate. We have done this by considering a potential loss of 50% of the difference between our current DO and RA abstractions in our central best estimate for all sources in this category.

We are required to determine whether our existing abstractions are meeting RBMP sustainability objectives and if they are at risk of not meeting these, what changes will be required to our abstractions to meet RBMP objectives. In order to meet these requirements, we have determined, for each of our groundwater sources, what we believe is a sustainable, long term abstraction. We used historical datasets and predictive tools like groundwater models and hydro-ecological relationships to derive sustainable abstraction figures. We have used our sustainable abstraction figures, as opposed to the EFI, to determine what sustainability changes we may require in the future to prevent deterioration. These figures are still being developed and will be included in our final WRMP. For our surface water sources, the EA only classified a relatively small number as category 1 or 2. Out of this modest number of sources there are hands off flows (HoF) conditions in many of the licences. If a licence has a HoF in it then this provides appropriate protection for the environment. If the HoF is not considered appropriate then we will have already investigated the sources as part of previous Habitats Directive (HD) or Low Flows programmes.

We have used scenario modelling in our dWRMP18 to account for uncertainty at this stage. Final changes to the draft WRMP will be incorporated into WINEP 3 which will be released in March 2018.

We have modelled three scenarios for no deterioration for both surface and ground water sources:

- A lower scenario that accounts for a 50% loss of deployable output above recent actual abstraction values; losses of deployable output would occur from 2030 onwards.

- A middle scenario that accounts for an 80% loss of deployable output above recent actual abstraction values; similarly to the low scenario, losses of deployable output would occur from 2030 onwards.
- An upper scenario that assumes that our sources are capped at recent actual abstractions from 2020 onwards (recent actual abstractions are calculated using the average of the last 5 or 15 years of abstraction figures, depending on the geological nature of the aquifer for the groundwater sources).

The extent of the deployable output impacts to our water resource zones by 2035 arising from no deterioration, and included in our draft WRMP scenario testing, is summarised in the Table A5.1.

Table A5.1: Range of DO losses considered in our scenario modelling.

Water Resource Zone	DO loss – Low Scenario (Ml/d)	DO loss – Medium Scenario (Ml/d)	DO loss – High Scenario (Ml/d)
Nottinghamshire	20	10	20
Shelton	10	23	33
Forest of Stroud	2	3	4
Strategic Grid	11	97	105
North Staffordshire	0	8	11
Bishops Castle	0.69	1.10	1.38
Kinsall	0	0	0
Mardy	0.54	0.86	1.08
Llandinam	0	0	0
Newark	0	0	5
Ruyton	0	0	0
Staffordshire	0	0	0
Wolverhampton	0	2	3
Whitchurch/Wem	1.09	1.75	2.19

Due to the timing of WINEP2 being issued, we have not fully incorporated WINEP 2 into our draft WRMP modelling as this was completed prior to WINEP 2 being issued at the end of September 2017. Following the release of WINEP 2, we assessed what we incorporated into our modelling against what has been included in WINEP 2. Table A5.2 below summarises these differences at WRZ level and includes both No Deterioration and RSA.

Table A5.2: Estimated DO losses in our dWRMP18 compared to potential losses had we fully considered WINEP 2.

Water Resource Zone	DO losses – Draft WRMP (Ml/d)		DO loss – WINEP 2 (Ml/d)	
	2030	2035	2030	2035
Nottinghamshire	84.8	0.0	84.8	0.0
Shelton	18.6	0.0	22.1	0.0
Forest of Stroud	3.5	0.0	4.7	0.0
Strategic Grid	23.3	4.6	25.6	4.4
North Staffordshire	25.9	4.4	26.1	4.4
Bishops Castle	0.7	0.0	0.7	0.0
Kinsall	0.5	0.0	0.5	0.0
Mardy	0.5	0.0	0.5	0.0
Llandinam	0.0	0.0	0.0	0.0
Newark	1.6	0.0	1.6	0.0
Ruyton	0.0	0.0	0.0	0.0
Staffordshire	0.7	0.0	1.2	0.0
Wolverhampton	3.9	0.0	3.9	0.0
Whitchurch/Wem	1.1	0.0	1.1	0.0
TOTAL	**165.3**	**9.0**	**172.8**	**8.8**

It can be seen that the differences are small. Our dWRMP18 predicts a slightly lower DO loss for some WRZs compared to what was published in WINEP 2. This is due to the fact that, prior to the release of WINEP 2, we had envisaged that eight groundwater sources (Swynnerton, Wellings, Moddershall, Blacklake, Hollies, Racecourse Lane, Green Street, and Nescliffe) would be dropped from WINEP. Instead, these have been included with an investigation driver.

A5.2 Invasive non-native species (INNS)

Invasive non-native species (INNS) are animals or plants that have the ability to spread outside their native range, which are having a detrimental impact on the economy, wildlife or habitats. Of particular concern are species new to the country, on the list of EU concern, or listed on schedule 9 to the Wildlife and Countryside Act (1981), or not ordinarily resident in the wild.

Some of the activities that we undertake have the potential to create pathways to spread INNS. These activities include recreational activity at our sites and some of the activities we undertake when we treat water and waste water. As part of our supply network we transfer raw water between waterbodies and this can be a potential pathway for spreading INNS.

The Environment Agency has told us its position on raw water transfers and has provided a list of sites to investigate through the Water Industry National Environment Programme (WINEP) to assist us with developing our dWRMP18. This has assisted us to develop our approach to INNS in the draft WRMP, which focuses on the pathway that the transfers create, not where INNS currently occur. The ways we will deal with INNS in our supply system are:

- Where new schemes create a connection between locations not already connected we will design mitigation measures into the scheme to ensure INNS cannot be spread by the new transfer.
- Where new schemes create a connection between locations that have an existing hydrological link, we will undertake an assessment of the increased risk that the scheme poses and develop mitigation measures if required.

- For our existing transfers which have been operating for many years, implementation of mitigation on existing transfers will be gradual and prioritise those of greater risk first. We have provided a list of our major transfers in Table A5.3. We are planning to work with the EA and carry out a detailed risk assessment of these transfers by 2022.

Table A5.3: Major raw water transfers in our region

Licence	Description of Transfers
3/28/38/18	River Ashop and River Noe into Derwent reservoirs (Derwent and Ladybower)
18/54/10/0717, 18/54/10/07 & 18/54/12/053	River Avon to Draycote Reservoir and Leam catchment
03/28/40/121	River Derwent to Ogston and Carsington Reservoirs
03/28/36/147& 03/28/36/148	River Dove to Staunton Harold & Foremark reservoirs in Trent catchment
03/28/56/030	Rothley Brook and Swithland Reservoir to Cropston Reservoir
n/a n/a	Site S from Elan Valley Reservoirs to Site U River Cownwy and River Marchant diversions into Lake Vyrnwy

We have the infrastructure and a licence to allow us to transfer water from Rothley Brook into Cropston Reservoir. Due to the presence of signal crayfish in Rothley Brook we are unable to use this transfer, so we have not included it in our assessment of deployable output (DO) for the our WRMP. This is the only reduction in DO that has been specifically driven by INNS.

A5.3 Abstraction reform and licences

Water Minister Therese Coffey announced at the end of March 2017 that there are no immediate plans to progress with abstraction reform or associated changes to primary legislation. In line with this announcement we have not included any changes to DO from abstraction reform. On the 14th September 2017 Defra released its ‘abstraction plan’ which sets out a vision for reforming abstraction management using local catchment leadership using solutions developed on a voluntary basis.

With specific regard to our sources that have unused licence volumes that are required for emergency and/or drought purposes, this information can be found within our statutory draft Drought Plan which is due to be published for consultation in February 2018 and will cover the period 2019-2024.

We operate using abstraction licences within three cross-border catchments (Rivers Dee, Wye and Severn). Where there are unused licenced volumes associated with licences that fall within these catchments our dWRMP18 options appraisal has considered whether we can utilise this licensed volume within our supply / demand options. We are also exploring the future possibilities for water trading and how we can make best use of any underutilised licensed quantity within these catchments.

Any of our abstraction licences that have the potential to cause environmental harm have been flagged through the Restoring Sustainable Abstraction work or through the Water Industry National Environment Programme (WINEP) analysis that has been jointly undertaken by the Environment Agency and Severn Trent Water.

A6 Outage - Redacted

A7 Imports and Exports – Redacted

A8 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, prior to the change to the legislation/ regulation in 2010, we would have called a hosepipe ban.

We have not changed our stated levels of service for customer restrictions since our WRMP14. As a response to drought, we offer the following levels of service:

Table A8.1: Company level of service in relation to restrictions on customers' use

Restriction	Frequency	Average annual percentage risk over the first 25 years
Temporary use bans (TUBs) to restrict customers' use of water	No more than 3 times every 100 years	Not more than a 3% risk each year: equivalent to a 75% risk over the 25 years.
Drought orders to restrict non-essential use (NEUBs)	No more than 3 times every 100 years	Not more than a 3% risk each year: equivalent to a 75% risk over the 25 years.
Emergency drought measures, such as rota cuts or standpipes	We consider these are unacceptable. We discuss the frequency of these in more detail in section 6.1	n/a

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 (source: Environment Agency water situation report, February 2012). Despite this extremely dry period we were able to manage our water resources without recourse to customer restrictions. Although we have not needed 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.

For example, one of the conclusions of the 2015 EA 'Water supply and resilience and infrastructure: Environment Agency advice to Defra' (https://www.gov.uk/government/publications/water-sector-improving-long-term-resilience) was that many water companies are overstating their resilience to extreme drought events. We have reproduced the relevant section of this report below:

Figure A8.1: Extract from 2015 EA report

Executive summary

Click on Tools to convert PDF documents to Word or Excel.

This advice report sets out information to support Defra in delivering the Water White Paper[1] commitments related to assessing future needs for water resilience and associated strategic water infrastructure.

In this document, we treat resilience as the capacity to maintain essential services under a range of circumstances from normal to extreme.

Our advice is based on a review of the available evidence across sectors which rely on water and encompasses the economic, social and environmental impacts which would result from compromised supplies.

The review has focused on supply pressures associated with severe and extreme droughts, although it does note some non-drought hazards. The options to enhance resilience levels to drought could have wider benefits in terms of other threats to security of supply.

Our review of the evidence has concluded seven key findings:

1. Large parts of society, industry and commerce are currently exposed to the risk of emergency water restrictions (stand pipes, rota cuts etc.) at a likelihood in the order of 1% every year. The risk is often uncertain and is probably understated in some water company plans. The future risk of emergency water restrictions is likely to increase due to a combination of growth pressures and changes to droughts associated with climate change, unless water companies and other businesses invest to maintain current resilience.

We think this is a valid conclusion. We still consider these emergency measures 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 200 year droughts we have modelled. We describe our drought modelling in section A9.

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, customers' bills would have to be higher. Conversely there are potential savings if we planned to restrict customers more frequently.

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 PR19 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 2019 (PR19) process.

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

Our stated levels of service are consistent with those we have quoted in previous Severn Trent publications, such as WRMP14, our 2014 drought plan and the draft drought plan we are currently preparing to cover the period 2019-2024. 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. Refer to section A9 for more information on the drought resilience work we have carried out to produce our PR19 plans.

Consistency with the EA and NRW drought plans

When preparing our draft drought plan and this draft WRMP we have considered and referred to the Environment Agency's 2016 National Drought Framework. We have also referred to the EA area and/ or NRW drought plans as appropriate and where they are 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?

Throughout the planning period (2020 to 2045) we plan to maintain the level of service we currently provide to our customers and not make any changes to it. If there is a supply-demand deficit in any WRZ we will report the timing and magnitude of it (in Ml/d) in our baseline WRMP tables. In our final planning tables we show how we plan to reduce demand or increase supplies to make up any predicted deficits. One of the options we have modelled to help us make up any deficits is increasing the frequency of customers' use restrictions. However, this option to balance supply and demand has not been selected as part of our best value mix of options. Refer to section A2 to see the relationship between DO and different levels of service as quantified by our Aquator model.

A8.1 Reference levels of service

As suggested in the current Water Resources Planning Guideline (WRPGs, interim update April 2017) we *have "set out a reference level of service that would mean resilience to a drought with at least an approximate 0.5% chance of annual occurrence (i.e. approximately a 1 in 200 year drought event). Resilience in this context would be avoiding emergency drought orders that allow restrictions such as standpipes and rota cuts".* We explain how we have selected and modelled this drought event and numerous other drought scenarios in section A9 and we present the results of these scenarios in table 10 of the tables that accompany this WRMP. In addition we have written a drought resilience statement in section A9.2 of this draft WRMP

As described below, the DO effect of the reference level of service (1 in 200 drought) is minor. As the DO reduction does not cause any WRZs into deficit we achieve the reference levels of service described in the WRPGs throughout the 25 year planning period.

A8.2 Additional DO required

Our Aquator modelling has indicated a reduction of 2 Ml/d DO in the Forest & Stroud WRZ in a number of 1 in 200-year droughts. However, this does not take the WRZ into deficit. As a result it does not drive any investment.

This modelling also indicated that we could continue to supply water throughout a 1 in 200 drought without the need for emergency drought orders. However, it is worth noting that there is no single 1 in 200 year drought. There are an extremely large number of plausible droughts that all have return periods of 1 in 200 years. See section A9 for more information on our drought resilience work.

We are not planning any changes to our levels of service over the WRMP planning horizon so there is no point at which the planned frequency of TUBs or NEUBs changes. We have used the information from our reference level of service when we gather our customers' views but we have been careful to use this information in a way that truly engages customers.

A8.3 Customer views on our levels of service

In preparation for our WRMP14 we reviewed the evidence we have about customer support for different levels of service. In summary:

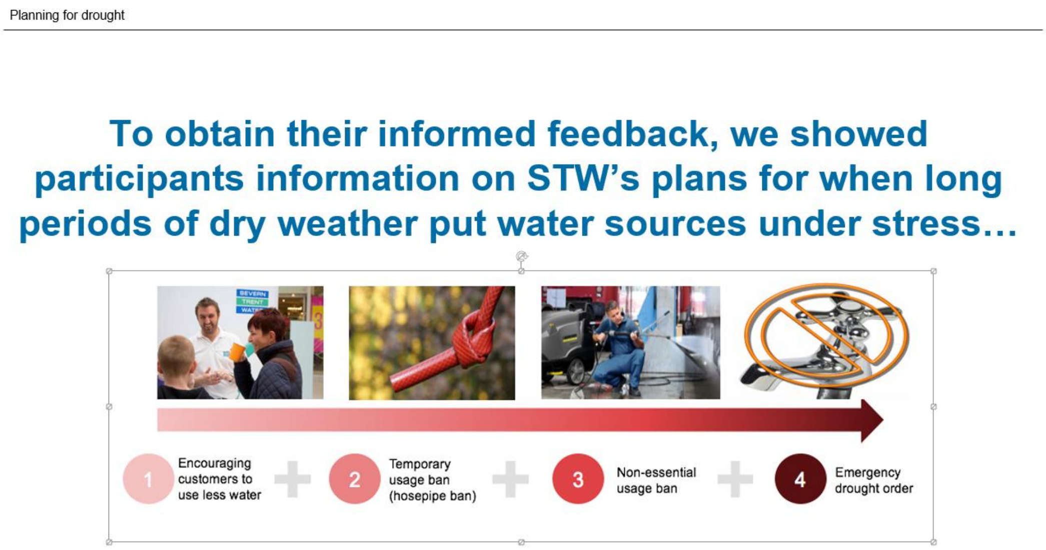
- We carried out willingness to pay research and also produced an on line 'sliders' game that allowed visitors to our website to see the impact of competing priorities on total water and wastewater bills
- Evidence from our 2012 survey suggests that customers may not have been clear about the options that we proposed.
- Our customers then supported a frequency of restrictions of once every 38 years.
- This was so close to our existing (once every 33 years) level of service that we did not change it at PR14.

During the customer research we have carried out we have not made a distinction between temporary use bans and non-essential use bans. We believe that this helps to avoid confusion. When we gathered customer views on levels of service for WRMP19 we improved our approach by carrying out different phases of work:

1. Willingness to Pay (WTP) work – this is similar to the work we carried out for WRMP14

2. Immersive research – we did not carry out research like this for WRMP14 but 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 A8.2 below is from the immersive research we carried out into the topic of drought.

Figure A8.2: Extract from immersive research



The summarised results of this work are that the customers we engaged generally felt that:

- Drought is not an issue they anticipate will affect the UK
- They would feel little impact from scenario 1 (i.e. being encouraged to use less water), and therefore find the current frequency (once every one to two years) acceptable
- Due to the perceived minimal impact of temporary use ban (TUB) restrictions, the expected frequency (once every 33 years) is mostly seen as acceptable
- They do not see non-essential use bans (NEUBs) as having direct impact on them, but worry about the impact on businesses
- Level 4 is seen as extreme, although probably proportionate and very unlikely to occur (we described the frequency of this as ‘never (once every 200 years)’.

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 2017 WRPGs, we considered using the 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 half 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. The following table shows the modelled frequency of different restrictions:

Table A8.2: Modelled frequency of restrictions on customers’ use

Restriction	Number of events in the record from water resources modelling simulation	Length of record (years)	Frequency per 95 year length of record (%)	Company stated LoS frequency
Temporary use ban (TUB)	2 (1976 and 1984 both affecting Elan Valley group)	95	3.3	Not more than 3 in 100
Non-essential use ban (NEUB)	1 (1984 for Elan Valley)	95	1.1*	Not more than 3 in 100
Rota cuts/ standpipes	0	95	0	Not acceptable

** This is the frequency of this occurring in our baseline DO model run – it will differ in other modelled scenarios and does not change the stated company levels of service*

We are aware that there are challenges involved in helping customers to better understand the likelihood of extreme drought events. We have reproduced a table below that was produced as part of UKWIR (United Kingdom water industry research) work on the topic of resilience metrics. It is a purely 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 8.3 Illustrative example of different descriptions of 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

A8.4 Critical droughts within our 95 year hydrological record

Our baseline deployable output (DO) modelling of the 95 year period from 1920 to 2014 shows that the two most critical droughts in our region in terms of causing TUBs or NEUBs are those that included the following 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. The following figures show both a 'winter' and 'summer' crossing of the trigger zones E and F.

Figure A8.3: Tittesworth reservoir modelled baseline DO storage entering drought trigger zones E and F in the 1995-96 'winter'

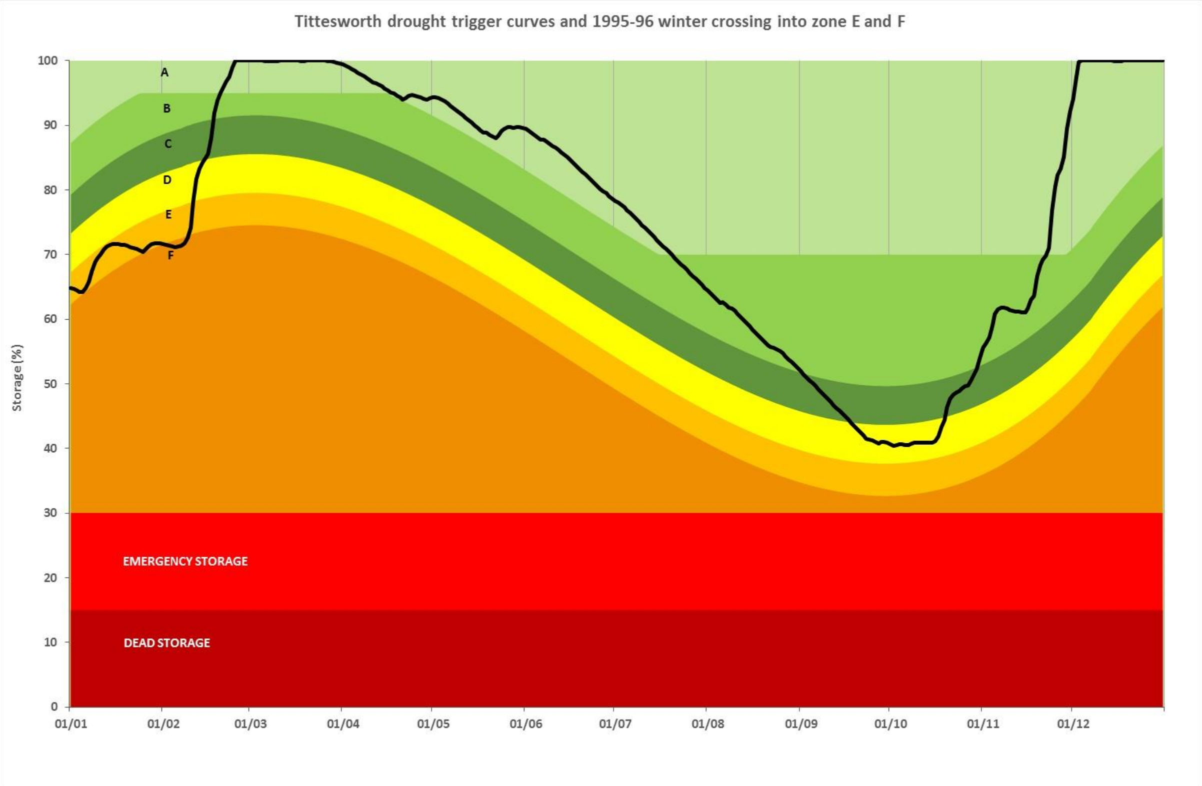
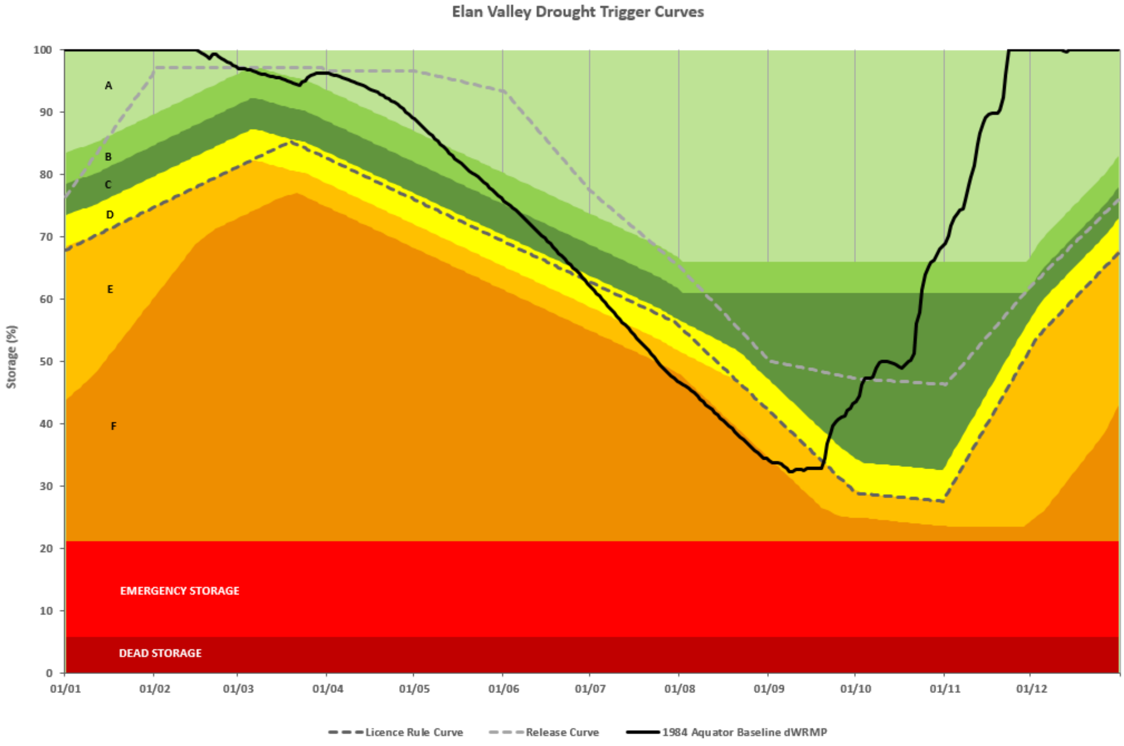


Figure A8.4: Elan Valley reservoir modelled baseline DO storage entering drought trigger zones E and F in the 1984 'summer'



A8.5 Extending the period of our hydrological analysis

The modelling we undertook to support our WRMP19 used a 95 year flow time series for catchments across our region. This flow record extends from 1920 to 2014. As a frequency of three TUBs in 95 years is equivalent to 3% of the modelled years having TUBs, we consider this to be consistent with our three in 100 level of service.

In order to provide us with further confidence in our ability to meet our stated level of service, we have worked with University of Liverpool to study rainfall records within our region that date back to the 1800s. We provide more details on this work in section A9. Section A9 also describes the other techniques we have used to better quantify the impact of extreme droughts on our region.

A9 Drought Resilience

A9.1 Testing our plan with challenging droughts

We have made a step change in terms of improving our understanding of drought resilience for this dWRMP18 when compared to previous WRMPs. In developing this plan we have used three techniques that have 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 suggest that water companies should, at a minimum, use the worst drought on record to assess drought risk. In our case this includes droughts observed between 1920 and 2014 (the period of observed data we use in our baseline Deployable Output assessment see section A2). Our approach considers not only the worst droughts in the 1920 to 2014 record but also-

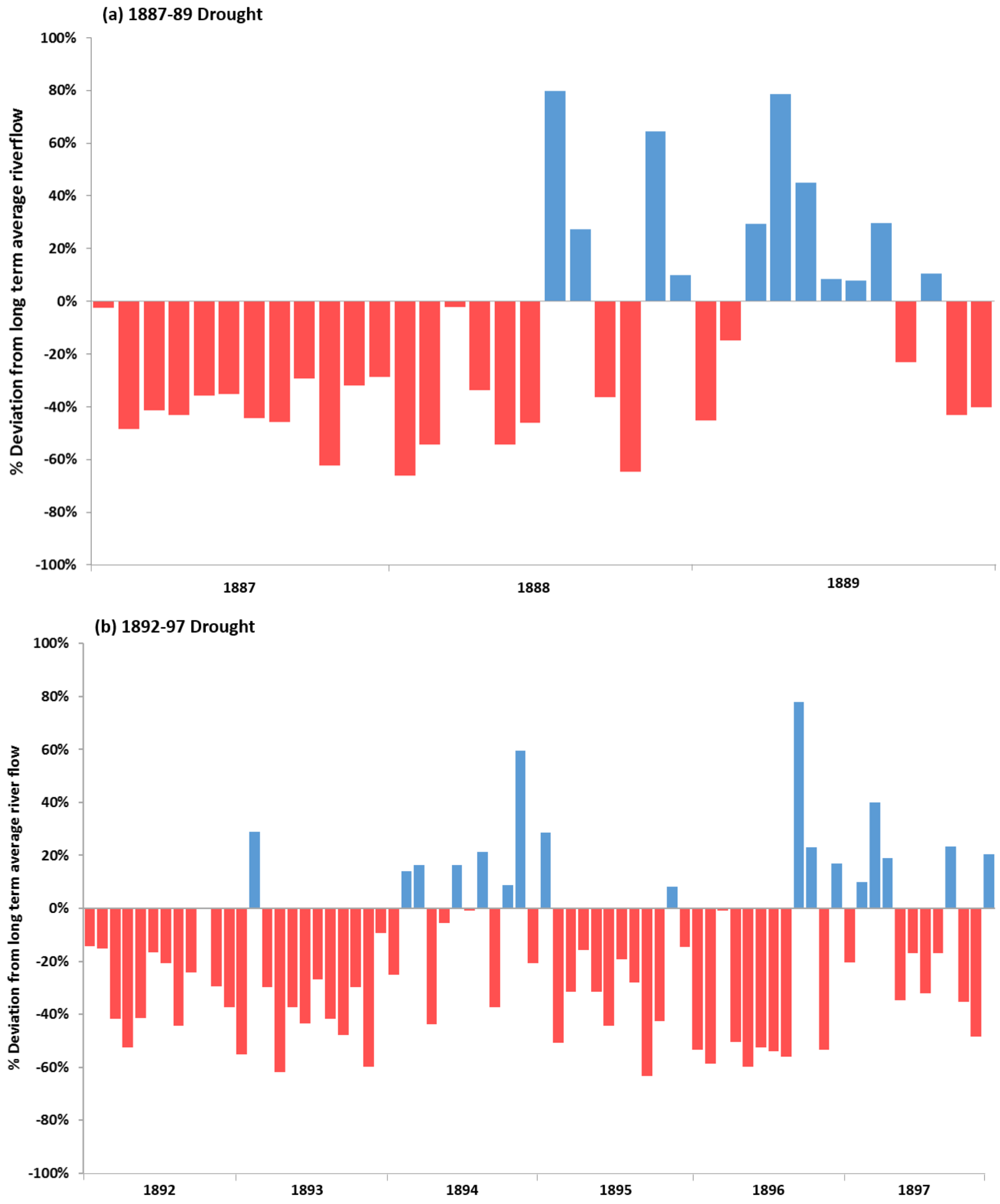
1. late 19th Century droughts
2. drought response surfaces
3. stochastically generated drought scenarios

Late 19th Century droughts

Our baseline modelling to assess deployable output uses 95 years (1920-2014) of climate data and this period captures a number of historic droughts (1921, 1933-34, 1975-76). This allows us to test how our current water resource system would respond if those events were to occur within our 25-year planning period (2020-2045). However, as each drought is unique (in duration and severity), it is important to understand how our system responds to different droughts. We simulated what could happen to our current system if we had a repeat of the long dry periods that occurred between the 1880s and 1910s. We know through Research and Development (R&D) work with the University of Liverpool that some of these droughts were more severe or lasted for longer than the droughts observed in our 95-year observed record. Part of this R&D work involved the co-funding of a PhD project which used historic climatic data to improve our understanding of drought characteristics, propagation and impacts on water resources across the Severn Trent region. This research has better enabled us to quantify this challenge.

Our analysis of historic climate data identified two notable droughts- (1) 1887-89 and (2) 1892-97. The 1887-89 drought ranks as one of the most severe 24-month droughts in the 1884 – 2014 record in our region (Figure A9.1). Between January 1887 and December 1889 25 of the 36-months have flows below the long-term average conditions. Whilst the 1887-89 drought was identified as a severe flow deficit event the 1892-97 drought was one of the longest duration events observed in our region (Figure A9.1).We used historic records of rainfall available across our region dating back to 1884 to create a 131-year dataset to investigate the impact of the identified historic droughts. We used this rainfall data to model river flows using the same rainfall-runoff modelling approach outlined in section A2. We also used groundwater models with the historic climate data to reconstruct groundwater levels and borehole output for the extended analysis period. We then used this modelled river flow and groundwater data in our water resource system model (Aquator) to assess whether the historic droughts had an impact on deployable output. Results of this extended modelling showed that the late 19th Century events did not reduce the deployable output values calculated using our 95-year baseline record. However, our extended 1884-2014 modelling results did highlight the severity of these earlier droughts. For example, we would have had to implement temporary use bans in 1896 and 1897 in the final two years of the 1892 – 1897 drought. As this work is based on a limited number of rain gauges, there is more uncertainty than there is in our current 95-year record. Therefore, we are only using these droughts as scenarios to test our water resources system rather than part of our baseline deployable output modelling.

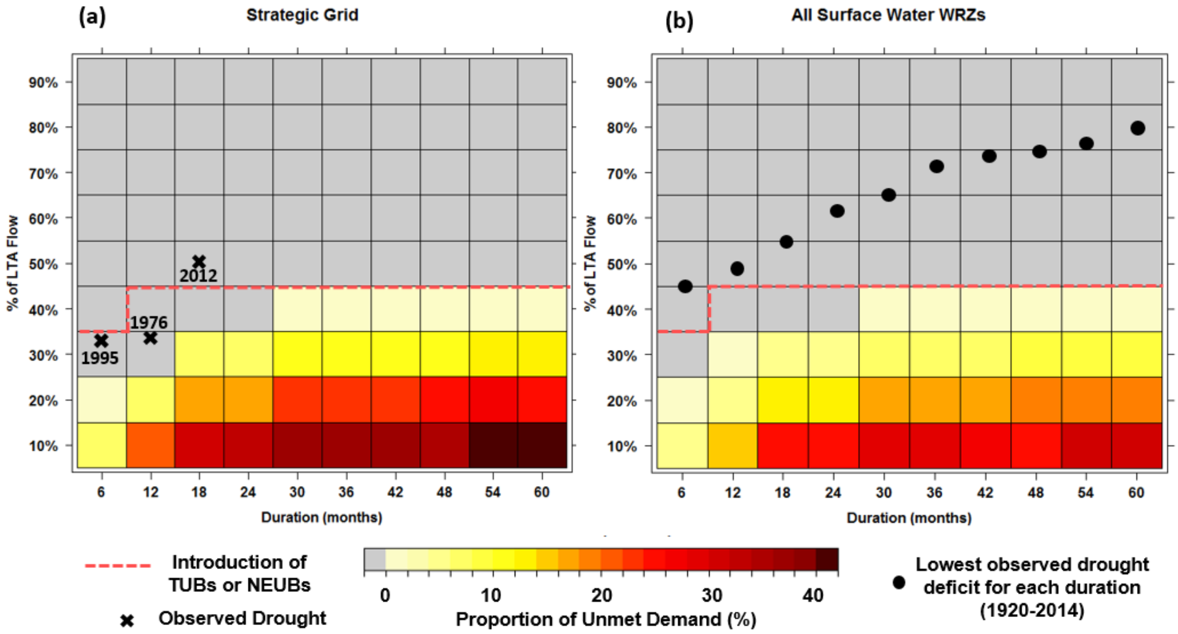
Figure A9.1: Late 19th Century Drought events- (a) 1887-89 and (b) 1892-97



Drought response surfaces

The EA produced a report in 2016 entitled "Understanding the performance of water supply systems during mild to extreme droughts". We have used the approach outlined in the report to show the impact on customers of droughts with different durations and different river flow deficits (severities). A river flow 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 water flowing down a river than average we would refer to this as a 50% of long term average (LTA) river flow deficit; Figure A9.2 below illustrates this. Each of the 81 boxes represents a different drought scenario. For example, the box in the bottom right represent the exceedingly unlikely scenario in which there is only 10% of average river flow for 60 months (5-years). By contrast the box in the top left is the much more likely scenario of having 90% of average river flow for six months. In the example below (Figure A9.2) we have used colour coding to show the proportion of demand that would not be met for each of the 81 drought scenarios. The grey boxes show that all water demands can be met whilst the boxes shaded from yellow to dark red indicate the proportion of demand that would be not met under each drought scenario. We have developed drought response surfaces for the WRZs that we model in Aquator. As this approach requires Aquator modelling we did not use it for the other (groundwater only) WRZs. These other WRZs are more drought resilient (see later section on drought risk composition). We consider that producing drought response surfaces would be disproportionately complex for the WRZs that have high drought resilience.

Figure A9.2: Drought Response Surface for the (a) Strategic Grid WRZ and (b) all surface water WRZs



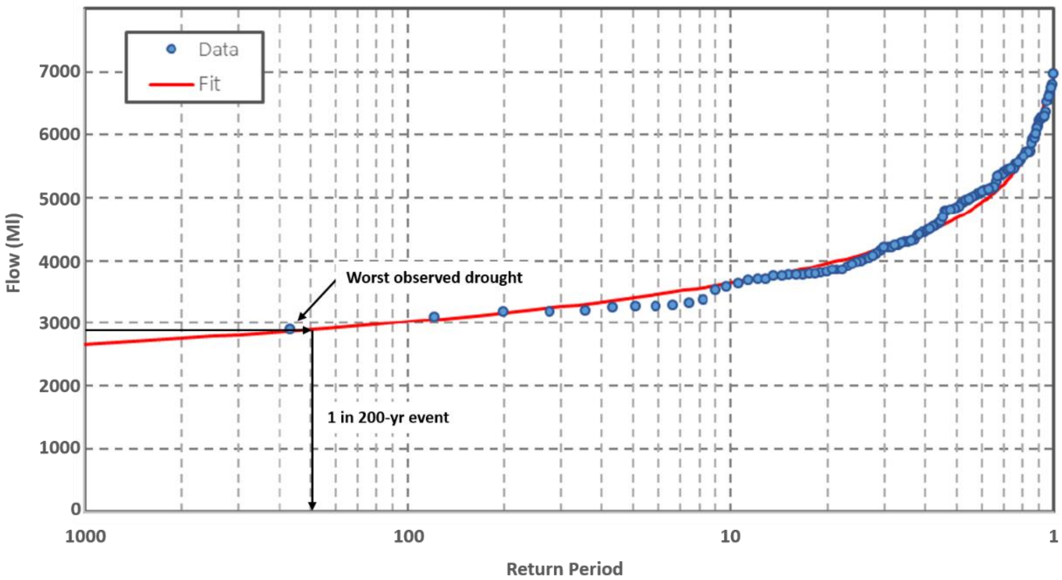
We developed these drought response surfaces by using synthetic droughts for severity and duration characteristics between 6- and 60-months for river flow deficits between 10% (most severe) and 90% (least severe) of the long-term average conditions. We created 81 synthetic drought scenarios using our baseline observed data from 1920 and 2014. We produced these synthetic droughts by selecting a month known to have been part of a drought e.g. January 1976, February 1995 etc. for each month of the year to develop a "drought profile" to represent river flow characteristics during a drought which could then be scaled to reflect each of the duration/severity scenarios. Under each scenario the drought begins in April with a varying end month to reflect the drought duration e.g. a 6-month drought would have an end date of September. We used this process to create scenarios for the 64 river catchments we use in our Aquator water resources model. We then used each scenario to model whether supply can meet demand. We plotted the results of this onto a grid using a range of colours to represent the impacts. We added additional information to the drought response surfaces to show the characteristics of past significant droughts (see Figure A9.2a) and the lowest observed river flow deficit for all durations between 6- and 60-months (see Figure A9.2b). This information provides useful context for how plausible the synthetic drought scenarios are compared to observed events. We have used elements of the UKWIR Drought Vulnerability Framework project when preparing our drought plan and dWRMP18.

Stochastic Drought Scenarios

In order to test how our water resources system responds to droughts that are worse than those observed in our baseline and in the 19th Century analysis we adopted an additional approach. The approach we selected was the creation of a number of stochastically generated drought 'what if' scenarios that haven't happened but plausibly could. The WRMP19 Methods – Risk Based Planning: Guidance (UKWIR, 2016) has informed the techniques we have used to develop our stochastic drought scenarios. We created our scenarios using a stochastic weather generator to develop 200 'what if' drought scenarios. Stochastic weather generation is a modelling technique which uses the relationship between climate drivers and our observed rainfall data over the 20th Century. We then used these 200 sets of rainfall data and corresponding evapotranspiration data to model river flows using the same rainfall-runoff methods used for our baseline DO assessment and the 19th Century drought assessment. We also used the stochastic rainfall and evapotranspiration data to model groundwater level changes within spreadsheets. We then transposed these data onto Source Performance Diagrams (explained more in section A2) to determine the corresponding borehole deployable output.

To select drought scenarios which are more severe than observed events we used extreme value analysis (Site S) techniques to assign return periods to observed droughts and to estimate the return periods of more severe events. The graph in Figure A9.3 shows an example of how we have used these techniques. This example is for 18-month duration droughts but we have also used similar techniques for droughts of different durations. The blue circles represent actual river flows accumulated over an 18-month period for each year across the 130-year flow record. We derived the red line statistically from the observed data and used it to estimate the return periods of 18-month droughts up to 1 in 1000 year events. We used the same type of Site S approach to estimate the return periods of 24-month and 30-month droughts with return periods up to 1 in 1000-years.

Figure A9.3: Example of Extreme Value Analysis to estimate drought return periods



The Site S enabled us to estimate what the total accumulated river flows would be across our region for droughts with a specific event duration and return period (severity). For example, in Figure A9.3 an 18-month duration 1 in 200-year event has an estimated 18-month flow total of 2900 Ml. We then searched the 200 stochastic flow scenarios to identify a similar 18-month accumulated flow value. We repeated this process a number of times to identify suitable droughts to test our water resources system for droughts with duration characteristics of 18-, 24- and 30-months and for return periods (drought severity) up to approximately 1 in 1000-years. From the 200 stochastic scenarios, we selected 30 for analysis in our Aquator model. See Figure A9.4 for an overview of our stochastic drought scenario generation and modelling. We have also added borehole deployable output values in to the Aquator model to account for changes in output from our groundwater sources (see Figure A9.4). As the surface and groundwater drought stochastic scenarios were developed using differing methods the borehole deployable output values have a smaller range of return periods (1 in 200-years and 1 in 500-years) than the surface water scenarios. In our Aquator modelling the surface water scenarios with a return period greater than 1 in 500-years are all modelled using 1 in 500-year groundwater DO values. As there is little variability between the stochastic groundwater DO values we consider this a suitable modelling approach.

Results of this modelling indicates that for a range of drought scenarios between 1 in 190-years to 1 in 330-years there is a small reduction in DO in the Forest and Stroud WRZ. This is reduction of 2 Ml/d. In all other WRZs these drought scenarios had no reduction in DO from the baseline 1920-2014 modelling. We found that larger decreases in deployable output occurred for scenarios with return periods between 1 in 500-years and 1 in 1000-years with a maximum deployable output reduction at approximately -230Ml/d for a 1 in 1000-year 24-month drought. We have presented a selection of drought scenario DO values in Table 10 of our WRMP data tables.

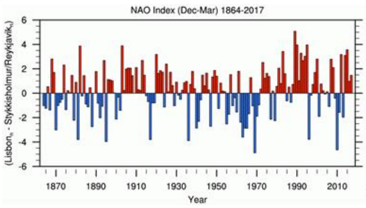
We note that drought is a complex phenomenon, the events we have selected for analysis provide an understanding of how future severe droughts could impact our water resource system however the results should only be regarded as estimates. This is recognised by the EA guidance on the completion of WRMP19 tables which describes some of the more extreme scenario values they expect to be in WRMP table 10 as “a series of estimates”. Although this is true we will continue to stay abreast of relevant R&D and innovation as techniques, modelling and knowledge improves. We will reflect these advances in our future plans. Whilst two drought events could have the same return period and duration (e.g. a 1 in 500 18-month event) the unique characteristics of these droughts could result in different water supply impacts. However, by analysing a large number of drought scenarios with varying drought characteristics we are able to better understand a range of potential impacts and provide challenging drought scenarios for our investment modelling.

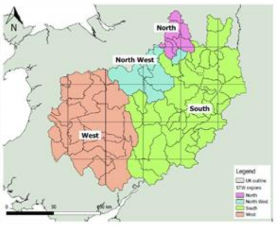
We also note that there is some uncertainty in estimating the return periods of our extreme droughts. Whilst extreme value analysis is a very useful method, return period estimates are dependent on number of factors including data length and the choice of statistical analysis approaches. We have improved the robustness of our Site S estimates by using our extended flow records developed through the 19th Century drought analysis. This provided 130 years of data rather than the 95 years of our baseline data. The longer dataset provided a wider range of flow conditions including a larger number of droughts which has resulted in a better quantification of drought return periods.

We have worked in close collaboration with South Staffordshire Water (SSW) to ensure we assess the impact of extreme droughts in a way that is consistent with this neighbouring company. It is particularly important that we are consistent with SSW in work of this sort as we both operate within the River Trent and River Severn hydrological catchments. We share one source on the River Severn and we share our Aquator models and output too. We have also been in contact with Dwr Cymru Welsh Water (DCWW) to compare consistency between our stochastic drought inflows for the Elan Valley Reservoirs.

Figure A9.4: Stochastic Drought Analysis Flow Diagram

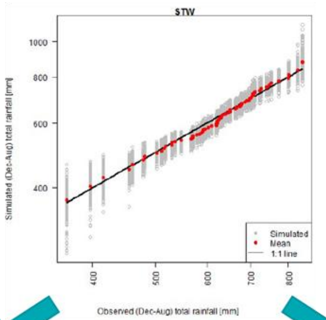
Stochastic Drought Analysis Flow Diagram





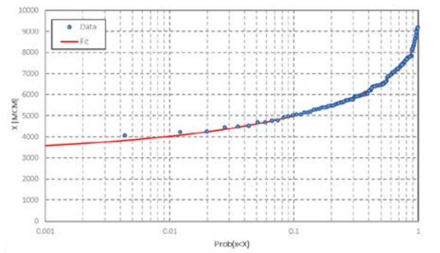
Statistical relationship between observed rainfall across our region and climate drivers used to develop weather generator model.

Observed rainfall records covering our region from 1920 to 1990 (71 years) are used by the weather generator to create 200 'what ifs' that contain a number of drought phases that are more severe than in the observed records.



Surface Water

The 200 rainfall and evapotranspiration scenarios are used to model river flow across the 64 catchments in our region using the rainfall-runoff model Hysim.



Extreme value analysis is used to estimate the return period of droughts with specific durations e.g. 18-, 24- and 30-months. Each return period and drought duration will have an associated 'target' river flow total. The 200 scenarios are searched for these 'target' river flows to identify 30 scenarios with return periods between 1 in 200 and 1 in 1000 years.

Ground Water

The observed rainfall (P) and evapotranspiration (PET) records are analysed to estimate accumulated values for droughts with return periods between 1 in 200 and 1 in 500 years with durations of 18-, 24- and 60-months. These target values are used to identify 6 corresponding droughts within the 200 'what if' rainfall scenarios.

The P-PET data for the worst case historical droughts, and the corresponding 6 synthetic droughts, are used with the groundwater GR2 models to determine changes in groundwater levels from droughts.

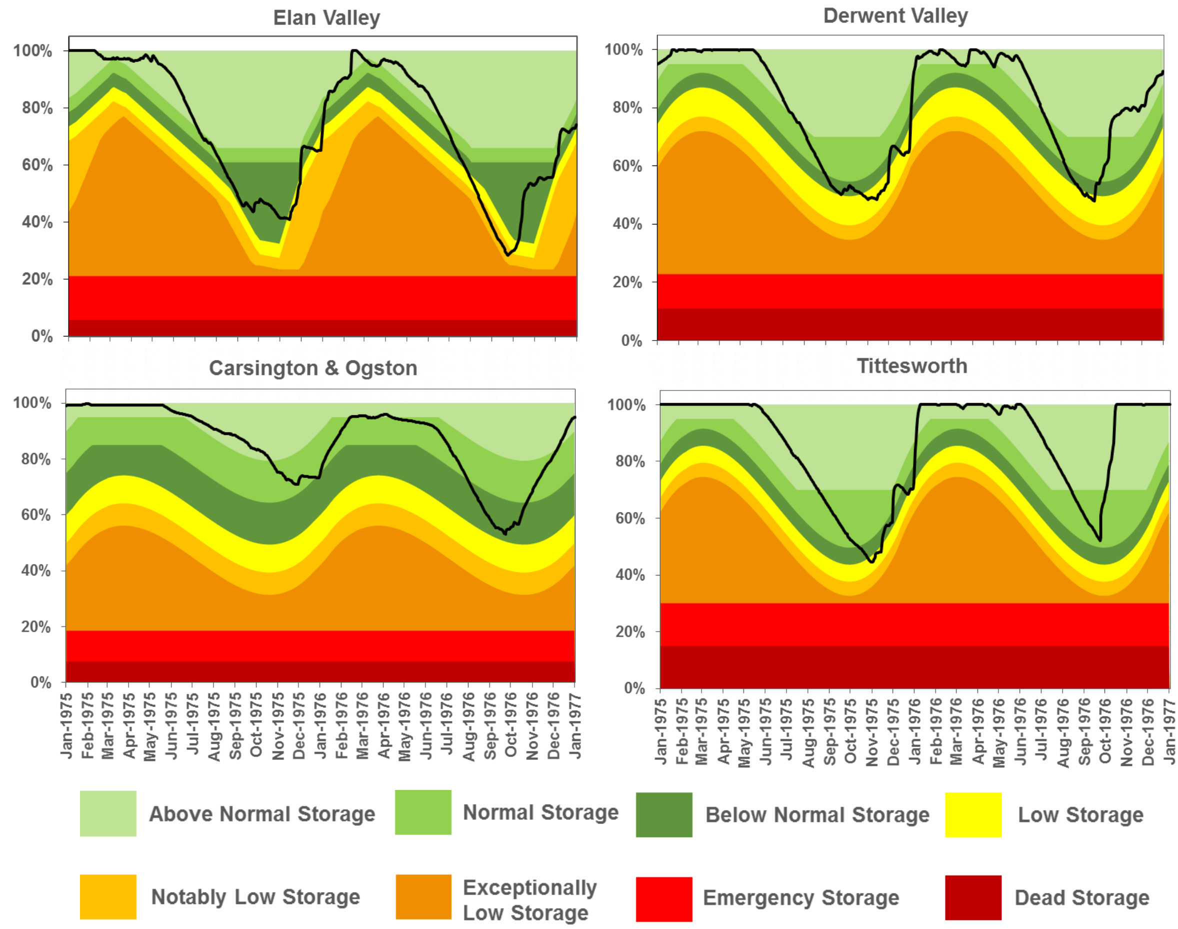
Changes in Deployable Output at the groundwater sources are calculated from the modelled groundwater level change and the transposition on to the source performance diagram, to indicate a range of DO changes for drought scenarios with return periods between 1 in 200 and 1 in 500 years.

30 scenarios modelled in Aquator to provide a range of deployable output values. This allows us to better understand how droughts with different severity and durations can impact on water resources.

Design drought

The Water Resource Management Plan Guidelines state that our base supply forecast should be based on a design drought which should be either (1) our worst drought on record or (2) a more challenging event. Our base supply forecast uses our baseline flow record (1920-2014) therefore, our design drought is our worst historic drought; 1975-76. This analysis period also includes a number of other droughts to test our base supply forecast (e.g. 1933-34 and 1995-96). Analysis of our baseline flow record and our extended 19th Century record indicated that accumulated river flows in the 18-months from April 1975 to September 1976 were the lowest across our region. The selection of our worst historic drought was also informed by our stochastic drought modelling results which identified a very minor change in DO between the baseline data (1920-2014) and a 1 in 200-year stochastic event (-2 Ml/d). We observed significant reductions in DO for droughts with return periods between 1 in 500-years and 1 in 1000-years but we consider that using these events is unsuitable for our base supply forecast. In addition to our modelled findings, our customer research to date has indicated that customers show little appetite to pay for increased drought resilience, however, our customer research is ongoing (see A8.2 for more information). Figure A9.5 shows the modelled storage levels in four of our reservoirs during the design drought. We have plotted these with our drought trigger zones to highlight the impact of this event on the water resource system. These results show that this drought has the greatest impact on the Elan Valley and Derwent Valley reservoirs.

Figure A9.5: Reservoir Storage during Design Drought



Risk composition

We have developed our drought resilience work using the WRMP 2019 Methods – Risk Based Planning: Guidance (UKWIR, 2016). A key component of this guidance is the need to state our risk composition. This composition indicates how we have incorporated drought resilience into our WRMP analysis.

Table A9.1: 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 A9.1). In addition to our baseline supply forecast we have used our stochastic drought events to test our plan and examine the implications of more severe droughts on our investment programme through our Decision Making Unit (DMU) analysis. This choice of risk composition reflects the complexity needed as part of our wider decision making approaches (see appendices D and E 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) 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, Llandinam and Llanwrin, Ruyton, and Kinsall) and they are therefore risk composition 1- “conventional plan”. These WRZs were not included in the stochastic drought assessment as these zones to 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 A9.2: Risk composition used for each WRZ

WRZ	Risk composition	Comment
Strategic Grid	Composition 2 - “resilience tested”	Conjunctive use WRZ
N. Staffs	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
Llandinam and Llanwrin	Composition 1	As above
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 10 of the WRMP data tables provides a link between the WRMP and Drought Plan. Within Table 10 we report a range of deployable output values from our drought resilience modelling. We based these DO numbers on a number of model runs which includes DO for historic droughts in our baseline data (1920-2014) and for a number of stochastic drought scenarios with return periods between 1 in 200-years and 1 in 1000-years. In both cases we report DO values for three conditions- (1) no demand saving restrictions, (2) with demand saving restrictions e.g. demand savings linked to Temporary Use Bans (TUBs), and (3) with 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 2014 Drought Plan. We will also include them in our next drought plan which is due for draft submission in February 2018.

Our baseline supply forecast does not include drought permits or drought order interventions but it does include several 'lower level' drought actions. For example, we list several drought management actions in our drought plan that we consider when we are in drought trigger zones C or D. Refer 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 is 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 10 of the WRMP tables. The table 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 A9.3: Estimated yield from supply side drought interventions

WRZ	Drought measure/ source	Estimated peak yield Ml/d	Estimated average yield Ml/d	Comment
N. Staffs	None	n/a	n/a	n/a
Grid	Witcombe	8.7	1.4	We assume this is licence constrained but we'd undertake flow gauging and/ or a hydrological yield assessment if we were going to use it.
Grid	Linacre	9.1	6.8	As above
Grid	Monkdale	2	1.5	As above
Grid	Stanley Moor	2.2	0.5	As above
Grid	Norton emergency	n/a	0.7	As above and in addition, we can't 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.
Grid	Beechtree Lane emergency	18.0	0.9	We assume licence constrained but we'd undertake flow gauging and/ or a hydrological yield assessment if we were seriously thinking of using it
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.
Notts	None	n/a	n/a	Covered by the Strategic Grid East actions that affect the Grid to Notts transfer
Llandinam & Llanwrin	Esgaireira Reservoir	n/a	1.1	We assume licence constrained but we'd undertake flow gauging and/ or a hydrological yield assessment if we were seriously thinking of using it
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 EA/ 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.

A9.2 Drought Resilience Statement

We have planned our system so that it can withstand any drought that is as severe as those we have seen over the last 95 years and up to a 1 in 200-year event. We have also tested our investment proposals against a range of plausible future droughts not seen in the historic record that have quantified probabilities for drought severity and duration. We are confident that our plans represent a good balance between cost, environment and resilience to severe droughts. Our stochastic drought modelling indicates that we are resilient to a 1 in 200-year drought without the need for emergency drought orders.

A10 Baseline supply projections

Bishops Castle Zone

Figure A10.1: Bishops Castle baseline deployable output

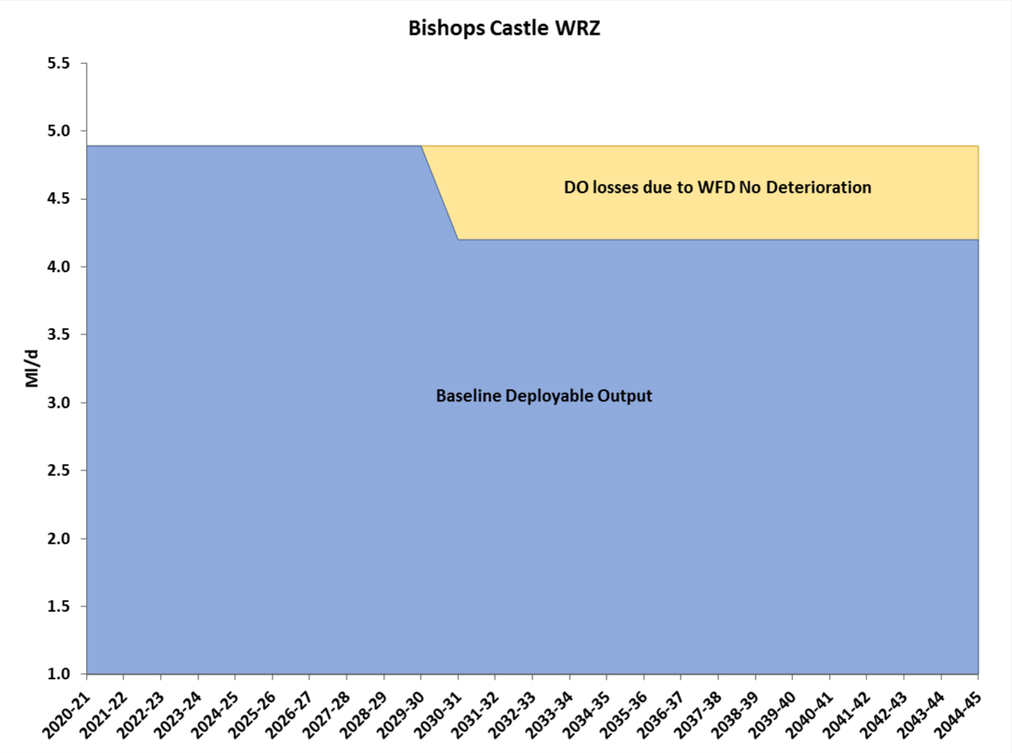
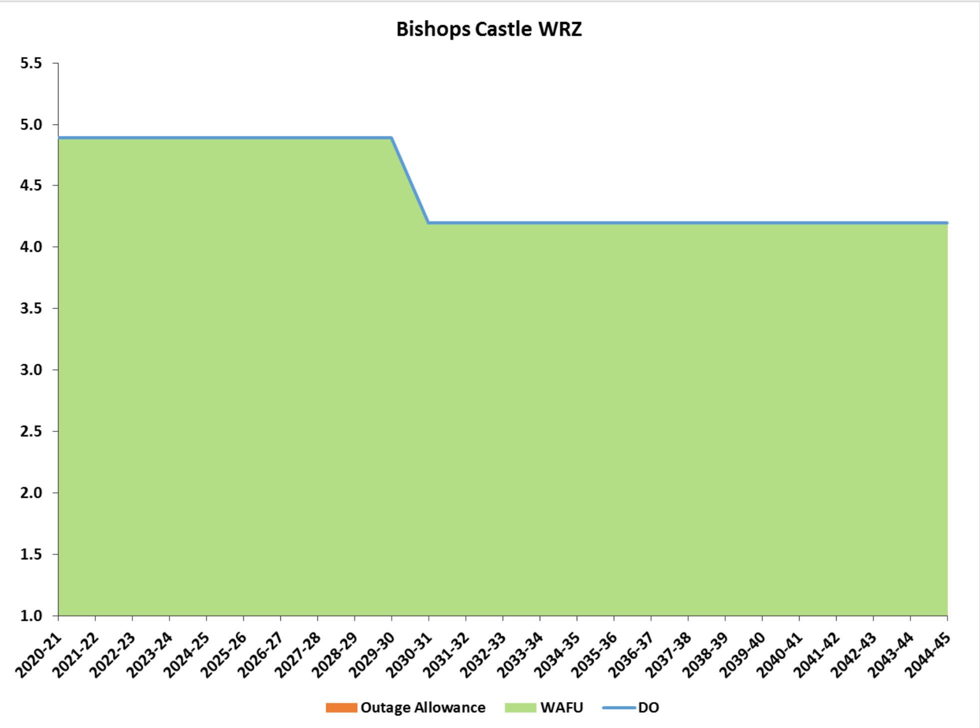


Figure A10.2: Bishops Castle baseline water available for use



Forest and Stroud zone

Figure A10.3: Forest and Stroud baseline deployable output

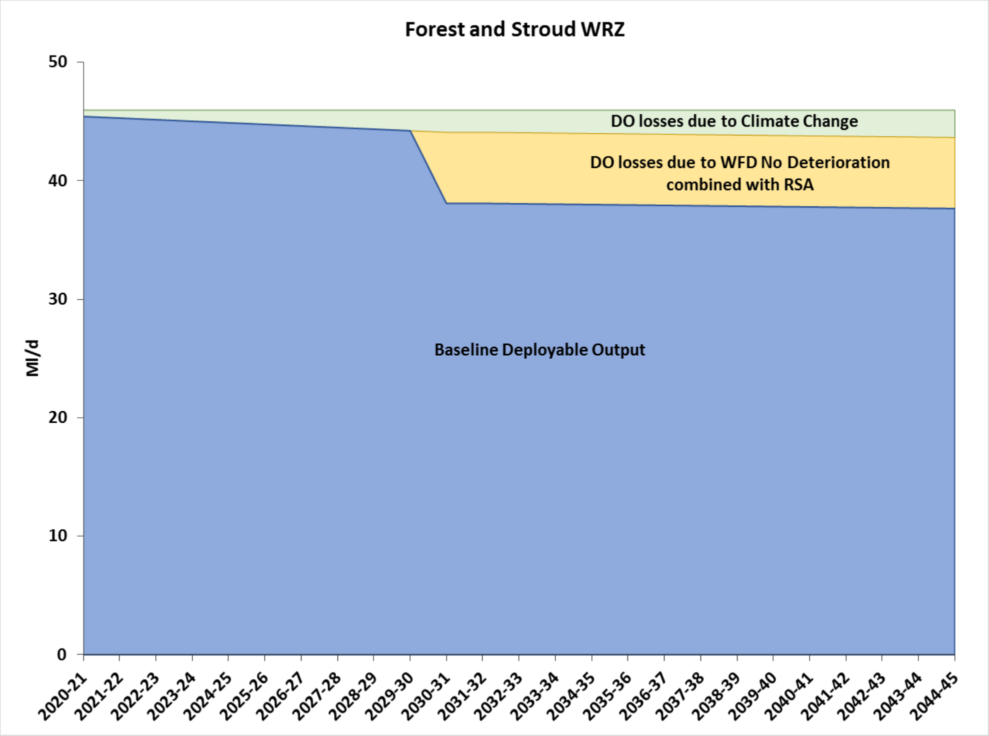
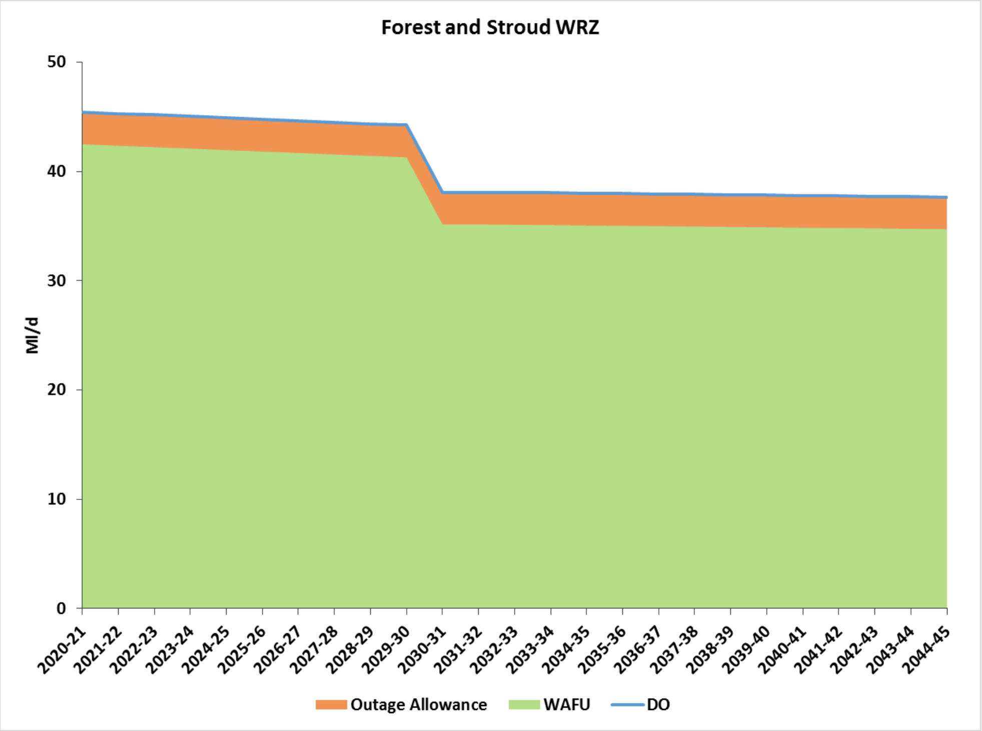


Figure A10.4: Forest and Stroud baseline water available for use



Kinsall zone

Figure A10.5: Kinsall baseline deployable output

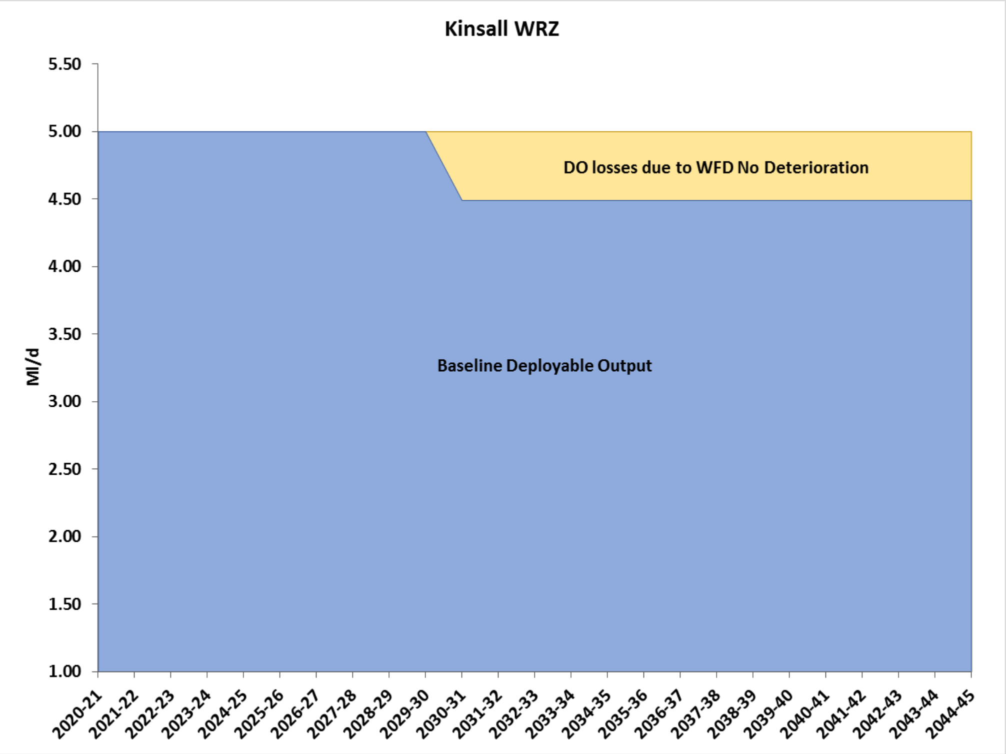
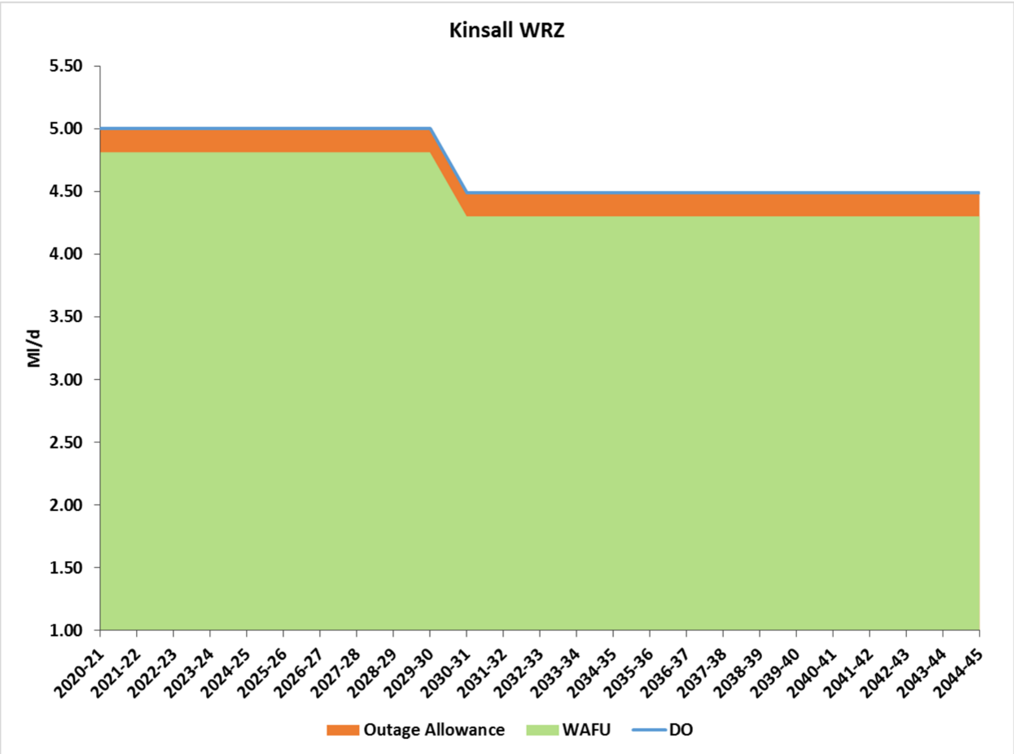


Figure A10.6: Kinsall baseline water available for use



Llandinam and Llanwrin zone

Figure A10.7: Llandinam and Llanwrin baseline deployable output

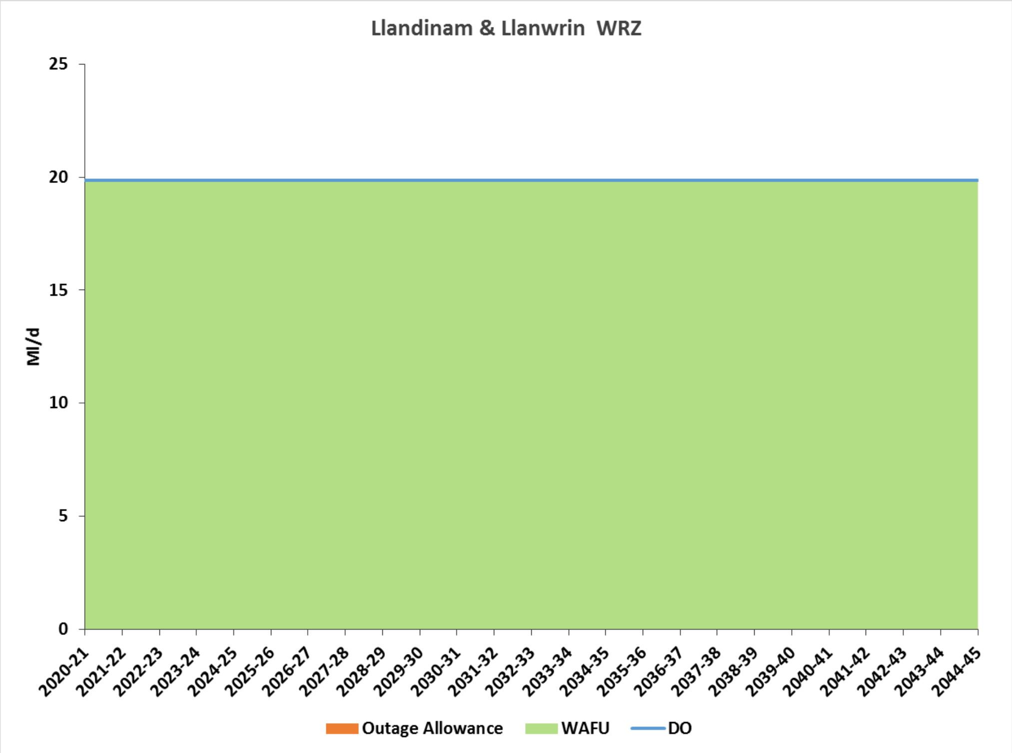
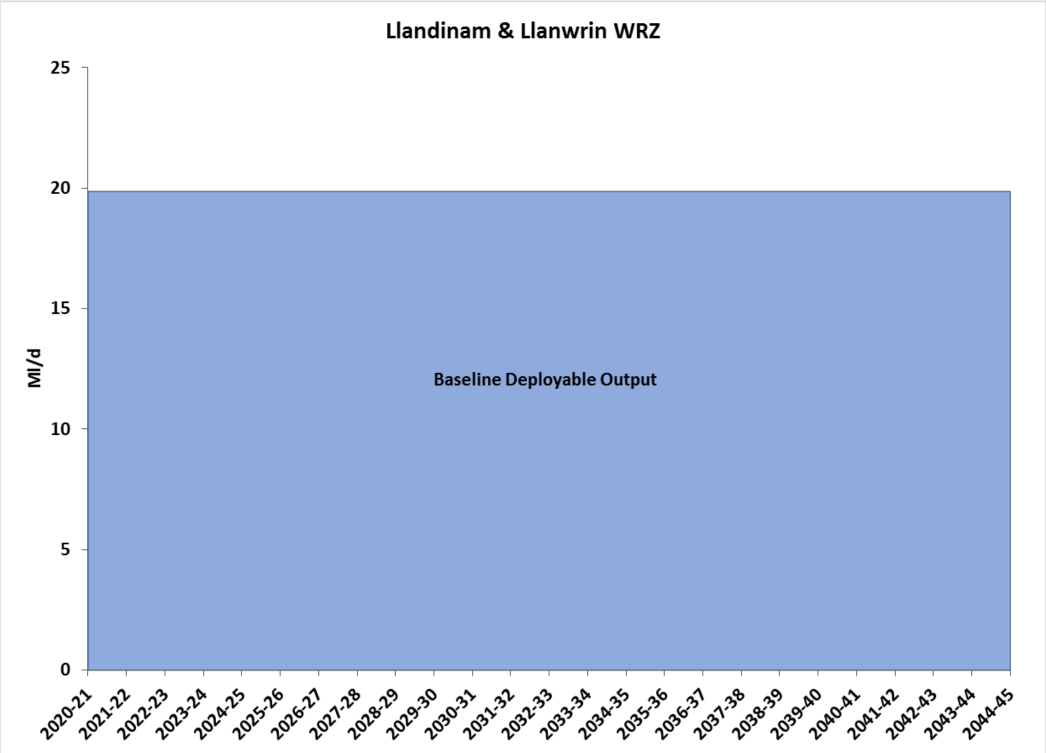


Figure A10.8: Llandinam and Llanwrin baseline water available for use



Mardy zone

Figure A10.9: Mardy baseline deployable output

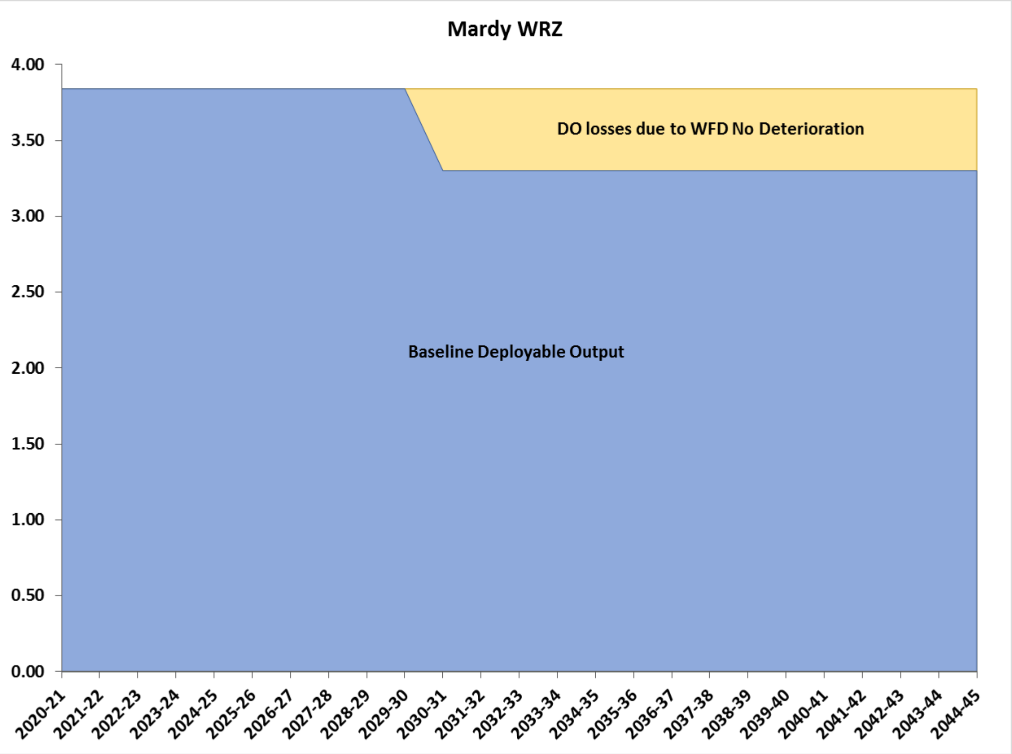
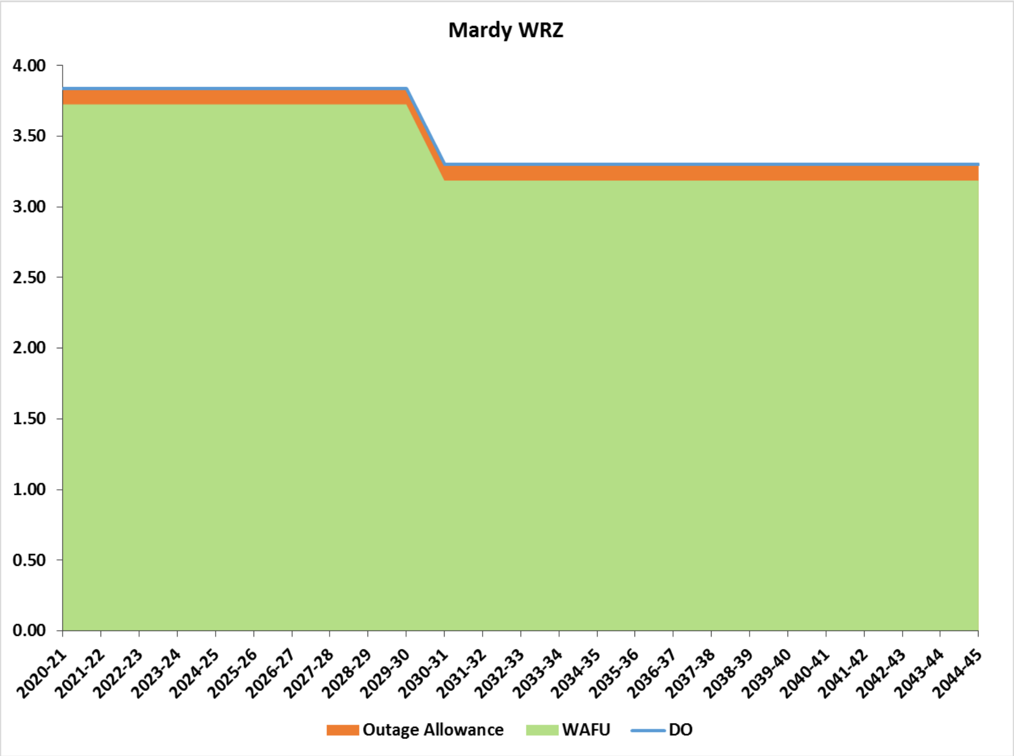


Figure A10.10: Mardy baseline water available for use



Newark zone

Figure A10.11: Newark baseline deployable output

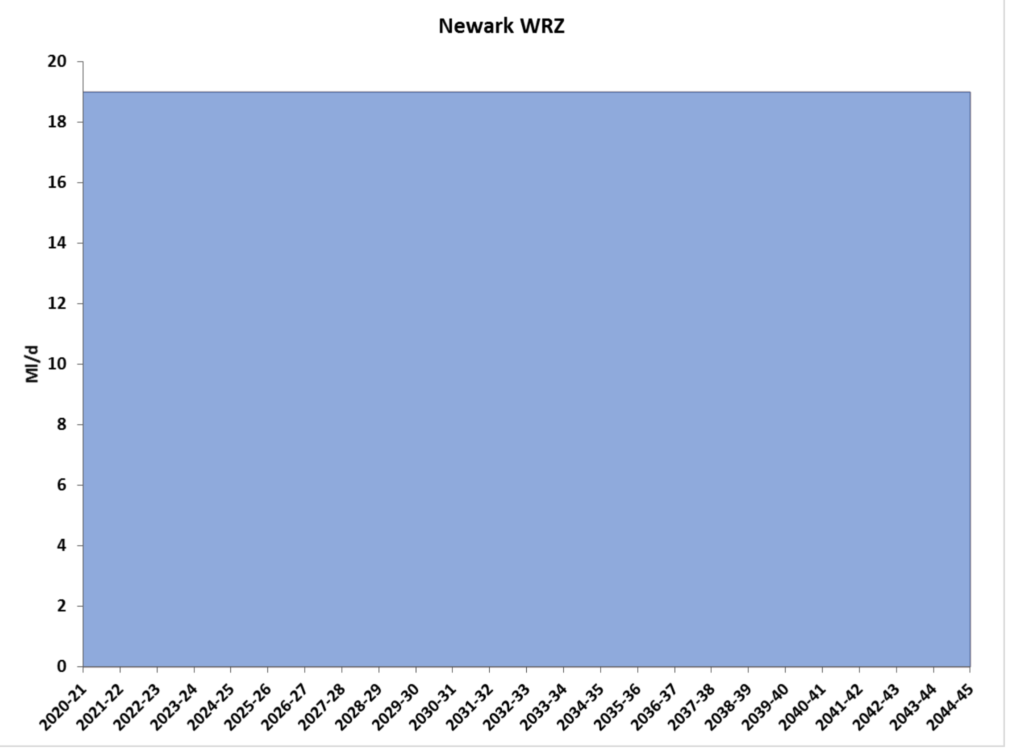
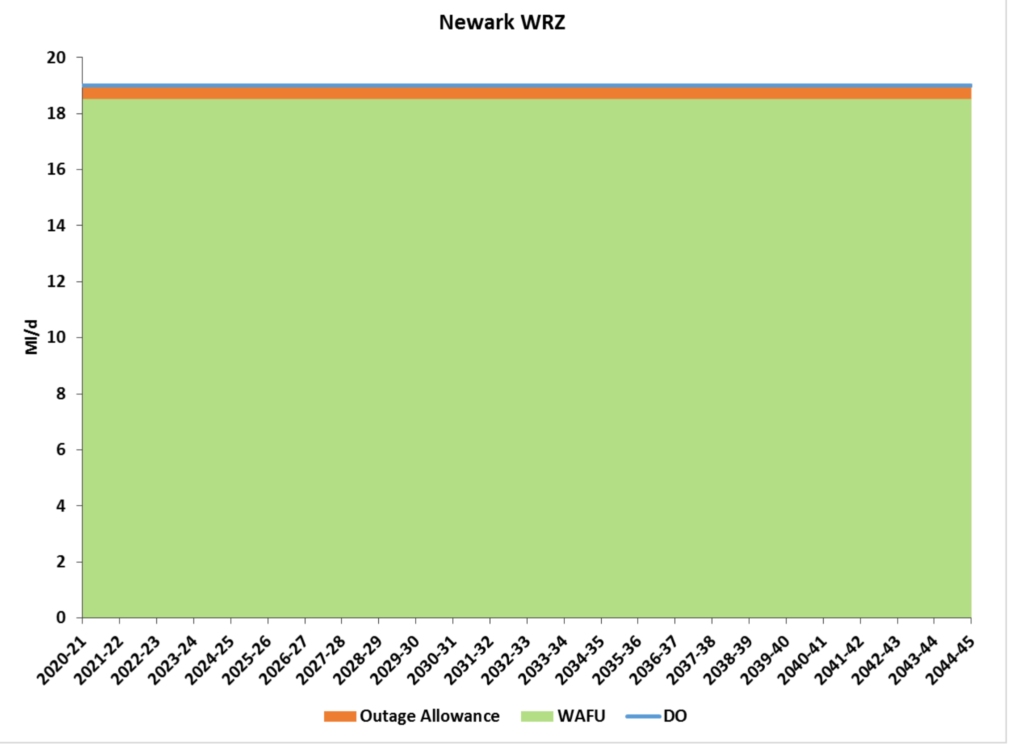


Figure A10.12: Newark baseline water available for use



North Staffs zone

Figure A10.13: North Staffs baseline deployable output

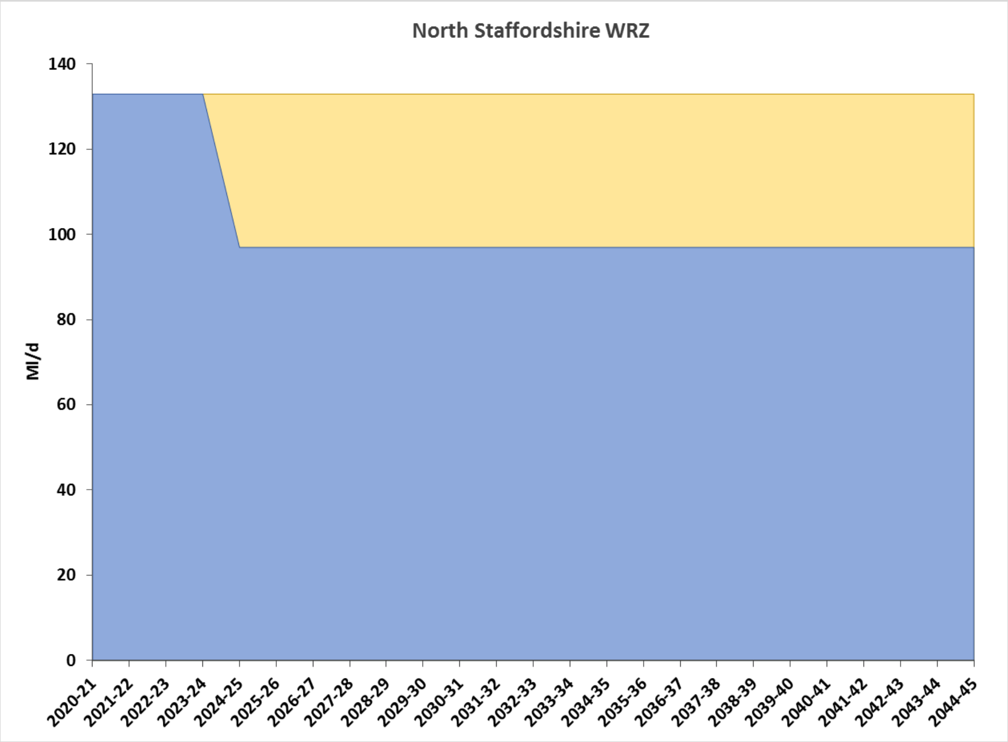
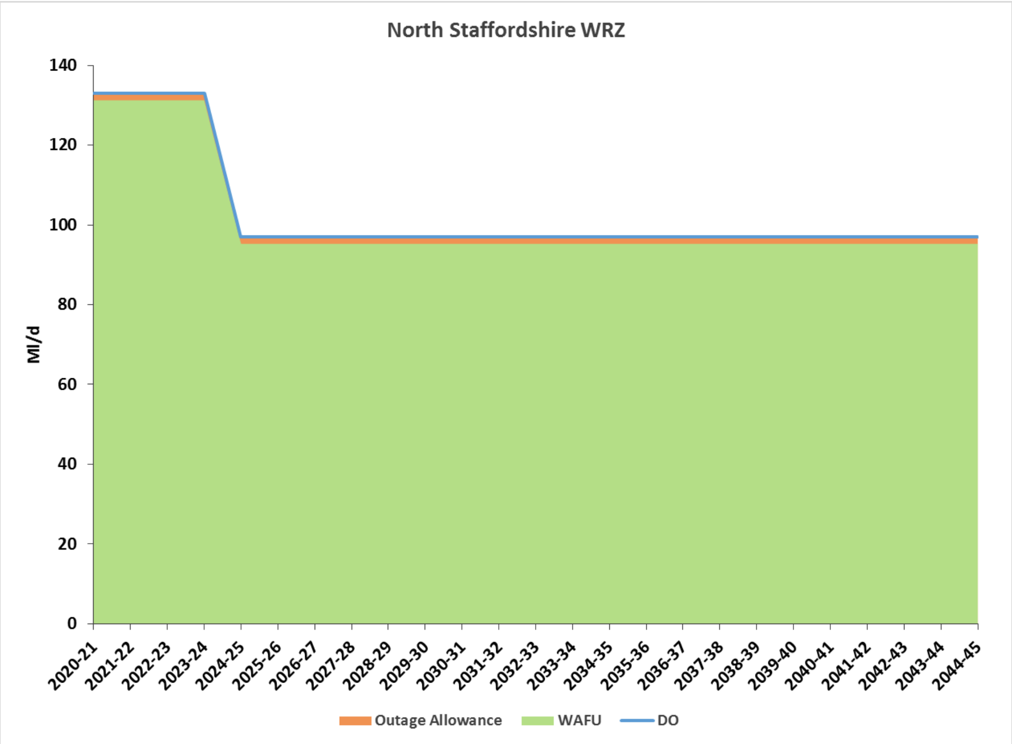


Figure A10.14: North Staffs baseline water available for use



Nottinghamshire zone

Figure A10.15: Nottinghamshire baseline deployable output

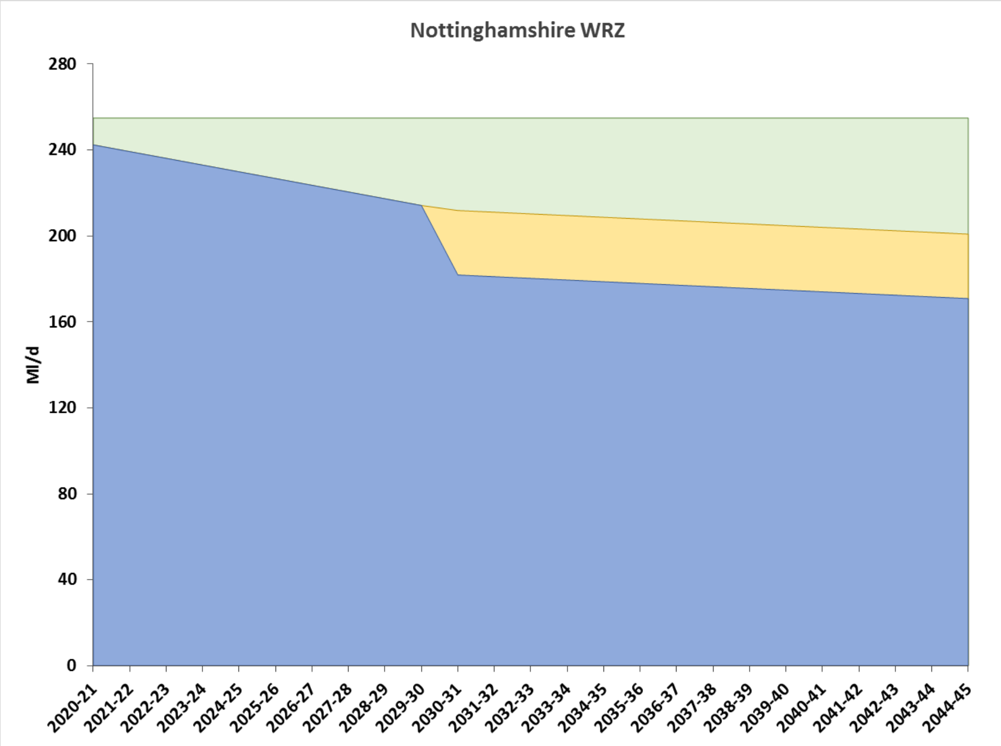
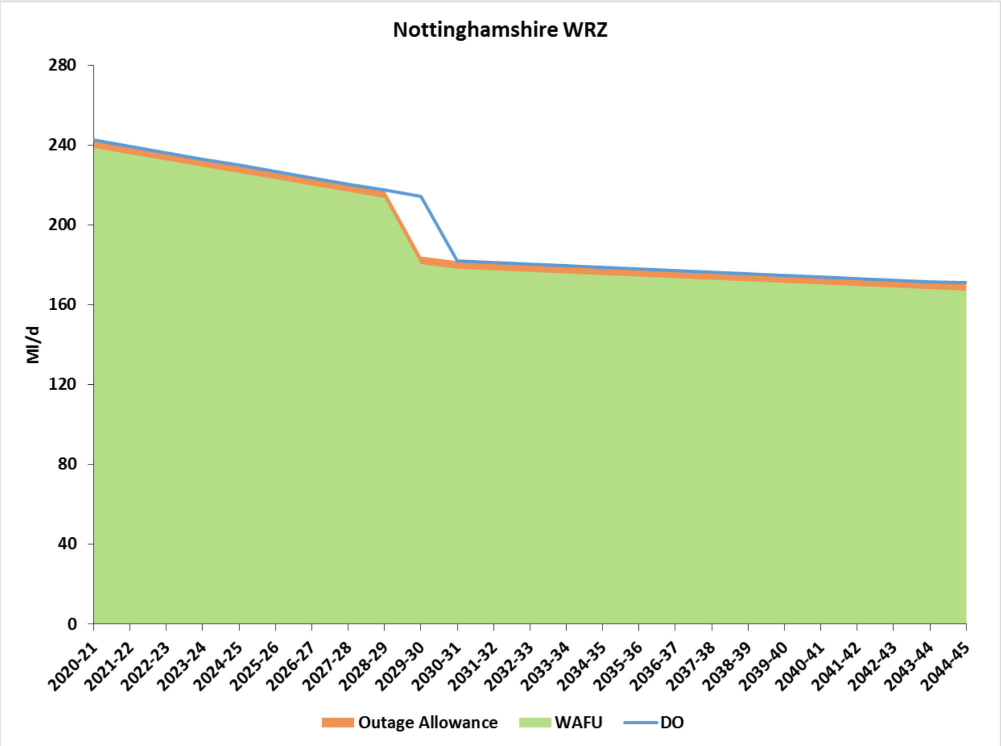


Figure A10.16: Nottinghamshire baseline water available for use



Rutland zone

Figure A10.17: Rutland baseline deployable output

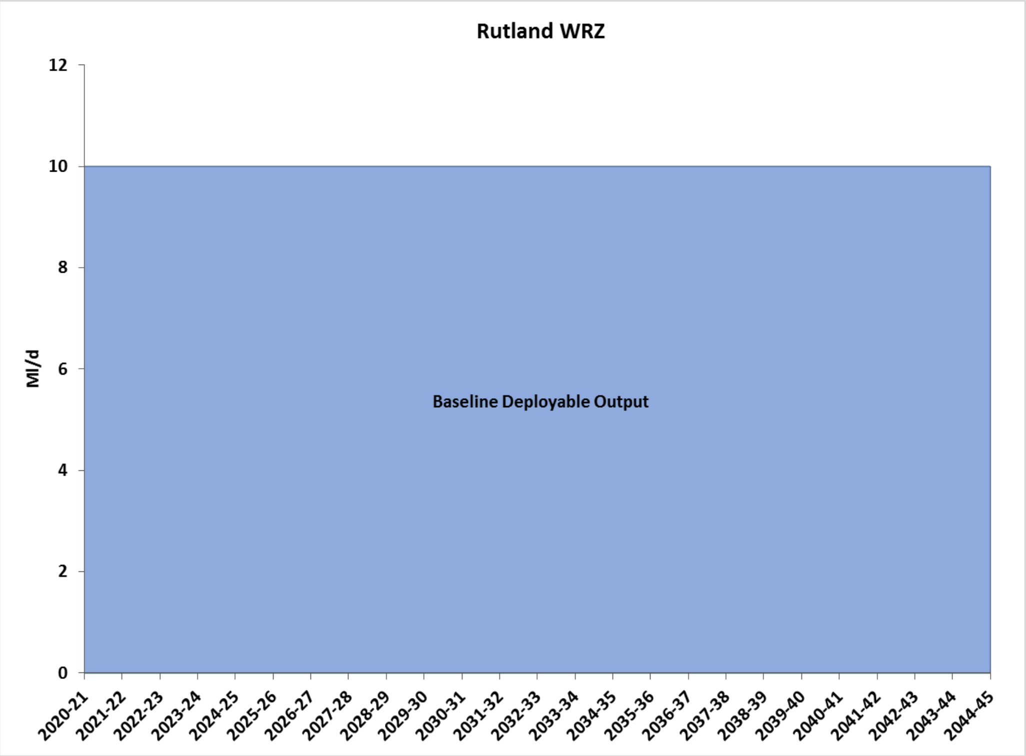
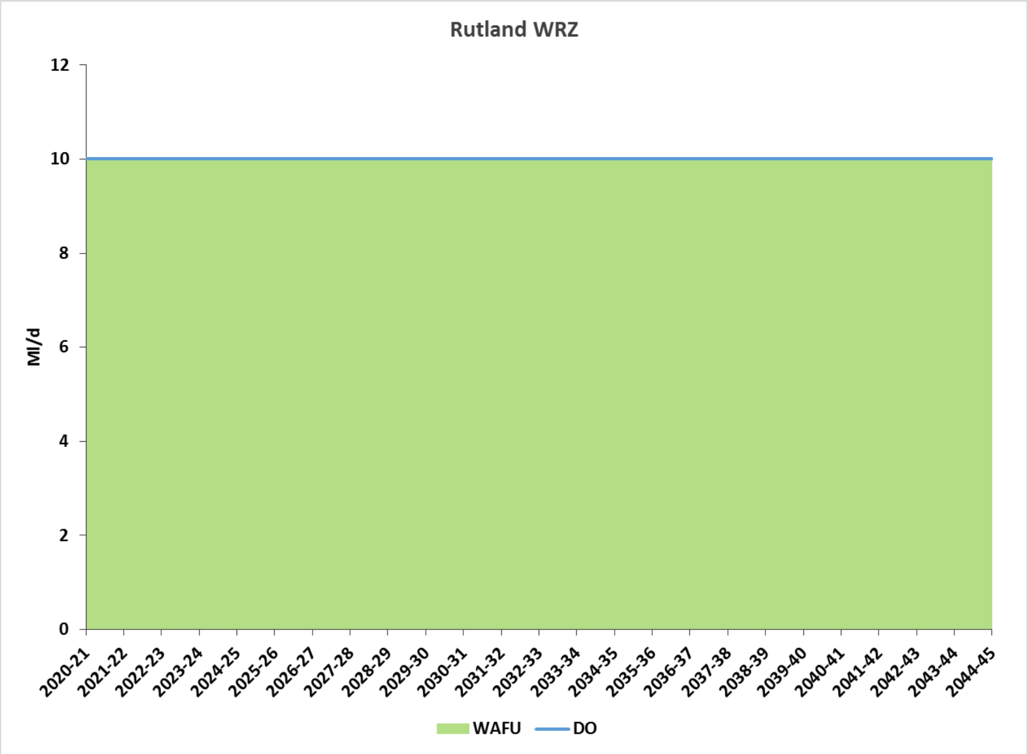


Figure A10.18: Rutland baseline water available for use



Ruyton zone

Figure A10.19: Ruyton baseline deployable output

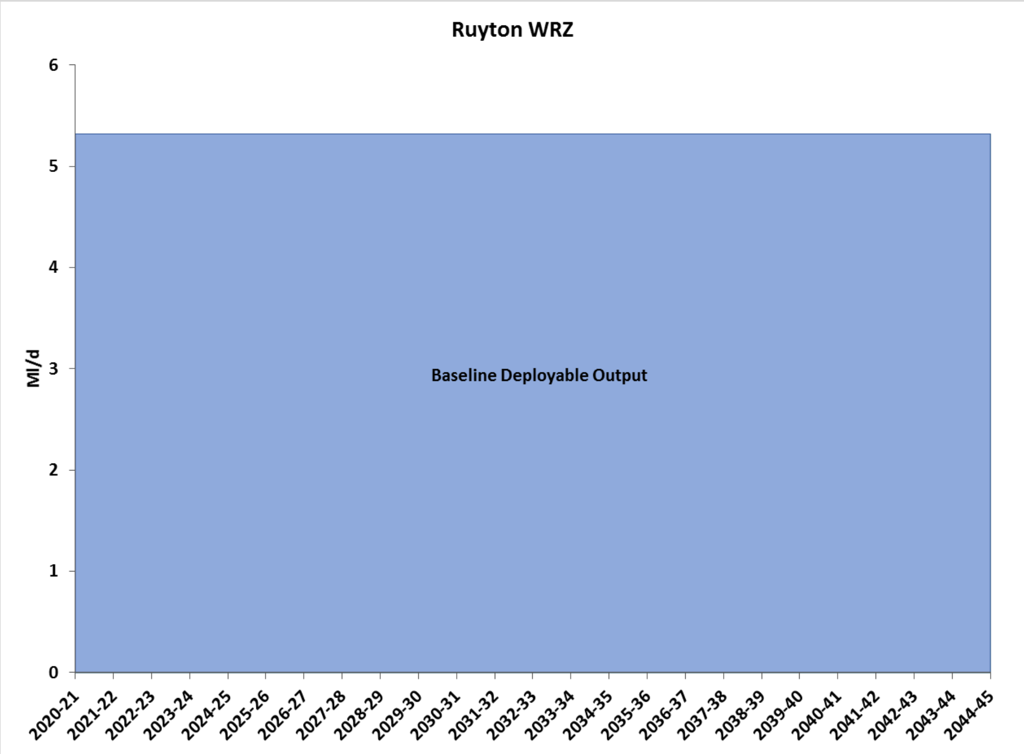
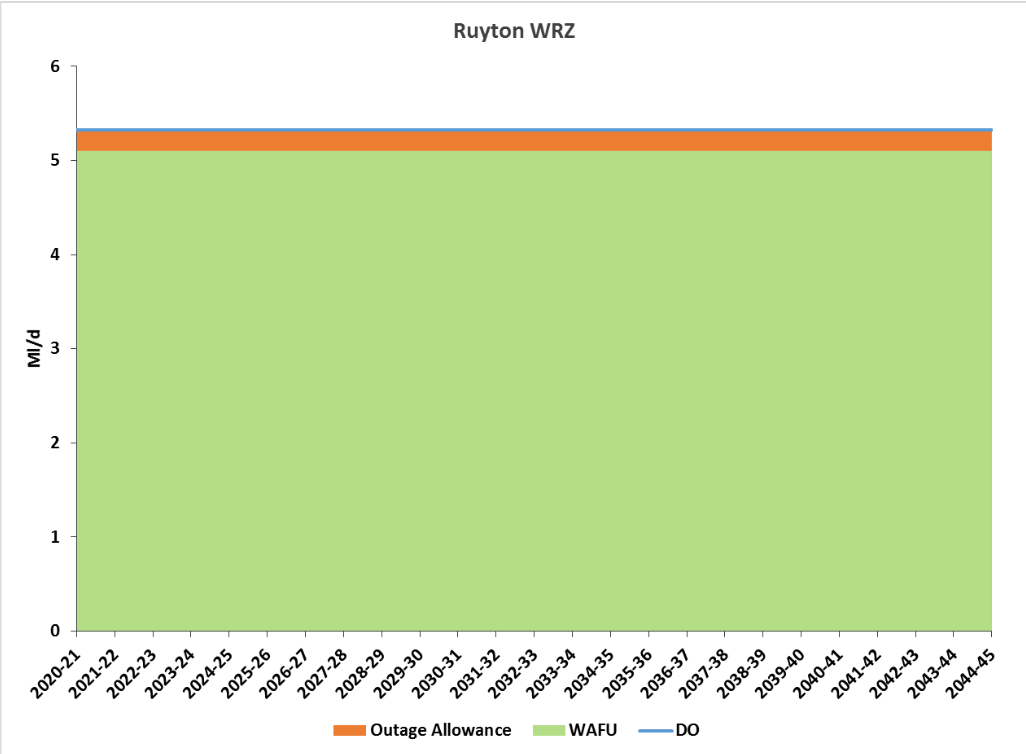


Figure A10.20: Ruyton baseline water available for use



Shelton zone

Figure A10.21: Shelton baseline deployable output

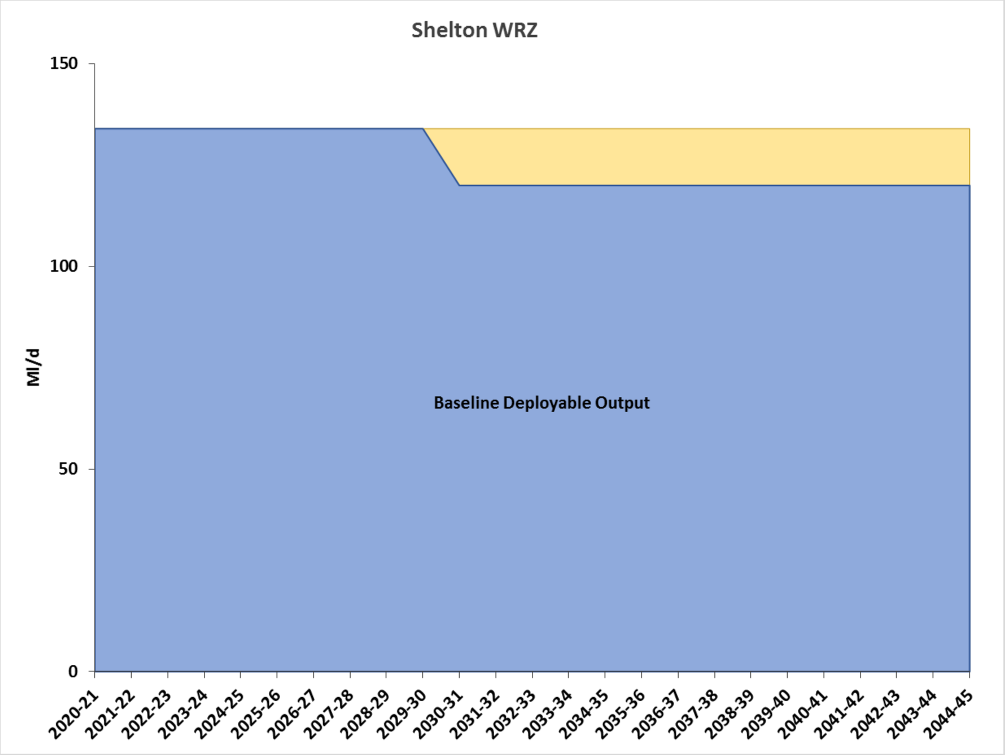
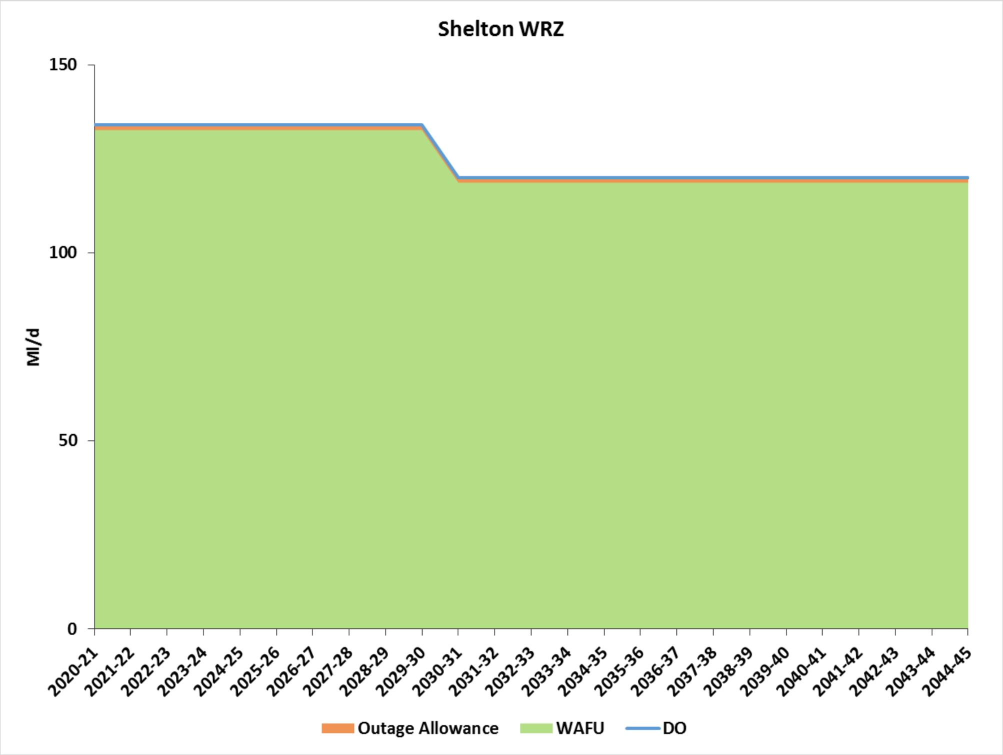


Figure A10.22: Shelton baseline water available for use



Stafford zone

Figure A10.23: Stafford baseline deployable output

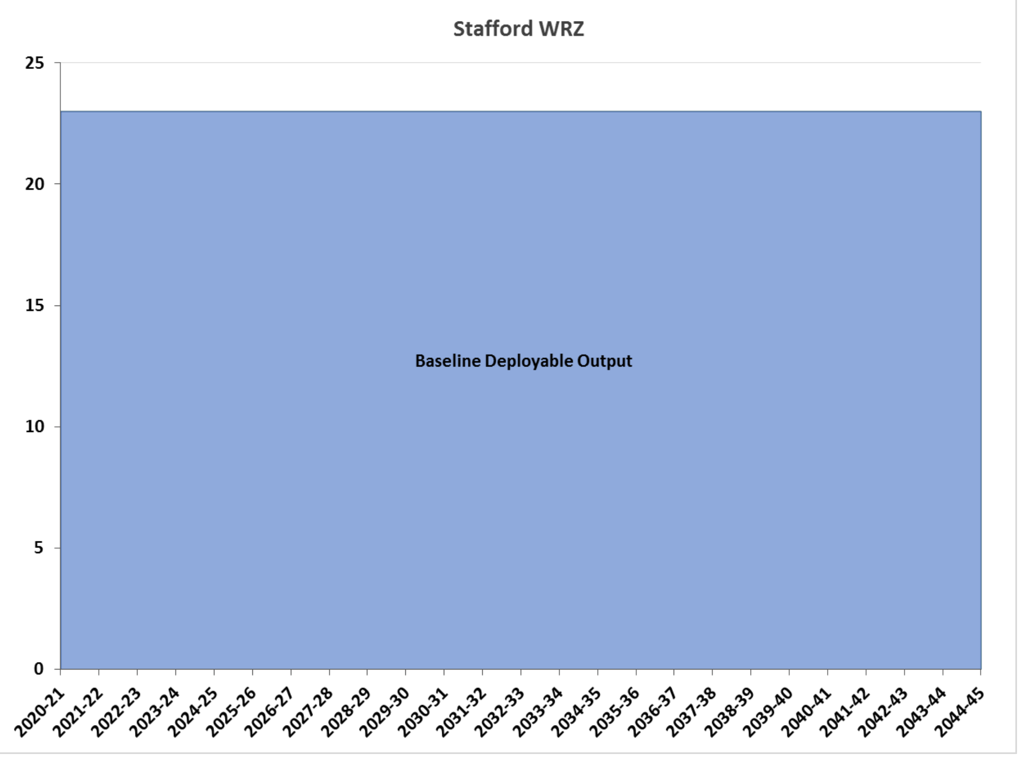
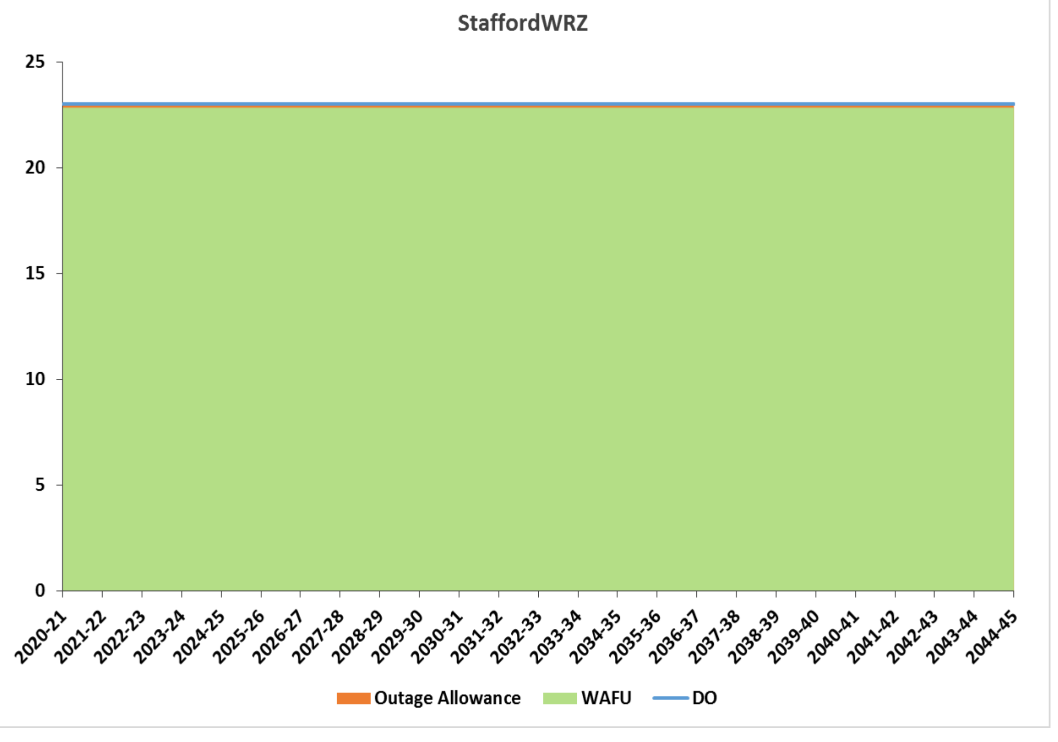


Figure A10.24: Stafford baseline water available for use



Strategic Grid zone

Figure A10.25: Strategic Grid baseline deployable output

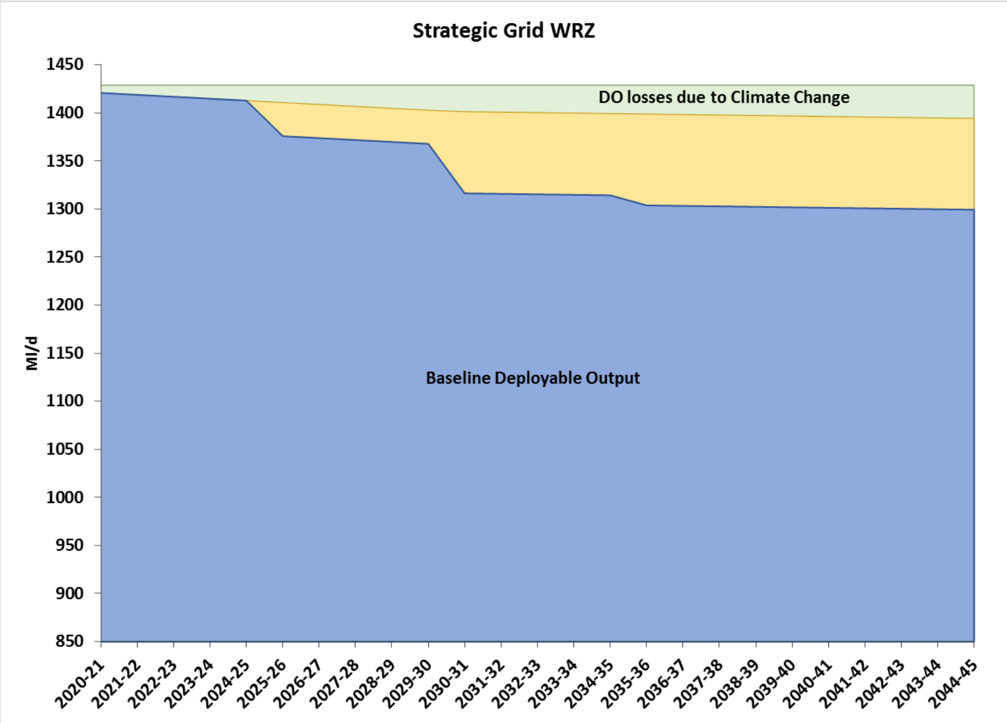
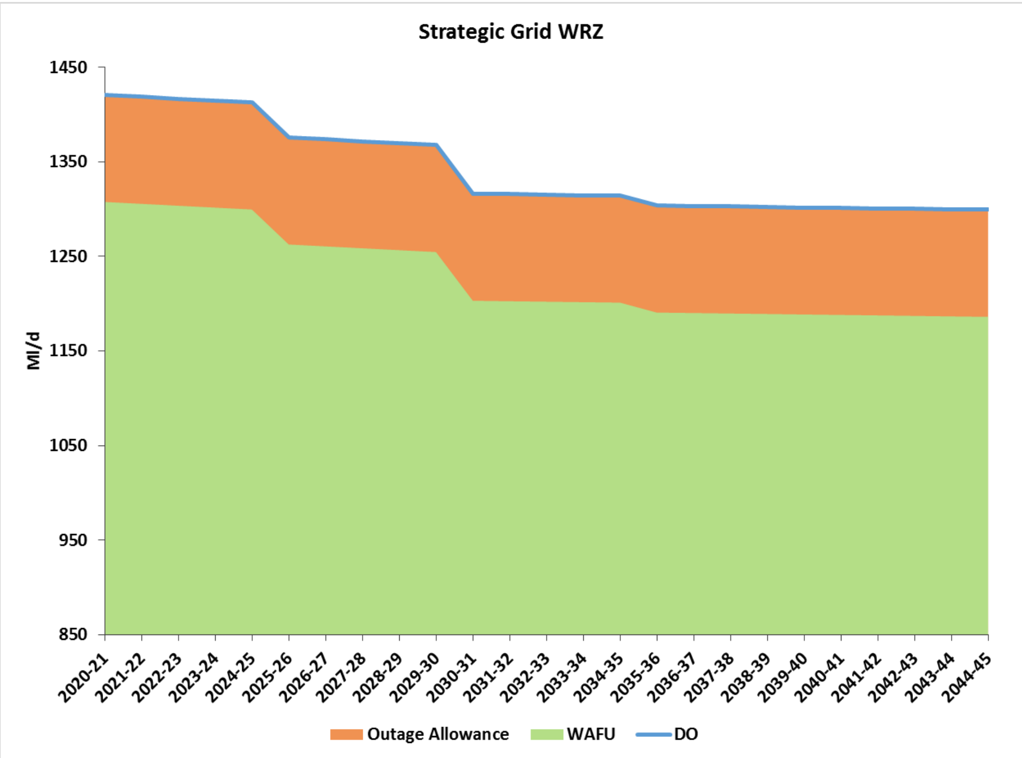


Figure A10.26: Strategic Grid baseline water available for use



Whitchurch and Wem zone

Figure A10.27: Whitchurch and Wem baseline deployable output

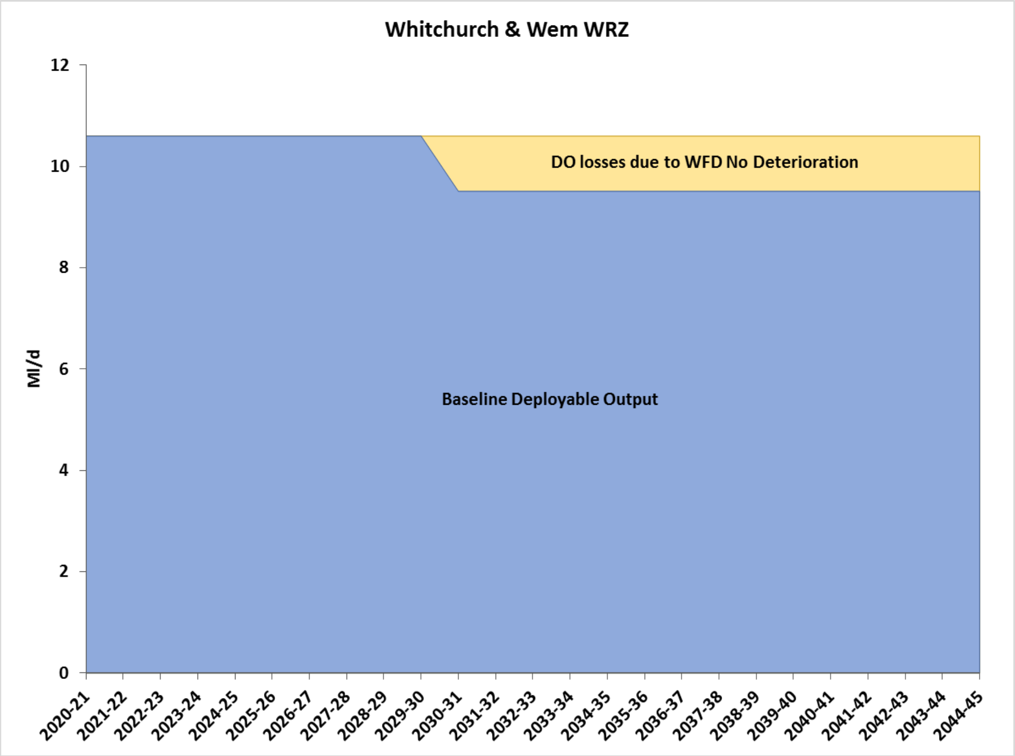
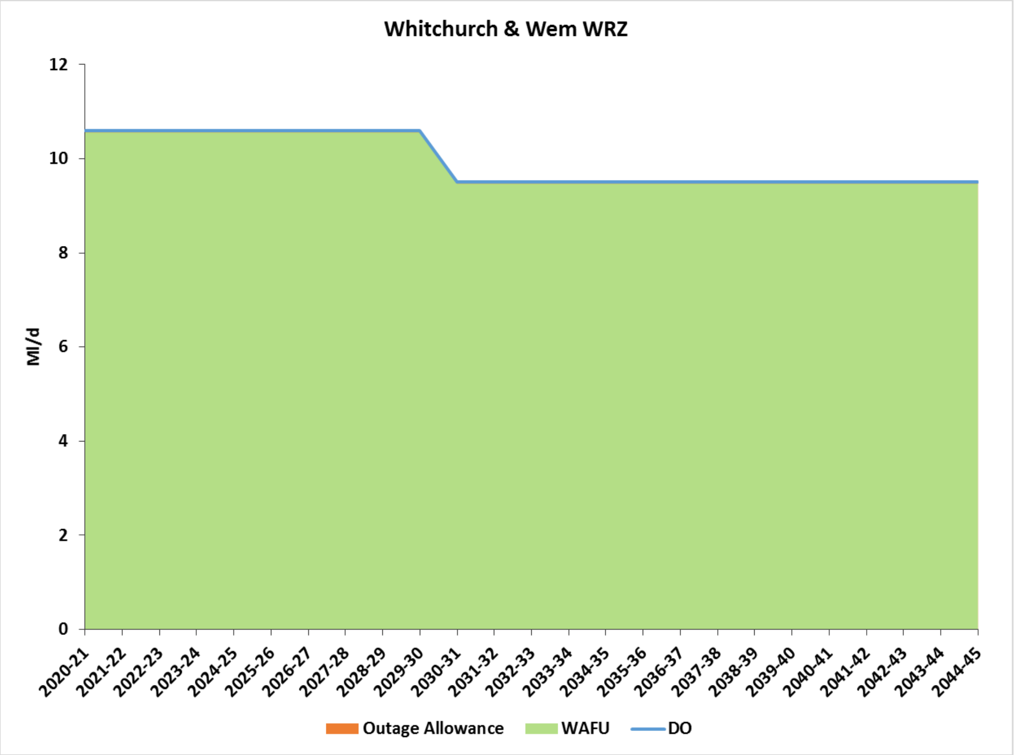


Figure A10.28: Whitchurch and Wem baseline water available for use



Wolverhampton zone

Figure A10.29: Wolverhampton baseline deployable output

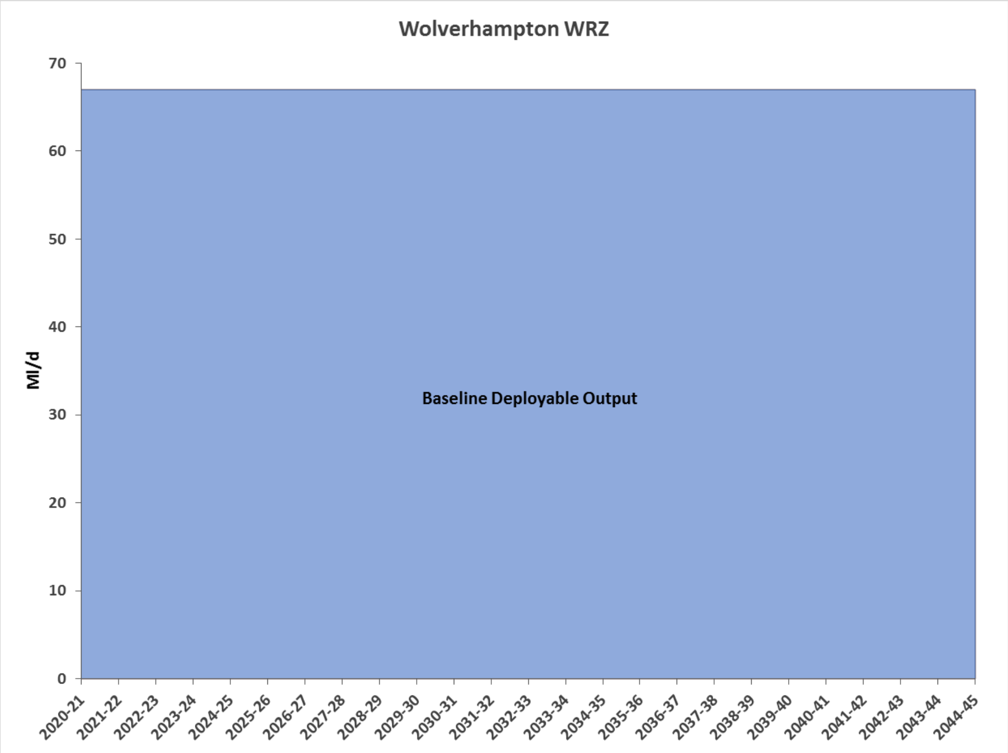
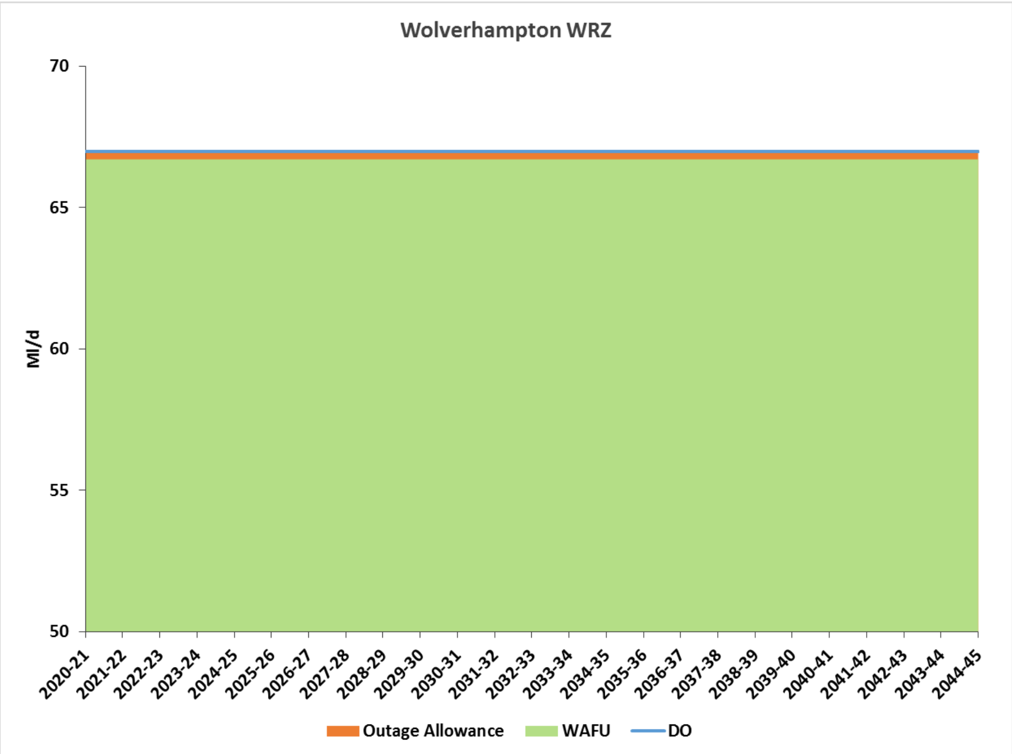


Figure A10.30: Wolverhampton baseline water available for use



A11 Protecting drinking water quality – Redacted

A12 Critical period

The WRMP guidance requires that we report a Dry Year Annual Average (DYAA) supply / demand scenario as a minimum. The guidance also gives the option of reporting under the critical period scenario if relevant.

As an improvement to our 2014 WRMP, we have reviewed how a critical period scenario would affect each of our water resource zones. Our 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.

Figure A12.1 illustrates an example of a conjunctive use zone affected by the critical period, peak month scenario. In this example, the zone is supplied from a combination of groundwater and river abstraction sources, and there is no reservoir storage within the zone.

Figure A12.1: A conjunctive river and groundwater abstraction zone

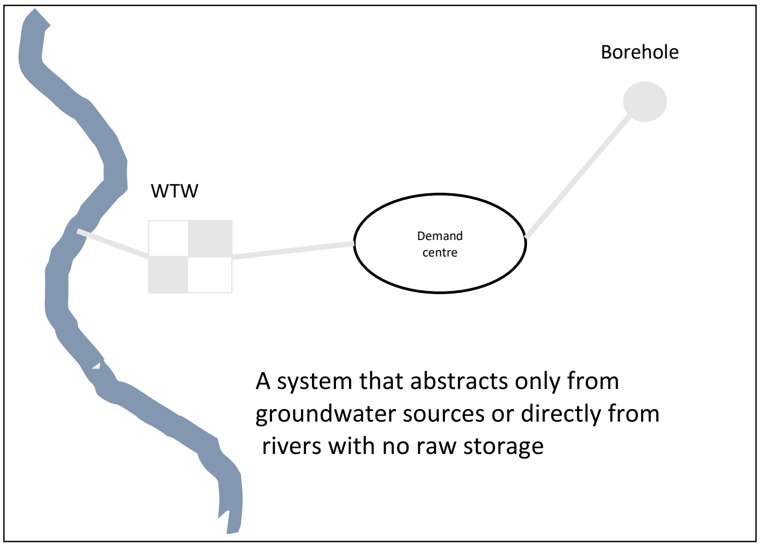
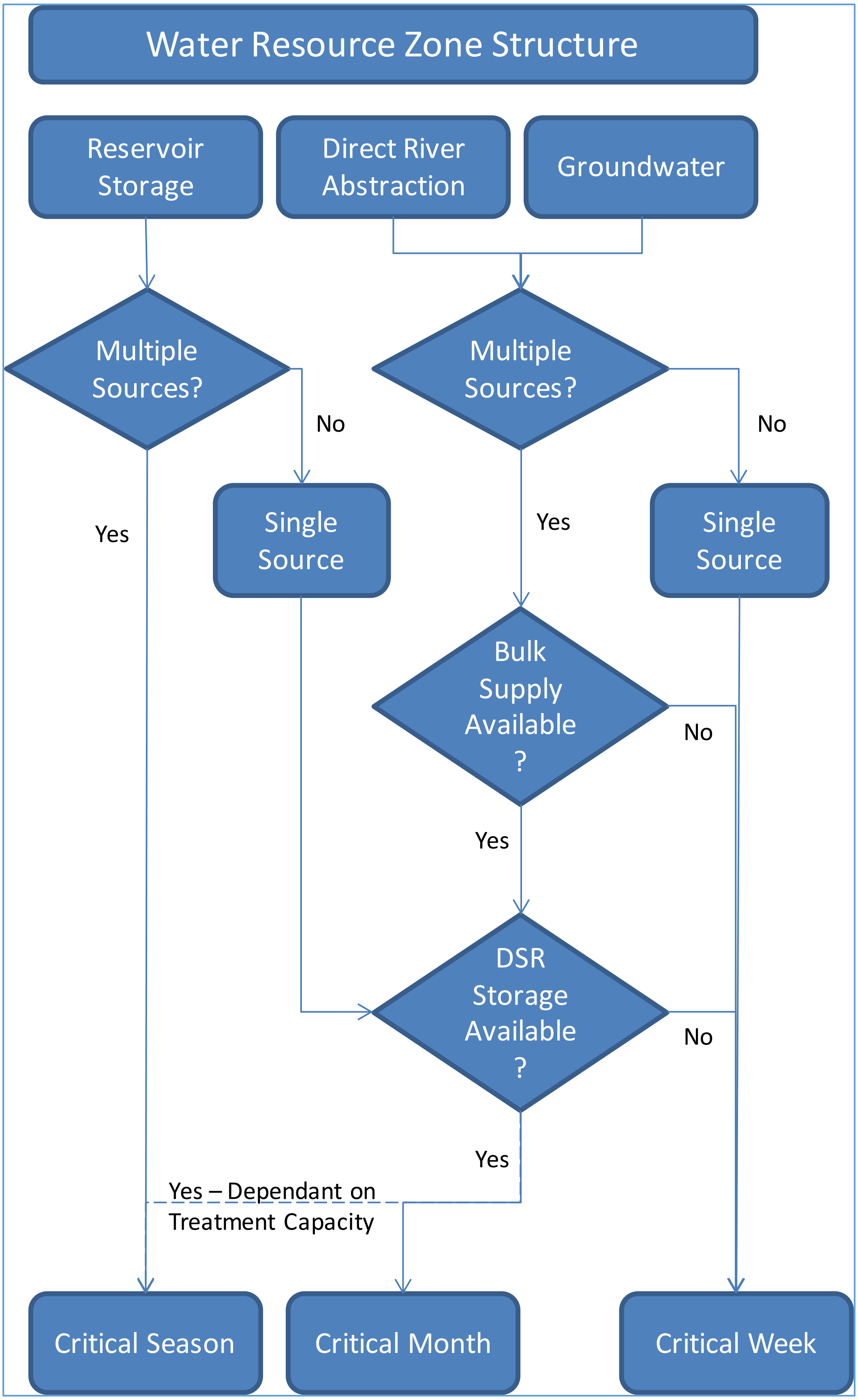


Figure A12.2 shows the criteria we have used to assess whether critical period conditions might apply to a zone.

Figure A12.2: Critical period assessment framework



The following section describes how we derive the peak demand and supply for this assessment.

Critical period demand

Critical Period demand factors are derived using 2006 regional demand data. We have used 2006 as a reference year for a peaking factor as it was during that year that we recorded our highest peak week demand event since 1995. We have calculated the ratio of peak week or peak month to the annual average demand in each County region, and mapped to our WRZs. The peak week or peak month factor is applied to the normal year annual average household demand forecast to give the Critical Period demand input to the Critical Period supply demand assessment.

Table A12.1 below sets out the critical period factors derived for each WRZ factors

Table A12.1: Critical period demand factors per water resource zone

WRZ	Critical Period	Peak factor
Bishops Castle	Peak week	1.22
Forest and Stroud	Peak month	1.10
Kinsall	Peak week	1.22
Llandinam and Llanwrin	Peak week	1.22
Mardy	Peak week	1.22
Newark	Peak week	1.22
North Staffs	DYAA	n/a
Nottinghamshire	DYAA	n/a
Rutland	Peak week	1.13
Ruyton	Peak week	1.22
Shelton	Peak month	1.13
Stafford	Peak month	1.07
Strategic Grid	DYAA	n/a
Whitchurch and Wem	Peak week	1.22
Wolverhampton	Peak month	1.07

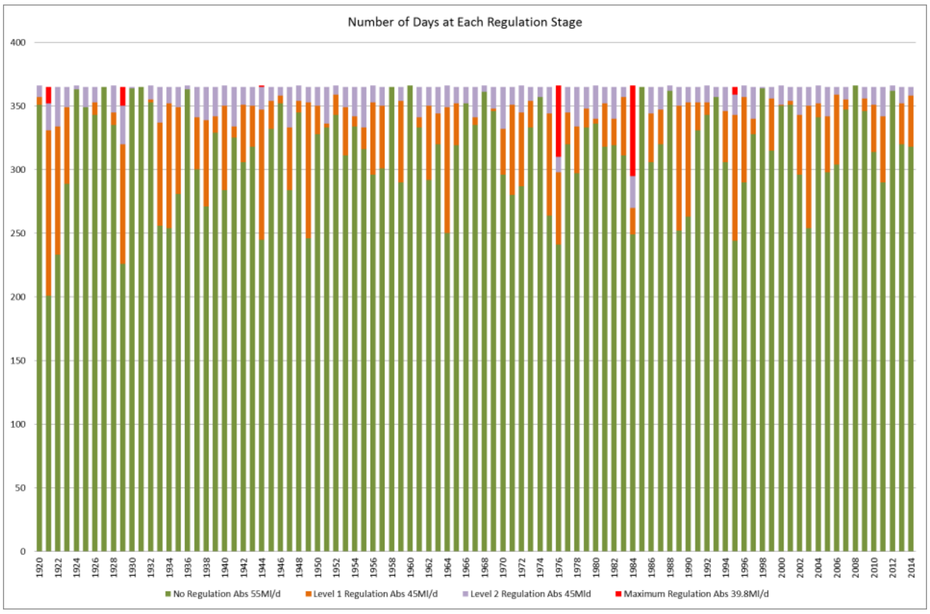
Critical period supply

Critical period supply deployable output (CPDO) has been assessed using two methods depending on the critical period of the zone. For those zones with a peak week critical period, the CPDO assessment has been based on the individual groundwater peak DO assessments for each groundwater source as described in section A2.1.

For zones with a peak month critical period. The available peak month CPDO 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.

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. Figure A12.3 illustrates that this only occurs twice in our 95 year model run for prolonged periods. This helps to show that this zone is within our 3 in 100 temporary use bans level of service.

Figure A12.3 Number of days of restricted river abstraction levels at Site K WTW



Critical Period supply demand assessment

Table A12.2 below shows that the only zone with a projected deficit under the critical period analysis is the Forest and Stroud WRZ.

Table A12.2 Critical Period Balance of Supply and Demand

		Supply Demand Balance at 5 year steps (Ml/d)					
WRZ	**Scenario**	**2020**	**2025**	**2030**	**2035**	**2040**	**2044**
Bishops Castle	CP – Peak Week	2.81	2.80	2.08	2.08	2.08	2.09
Forest and Stroud	CP- Peak Month	5.17	4.62	-2.12	-2.25	-2.26	-2.34
Kinsall	CP – Peak Week	1.06	1.02	0.46	0.42	0.38	0.34
Llandinam and Llanwrin	CP – Peak Week	6.63	6.80	6.88	7.03	7.22	7.35
Mardy	CP – Peak Week	1.07	1.13	0.58	0.56	0.55	0.54
Newark	CP – Peak Week	6.19	6.19	1.06	0.97	0.87	0.87
Ruyton	CP – Peak Week	1.45	1.38	1.30	1.26	1.22	1.19
Shelton	CP- Peak Month	29.29	27.77	15.40	14.52	13.59	12.47
Staffordshire	CP- Peak Month	3.71	3.78	3.70	3.44	3.00	2.77
Whitchurch and Wem	CP – Peak Week	1.87	1.78	0.63	0.56	0.51	0.44
Wolverhampton	CP – Peak Week	15.75	15.68	15.03	14.57	13.96	13.51

The deficit in the Forest and Stroud WRZ is caused by the reduction of the available ground water sources as a result of the need to reduce unsustainable abstraction. The solution to this reduction in baseline deployable output is the same as described in table WRMP6 for this zone, and involves transferring more water from the Strategic Grid zone to this zone.

Because we are not projecting any wider critical period deficits, we have not produced a separate set of WRMP data tables.