Draft

Final Drought Plan

2022

Appendix J: Drought resilience in the North West

United Utilities

Water for the North West

1 Introduction

In order to produce an effective drought plan it was crucial to understand the nature of droughts that we are at risk from. Specifically, we needed to identify the different drought patterns that could plausibly impact our region during the lifespan of the plan. We then tested how our supply system would likely respond, including identifying any vulnerabilities. This process helped us to design our drought actions and levels to achieve the best possible levels of resilience.

Most of the technical work undertaken for our 2018 Drought Plan was completed by 2016, and in the intervening years we have worked hard to improve our understanding of droughts. As outlined in Appendix A, this has involved significant water resources model development, the use of new data recorded in recent dry weather events and the derivation of synthetic data using a stochastic "weather generator". The draft plan was developed using the outputs of the 2016 "weather generator" for both the Carlisle and Strategic RZ. This produced 200 versions of an 87-year record (totalling 17,400 years of data). The "weather generator" has been updated since the draft plan to simulate 400 versions of a 48-year record (totalling 19,200 years of data). The Strategic RZ assessment has been updated with the latest dataset due to changes in the model requiring it to be rerun for the draft final drought plan. The Carlisle RZ will use the updated stochastics for WRMP24 and the next drought plan.

We used new assessment techniques developed collectively by the water industry, as well as developing our own bespoke methods where value could be added. The remainder of this document is structured around three main areas:

- Drought vulnerability framework (DVF) (Section 2)
- Drought characterisation (Section 3)
- Ongoing research (Section 4)

In accordance with the DVF guidance the North Eden and Barepot resource zones (RZ) were screened out of that assessment due to there being no plausible drought risk. However, we have included some of our own analysis in Section 5 to help further demonstrate the extremely low level of risk.

2 Drought Vulnerability Framework

We completed the DVF in accordance with the guidance published by the Environment Agency (UKWIR, 2017). The concepts and format of the DVF are fully described in the 2017 guidance report, but in summary it is an evaluation process that seeks to identify the level of drought risk that is faced by a RZ across a range of droughts of varying durations and severities, as characterised by rainfall deficits. The drought risk is quantified by calculating the number of days of supply-demand 'failure' (the simulated implementation of emergency drought orders) that are expected to occur for each scenario. In this case, each 'scenario' represents a specific combination of duration and percentage rainfall deficit that occurs prior to a defined critical month for the drought (e.g. a 40% rainfall deficit experienced over a period of 12 months, ending in September). The deficits for each scenario are plotted on a Drought Response Surface (DRS), along with curves that indicate the likelihood that each deficit will be experienced, based on rainfall return period analysis.

We had some concerns about the suitability of this approach for our supply system, in particular that the sample of drought events captured for each rainfall scenario gave a wide range of system responses (i.e. the rainfall return period was a poor indicator of drought severity). We established two reasons for this:

1. Ascribing drought severity to multiple events based on a single rainfall statistic has significant practical limitations. Temporal and spatial rainfall patterns within each event are not accounted for by the statistics used to define the return period, but play a key role in determining the overall impact.
2. While rainfall is clearly the most dominant factor in drought severity there are other critical aspects not captured by the DRS such as temperature, antecedent conditions (i.e. soil moisture and reservoir storage levels at the start of an event) and the physical characteristics of the supply network, for example reservoir and water treatment work capacities (these aspects would be captured in deployable output, which demonstrates their criticality).

We applied a range of post-processing steps to help improve the quality of our DRS, for example: (i) filtering events for each rainfall scenario based on simulated drawdown period duration; and (ii) smoothing the DRS shading to remove misleading failure trends caused by inconsistent numbers of events sitting behind each cell (e.g. removing the suggestion that the system would fail at 1 in 50 years but pass at 1 in 100 years). We are relatively comfortable that the final outputs reflect the drought vulnerability of our resource zones, however we feel that an approach led by system response is more robust (Section 3).

The DRS for the Carlisle and Strategic RZs are shown below in Figure 1 and Figure 2 respectively. As noted previously, Barepot and North Eden were screened out due to a lack of plausible drought risk. The critical periods were determined most likely to end in June or September for the Carlisle RZ and September or October for the Strategic RZ.

The Carlisle RZ was shown to be very resilient to drought, with no failures (i.e. shaded light yellow) below dead water (i.e. the implementation point for emergency drought orders) occurring within the simulation of the stochastic dataset, which contains a wide range of different severity events. Only four out of the 17,400 years tested resulted in storage reaching emergency storage (not shown in the DRS below); all were related to three-six month duration events with extremely high rainfall return periods.

Failures, as indicated by orange shaded cells, were longer and more frequent for the Strategic RZ. Nevertheless, this RZ was shown to be relatively drought resilient, with a small number of failures below dead water occurring only for severe rainfall return periods. The failures were present in droughts with a duration of between 6-24 months.

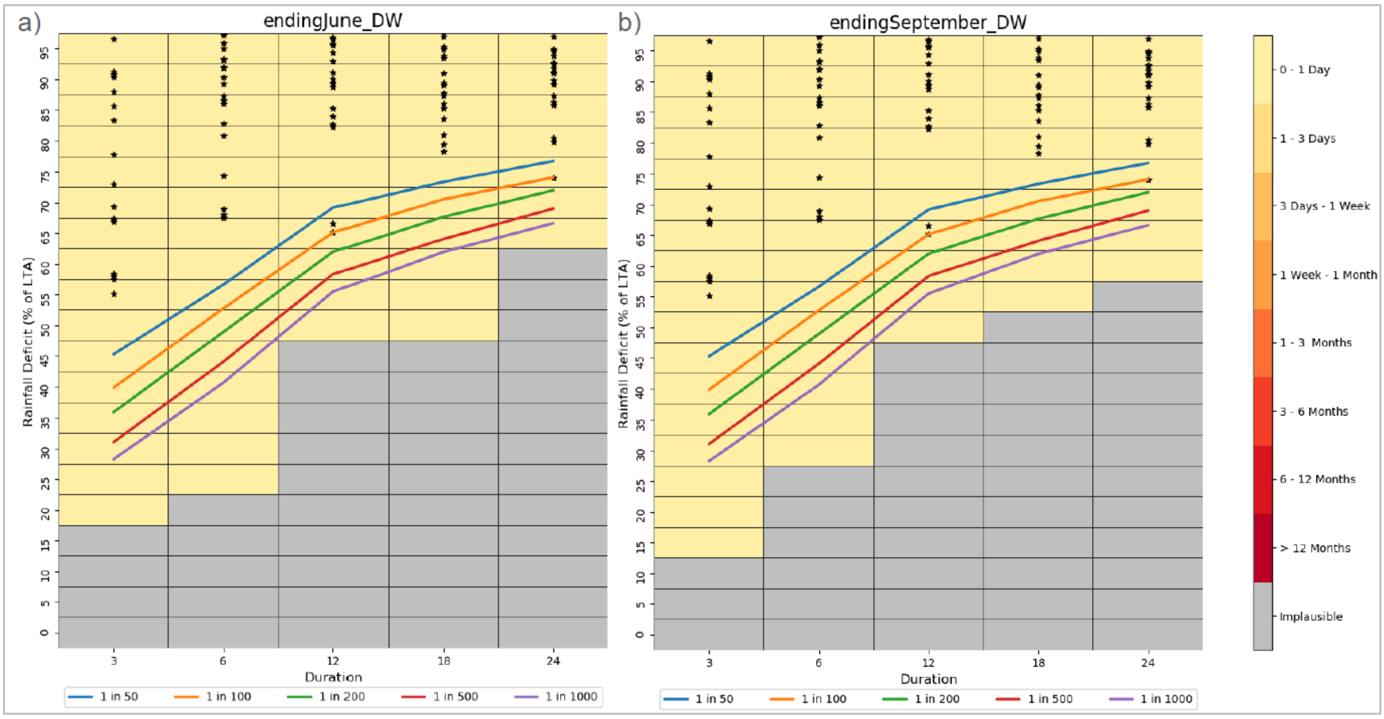

Figure 1 – Final DRS for Carlisle with failure measured as number of days below dead water for period ending in a) June and b) September

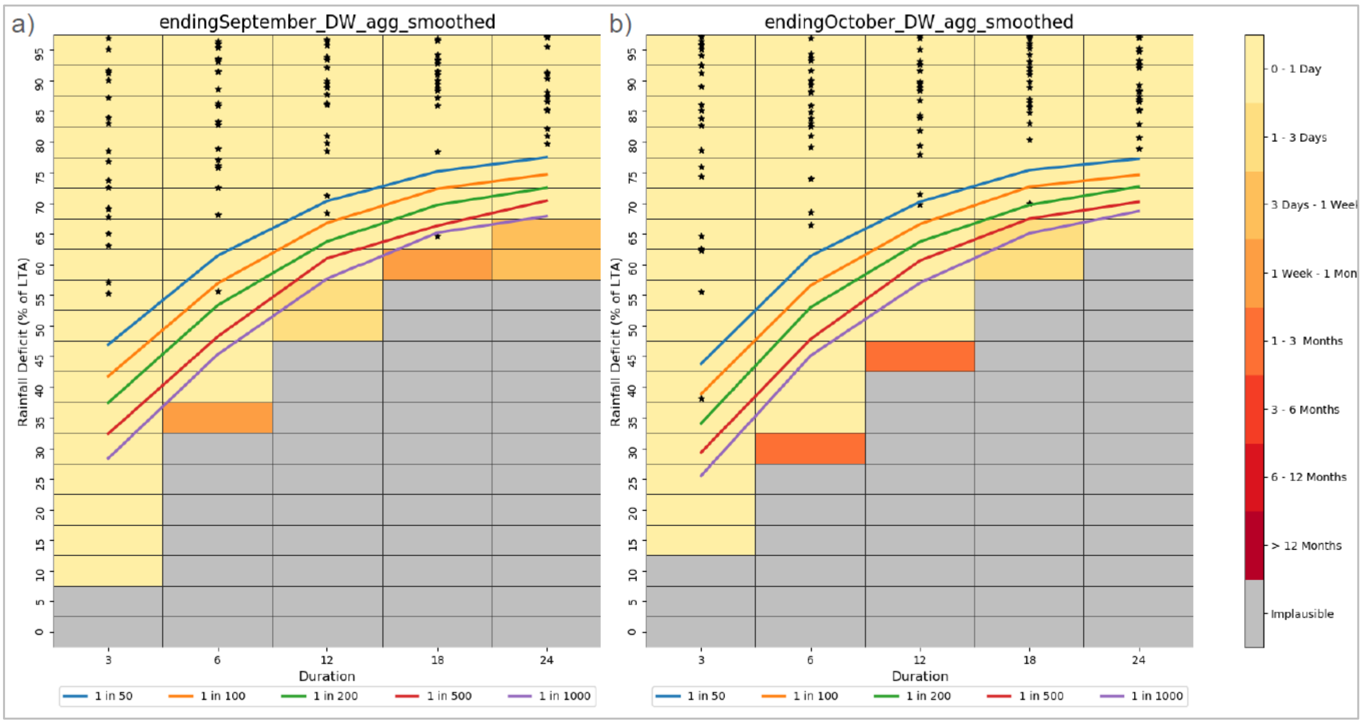

Figure 2 – Final DRS for SRZ with failure measured as number of days below DW, after smoothing, using storage aggregated over the key reservoirs to determine failure for period ending in a) September and b) October

3 Drought characterisation

Following on from the DVF assessment we used similar tools to assess our vulnerability to drought through the lens of system response, focussing initially on the estimated risk to customers and the environment related to weather variability. Note that we looked at the risk posed by other factors such as demand (e.g. due to population growth or changes in customer behaviour) and leakage reduction performance in sensitivity testing outlined in Appendix E.

The underlying synthetic droughts which were created using the "Weather Generator" as described in Appendix A have been updated since 2018, after the completion of the DVF assessment as detailed in Section 2. The sensitivity testing outlined in Appendix E, and this drought characterisation assessment, have been updated for the Strategic RZ model using the latest 19,200 year stochastic record. We simulated all of the events in the 19,200 year stochastic record to determine the estimated frequency of implementing customer restrictions and drought permits. In the events that led to more severe restrictions we then explored the main causal factors. This work was undertaken only for the Strategic RZ to better understand the failure events. We also used the approach to help select scenarios to provide a robust test of our drought plan, as further explained below and covered in Appendix E.

Table 1 provides the estimated risk of customer restrictions and drought permits during the period covered by the drought plan, expressed as event count, return period, annual risk and overall chance of occurrence. It also includes the average date of implementation, though in reality this is drawn from a relatively wide date range, hence is only indicative. Table 2 shows the duration of more severe events where the implementation of either non-essential use bans (NEUBs) or emergency drought orders (EDO) was simulated, as measured by the length of the reservoir drawdown period. The length of most events is between six to nine months though there are 4 events that extend beyond two years. we have also undertaken separate groundwater analysis for the next Water Resources Management Plan (WRMP) to help determine the 1 in 500 year deployable output. This showed that groundwater drought events in the North West also have a duration of either one or two years.

Table 1 - Strategic RZ system response drought vulnerability

Action	Number of events where the restriction is implemented (out of 19,200 year record)	Return period	Annual risk of implementation	Risk of occurring in at least one year during 2022-2026	Average date of implementation
Voluntary Use Restraint	1701	1 in 11 years	8.9%	37.1%	14-Aug
Temporary Use Bans (TUBS)	< 960	Better than 1 in 20 years	< 5%	< 22.6%	19-Aug
Drought Permits	< 960	Better than 1 in 20 years*	< 5%	< 22.6%	30-Aug
Non Essential Use Bans (NEUB)	< 192	Better than 1 in 100 years	< 1%	< 4.9%	03-Sep
Emergency Drought Orders (EDO)	< 96	Better than 1 in 200 years	< 0.5%	< 2.5%	26-Aug

**Level of service* improves *to 1 in 40 years (or 2.5% annual risk) by 2025 as part of our WRMP19 commitment. Note that whilst TUBs and drought Permits are both implemented in Level 2 their sequencing means that Drought Permits would be implemented less frequently (because in some events the water resource zone would recover before drought permits are implemented)*

Table 2 – Duration of events reaching either NEUBs or EDO as measured by reservoir drawdown period

Length of Event	Number of events in 19,200 year stochastic record
Less than 3 months	0
3-6 months	58
6-9 months	29
9-12 months	2
12-15 months	12
15-18 month	45
18-21 months	3
21-24 months	1
More than 24 months	4

We then worked backwards to attempt to identify the causes of the restrictions being implemented, asking questions such as:

- What scale of rainfall deficit is required? Over what period? What intensity?
- How does this translate to flow? Or reservoir storage?
- How does the spatial distribution of rainfall affect drought severity?
- How does the supply system map to the rainfall distribution? Which assets act as critical constraints?

We adopted an approach called “scenario discovery” to identify the critical thresholds, but in the time available we were unable to draw firm conclusions. The main finding to date, perhaps unsurprisingly, is that drought events affecting the Strategic RZ are complex, varied and often difficult to describe using simple metrics. The best approach therefore to ensuring that a large conjunctive supply system is resilient is to test it using as many different plausible drought events as possible. Preselecting one or a small number of droughts based on rainfall metrics evidently does not provide a robust test of this type of supply system. The work undertaken for the original drought plan used the stochastic dataset produced in 2016, which has 17,400 years of data. This assessment, along with Appendix E, have been updated using the latest stochastic dataset which now has 19,200 years of data. Due to new regional planning requirements we now have two further stochastic datasets and have amassed a total of almost 60,000 years of stochastic hydrological events to use in future testing[1].

We are planning further drought characterisation work for WRMP24, including continuing the scenario discovery tasks. In the meantime our understanding of the droughts that the North West is vulnerable to is best formed from studying a wide range of events individually. Figure 3 and Figure 4 provide examples of some of the graphics we are currently using in our analysis; here showing stochastic events with the IDs “4154” and “18381” respectively (the ID is simply a label we use). Both of these events can be classed as “extreme”, with 4154 resulting in the simulated implementation of NEUBs and 18381 the implementation of EDO. Whilst their severity means they are actually very unlikely to happen, it helps here to demonstrate clearly the underlying climatological factors that led to these simulated customer restrictions.

Table 3 shows how each of these events are ranked (from most to least severe) according to a range of salient metrics, along with the corresponding return periods which are calculated based on inverse ranking (i.e. 19,200 years divided by the rank). Despite return period being the most commonly used industry expression to indicate drought severity, care is required in its interpretation. If an event has a return period of 1 in 100 years this does not mean that we anticipate it will happen only once in a 100 year period. It means that each year there is a 1 in 100 chance of it happening. A better way to express this would be as a 1% annual chance, therefore annual chance has also been added to the table below.

The metrics in the table can be used to help tell the story of these events. Event 18381 is one of the worst plausible droughts created by the weather generator. It is ranked 16th out of 19,200 (corresponding to an annual chance of 0.08%) according to minimum reservoir storage levels and, worst still, this impact occurs within only one drawdown season. It is ranked 1st in terms of total April to September inflow, but only 7276th if the preceding year’s inflow is included. Event 4154 is more likely to occur but still only has an annual chance of just 0.2% based on the reservoir storage levels reached. Unlike event 18381, the implementation of restrictions can in part be attributed to poor winter refill; the 18 month April-September inflow metric has a return period of only 1 in 175 years.

Whilst in these two cases the metrics are very helpful in describing the events, care is still required when moving between different metrics and expressing severity as return periods. There is reasonable agreement between the best explanatory rainfall and flow metrics for 4154 and 18381 respectively (18 month April to September) at 1 in 282 years versus 1 in 175 years and 1 in 4 years versus 1 in 3 years. The corresponding reservoir storage metrics, which ultimately lead to the implementation of restrictions, are 1 in 505 years and 1 in 457 years respectively. This lack of correlation between metrics is repeated across other events and generally the relationship deteriorates as the severity of the events reduces. As noted in Section 2, for system response metrics such as reservoir storage the physical characteristics of the supply network will reduce or increase the severity of events depending on the specific patterns of the event, for example the rainfall intensity, and antecedent conditions that are not reflected in the rainfall and flow metrics. In the most extreme events there is so little rainfall that the differences in spatial and temporal patterns are less pronounced.

As with the previous DVF assessment, Table 3 masks spatial differences in metrics across the region as they are all calculated at resource zone level. These are too complex to show here and as noted above we are still working out how best to interpret them. In terms of rainfall, for example, event 4154 has an 18 month April to September overall return period of 1 in 282 years. This is very similar to the south of the region which has a return period of 1 in 216 years, but the north of the region has a return period of 1 in 400 years. On an individual catchment basis the return period range is wider still. Unsurprisingly given its overall severity, event 18381 is extremely dry across the whole region; based on 6 month April to September rainfall it is ranked 6th overall, 16th in the south and 4th in the north.

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[1] The new datasets have been produced using a very similar “Weather Generator” approach to 2016 but with some modifications to the climate drivers, a new base rainfall dataset (HadUK: https://www.metoffice.gov.uk/research/climate/maps-and-data/data/haduk-grid/haduk-grid) and to be spatially coherent with the other supply areas in the Water Resources West planning region.

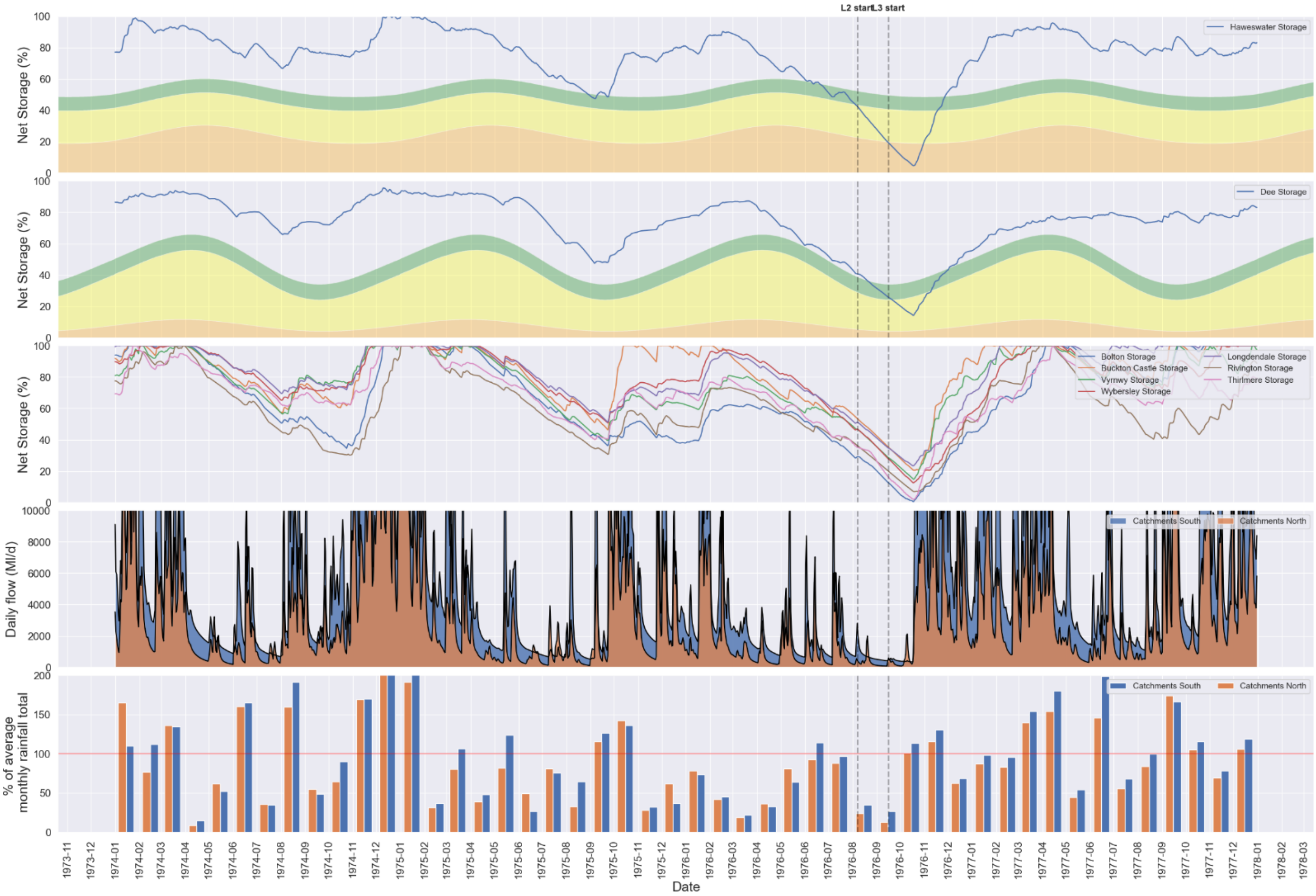

Figure 3 – Break down of stochastic event 4154 which led to the simulated implementation of non-essential use bans in September.

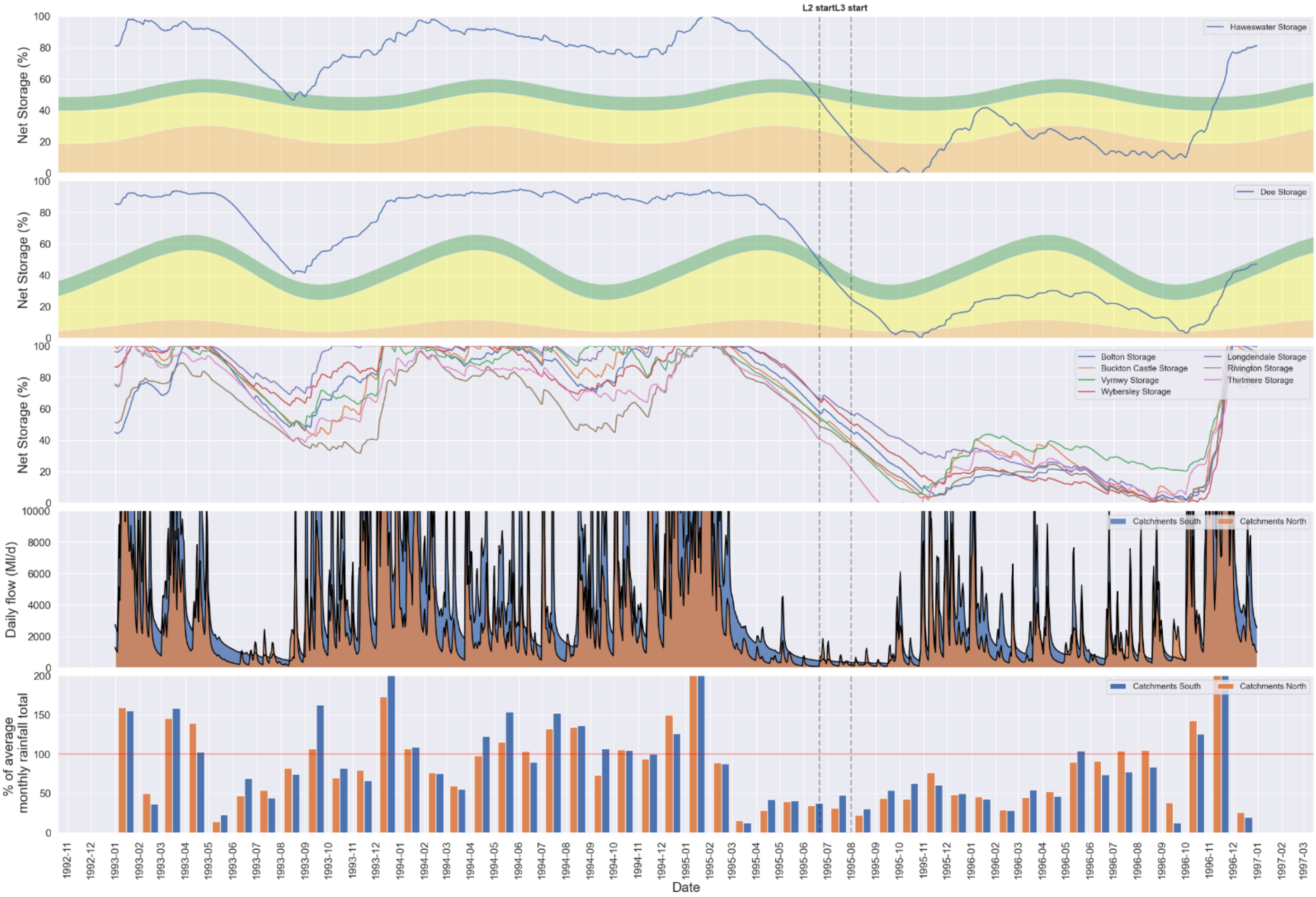

Figure 4 – Break down of stochastic event 18381 which led to the simulated implementation of emergency drought orders in September.

Table 3 – Salient metric break down of stochastic events 4154 and 18381

Metric (all reservoirs / catchments combined)	Event 4154 severity			Event 18381 severity		
	Rank out of 19,200 years	Return period	Annual chance	Rank out of 19,200 years	Return period	Annual chance
Most severe customer restriction implemented	Non-essential use ban			Emergency drought order		
Minimum reservoir storage	38th	1 in 505 years	0.20%	16th	1 in 1200 years	0.08%
Reservoir inflow during event drawdown period	159th	1 in 121 years	0.8%	1st	1 in 19200 years	0.01%
Reservoir inflow during April to September (6 months)	112th	1 in 171 years	0.58%	1st	1 in 19200 years	0.01%
Reservoir inflow during previous April to September (18 months)	110th	1 in 175 years	0.57%	7276th	1 in 3 years	38%
Rainfall during event drawdown period	489th	1 in 39 years	2.5%	10th	1 in 1920 years	4.6%
Rainfall during April to September (6 months)	234th	1 in 82 years	1.2%	6th	1 in 3200 years	0.03%
Rainfall during previous April to September (18 months)	68th	1 in 282 years	0.35%	5039th	1 in 4 years	26%

Our drought characterisation analysis was also used to select challenging events for our drought plan scenarios. Covered in Appendix E, the work focussed on testing our specific response to droughts through the actions we plan to take as set out in our drought plan. In the past, to test the drought plan to events more severe than recorded historically we were reliant on either splicing together historic events or applying arbitrary perturbations to inflows, for example a reduction of 10 percent. Whilst these synthetic events effectively stressed the system we were unable to determine their plausibility or risk of occurrence. Therefore, our new understanding of droughts has significantly improved the testing undertaken for this drought plan. Of course, our understanding of droughts and climate change is still far from complete and as a company we are always striving to improve this, as outlined in Section 4.

4 Ongoing research

We are continually looking for new ways to better understand the droughts that may occur in the North West, how they could impact our supply system, and how they are evolving over time.

The recent period 2018 to 2021 has contained some exceptionally dry spring-time weather and in 2018 this almost led to the implementation of a temporary use ban. During the same period there has been a shift in industry planning requirements towards resilience to more severe droughts, specifically with a return period of 1 in 200 years and moving to a return period of 1 in 500 years further into the future. At the time of writing our current research is largely driven by these two considerations and ongoing tasks include:

1. Review of streamflow trends – Mann Kendall statistical testing of long-term changes in river flows and reservoir inflows.
2. Review of trends in climate teleconnections, which are spatially and temporally large-scale anomalies that influence the variability of the atmospheric circulation (example outputs shown in Figure 5).
3. Weather generator – using the Weather Generator used to generate our stochastic hydrological datasets (Appendix A) to help explore the potential impact of changes in the climate on the prevalence and patterns of low rainfall events.

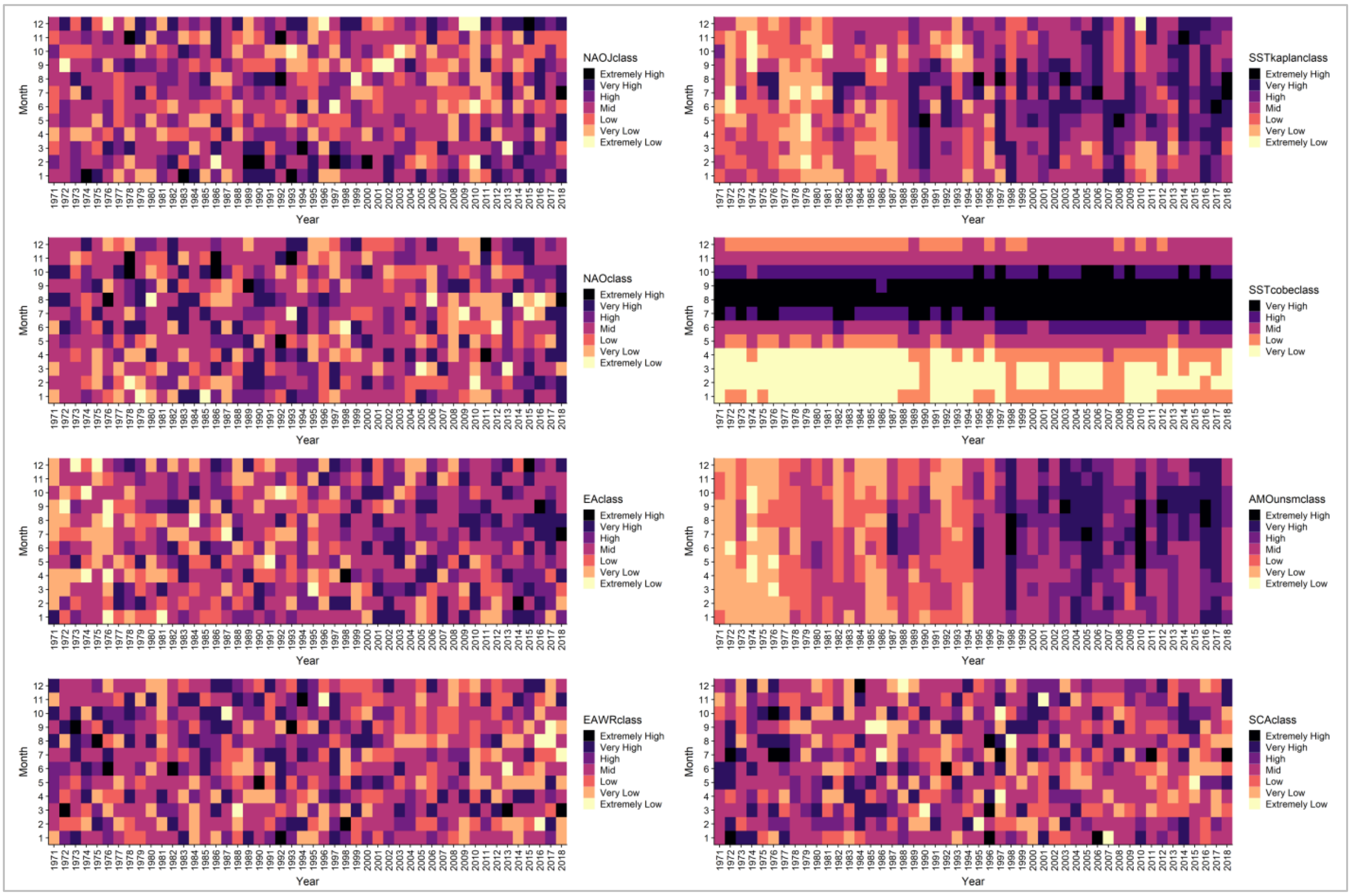

Figure 5 - Monthly teleconnection values for the period 1971-2019 for key climate drivers: North Atlantic Oscillation (NAO); Sea Surface Temperature (SST); Atlantic Multidecadal Oscillation (AMO); East Atlantic (EA); East Atlantic West Russia (EA-WR); Scandinavia (SCA)

5 Other Resource Zones

5.1 Barepot

As noted in Section 2, the Barepot RZ was screened out of the DVF assessment due to a lack of plausible drought risk. We conducted additional analysis to ensure this was the case. The flow duration curve shown in Figure 6 is a way to visualise the full spectrum of river flow at the Barepot intake on the River Derwent in Workington (the sole abstraction in this RZ). Even when combining the most severe events in the stochastic record (a return period of up to 1 in 3000 years is shown here) with extreme climate change flow factors, flow remains well above the required abstraction amount.

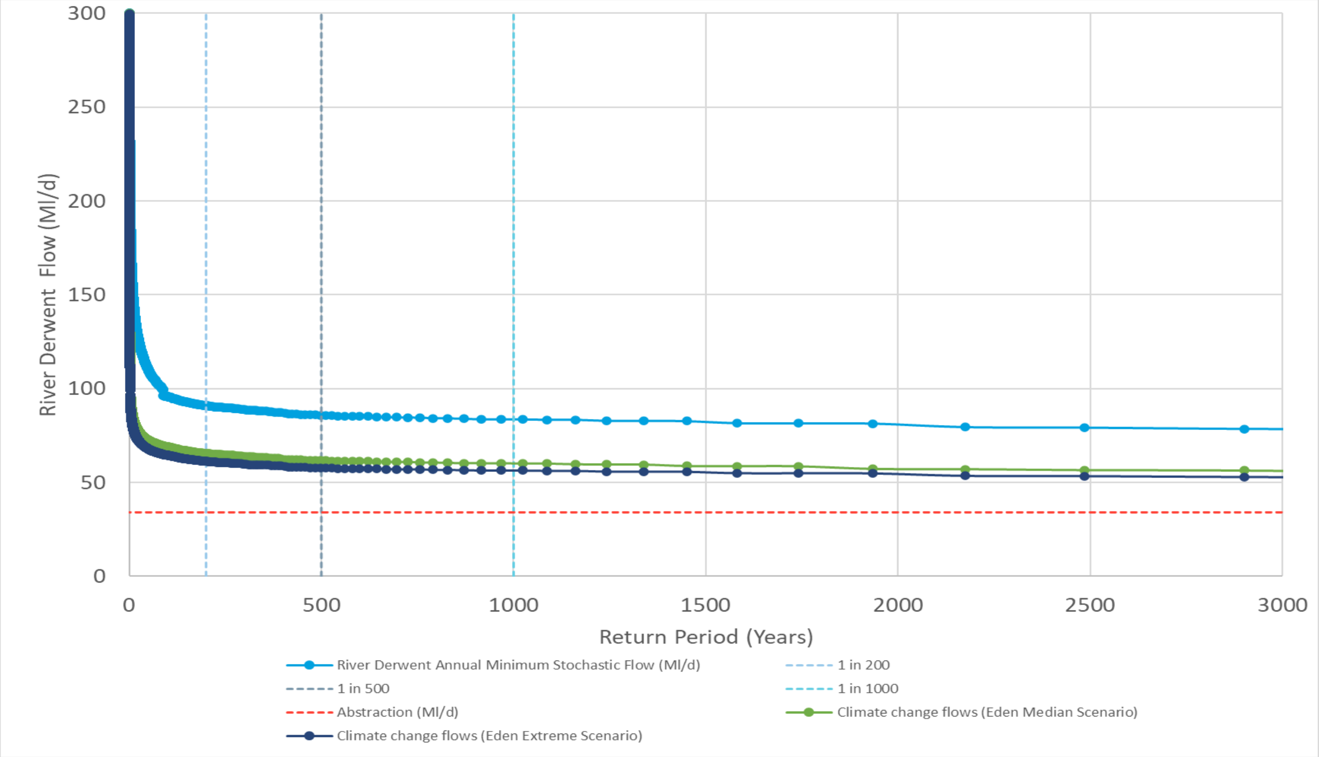

Figure 6 - River Derwent Flow Duration Curve also showing the impacts of climate change

A separate point worthy of note is that there are planned works to Yearl Weir to improve geomorphology and fish passage. Work could affect the ability to abstract water at very low river levels and therefore costs to re-engineer an intake structure to eliminate this risk have been factored into the project.

5.2 North Eden

Extreme drought analysis was carried out using evidence from the WRMP19 climate change modelling and observed water levels at Staffield borehole to estimate the likely water levels in extreme drought events in the North Eden RZ. Figure 7 shows that the estimated minimum water level would be less than a metre below the minimum observed level. This would not restrict supply other than at Bowscar where the change could be easily accommodated by lowering the pump levels. The available water is still therefore constrained by abstraction licences.

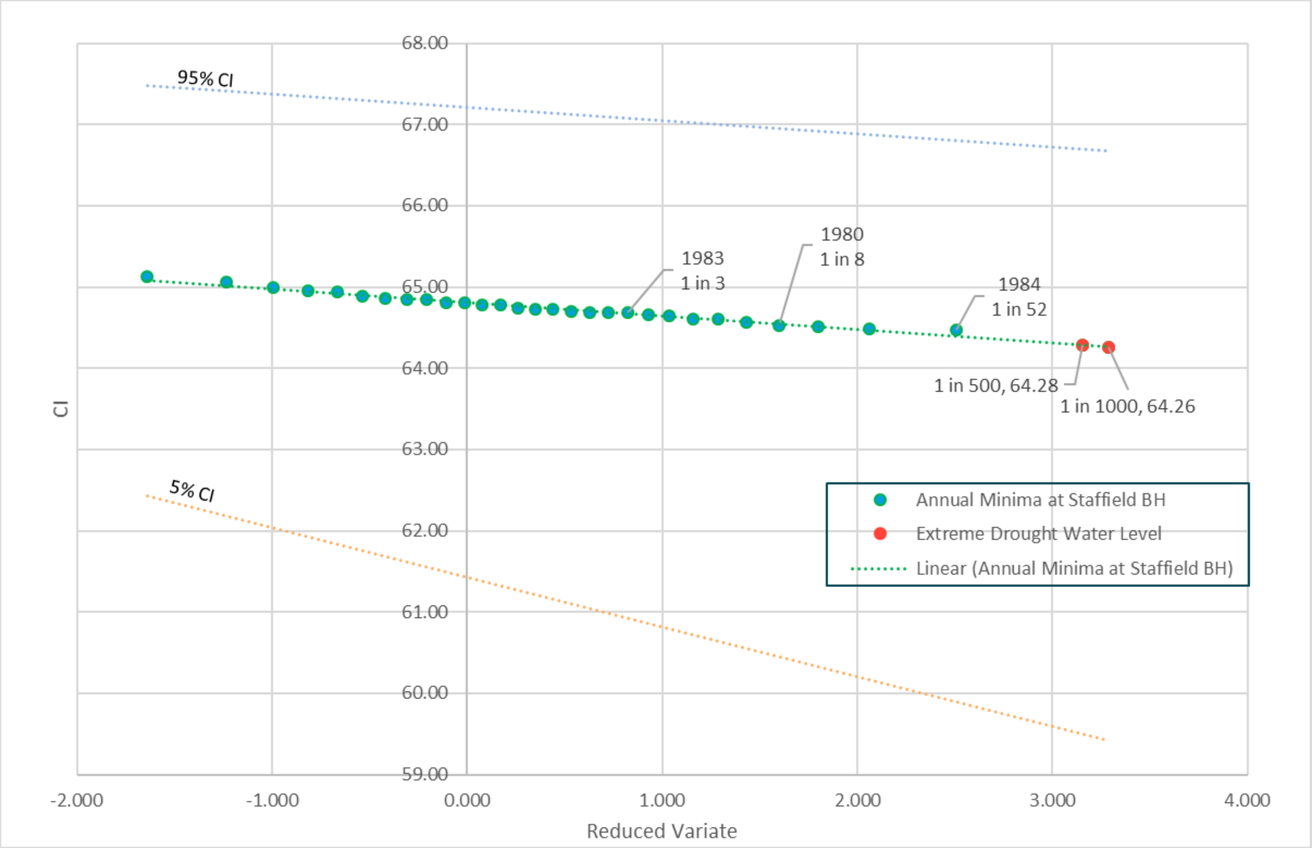

Figure 7 – Staffield Borehole (North Eden) extreme drought analysis