Our draft
Water Resources
Management Plan

Appendix 5.2: Supply Forecast Methodology

Contents

Appendix 5.2: Supply forecast methodology

1 Introduction

1.1 Overview

This document provides an overview of South West Water's deployable output (DO) assessment for Colliford, Roadford, Wimbleball and Bournemouth WRZs. The Isles of Scilly are reported in their own technical appendices (Chapter 14).

1.2 Requirements

As part of developing the supply-demand balance, we are required to estimate the yield of our resource zones in terms of deployable output (DO). DO is the output of a commissioned source or group of sources for the design drought that a water resource zone is assessed against, as constrained by

- Hydrological yield
- Licensed quantities
- Environment (represented through licence constraints)
- Pumping plant and/or well/aquifer properties
- Raw water mains and/or aqueducts
- Transfer and/or output main
- Treatment
- Water quality

The Environment Agency's Water Resources Planning Guideline (WRPG) requires water companies to be resilient to a drought with an annual probability of occurrence of 0.2%. This is commonly referred to as the '1 in 500 year' level of drought resilience, and water companies must plan to meet this level of resilience by 2039 at the latest. The WRPG states that this should not be derived from the historical record alone and that stochastic weather datasets should be used to create sequences from which the 1 in 500 year drought can be derived.

2 Data and Models

2.1 Rainfall

We have used the Met Office HadUK (Hollis et al, 2019) rainfall dataset to provide rainfall data across all our WRZs. We have used data from 1890 to 2020 in the development of our rainfall runoff models and to help underpin elements of the historical deployable output assessment.

2.2 Evaporation

We have used the new Environment Agency Potential Evaporation (PET) data which also includes a version of PET which includes a rainfall interception component (PETI). This dataset is available from 1961. Prior to 1961 we have used a relationship between temperature and PET to hindcast the PET datasets to 1900 (HR Wallingford, 2021a).

2.3 Rainfall-runoff modelling

Our previous WRMPs have used historical river-flow records to determine our worst historical DO. To better understand our resilience to drought and 1 in 500 DO we have developed new rainfall runoff models to support our WRMP24 DO assessment.

2.3.1 Model development and calibration

Our rainfall-runoff modelling uses the URMOD rainfall runoff model (Fidal and Kjeldsen, 2020). URMOD is a conceptual rainfall runoff model that uses transfer functions with calibrated parameters to translate rainfall and evaporation to simulated river flow and is similar in approach to other widely used industry models (e.g. CatchMOD, GR6J, PDM).

Model calibration was undertaken against naturalised flows using a range of evaluation metrics and visual inspection of hydrographs and flow-duration curves. Additional checks were made using reservoir mass balances to compare the historical reservoir drawdown with the drawdown achieved using simulated inflows.

2.3.2 Overview of catchment models

For WRMP24 our focus has been on developing rainfall-runoff models at key reservoir locations across our Colliford, Roadford and Wimbleball zones. We have focussed on reservoir catchments because these are most critical to understand our deployable output. For WRMP29, we plan to have rainfall-runoff models for all river-flow locations required in our water-resources modelling.

Table 1 Overview of rainfall-runoff models by WRZ.

Colliford WRZ	Roadford WRZ	Wimbleball WRZ
Colliford Siblyback Stithians	Fernworthy Meldon Roadford Upper Tamar Lake Venford Wistlandpound	Wimbleball

2.4 Groundwater assessment

We have several groundwater sources in each of our WRZs. We assess the yield of our sources following the UKWIR Source Yield Handbook (UKWIR, 2014) by deriving source yield diagrams from which we derive our dry year reliable output.

Modelling studies undertaken for our previous WRMPs have demonstrated that our groundwater sources are generally resilient to drought and/or constrained by licences. We use annual DO profiles of our groundwater sources within our water resources modelling to determine the conjunctive use DO of our supply system.

2.4.1 Saline intrusion risks

Key groundwater sources on the Otterton peninsula have been assessed for the saline intrusion risk associated with sea level rise and possible reduction in groundwater recharge.

As part of the recent decision by the Environment Agency to implement the Lower Otter Restoration Scheme, which has the potential to influence brackish water ingress into the local groundwater system, we will be developing and maintaining a groundwater quality monitoring network for our Otterton boreholes. This will act as an early warning system for saline intrusion and the data generated will allow us to improve our assessment of climate change impacts on the Lower Otter in the coming years.

2.5 Water resources modelling

Our MISER is complex, representing both our raw water systems and our treated water system and distribution network, to demand-zone level. It includes all our reservoirs; river abstraction points; groundwater sources; the links between these sources; the links between sources and Water Treatment Works (WTWs); pumped storage schemes; and our fisheries enhancement schemes. All our WTWs are included, as well as the treated water distribution network and the links between our water-demand zones. The model includes over 1,200 elements and allows us to fully represent our conjunctive use system.

We use specific demand patterns within the distribution network in our model to ensure that we simulate a representative demand for water in each of our WRZs across the year. These demand patterns account for increased water use due to tourism and warm, dry weather during summer months, and other factors.

Our water-resources model includes assumptions which try to accurately reflect how the system operates in practice. For example, we ensure the fisheries bank volumes in Colliford, Roadford and Wimbleball reservoirs are accounted for in our deployable output calculation by including annual releases profiles in our modelling.

2.6 Bournemouth WRZ

Historically, for previous WRMPs Bournemouth WRZ has been an infrastructure-constrained zone which has not required detailed supply-side modelling. This is because our river abstractions from the Rivers Avon and Stour are not hydrologically constrained, even during severe drought or from future climate change.

For WRMP24, Bournemouth WRZ has changed from a healthy surplus in its supply-demand balance to a deficit in the supply-demand balance driven by potential sustainability reductions in the River Avon.

To better understand the impacts of the potential sustainability reductions we commissioned WSP to undertake an assessment using the Wessex Basin Groundwater model combined with stochastic weather datasets and a range of climate change scenarios. This work demonstrated that, due to the sustainability reductions, climate change also impacts upon DO.

3 Baseline Deployable Output Assessment

3.1 Deployable output assumptions

For WRMP24, the DO assessment is undertaken for an unconstrained demand with no demand restrictions or drought permits included[1]. The constraint on DO is the point at which Level 4 drought management interventions would be required. Therefore, the DO is defined as the maximum that can be supplied from the water supply system without the requirement for Level 4 interventions.

For Colliford, Roadford and Wimbleball zones Level 4 restrictions would be implemented upon entering the WRZ reservoir emergency storage. In Colliford and Roadford, this is assessed as a WRZ group emergency storage, noting that Colliford and Roadford reservoirs make up a large proportion of the total WRZ storage. The DO is defined by the maximum demand the system can sustain without entering its emergency storage, subject to other system and infrastructure constraints. Colliford WRZ, for example, typically reaches a licence constraint at Restormel, and Wimbleball WRZ can reach water treatment capacity constraints.

Table 2 WRZ group emergency storage

WRZ	Strategic Reservoir Emergency Storage (Ml)	WRZ Group Emergency Storage (Ml)
Colliford	2,854	4,473
Roadford	5,370	7,581
Wimbleball	2,132	2,132

Bournemouth does not have any storage and its DO is constrained by the amount of water that can be abstracted from the main river sources. Note that this constraint only applies under future climate-change scenarios.

3.2 Historical deployable output assessment

Our approach to historical DO assessment is consistent in approach with WRMP19 and uses naturalised river flow sequences as inflows to our MISER model. The historically recorded flow series is available for the period of 1957 to 2021 for Wimbleball and Roadford WRZs and 1962 to 2021 for the Colliford WRZ. These are the earliest periods that have reliable flow records. They include several different types of historic droughts such as 1975/76 (multi-season drought), 1959, 1978, 1984, 1989 and 1995 (single season droughts).

For our Bournemouth WRZ, we have calculated both our dry year annual average DO and dry year critical period DO using reliable historically recorded river flows for the period of 1973 to 2021, which includes the historic drought 1975/76. Within our WRMP14, a river flow analysis using hindcast flow series back to 1883 was undertaken to

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[1] The benefits from drought measure are included as options in our programme appraisal. Our methodology for calculating the DO benefit of each drought measure is outlined in Annex A.

determine the severity of historic droughts, including the 1934 drought. This analysis confirmed that the 1975/76 drought was the most severe historical drought experienced in Bournemouth WRZ.

Table 3 Deployable Output (DO) in the worst historical year

Zone	Planning Scenario	Historical Year	DO (Ml/d)
Bournemouth	DYCP	1975/76	249.78
Colliford	DYAA	1975/76	167.68
Roadford	DYAA	1975/76	249.33
Wimbleball	DYAA	1975/76	97.46

3.3 1 in 500 deployable output assessment

Since WRMP19, South West Water's WRZs have moved from a position of supply-demand surplus to a supply-demand deficit. The change to this position has materialised part way through the WRMP planning process, driven in a large part by the Environmental Destination. To respond to this challenge, we have prioritised the development of new rainfall-runoff models to better inform our understanding of drought resilience and reflect the greater risk in the security of our supply. This has allowed us to use stochastic approaches to support our assessment of a 1 in 500 DO and better understand the impacts of climate change.

Improvements to our capability in rainfall-runoff modelling has resulted in a step change in our ability to explore hydrological drought using stochastic datasets. However, our MISER model cannot readily assess the full stochastic datasets in a deployable output assessment like other modelling platforms (e.g. Aquator, Pywr). We have plans to develop our water resources modelling capacity ahead of WRMP29 to allow us to undertake a full stochastic assessment. We have made updates to our MISER model to facilitate our 1 in 500 DO assessment and sought to make pragmatic assumptions where appropriate.

3.3.1 Stochastics dataset

Stochastic weather datasets are sequences of rainfall and evaporation that have been created using statistical models and relationships with the aim to extend beyond relatively short historical datasets to explore different patterns. West Country Water Resource Group commissioned Atkins to develop a regional coherent stochastic weather dataset (Atkins, 2021) which follows the same approach as other regional planning groups.

Daily rainfall sequences were generated for a number of key rain-gauge locations across the South West of England using data for a period of 1950-1997. In total 400 sequences of 48 years were created providing 19,200 years of data. Temporal coherent evaporation data (PET/PETI) was provided by sampling the historical datasets to find historical months which match equivalent total monthly rainfall in the stochastics.

3.3.2 Rainfall runoff modelling of stochastics

The Atkins stochastic dataset provides rainfall sequences at key rain gauges across the south west region. These point locations are used to create a catchment average time series for each of our rainfall-runoff models (see Table 1) using Thiessen polygons to apportion weights. The areal-weighted timeseries derived from the stochastic rain gauges was compared with the HadUK catchment-average timeseries and an adjustment factor was derived based on annual total rainfall as recommended by Atkins (2021). The adjustment factor compensates for differences in the underlying datasets resulting from factors such altitude or topography. The adjustment factor is applied to all 400 stochastic areal-weighted rainfall sequences.

The stochastic evaporation dataset for each rainfall-runoff model was provided directly on a catchment average basis based on resampling each catchment's historical record.

URMOD was used to simulate river flows from the rainfall and evaporation time series to create 19,200 years of river flow data for each model to underpin our assessment.

3.3.3 WRZ Drought Library

We have created a drought library of events for each water resource zone to target the stochastic design events for which we undertook detailed MISER water resources modelling within our DO assessment. Each WRZs drought library was selected based on extreme value analysis (EVA) of historical river flows which is then used to sample stochastic design events. This is undertaken for all rainfall-runoff models in each zone with a unique drought library create per WRZ.

EVA was undertaken for the critical duration of river flows in each WRZ as identified in our drought vulnerability assessment (see Annex B). Colliford and Roadford are multi-season vulnerable with 18 month critical drought durations from April year 1 to September year 2. Wimbleball is a single season vulnerable system with a 12-month critical duration from November to October. For these critical durations, total river flow was calculated for each year in the historical record. EVA was undertaken on the historical record from 1900 to 2020, covering 120 years of data. Following the methods outlined in the EA's DVF guidance (UKWIR, 2017), we tested different approaches to fitting statistical distribution to the critical duration flows. An example for Colliford reservoir is show in Figure 1.

The EVA analysis provides an estimate of the design 1 in 500 river flow volume for each rainfall-runoff model. The 19,200 years of stochastic river flows were then used to identify stochastic events with flows of an equivalent critical duration flow volume. This is repeated for each catchment within a WRZ and the drought library contains all of these events.

The process is summarised in the steps below for each WRZ:

- Undertake EVA on the historical simulated river flows for critical duration
- Derive a 1 in 500 return period and associated total flow volume
- Analyse 19,200 years of stochastic data to identify events with a similar flow volume
- Select a sample of stochastic events for each catchment model
- Combine events for all catchments into a single drought library

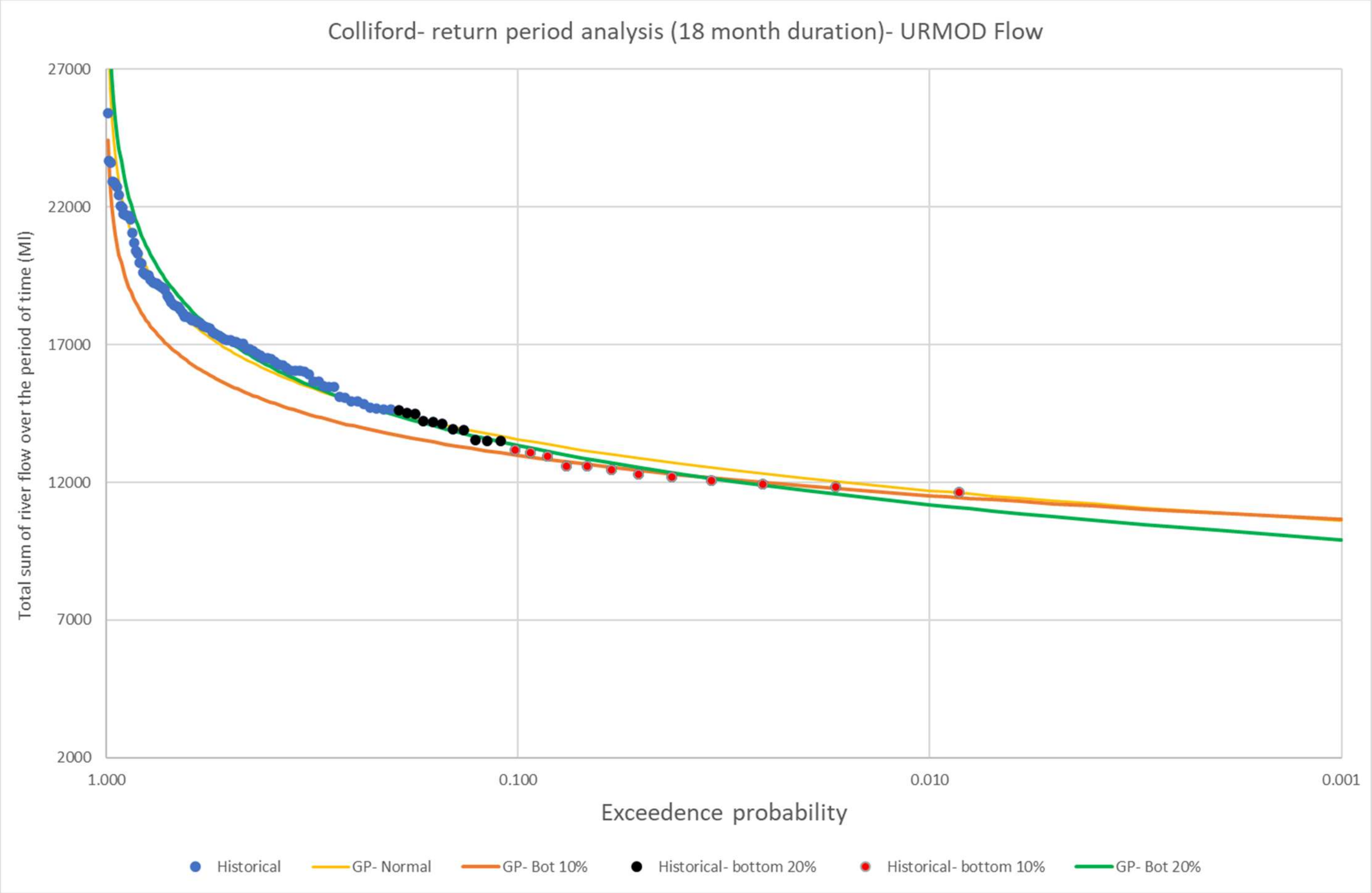


Figure 1 EVA for Colliford catchment. Compares different approaches to fitting statistical distributions to the critical duration flows. The y-axis show the total flow over 18 months. The x-axis shows the exceedance probability which is equivalent to a return period e.g. 0.01% is 1 in 100.

3.3.4 1 in 500 deployable output results

Each WRZ drought library contains a range of events that are 1 in 500 river flow-return periods in at least one of the catchments in the WRZ. The deployable output of each stochastic event in the WRZ drought library is determined by increasing demand to point at which WRZ reservoir storage would reach emergency storage as outlined in Section 3.1. There is a degree of variability in the performance of the stochastics across our region, with a balance to strike between the performance of our smaller reservoir systems and our larger strategic reservoirs. Our 1 in 500 design event in each WRZ was selected based on the water supply system performance across the WRZ and the design return period of flow across all of the WRZ sub-catchments. In our Bournemouth WRZ, we have not used a drought-library approach and have instead aligned with the WCWRG work undertaken with Wessex Water, which identified a common 1 in 500 year event within the stochastics dataset across the Wessex Basin Model.

Table 4 Overview of WRZ 1 in 500 DO

WRZ	Planning Scenario	DO (Ml/d)
Bournemouth	DYCP	249.78
Colliford	DYAA	165.68
Roadford	DYAA	249.33
Wimbleball	DYAA	92.46

4 Climate Change

4.1 Introduction and guidance

The EA's WRPG has supplementary guidance on climate change which outlines the methods and evidence sources water companies should consider in their WRMP. The guidance follows a tiered approach which adds greater complexity to the assessment where there is a higher vulnerability of a WRZ to the impacts of climate change. Our WRZs cover all three vulnerability categories: Low to High. We have sought to align our climate-change methodology with the West Country Water Resource Group (WCWRG) regional plan to ensure a consistent approach to climate change across the region and have therefore adopted a Tier 3 high-vulnerability assessment across our WRZs.

Table 5 Overview of climate change vulnerability

WRZ	Climate Change Vulnerability Score
Bournemouth	Low
Colliford	Medium
Roadford	High
Wimbleball	Medium

For a Tier 3 high-vulnerability assessment we have considered multiple climate change evidence sources from UKCP18 and simulated the impacts of these climate change scenarios using rainfall runoff models and water resources models to determine the impact of climate change on deployable output.

4.2 UKCP18 Datasets

UKCP18 provides a combination of evidence sources which we have considered in our dWRMP as outlined in Table 6. These datasets have been derived from UKCP18 in a consistent approach for all WCWRG companies (HR Wallingford, 2021b). The regional (RCM) and global (GCM) projections are only available from UKCP18 for RCP8.5, which is the highest emissions scenario, so we have also used UKCP18 probabilistic data for RCP6.0 the medium emissions scenario. We used all the projections to undertake a historical climate change assessment to compare the range of impacts across the evidence sources.

Table 6 UKCP18 evidence sources

UKCP18 Dataset	Emissions Scenario	Historical	Stochastics
RCMs	RCP8.5	Y	
GCMs	RCP8.5	Y	
Probabilistic	RCP6.0	Y	Y

4.3 Climate change and deployable output

4.3.1 Climate change scaling

The impacts of climate change derived from the UKCP18 projections are for a future period of 2061-2080 relative to a baseline period of 1981-2000. To incorporate the climate-change impacts within our 25-year dWRMP, we have applied a linear scaling to climate change impacts as per the WRPG. We have assumed a two-part scaling relationship such that climate change impacts are tapered slightly in the first 5 years of our plan (2025-2030), with linearly scaled impacts reported from 2030s onwards.

4.3.2 Climate change results

We have outlined our central climate change impact from UKCP18 RCP6.0 on each WRZs DO at the end of plan 2049/50 in Table 7.

Table 7 Climate change impact on DO in 2049/50

	Bournemouth	Colliford	Roadford	Wimbleball
Climate change impact on DO 2049/50 – UKCP18 probabilistic RCP6.0 (Ml/d)	-58.57	-12.58	-12.11	-6.66

We have considered the uncertainty in climate change in our headroom assessment using a range of impacts from UKCP18 probabilistic RCP6.0. We have used the other UKCP18 evidence sources (RCMs/GCMs for RCP8.5) to inform our scenario testing to explore the uncertainty associated with different emissions pathways.

5 References

Atkins 2021, Regional Climate Data Tools Final Report.

HR Wallingford 2021a West Country Water Resource Group deployable output assessment support – Potential evapotranspiration data extension.

HR Wallingford 2021b, Regional Planning Climate Change Assessment – Climate change methodology

Fidal, J. and Kjeldsen, T., 2020. Operational comparison of rainfall-runoff models through hypothesis testing. Journal of Hydrologic Engineering, 25(4), p.04020005.

Hollis, D, McCarthy, MP, Kendon, M, Legg, T, Simpson, I, 2019, HadUK-Grid—A new UK dataset of gridded climate observations. Geosci Data J.; 6: 151– 159. https://doi.org/10.1002/gdj3.78

Hunt, D., Counsell, C. and Ledbetter, R. (2017) Drought Vulnerability Framework. UKWIR report Ref: 17/WR/02/12. UKWIR, London, 125pp.

Annex A: Quantifying Drought Measure Benefits

The benefits available to us in a drought, through the use of supply-side drought actions, have been estimated using data contained in our published Drought Plan (available to download from our website). The figures align to those achieved in the current drought, although there has been some variation in permitting, the benefits from the options have been achieved.

We have not assumed any benefit is available from supply-side actions in the DYCP scenario, as it would not be possible to obtain the required drought permits in sufficient time to allow their use in a peak week.

In the DYAA scenario we have assumed the following benefits:

Drought Plan ref.	Drought action	Level	Benefit (Ml/d)	Period of use	DYAA benefit (Ml/d)
Bournemouth					
B1	Wimborne	L2	2	2 months	0.333
B2	Stanbridge	L3	12.5	1 month	1.042
Colliford					
C1	Colliford licence	L1	7.5	6 months	3.750
C2	Stannon Lake	L2	4	3 months	1.000
C3	Porth & Rialton	L3	5.5	6 months	2.750
Roadford					
R1	River Lyd	L1	0 – superseded by Green Recovery scheme		
R2	Slade Reservoir	L2	1.5	2 months	0.250
R3	Challacombe Reservoir	L3	1.5	2 months	0.125
R4	Meldon/Vellake to Roadford	L3	4	6 months	2.000
R5	Lee Moor Quarries	L3	0 – uncertainty over benefit, excluded		
Wimbleball					
W1	Brampford Speke & Stoke Canon BHs	L1	8	4 months	2.667
W2	Hook Springs	L2	0.4	3 months	0.100
W3	Wilmington Springs	L2	0.4	3 months	0.100
W4	Wimbleball comp flow	L3	9	4 months	3.000

These drought options and benefits will be reviewed as part of our analysis of the lessons learned from the 2022 drought (see Chapter 1 and Appendix 1.1 for details).

We have assumed that, where a drought option is chosen to be part of our preferred plan, we will identify additional drought resources to replace the loss of drought benefits.

Annex B: Drought vulnerability assessment

Water resources planning guidance requires water companies to undertake drought vulnerability assessments for their WRZs, showing how resilient their current supply system is to droughts of varying severities and durations. The following graphs set out our drought vulnerability assessments for each WRZ.

We have compiled the drought vulnerability assessments using the same data that we have considered in understanding our vulnerability to droughts that are more severe than those experienced historically. We have combined this data with our existing understanding of the way that our WRZs responded to the droughts in the historic record. Our historic data contains a wide variety of drought events of different severities and durations and combining this with synthetic-flow sequences complied to represent more severe events provides an understanding of system performance. This understanding has been brought together with the data contained in the drought vulnerability assessments and considered within our modelling for this WRMP.

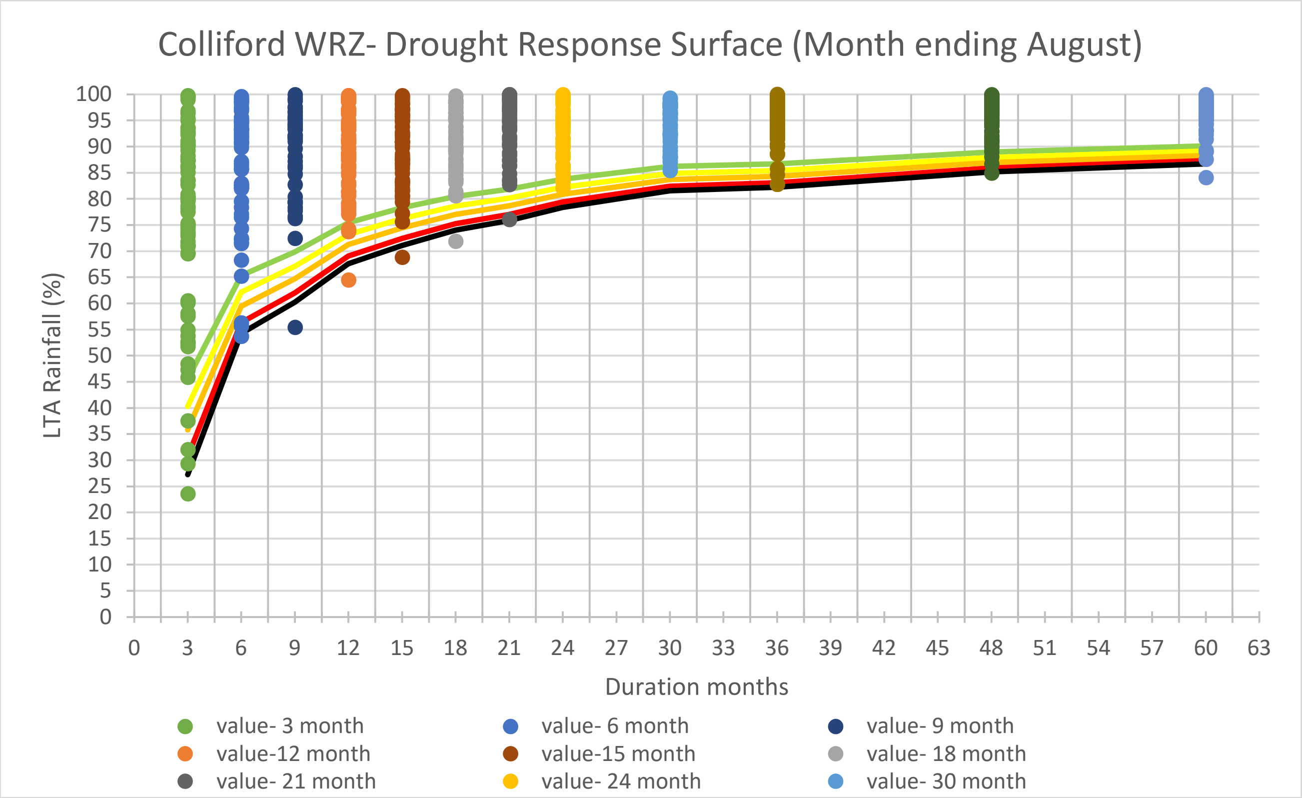
Both Colliford and Roadford WRZs contain large, multi-seasonal strategic reservoirs, which may not recover fully over the Winter following a dry Summer. This makes them vulnerable to very severe dry Summer periods, and longer duration rainfall deficit periods, which impact recovery after a dry Summer.

Wimbleball also contains a large strategic reservoir, but it is supported by a large, pumped storage scheme which allows full recharge in all historic, and all but the most extreme climate-change impacted years in the future. This makes the system primarily vulnerable to severe single-season droughts, rather than multi-season ones which are mitigated by the pumped storage scheme.

Bournemouth has no significant water resources reservoirs and is supplied by groundwater and run-of-river abstractions, making it peak-demand constrained.

We will assess droughts with durations that are different from our critical drought duration analysis, to inform our revised draft plan.

Colliford


Colliford WRZ- Drought Response Surface (Month ending August)
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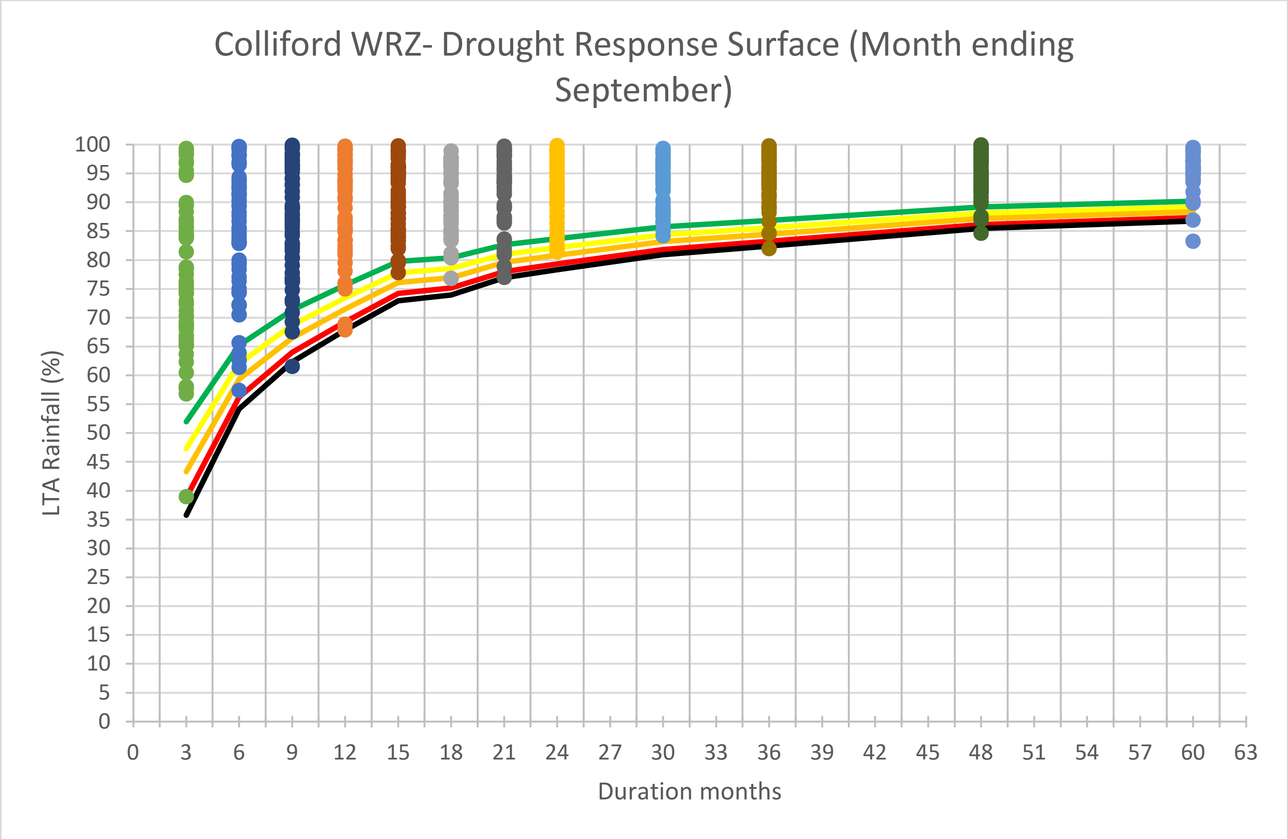
Colliford WRZ- Drought Response Surface (Month ending September)
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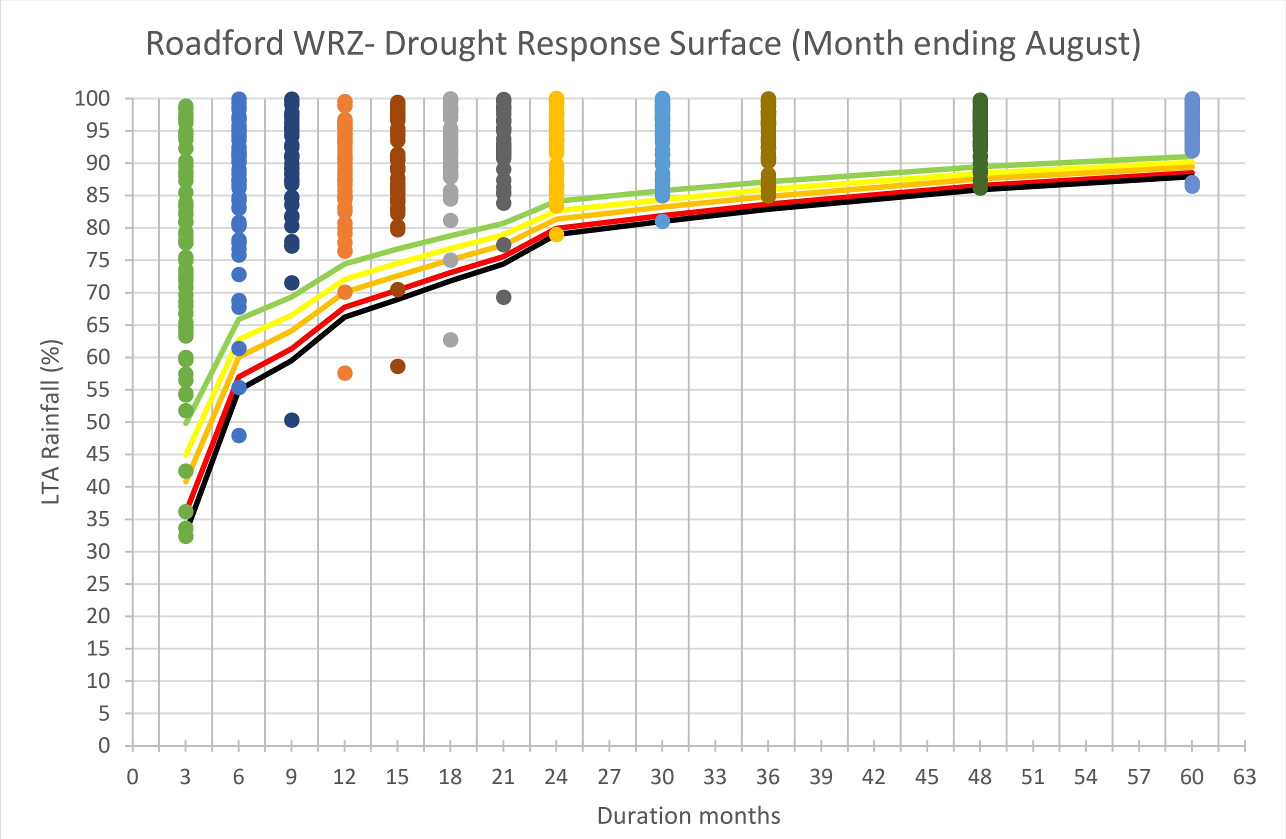
Roadford


Roadford WRZ- Drought Response Surface (Month ending August)
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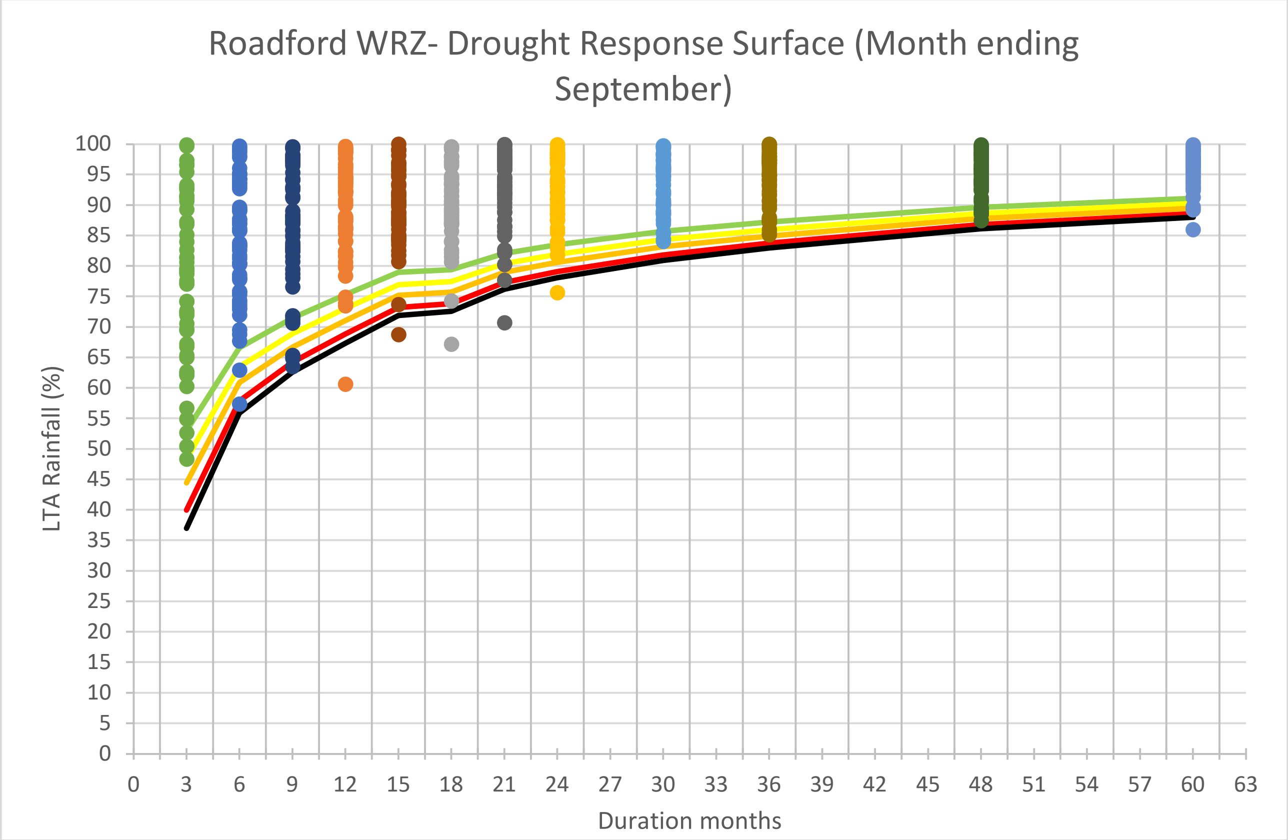
Roadford WRZ- Drought Response Surface (Month ending September)
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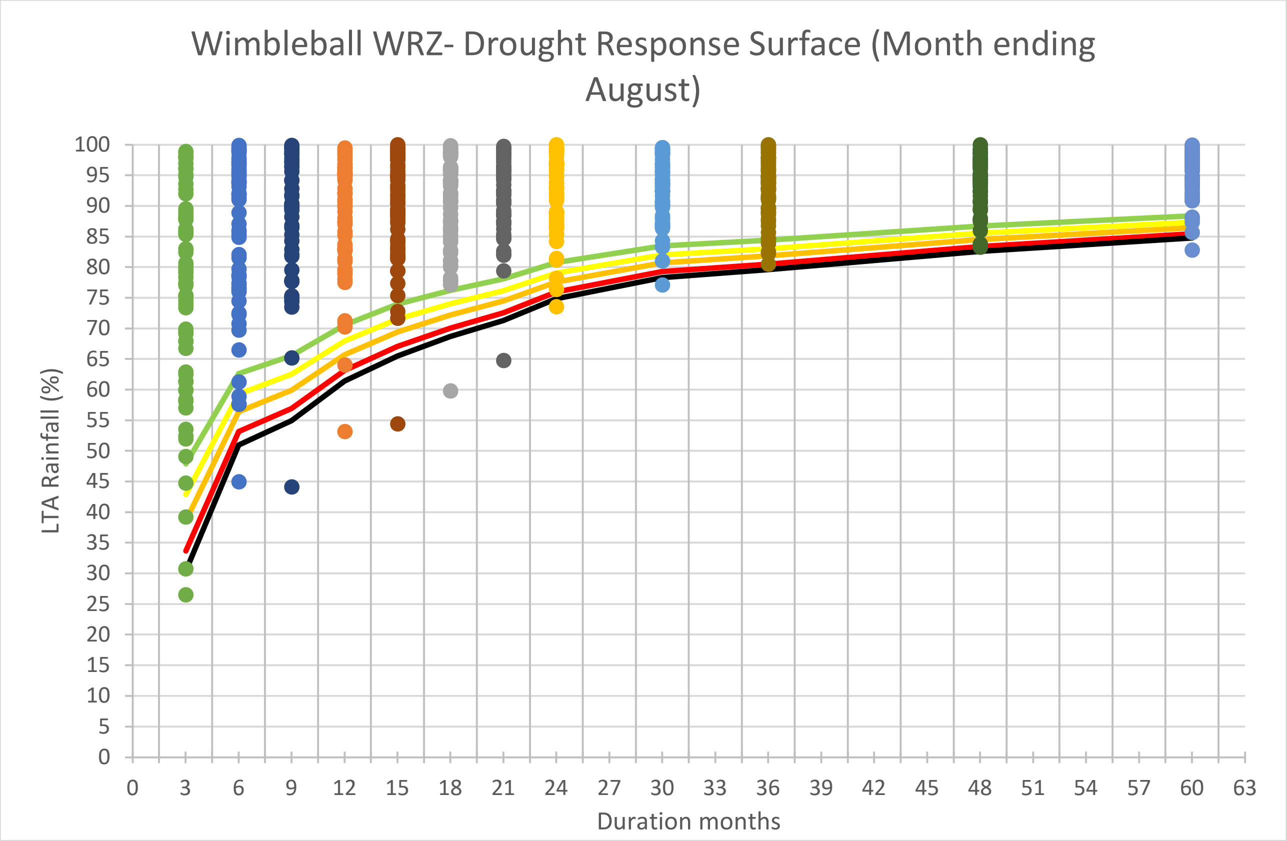
Wimbleball


Wimbleball WRZ- Drought Response Surface (Month ending August)
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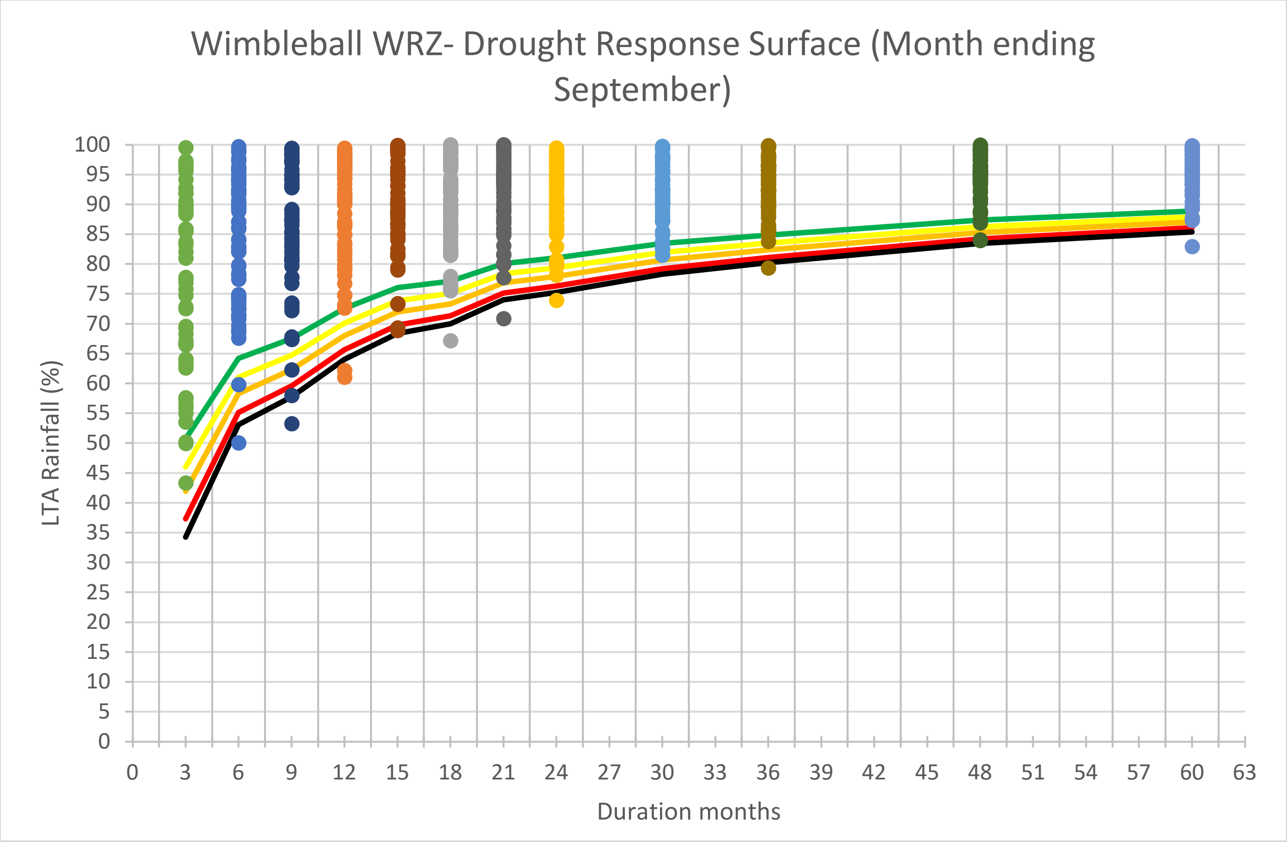
Wimbleball WRZ- Drought Response Surface (Month ending September)
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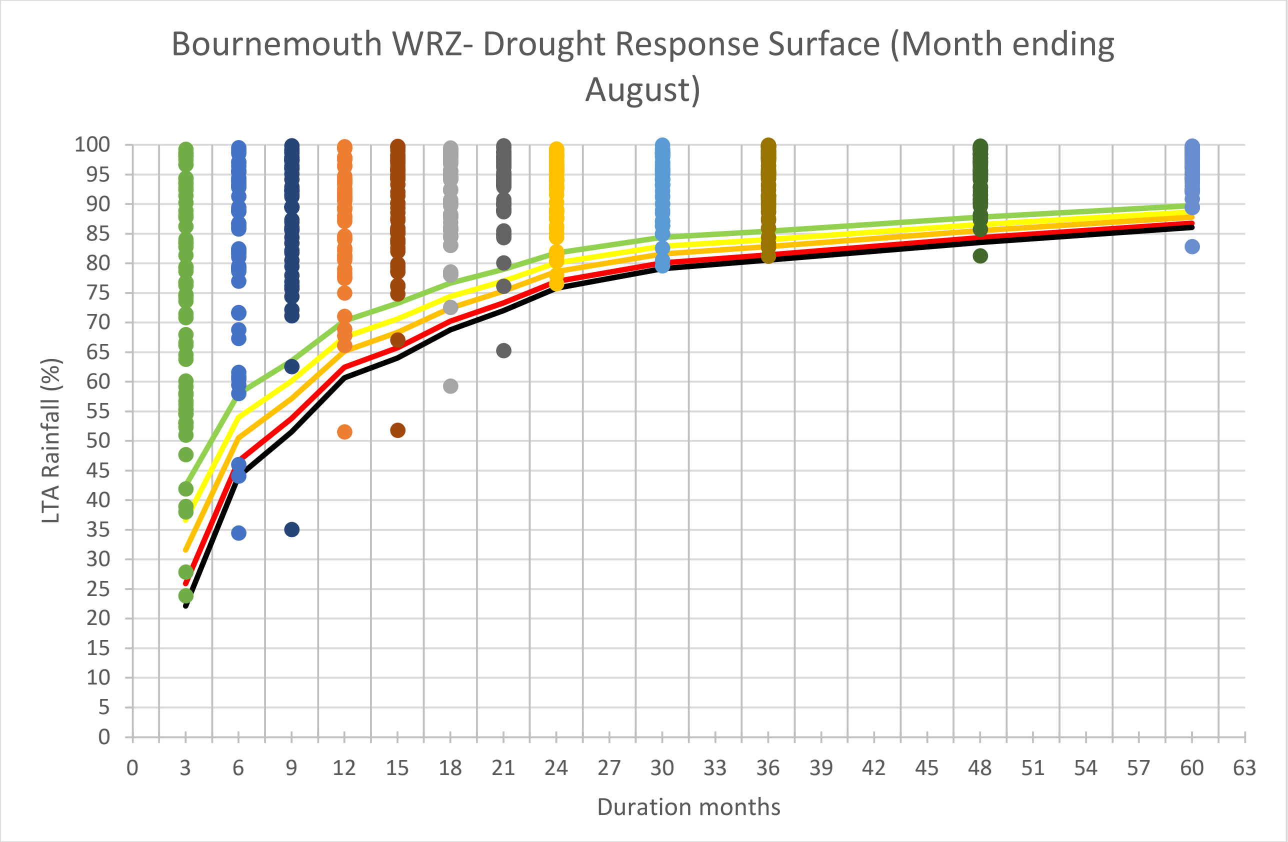
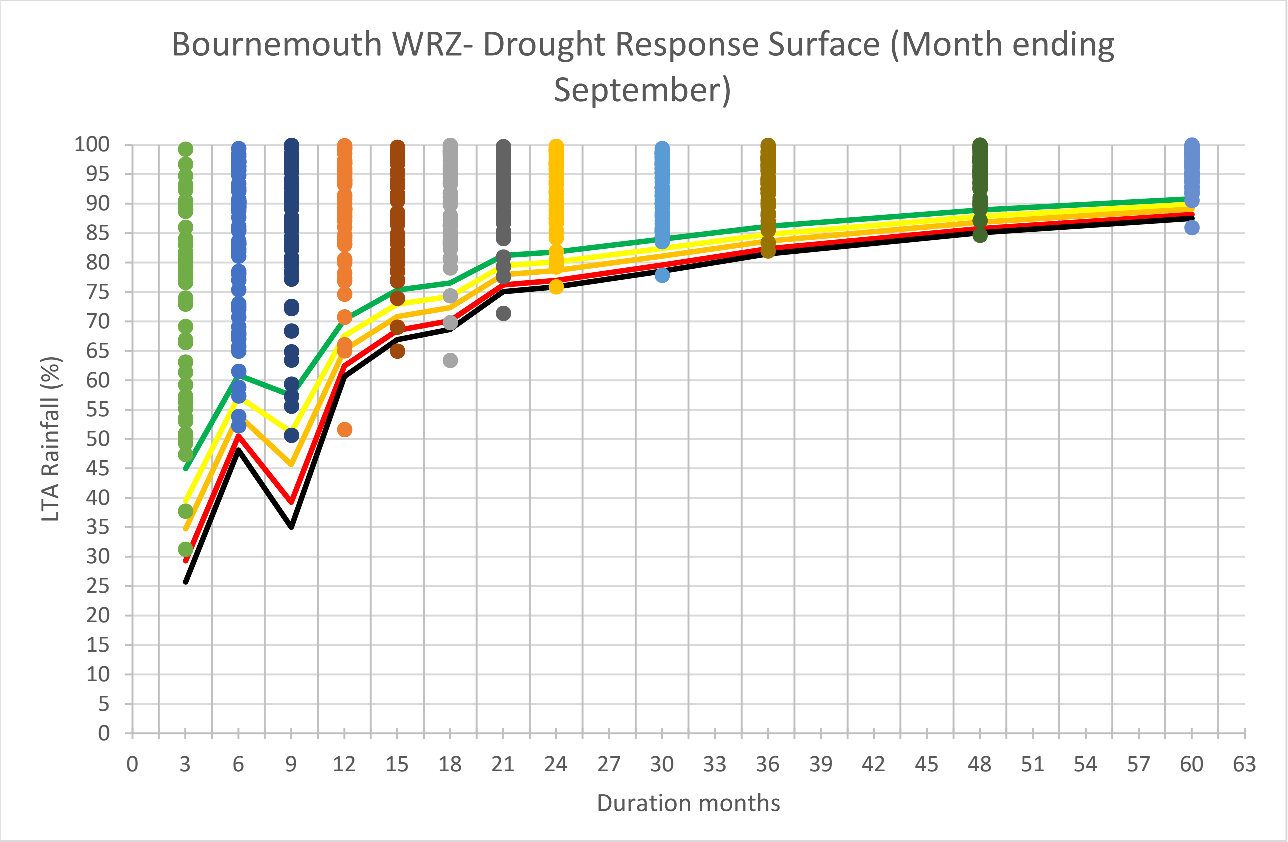
Duration months

Bournemouth





South West Water

Bournemouth Water

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