

# Draft Water Resources Management Plan 2024: Annex 4: Drought Vulnerability Assessment

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Version 0.1

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# 1. Introduction

Our 2019 Water Resources Management Plan (WRMP19) included an assessment of the drought vulnerability of our water resource zones (WRZs) under Annex 3, Section 4.5<sup>1</sup>. In our WRMP19 assessment we considered the rainfall deficits, probabilities and impacts upon our Deployable Output (DO) of droughts of varying severity (in terms of rainfall deficit) and duration.

We based our WRMP19 drought vulnerability assessment on methods developed under the Environment Agency (EA) 'Understanding the Performance of Water Supply System during Mild to Extreme Droughts' study<sup>2</sup>. We completed our assessment as part of our WRMP19 technical work prior to the publication of the Drought Vulnerability Framework (DVF)<sup>3</sup> in late 2017. Our assessment included development of Drought Response Surface (DRS) for each of our sensitive WRZs that compares rainfall deficits to DOs across vulnerable WRZs.

Since the publication of our WRMP19, we have updated our drought vulnerability assessment in line with the updated guidance and methods set out in the DVF (UKWIR, 2017)<sup>4</sup> and the results are presented herein.

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<sup>1</sup> Southern Water, 2020, Water Resources Management Plan, Annex 3: Supply Forecast

<sup>2</sup> Anderton, S., Ledbetter, R., and Prudhomme, C, 2015, Understanding the performance of water supply systems during mild to extreme droughts, Report SC120048/R Environment Agency, Bristol

<sup>3</sup> Counsell, C., Hunt, D., and Ledbetter, R., 2017, Drought Vulnerability Framework, UK Water Industry Research Limited, London.

<sup>4</sup> *ibid*

## 2. Methodology

### 2.1. Data sources

The input data for our assessment are based on our supply and demand modelling from WRMP19 and are summarised in Table 2.1.

Data	Description	Source
Rainfall	Stochastic rainfall for key rain gauge inputs to our water resource models	WRMP19 stochastic climate model
Deployable Output	DO of our sources	Time series of DO from our WRMP19 stochastic modelling
Demand	Distribution Input for WRMP19	Modelled DI for 2022 as set out for each WRZ in our Water Resource Planning Tables
Demand saving	Estimated impact (%) of demand restrictions (Temporary Use Bans and Non Essential Use Bans) on WRZ demand	WRMP19 Demand Savings Study <sup>5</sup> and WRMP19 Water Resource Planning tables
WRZ imports and exports	Volume of transfers both internal and external between a WRZ and neighbouring WRZs, including that of other Water Companies	WRMP19 Water Resource Planning tables
Headroom	Target Headroom to account for uncertainty in our supply demand balance	WRMP19 Water Resource Planning tables
Outage allowance	Allowance for the volume of sites water which might not be available due to planned or unplanned outages	WRMP19 Water Resource Planning tables

**Table 2.1.** Summary of input data used for our drought vulnerability assessment.

### 2.2. High-level screening

The first step in our assessment was to conduct a high-level screening to evaluate and evidence the WRZs that could be subject to a lower level of analysis due to their apparent drought resilience.<sup>6</sup>

The vulnerability of our supply system to drought varies across our supply area. This reflects differences in rainfall patterns and the nature of water resources and the varying proportions of groundwater, rivers and reservoirs that make up our supplies.

<sup>5</sup> Atkins, 2017, Effectiveness of Restrictions Technical Note, Southern Water Drought Plan.

<sup>6</sup>Counsell, C., Hunt, D., and Ledbetter, R., 2017, Drought Vulnerability Framework, UK Water Industry Research Limited, London.

The amount of water that we can supply to some WRZs is limited either by our abstraction licences or by the amount we can treat safely. These WRZs tend to show a high degree of resilience to drought, so a full drought vulnerability assessment of these WRZs would provide only limited benefit.

We have applied the high-level screening process set out in the DVF<sup>7</sup> to each of our WRZs. Any WRZs that could meet either, or both, criteria below are screened out from detailed assessment:

1. For run-of-river and groundwater dominated WRZs, the amount of DO that is at risk from drought is smaller in percentage terms than the following calculation:  
$$[Available\ Headroom\ net\ of\ outage\ (DO - demand - Target\ Headroom)] / DO$$
2. For more complex WRZs, the combined impact of the extreme drought risk (as outlined in Table 10 of the WRMP19) and climate change is less than 5% of DO, and available headroom is more than twice Target Headroom

In either case, a supply/demand deficit due to drought is implausible.<sup>8</sup>

The majority of our WRZs are assessed under the first category, as 11 of our 14 WRZs are groundwater or run-of river dominated with only minor or no reservoir storage. The remainder are more complex WRZs with some reservoir storage, and large inter-zonal transfers. This includes the Kent Medway East WRZ, which is 100% groundwater, but is also closely interconnected with the Kent Medway West WRZ and our reservoir system in Kent - The River Medway Scheme.

The key supply characteristics of each of our WRZs are summarised in Table 2.2.

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<sup>7</sup> Ibid

<sup>8</sup> Southern Water, 2019, Securing a resilient future for water in the South East Our Water Resources Management Plan for 2020–70

**Table 2.2:** Key supply characteristics by DO proportion of each of our WRZs<sup>9</sup>.

WRZ	Screening Criteria	Groundwater	Run-of-River	Reservoirs	Transfers
Hampshire Kingsclere	1	100%	0%	0%	0%
Hampshire Andover	1	100%	0%	0%	0%
Hampshire Winchester	1	100%	0%	0%	0%
Hampshire Rural	1	100%	0%	0%	0%
Hampshire Southampton East	1	48%	52%	0%	0%
Hampshire Southampton West	1	0	100%	0%	0%
Isle of Wight	1	47%	23%	0%	30%
Sussex North	1	35%	51%	8%	6%
Sussex Worthing	1	100%	0%	0%	0%
Sussex Brighton	1	100%	0%	0%	0%
Kent Medway West	2	44%	56% (Run-of-river and reservoirs)		0%
Kent Medway East	2	100%	0%	0%	0%
Sussex Hastings	2	5%	0%	79%	16%
Kent Thanet	1	77%	0%	0%	23%

To carry out the screening criteria for the groundwater and run-of-river dominated WRZ the Available Headroom net of Outage was calculated according to the screening criteria equation where:

DO = Deployable Output at a given drought probability. The amount of DO at risk from drought was determined as the difference for a given drought against the calculated normal year DO.

Demand = Taken to be the forecast 2022-23 WRZ Distribution Input as set out in our WRMP19 planning tables.

Target Headroom = Taken to be the WRZ Target Headroom for 2022-23 as set out in our WRMP19 planning tables

The results of the high-level screening are presented in Table 2.3.

<sup>9</sup> Ibid

**Table 2.3: Results by WRZ of High-level drought vulnerability screening against criteria 1, “Y” = WRZ is potentially drought vulnerable, “N” = WRZ may be screened out from detailed analysis.**

IOW = Isle of Wight; HW = Hampshire Winchester; HSW = Hampshire Southampton West; HSE = Hampshire Southampton East; HR = Hampshire Rural; HK = Hampshire Kingsclere; HA = Hampshire Andover; SN = Sussex North; SB = Sussex Brighton; SW = Sussex Worthing; KT = Kent Thanet; KME = Kent Medway East; KMW = Kent Medway West; SH = Sussex Hastings

	Drought return period	IOW*	HW*	HSW*	HSE*	HR*	HK*	HA*	SN*	SB*	SW*	KT*	KME*	KMW*	SH*
Minimum or Dry Year Annual Average	1-in-2	Y	N	N	Y	N	N	N	N	N	N	N	N	N	N
	1-in-20	Y	N	N	Y	N	N	N	Y	N	N	N	N	N	N
	1-in-100	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y
	1-in-200	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y
	1-in-500	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	N	N	Y
	1-in-1000	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	N	N	Y
Dry Year Critical Period	1-in-2	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	1-in-20	Y	N	N	Y	N	N	N	N	N	N	Y	N	N	N
	1-in-100	Y	N	N	Y	N	N	N	Y	N	N	Y	N	N	N
	1-in-200	Y	N	Y	Y	N	N	N	Y	N	N	Y	N	N	N
	1-in-500	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	N
	1-in-1000	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	N

The results of high level screening against the first criteria show there are five ‘simple’ WRZs that are screened out from detailed assessment. These are Hampshire Winchester (HW), Hampshire Rural (HR), Hampshire Andover (HA), Hampshire Kingsclere (HK) and Kent Medway East (KME).

The four northern Hampshire WRZs were also not considered in our WRMP19 drought vulnerability assessment.<sup>10</sup> These WRZs are 100% dependant on groundwater and our water resource modelling for WRMP19 indicated that the yield of these groundwater sources is either licence or infrastructure constrained and is not sensitive to drought or climate change. In addition, the DO of each of these WRZs exceeds forecast demand and target headroom.

KME is dominated by groundwater but receives some water from internal transfers from the neighbouring Kent Medway West (KMW) WRZ. KME is relatively drought resilient and whilst there are some drought sensitive sources, the zone demand is low compared to the DO available. There are also a large number of non-drought sensitive infrastructure or licence constrained sources which are able to maintain supplies.

The high-level screening considers only the native WRZ DO and ignores the effect of transfers. This affects some WRZs which are dependent upon transfers from neighbouring WRZs such as the Isle of Wight (IOW) and Kent Thanet (KT). If these transfers were included in the baseline DO then these WRZs would be more resilient.

Of the more 'complex' WRZs that include or are closely linked to a degree of WRZ storage; KMW and Sussex Hastings (SH), pass the first screening assessment for Dry Year Critical Period (DYCP), but SH fails for the Dry Year Annual Average (DYAA) period. When considered against the second screening criteria for WRZs that are more complex only KMW has sufficient headroom to pass in its own right. However, if considered collectively, given the interlinked nature of the WRZs, then both fail.

## 2.3. Characterisation of supply system and calculation approach

Following the high-level screening, the DVF must then consider the most appropriate modelling approach based on the available water resource assessments (from WRMP19) and the availability of data and models which can be applied.

All of our drought rainfall data and hydrological and hydrogeological water resource modelling for WRMP19 was undertaken using stochastic water resource models. Rainfall and Potential Evapotranspiration (PET) data were undertaken using an enhanced weather generator developed at Newcastle University<sup>11</sup>. We have 2,000 years of modelled coherent rainfall, runoff, groundwater, and DO data across our WRZs.

For our 'simple' groundwater and run-of-river dominated WRZs, DO was based on additive assessment of source-by-source DOs at a range of drought severities. System simulator or behaviour models were only used to assess DO where there were conjunctive use benefits from supply system storage.

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<sup>10</sup> Southern Water, 2020, Water Resources Management Plan, Annex 3: Supply Forecast

<sup>11</sup> Serinaldi, F. and Kilsby, C., 2012, A modular class of multisite monthly rainfall generators for water resources management and impact studies. *Journal of Hydrology* 464-465, pp. 528-540.



Our WRZs are therefore classified under the DVF as being consistent with DVF approach 1a or 1b.<sup>12</sup> For the WRZs being assessed full rainfall deficit/flow analysis will be carried out.

Our assessment considered rainfall deficits and accumulations from 3 to 60 months and droughts ending in the calendar months from July to December. The inclusion of shorter period rainfall deficits (3-month intervals) was considered following recent drought permit experience for the River Test.

## 2.4. Selection of ‘month ending’ attribute

The ‘month ending’ attribute relates to the period up to which rainfall deficits are calculated and the period at which ‘failures’ occur, or periods when abnormal restrictions might occur.

For the majority of our WRZs, key deficits and failures are driven by supply-demand deficits for the Average Deployable Output (ADO) or Minimum Deployable Output (MDO) period. This reflects the run-of-river and groundwater dominance of such WRZs where supplies become most constrained during the time of minimum flow or groundwater level typically in the autumn or early winter.

We have characterised each of our WRZs according to our understanding of their historical drought response and the composition of their supplies (Table 22). Our characterisation is presented in Table 2.4.

**Table 2.4: Selection of the two “month ending” response surfaces for our WRZs.**

Timing	Summer Critical Period (peak week) driven	ADO/MDO driven; small storage, flashy	ADO/MDO driven; Medium storage, normal (groundwater recession)	ADO/MDO driven; High storage, slow (groundwater) recession
WRZs in category		IOW, SB, SW	HSW, HSE, SN, KT,	KMW, SH, KME
Early ‘Month Ending’ DRS	Ending July	Ending July	Ending August	Ending September or October
Late ‘Month Ending’ DRS	Ending August	Ending October	Ending November	Ending November or December

Irrespective of the recommended response surface, our DVF assessment has been carried out in a semi-automated way such that it is straightforward to calculate a DRS for any given month ending and rainfall accumulation period. We have therefore considered all the data for droughts ending from July through to December and present the most appropriate data that best characterises each WRZ’s drought vulnerability.

<sup>12</sup> Counsell, C., Hunt, D., and Ledbetter, R., 2017, Drought Vulnerability Framework, UK Water Industry Research Limited, London.

## 2.5. Selection of demand level

The DRS is required to be generated for a single, specified level of demand to be used within the behavioural model or other assessment of WRZ failure (e.g. for comparison to DO). Four possibilities are presented under the DVF<sup>13</sup>:

1. Total WRZ demand (DI)
2. Total WRZ demand plus Target Headroom
3. Total WRZ demand plus Target Headroom plus Outage
4. Demand equivalent to DO

The framework recommends that the primary assessment of drought vulnerability should be against demand level 2 (Demand plus Target Headroom) and this corresponds to our main assessment. We have also produced DRS plots for demand level 3 (Demand plus Target Headroom plus Outage).

Although we have not directly assessed against level 4 (Demand equivalent to DO), we have generated response surface plots for scenarios equivalent to that under the 'Mild to Extreme Droughts Study'<sup>14</sup> which examines the relationship between rainfall deficits, drought duration and decline in DO. We have also plotted additional DRS plots that relate rainfall deficit and drought duration to hydrological variables that characterise each WRZ such as key flow time series or groundwater levels at indicator boreholes. Although not required by the DVF or for the vulnerability assessment, these analyses provide useful additional context that can more readily be related to drought trigger levels.

We have not considered an assessment at demand level 1.

The data for our demand levels are based on that presented in our water resource planning tables for the period 2022-23. Our forecast demand profiles typically decline due to our planned water efficiency and leakage reduction programme and hence this represents a worst-case demand scenario for the period covered by this plan.

- The value for demand is the Distribution Input - line 11FP
- The value for Target Headroom is the Target Headroom Allowance – line 16FP
- The value for Outage is the WRZ Outage Allowance – line 10BL

All of these data are based on the DYAA/MDO WRMP19 planning tables.

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<sup>13</sup> Counsell, C., Hunt, D., and Ledbetter, R., 2017, Drought Vulnerability Framework, UK Water Industry Research Limited, London.

<sup>14</sup> Anderton, S., Ledbetter, R., and Prudhomme, C., 2015, Understanding the performance of water supply systems during mild to extreme droughts, Report SC120048/R Environment Agency, Bristol

### 2.5.1. Demand management and drought permits/orders

We have included the benefits demand side effect of demand restrictions for Temporary Use Bans (TUBs) and Non-Essential Use bans (NEUBs) in our drought vulnerability assessment. This is consistent with our approach to completing Table 10 of the Water Resource Planning tables. The magnitude of demand saving benefits are based on those assumed for WRMP19<sup>15</sup> and are summarised in Table 2.5.

**Table 2.5: Summary of demand side benefits of restrictions applied to DI for failure assessment based on our MDO period.<sup>16</sup>**

Supply Area	WRZs	Effectiveness of TUBs and NEUBs (MDO period)
Western	HK, HA, HR, HW, HSE, HSW, IOW	3%
Central	SN, SB, SW	3%
Eastern	KMW, KME, KT, SH	2%

We have excluded the supply-side benefits of demand savings and the benefits associated with any drought permits/orders. This reflects that the benefits are uncertain, and that they do not provide long-term resilience. For example, our target level of service and reliance on drought permits/orders is expected to reduce as other planned water resource schemes provide a greater degree of resilience.

Where our drought vulnerability assessment has been applied outside of a behavioural model then we have made the simplifying assumption that the benefits are always on. Whilst this is inconsistent with our stated level of service for TUBs and NEUBs, we would generally not expect significant supply failures to occur in normal to mild droughts (<1-in-20 year return period) except for Hampshire Southampton West where we recognise the significant risk to the WRZ and its reliance on drought permits/orders.

## 2.6. Other supply and demand assumptions and failure calculations

In applying our vulnerability assessment, we have applied a consistent set of assumptions around other elements of our supply-demand balance. These elements are not covered in detail by the DVF and our assumptions are set out in Table 2.6.

<sup>15</sup> Atkins, 2017, Effectiveness of Restrictions Technical Note, Southern Water Drought Plan.

<sup>16</sup> Ibid

As the majority of our WRZs are dominated by supplies from run-of-river or groundwater supplies we have assessed system failures. For systems where there is no storage, failures are calculated to occur where:

$$WRZ\ DO + Imports - Exports < WRZ\ DI + Target\ Headroom\ (for\ demand\ level\ 2)$$

Where:

WRZ DO is input as time series outputs from our water resource modelling.

Imports and Exports are fixed values from our water resource planning tables.

DI is the fixed WRZ DI for 2022-23 from our water resource planning tables.

Target Headroom is the fixed Target Headroom for 2022-23 from our water resource planning tables.

For assessment against demand level 3, Outage is included as an additional demand (DI) volume.

**Table 2.6: Other assumptions in our drought vulnerability assessment.**

Supply Demand Element	Assumption
Process losses	Excluded from our assessment, as typically these are small and vary with DO. Process losses are not considered in WRMP19 Table 10.
Imports and exports	Net effect on WRZ DO included in our assessment. Although we have generally excluded transfers from WRMP Table 10, these volumes are important for maintaining supplies in some WRZs and may increase drought vulnerability in others.
Residual calculation to account for integrated risk model/scenario generator model approach - includes allowance for uncertain sustainability reductions	We have excluded this additional volume, which accounts for our risk based planning approach rather than target headroom. Uncertain sustainability reductions have also been excluded but they are important drivers of supply demand deficits and increasing drought vulnerability in some WRZs.
Climate change	Because our climate change modelling approach is probabilistic, it is inappropriate to apply a single climate change factor to our DO. Climate change may either increase or decrease DO and therefore we have excluded its effects in the assessment that is based on our baseline DO. Use of the baseline DO is consistent with how we have completed WRMP Table 10.
Other supply demand schemes	Where other supply demand schemes (e.g. increased water efficiency) are expected to be in place by 2022, we have included the impact of these schemes in our baseline DO. Note that this excluded the supply side benefits of any drought permits/orders.

For the more complex WRZs where storage in surface water reservoirs is a major component of the supply base, the full 2000-year stochastic flow sequence has been modelled in our behavioural Aquator model of our Eastern area. These WRZs (KMW, KME and SH) have been combined into a single vulnerability assessment due to the conjunctive use for these WRZs and the transfers between them.

The underlying calculation and generation of our DRS plots has been produced in Python code. This allows semi-automated construction of DRS plots, rainfall deficits and probability plots for each WRZ.

## 3. Results

### 3.1. Evaluation of rainfall deficit/probability bands

Our DO assessments for WRMP19 were based on calculations using stochastically generated rainfall time series in combination with hydrological and groundwater models. These models were used to produce output time series of flows and groundwater levels from which DO could be estimated.

Following our recent drought permit experience for the River Test we wanted to examine the relationship of shorter drought durations (<3 months). Because the calculations have been automated, we are able to assess the full range of rainfall deficits from 3 to 60 months inclusive.

Rainfall probability / deficit curves have been generated automatically from our stochastic rainfall data for each WRZ. Rainfall deficits for accumulations were compared to the long-term (1961-90) average. Rainfall probability and return period was determined by inverse ranking. An example pair of deficit versus return period plots are presented in Figure 2.1.

All of the rainfall deficit plots across our region show similar trends. Rainfall accumulations show that variance increases with return period and that rainfall deficit, as a proportion of long-term average rainfall, shows a higher variation for shorter drought durations and accumulation periods. Regression to the mean causes deficits to trend towards smaller deficits as the accumulation periods increase. Autumn and winter months also tend to show slightly larger deficits from the mean over short accumulation periods (>6 months) than summer months (July and August) which are typically drier anyway.

All years were allocated into rainfall deficit bands according to their annual rainfall totals by WRZ. The average number of days failure was calculated for each DRS cell by summing the number of days failure in each cell and dividing by the total number of years that fall within that cell. We have excluded short duration failures of less than 4 days.

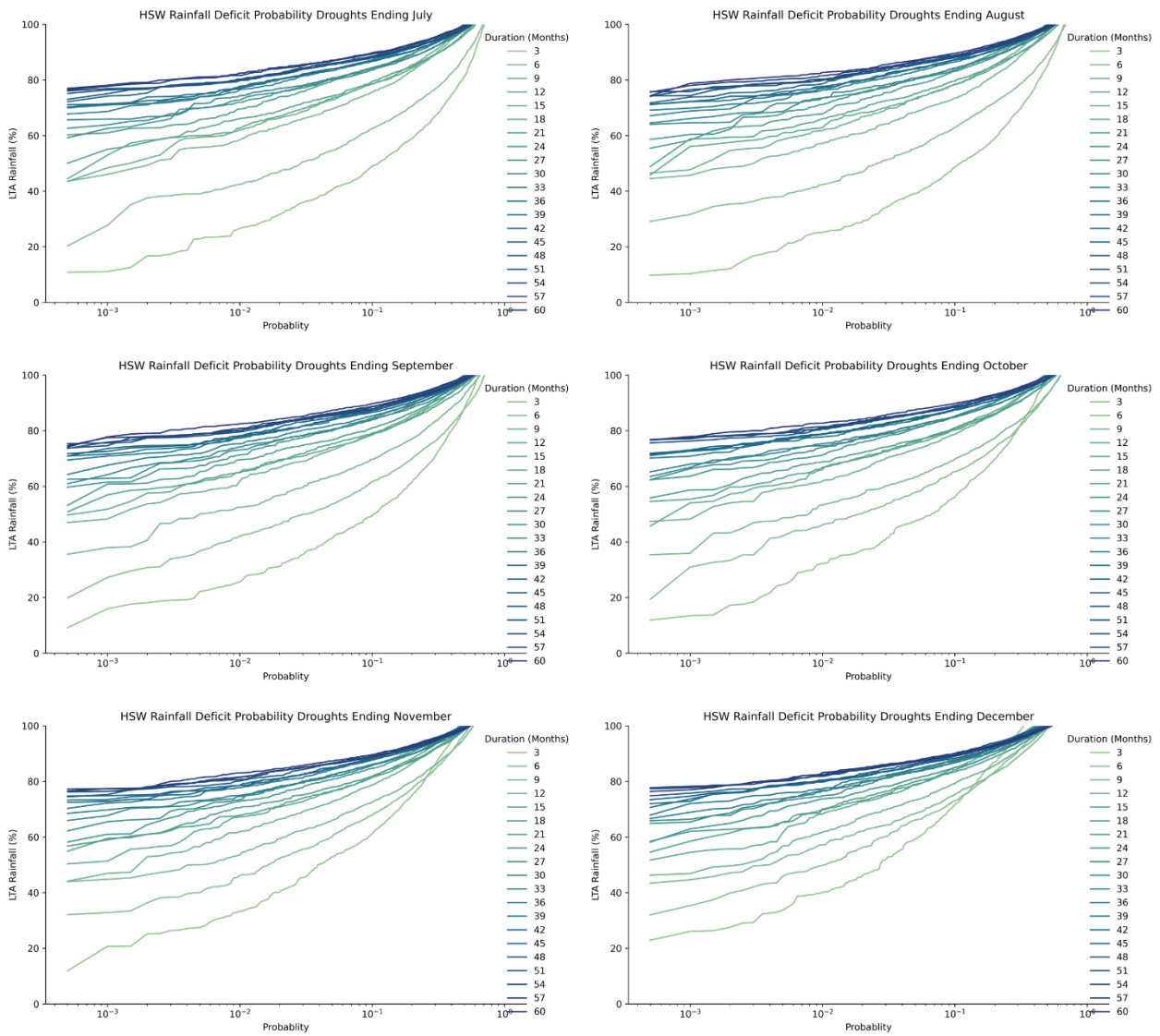


Figure 2.1: Example rainfall deficit versus return period plots for HSW WRZ.

### 3.2. Drought vulnerability – Hampshire Southampton West WRZ

A summary of the key DRS plots for this WRZ are presented in Figure 2.2.

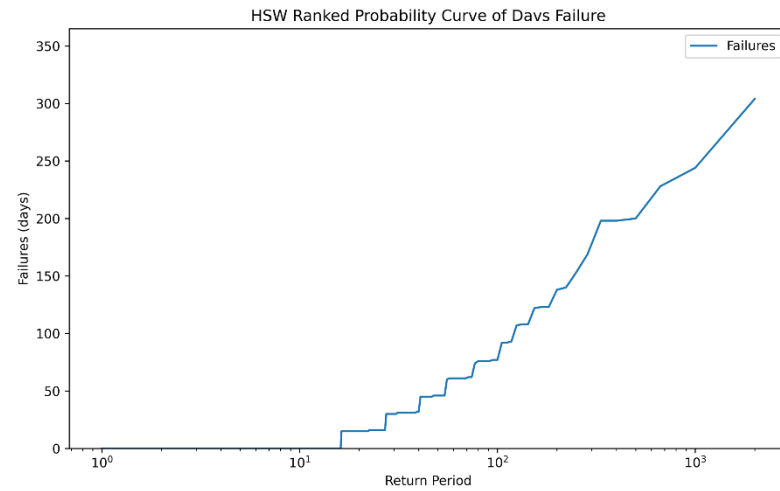
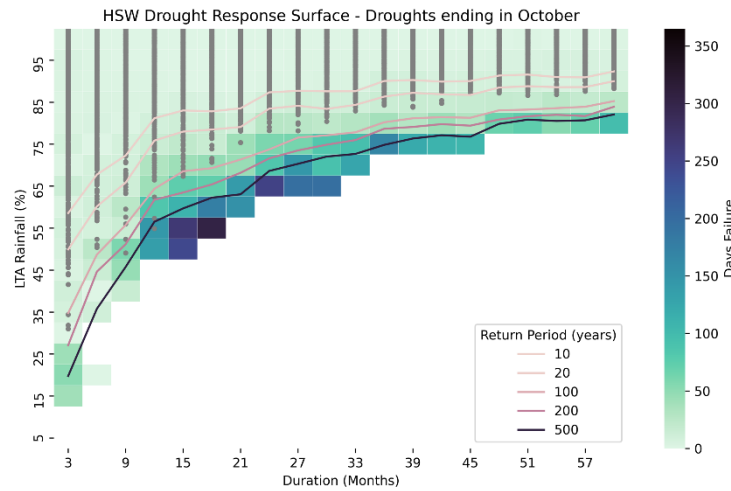
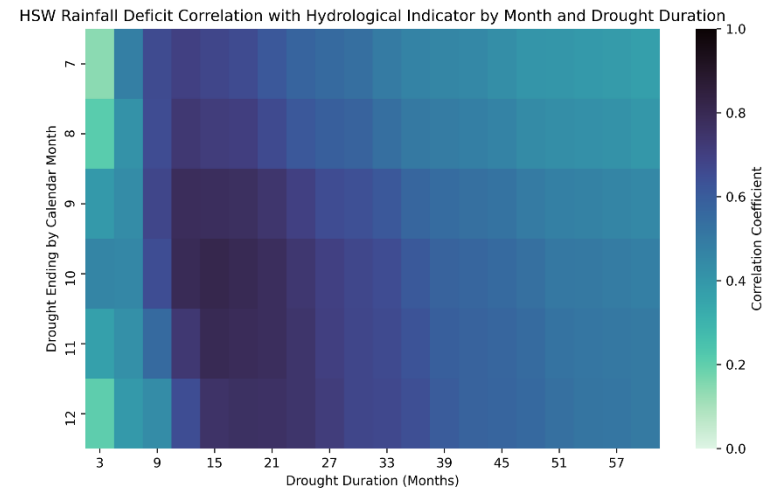
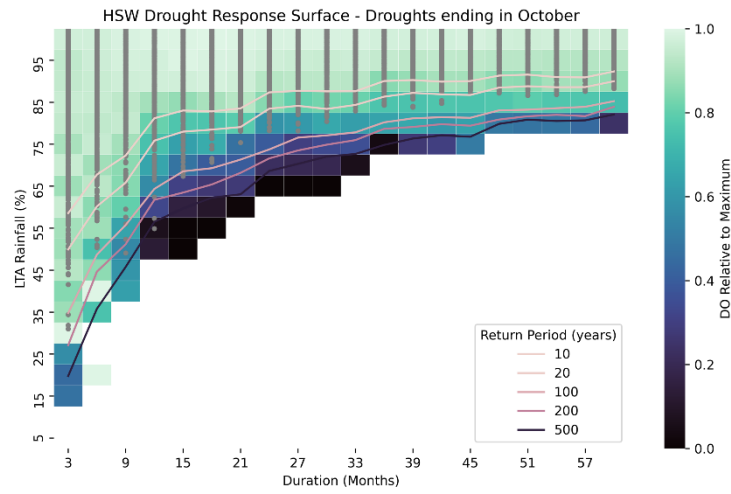


Figure 2.2: Drought response surfaces for HSW WRZ.

Summary plots like this (Figure 2.2) have been produced for each WRZ or group if WRZ comprises four sub plots that show the following:

- Top left, a DRS that relates the decline in DO relative to the normal year maximum to rainfall deficits. Although not required as part of the formal drought vulnerability assessment that focuses on supply failures, this analysis is still useful to understand the hydrology and hydrogeology of the WRZ supplies. It also provides an indication of WRZ resilience as, even though the system may not fail, reduced supplies during drought can restrict operational flexibility redundancy and make a WRZ more prone to shocks such as large unplanned outages or other external factors.
- The top right chart is a correlation heat map between the time series of a key hydrological indicator for a given WRZ and the rainfall deficits for different drought durations and drought ending months. This plot shows how the hydrological and hydrogeological systems of a WRZ respond to drought and is helpful for identifying the critical drought duration and month ending. For HSW the hydrological indicator time series is the modelled Test Total Flow.
- The lower left plot is the critical DRS for that water resource which relates rainfall deficits and drought durations to supply system failures for the most critical drought ending month. For HSW, as with many of our WRZs, this critical month appears to be for Droughts Ending October, generally, this reflects the timing of groundwater and flow minima.
- The lower right plot shows a ranked probability curve of failure days this is provided for comparison against our levels of service and for comparison of our expected failures against our target levels of service. This plot is also used to consider if any level of service scaling adjustments are warranted.

The DO DRS for HSW is similar to that from our WRMP19 preliminary vulnerability assessment. This indicates that in HSW, DO starts to decline for relatively mild droughts (<1-in-10 years) and very significantly declines for droughts of greater than 1-in-20 years severity. The most critical drought durations are for rainfall deficits for droughts between 9 and 30 months with the greatest impacts for droughts ending in October between 15-and 21 months duration. There is also some sensitivity to short-term rainfall deficits that arise from dry autumn and summer periods leading to extended recession of river flows.

The rainfall deficit – hydrological indicator plot shows similar results, with the greatest correlations between low flows occurring due to rainfall deficits between 12 and 18 months duration ending in the autumn months between September and November when minimum annual flows typically occur.

The DO response surface showing failures indicates that failures start to occur for relatively mild droughts (<1-in-20 years). This is consistent with the WRMP19 water resource modelling which showed this WRZ faces significant supply demand deficits following sustainability reductions that occurred in 2019. We are reliant on drought permits/orders to maintain supplies even in moderate droughts until a long-term water resource solution is in place for Hampshire. Failures can occur for all drought durations and even minor rainfall deficits but are most significant for rainfall deficits greater than 1-in-20 years and for drought durations between 12 and 24 months. This reflects that single dry winter events combined with dry summer and autumn conditions, similar in style to the 1976 historical drought have the most significant impact on this WRZ.

We have also considered a secondary “early” response surface for droughts ending August (Figure 2.3). This is more reflective of critical period responses. This shows a narrower range of failures relating to shorter duration, single winter drought events of 9-18 months but again showing vulnerability to relatively mild droughts from around 1 in 20-year return periods.

As we recognised in WRMP19, the failure probability curve illustrates that we cannot meet our target levels of service in this WRZ whilst we are reliant on drought permits/orders to close our supply demand balance. We expect that we will need to implement drought permits/orders on average between 1-in-10 to 1-in-20 years and will need to apply for drought permits much more frequently.



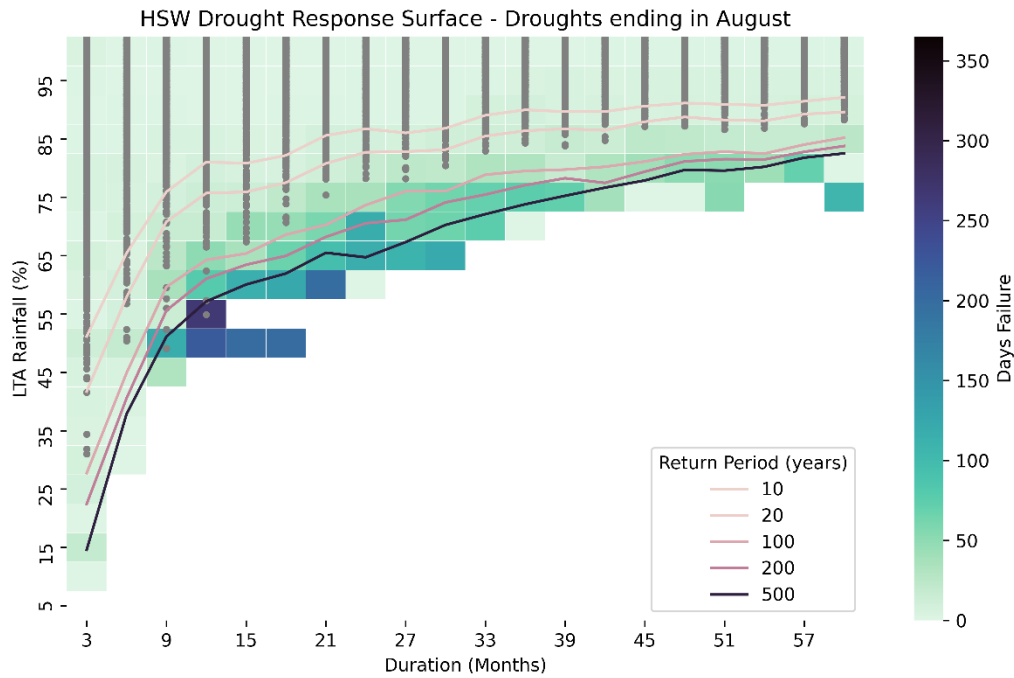


Figure 2.3: Secondary Early Drought response surfaces (August) for HSW WRZ

### 3.3. Drought Vulnerability – Hampshire Southampton East WRZ

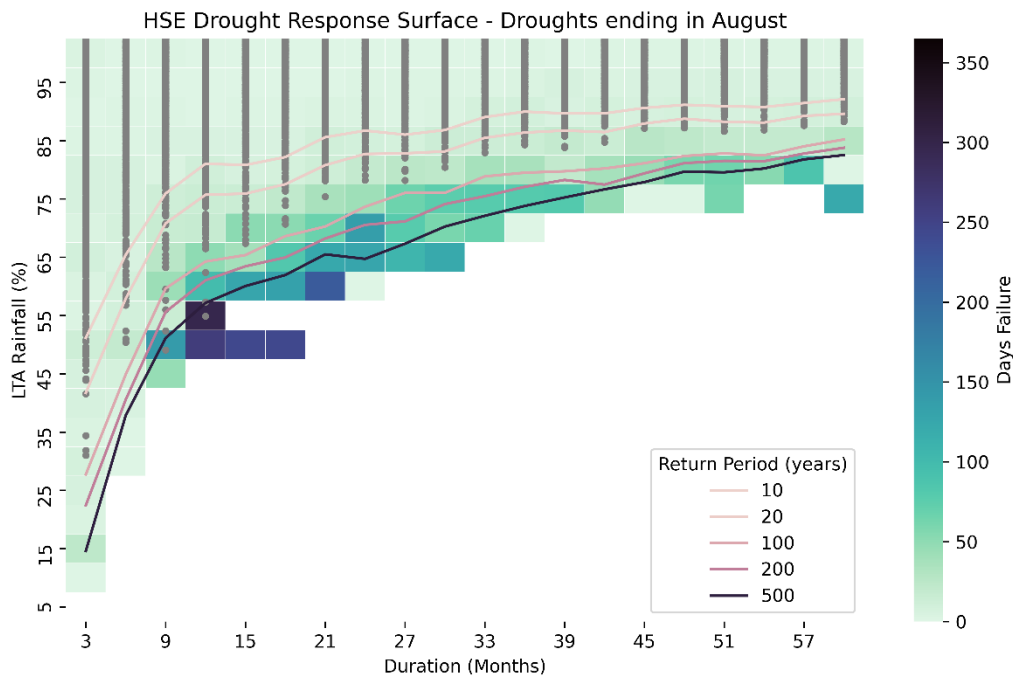
The summary DO response surfaces and associated plots for HSE are presented in Figure 2.4. These follow a similar format to those presented for HSW.

Overall, the response surfaces for HSE are very similar to that for HSW as the River Itchen shares many similar characteristics to the River Test, both being baseflow dominated chalk rivers and hence the hydrological response to rainfall deficits is very similar.

As with HSW, DO response, failures and hydrological indicators suggest the critical drought periods are for rainfall deficits between 9 and 24 months ending October with the largest DO deficits and failures for droughts between 15-18 months. Failure probabilities are similar to HSW and below our target levels of service, reflecting that this WRZ is partially reliant on water transferred from HSW and the WRZ was subject to large sustainability reductions in 2019, which have placed the WRZ in significant drought deficit.

For both HSE and HSW the sensitivity to some short term rainfall accumulations suggest that autumn drought effects are very important, this reflects that dry autumns lead to delayed onset of groundwater recharge and recovery of flow which can lead to Hands-off Flow (HoF) conditions being approached or crossed. This would favour development of triggers that reflect river baseflow and evapotranspiration (e.g. Standard Potential Evapotranspiration Indices).

DO falls rapidly when rainfall levels fall below 80% of long term average rainfall over periods of more than 12-18 months DO. For more severe drought events of <1% annual probability, DO effectively falls to zero. The groundwater contribution to HSE maintains DO for longer but ultimately yield from both WRZs is curtailed entirely by the imposed HoF conditions under severe droughts (<0.5% annual probability).



**Figure 2.4: Secondary Early Drought response surfaces (August) for HSE WRZ**

The secondary “early” response surface for droughts ending August (Figure 2.4) is more reflective of critical period responses showing a similar pattern to HSW, with a narrower range of failures relating to shorter duration, single winter drought events of 9-18 months but again showing vulnerability to relatively mild droughts from around 1 in 20-year return periods.

### 3.4. Drought vulnerability – Isle of Wight

The drought response plots for the IOW (Figures 2.5 and 2.6) show a much greater degree of resilience than the adjacent HSW and HSE WRZs. DO varies by only minor amounts with rainfall deficits and this reflects that in our assessment approach our DOs are set for severe droughts that maintain HoF conditions. Our larger groundwater abstractions and surface water abstractions are also relatively drought resilient to low groundwater levels and being sustained by a flow augmentation scheme.

However, the most dominant factor in the apparent drought resilience is that the WRZ is supported by transfer from the mainland and can maintain supplies whilst the transfer is active. This transfer, and by extension, the WRZ is subject to the same vulnerability as the rest of the HSW WRZ and hence actual failures are likely to be much more frequent than illustrated by this analysis.

Figure 2.7 shows a DRS for the IOW which relates rainfall deficit and drought duration to decline in groundwater levels at our indicator borehole for droughts ending in July and September. Both show similar trends but, as with the Hampshire WRZs, critical drought durations for the IOW are between 12 and 18 months for single dry winter and dry summers but ending earlier in the year, between August and September, as shown by the Hydrological Indicator correlation plot. This reflects that the chalk aquifer of the IOW shows characteristically very flashy rapid responses to groundwater recharge and dry periods with large groundwater fluctuations. Typically, recharge starts here earlier than the mainland chalk aquifers, but

groundwater levels are more sensitive to shorter periods of dry weather, especially in the autumn, but also recover faster.

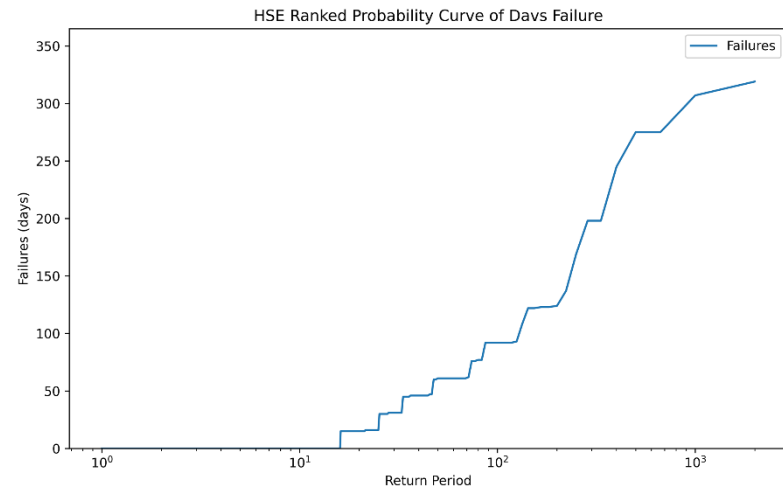
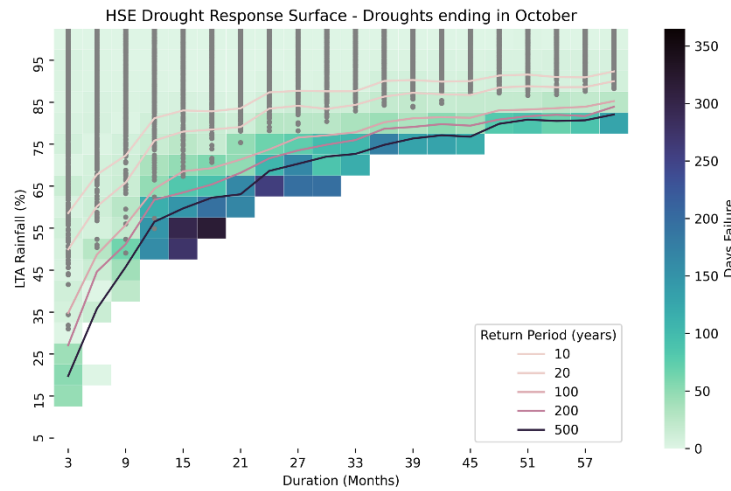
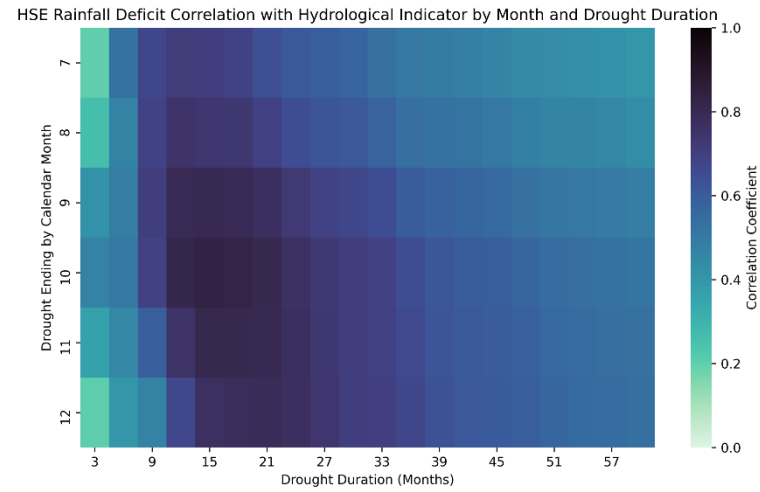
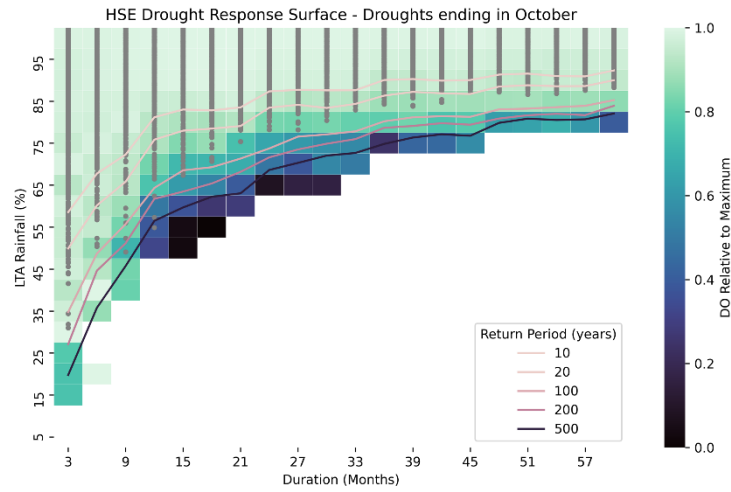


Figure 2.5: Drought response surfaces for HSE WRZ.

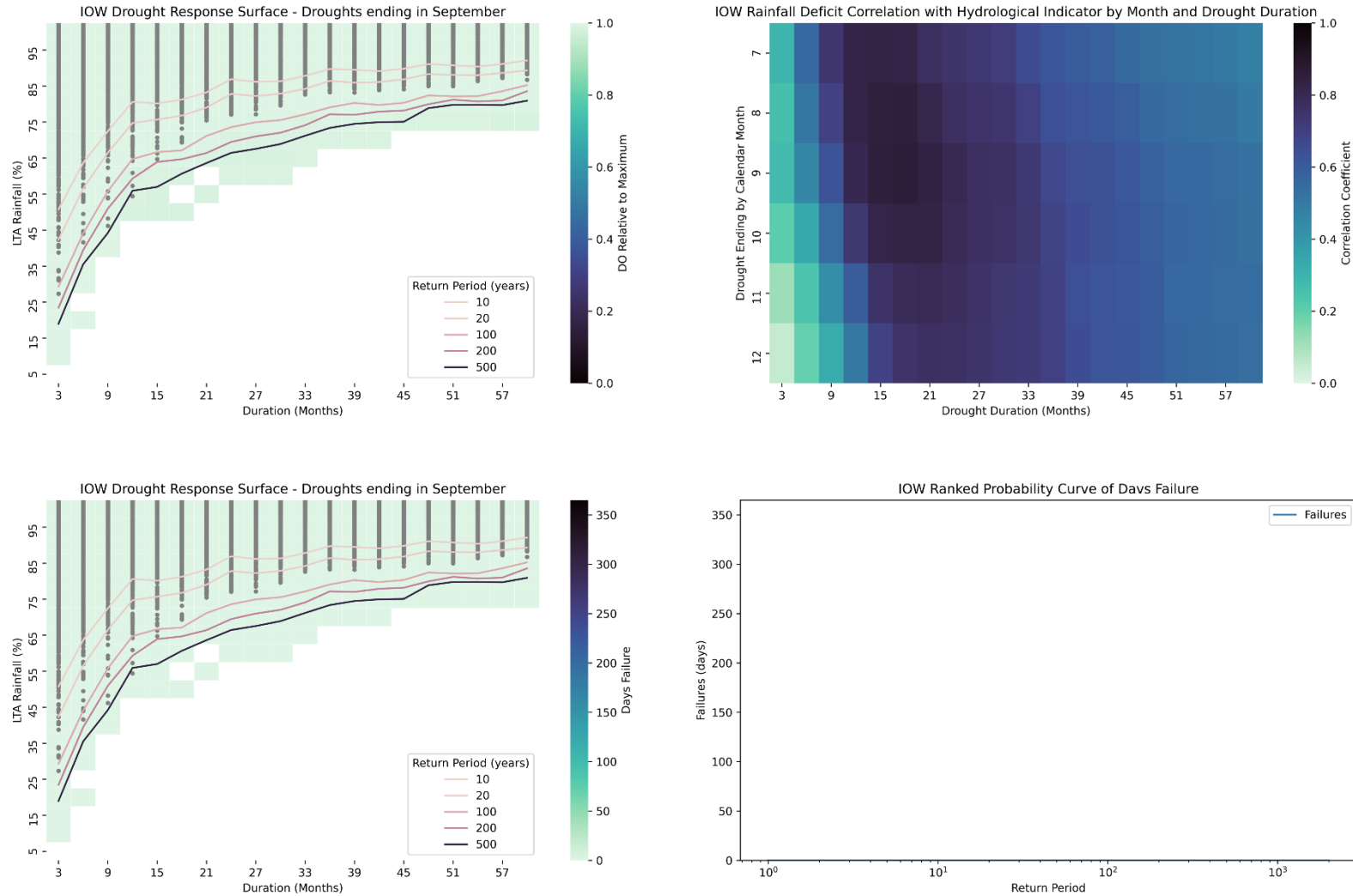


Figure 2.6: Drought response surfaces for IOW WRZ.

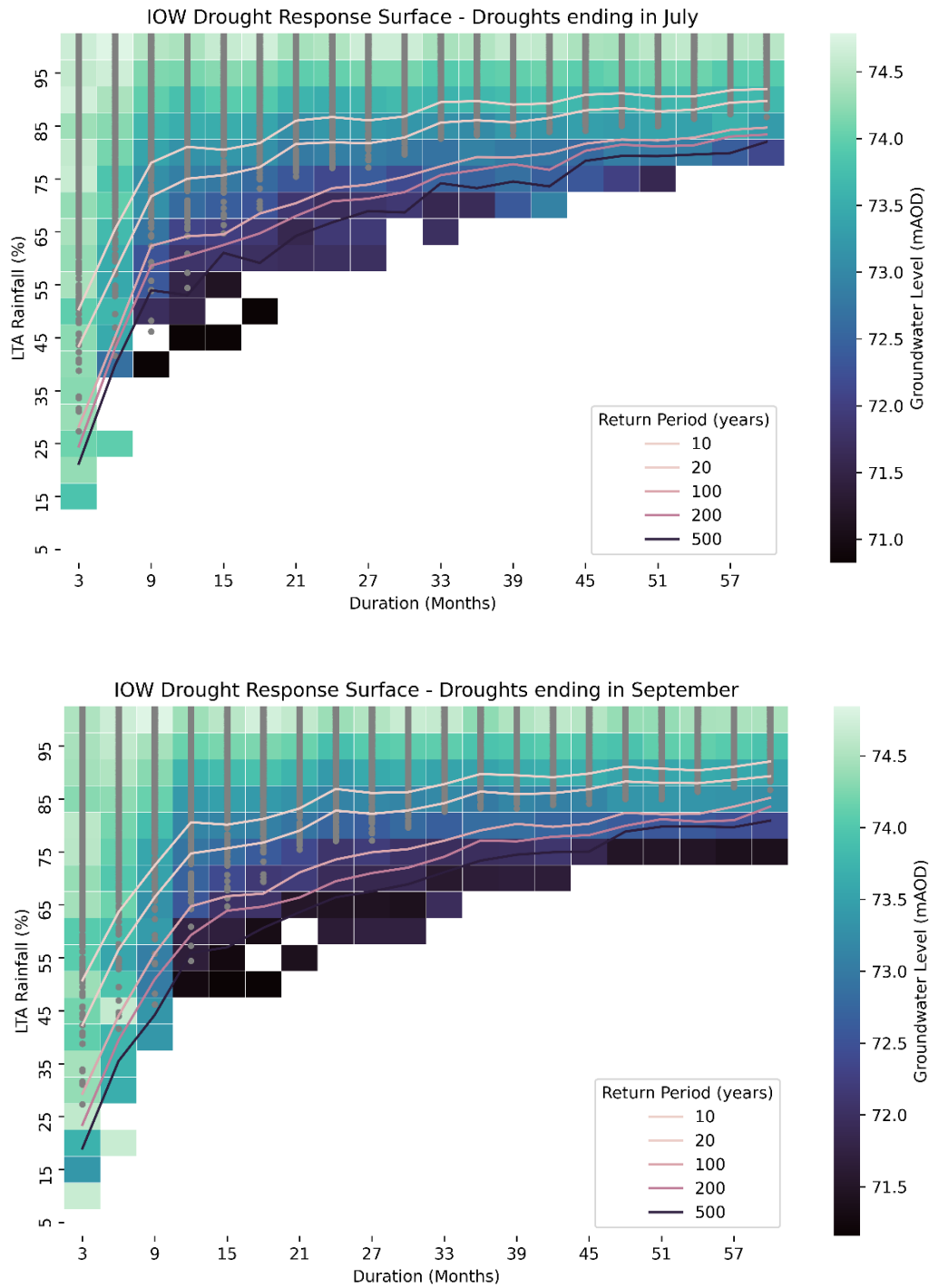


Figure 2.7: IOW DRS for Indicator Borehole Groundwater Levels

### 3.5. Drought vulnerability – Sussex North

Figure 2.9 shows the summary DRS plots for the SN WRZ.

Total DO in this WRZ is closely related to available flow above a Minimum Residual Flow (MRF) condition on the Western Rother. At low flows, abstraction from the river and associated groundwater which are subject to the MRF condition must reduce or cease to maintain the MRF condition. The DO drought response reflects this by showing declines in DO in line with increasing rainfall deficit with the largest declines occurring at long return periods for rainfall deficits of 12-21 months between 50% and 75% of long-term average rainfall. This is equivalent to a drought event worse than around a 1-in-20 year rainfall deficit. A Secondary DRS for droughts ending August (Figure 2.8) shows similar trends but also a response to shorter duration (9-month events).

As with the Hampshire WRZs, the correlation plot indicates that low flows are most closely associated with droughts ending in September to November of 15-21 months duration encompassing a single dry winter and dry autumn such as a 1976 historical drought style event.

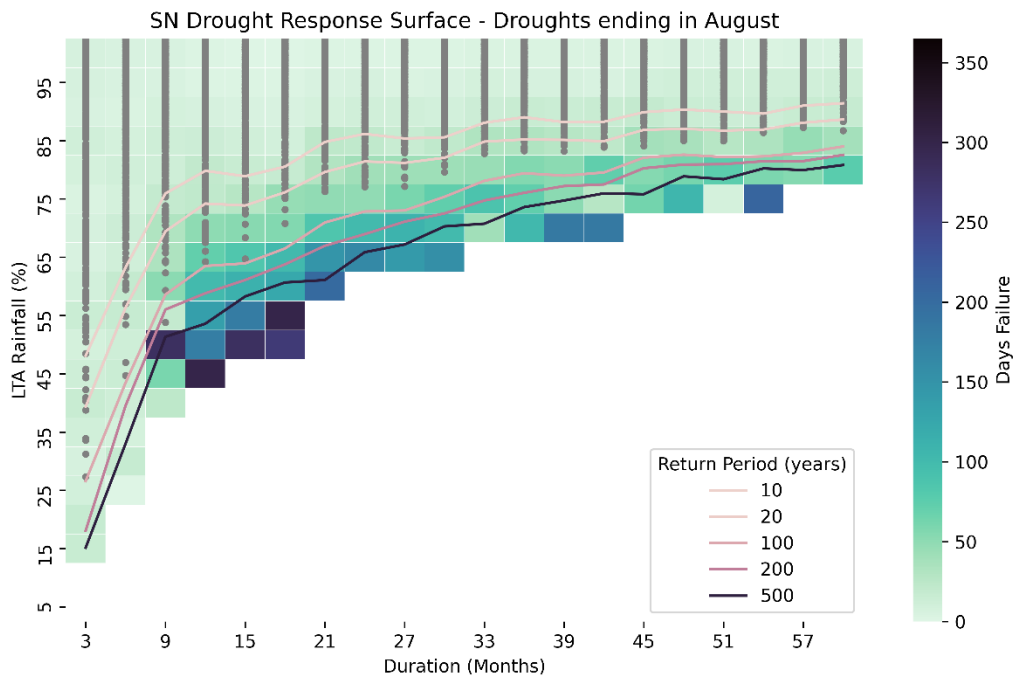


Figure 2.8: Secondary Early Drought response surfaces (August) for SNZ WRZ.

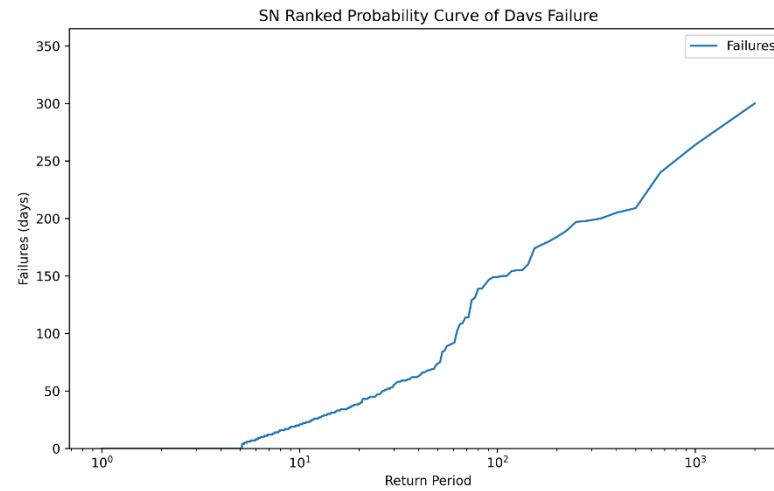
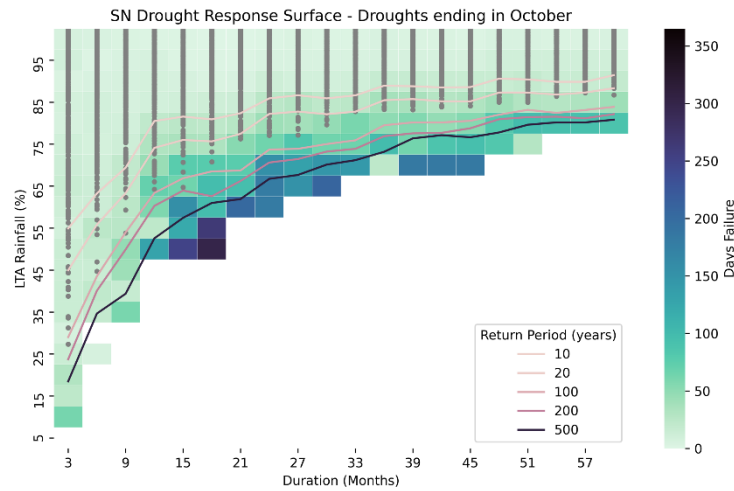
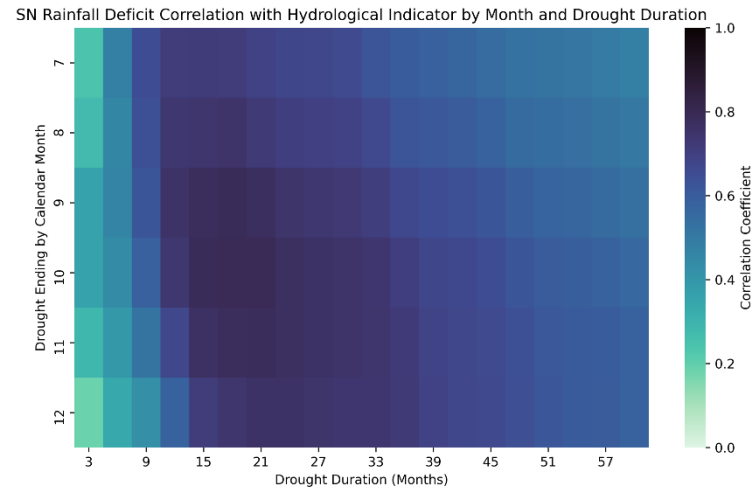
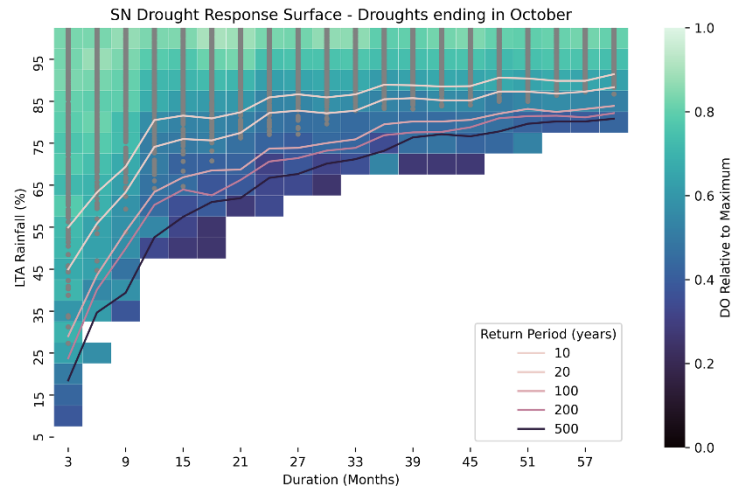


Figure 2.9: DRS plots for SNZ WRZ.



Due to the link between DO and flow, failures start to accumulate as flows recede in this WRZ even for relatively mild droughts. This reflects that the WRZ is reliant on drought permits/orders to maintain supplies in drought due to delays and potential environmental impacts associated with planned water resource schemes. Failures are most significant for 15-18 month duration droughts ending October.

### 3.6. Drought vulnerability – Sussex Brighton and Sussex Worthing

These two WRZs are considered together as they share many similarities. Both WRZs are supplied from the Sussex Chalk aquifer that shows similar drought and recharge responses and hence their drought vulnerability and responses are similar.

Drought decline in DO in these WRZs is directly related to groundwater levels (Figure 2.10) with a common indicator borehole used to determine DO. SB has a greater number of drought sensitive sources but as a proportion of lost DO due to rainfall deficits SW is more sensitive. The summary DRS plots for SW and SB WRZs are presented in Figure 2.11 and Figure 2.12 respectively.

The Groundwater level DRS show similar trends for both early (July) and late (October) ending droughts, though the autumn droughts which drive MDO are most significant for this zone. DO starts to reduce when rainfall levels fall below 90% of long-term average rainfall for periods of 12 months or more. The greatest DO impacts appear to occur for accumulations of 12-24 month rainfall deficits of 50-75% of long-term average. These events would be equivalent to around the 1% to 0.2% annual probability drought (1-in-100 to 1-in-500). Despite some drought sensitive sources, high yields, the large number of treatment works and interconnected networks provide a degree of drought resilience in this WRZ with failures only occurring in SB for extreme droughts. This is consistent with our finding from WRMP 19, which indicated the supply-demand deficits in these WRZs were driven by uncertain future abstraction licence changes.

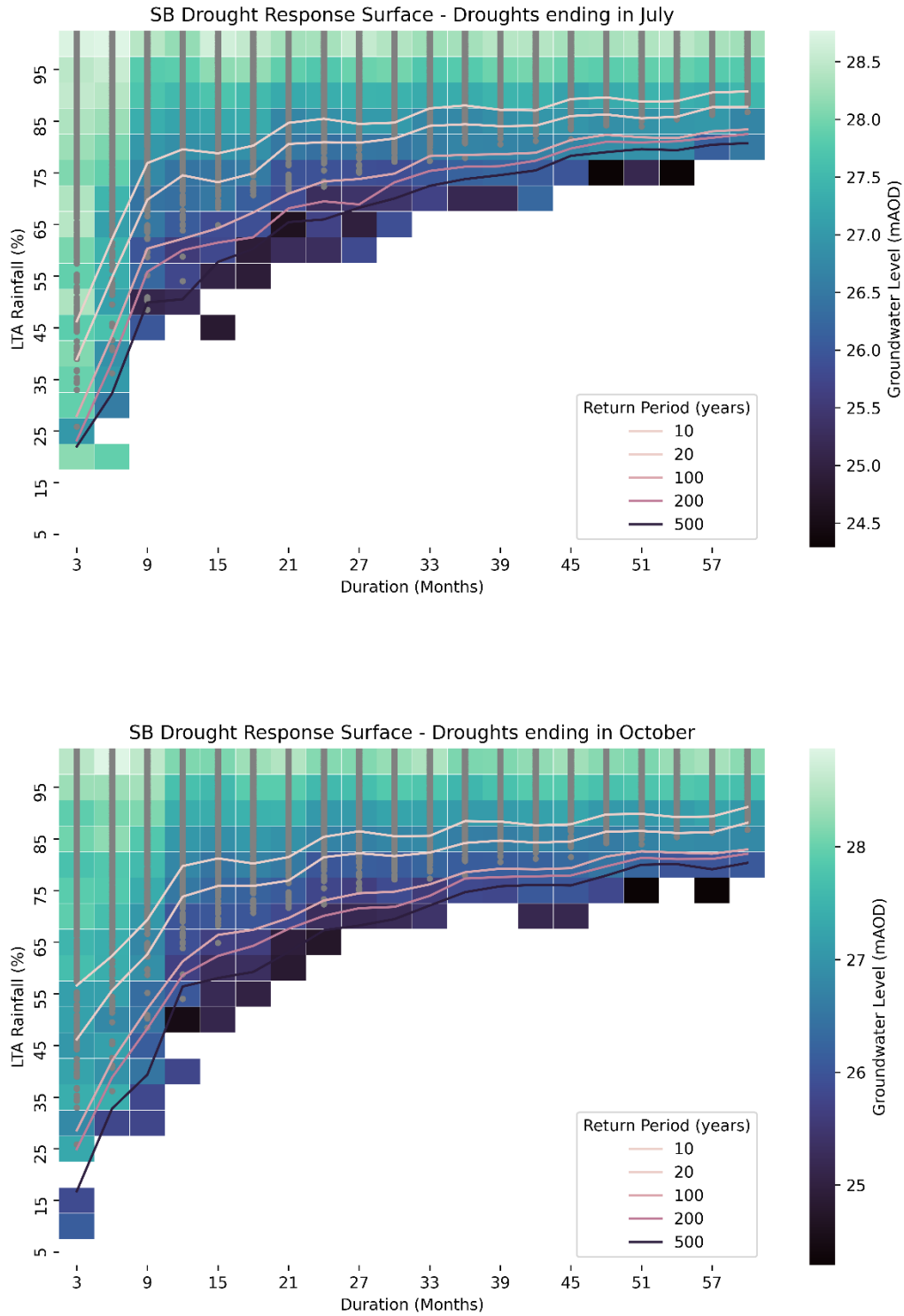


Figure 2.10: DRS for groundwater level decline, SB WRZ indicator borehole.

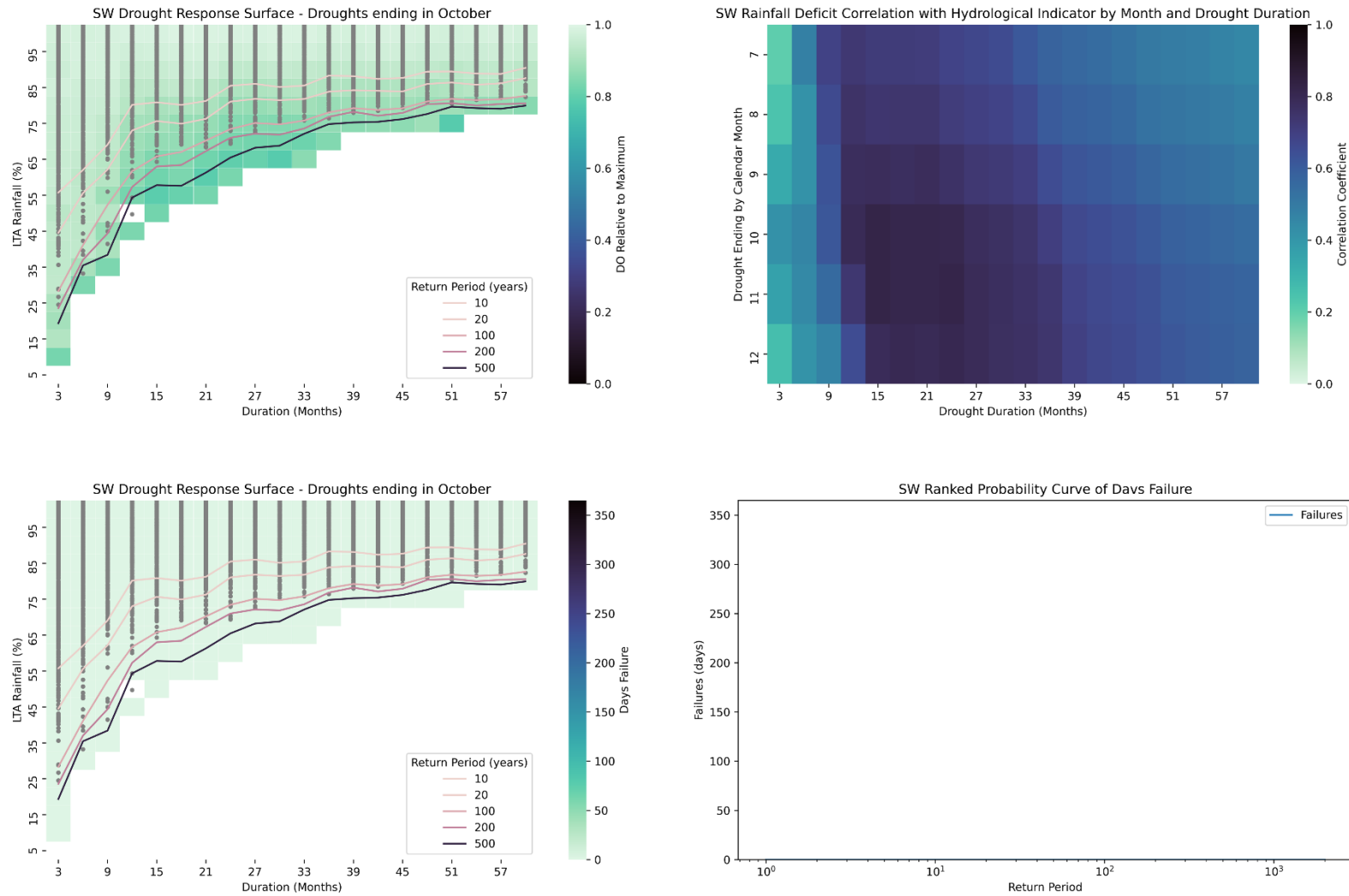


Figure 2.11: DRS plots for SW WRZ.

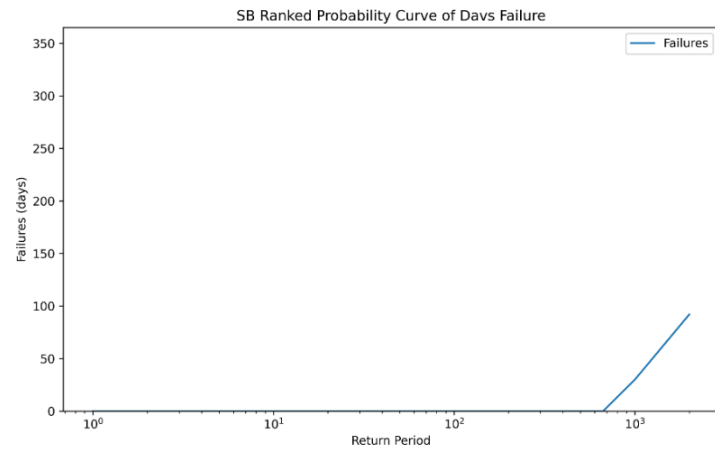
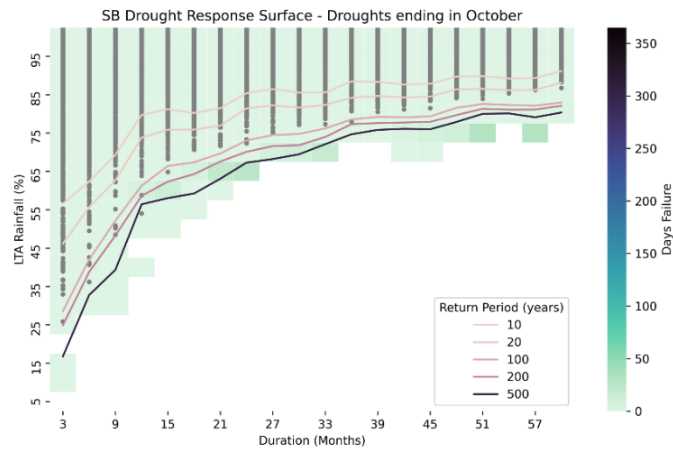
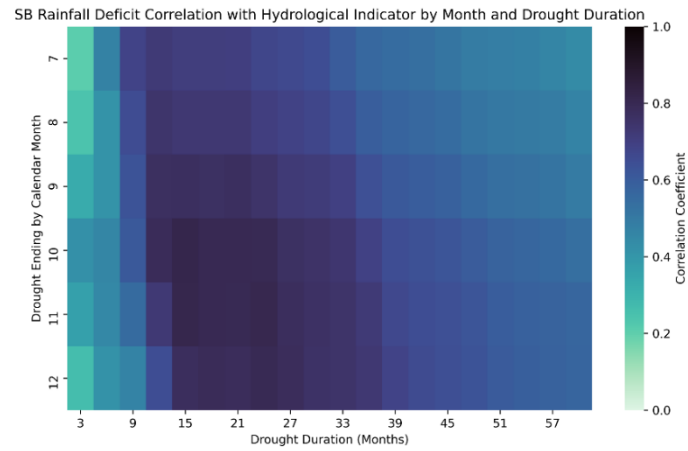
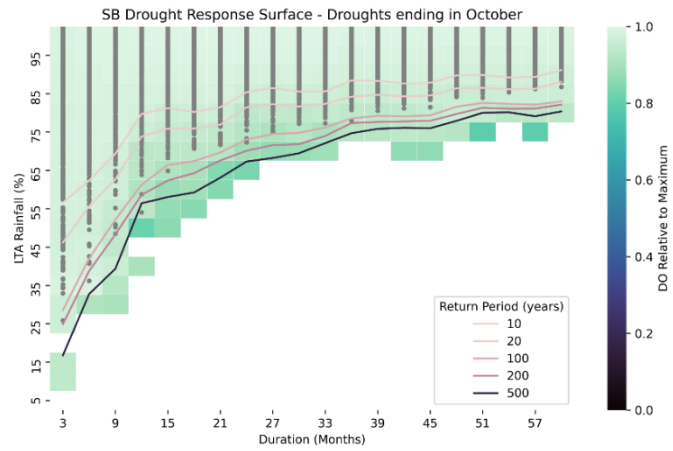


Figure 2.12: DRS plots for SB WRZ.

## 3.7. Drought vulnerability – Kent Medway West and Sussex Hastings

We have grouped our KMW and SH WRZs together for this assessment as they are coupled by the conjunctive use of the reservoirs associated with the River Medway scheme. A summary set of drought vulnerability plots are shown in Figure 2.13.

Failures in these conjunctive WRZs were assessed when reservoir volumes fell to emergency storage. When considered conjunctively between KMW and SH, failures are driven by the smaller SH reservoirs reaching their emergency storage levels, primarily Powdermill reservoir, though to a degree it is possible for the WRZ to be supplied from KMW via transfer from Bewl reservoir to Darwell reservoir.

Reservoir yields begin to decline around a 1-in-50 years drought and the critical drought duration appears to be for extreme droughts (>1-in-500 years) 12-18 months in duration months ending in October. There is also a degree of sensitivity to longer duration droughts >24 months in length. The late DRS plot (Figure 2.15) shows similar overall trends.

The key resource in these WRZs is Bewl reservoir - this supplies water to both Kent Medway Zones and can be used to transfer water to Darwell reservoir in the Sussex Hastings zone. When KMW/Bewl Reservoir is considered in isolation it shows a much greater resilience than the SH WRZ with failures in KMW being much less frequent and only for droughts greater than 1-in-200 years in severity (Figure 2.14). This may suggest that the use of Powdermill emergency storage may not be appropriate.

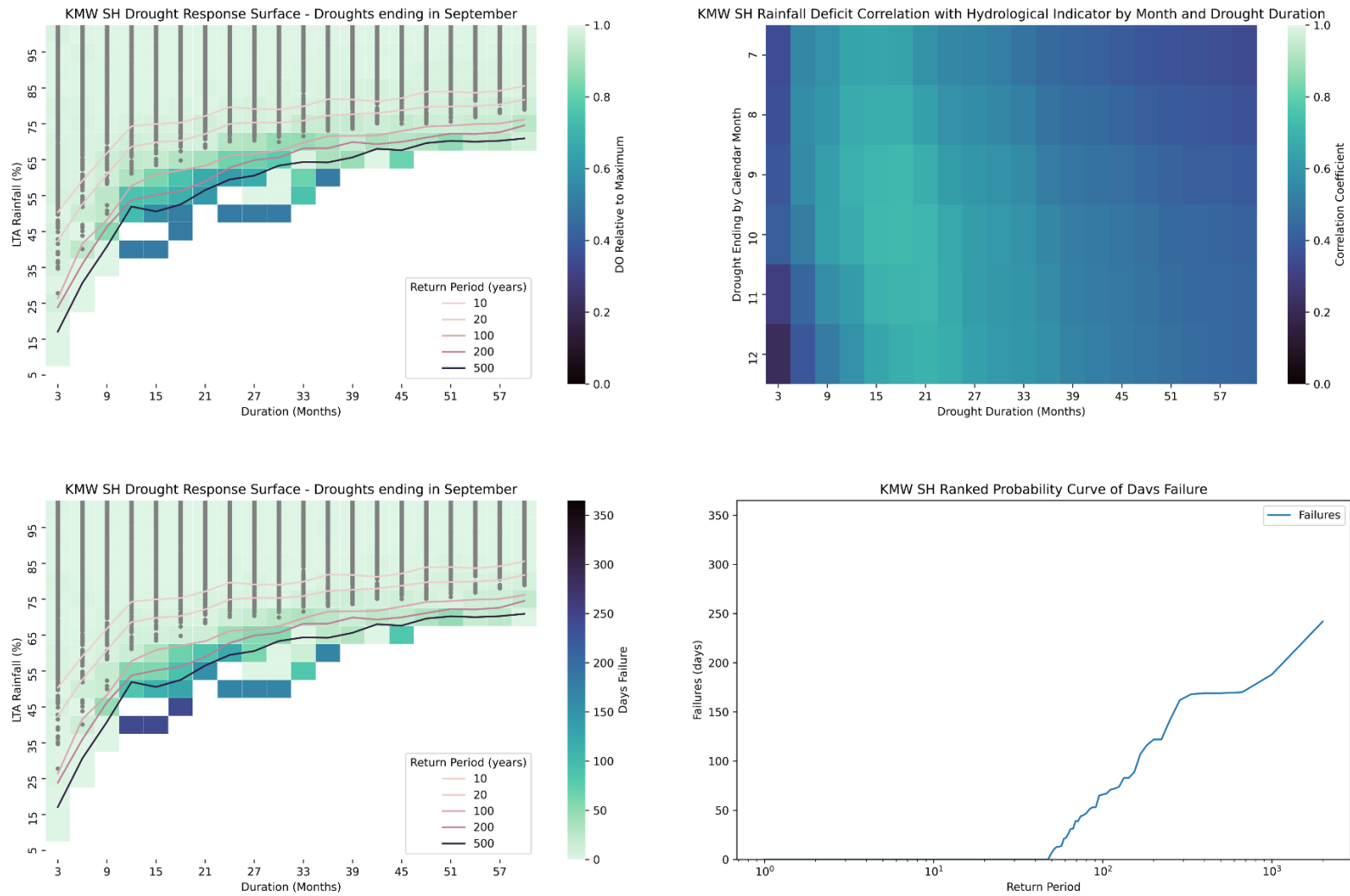


Figure 2.13: DRS plots for KMW and SH WRZs.

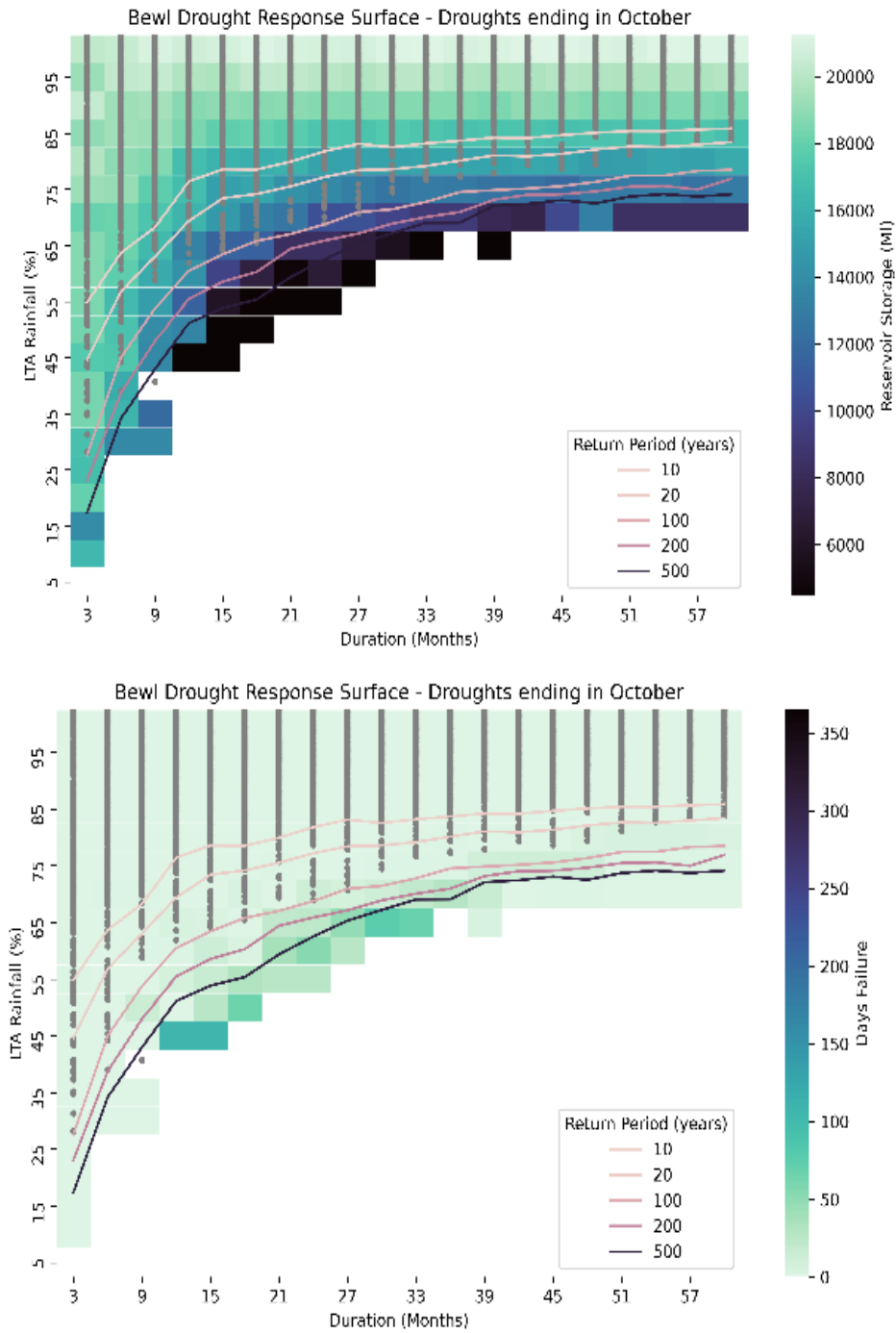


Figure 2.14: DRS plots for reservoir storage and failures associated with Bewl reservoir (KMW).

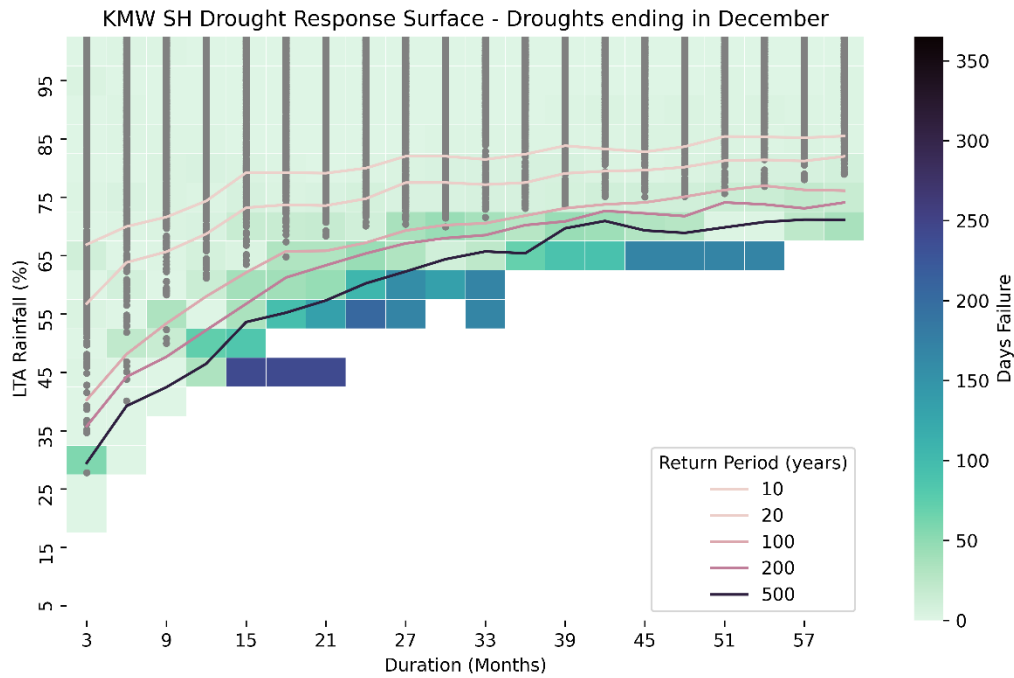


Figure 2.15: “Late” DRS plots for KMW and SH WRZs

### 3.7. Drought vulnerability – Kent Medway East

Although KME was flagged in the high-level screening as not requiring a full assessment, we have still developed summary DRS plots as the groundwater sources in this WRZ do show some drought sensitivity, which is not significant from a failure point of view but is useful to consider in terms of overall resilience and operational flexibility.

As expected from the high-level screening, this WRZ shows only a limited sensitivity of DO to rainfall deficits and no failures. This is consistent with a limited number of sources being groundwater level constrained but the majority of DO in the WRZ is supplied by licence or infrastructure constrained groundwater abstractions from which outputs are not drought sensitive

The hydrological correlation plot shows that Kent Chalk aquifer shows a stronger response to longer duration droughts than in many of our other WRZs at about 33-36 months reflecting a vulnerability to sustained droughts over multiple years and dry winters.

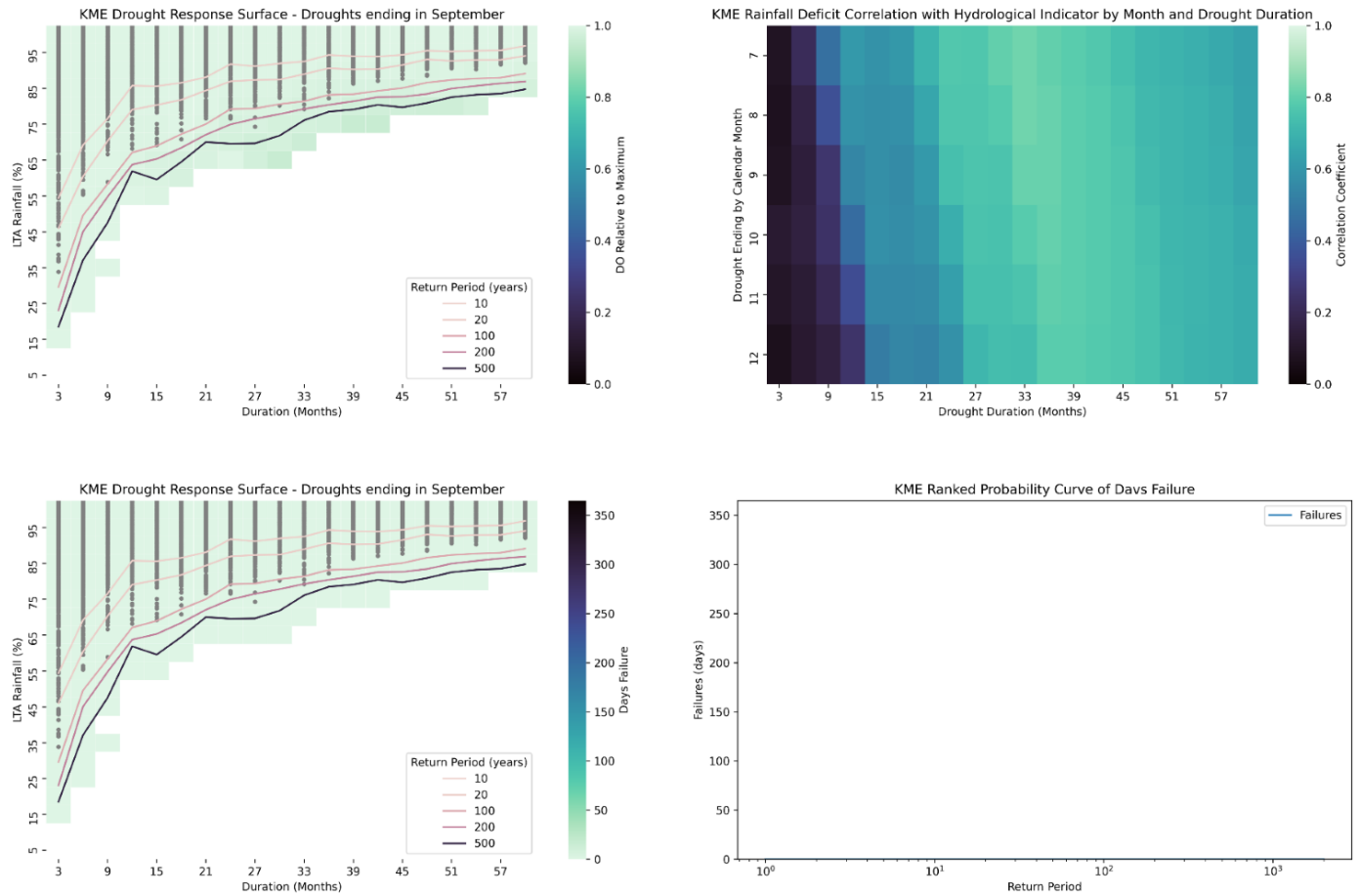
This is better illustrated by groundwater level DRS plots (Figure 2.17) which indicate that the lower groundwater levels are associated with severe to extreme (> 1-in-200 return period) long duration droughts greater than 21 months in duration ending in the autumn.

This is consistent with our general understanding of the Kent Chalk aquifer. Typically the aquifer responds more slowly to groundwater recharge and periods of dry weather, especially when contrasted with the relatively flashy and fast responding Sussex and IOW Chalk.

A suite of summary plots is provided in Figure 2.16.



Figure 2.16: DRS plots for KME WRZ.



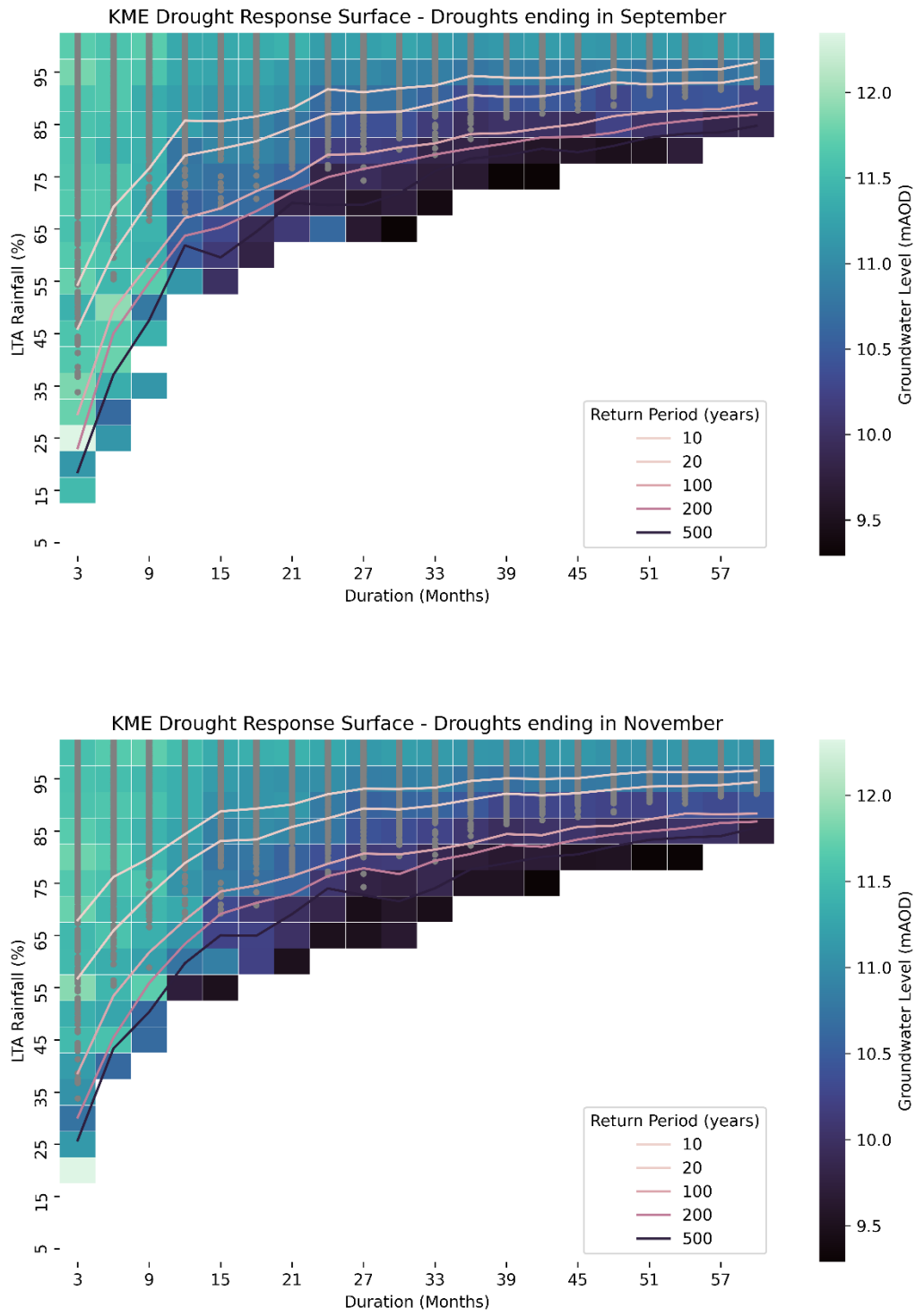


Figure 2.17: DRS for groundwater level decline, KME indicator borehole.

### 3.7. Drought vulnerability – Kent Thanet

Summary DRS plots for our KT WRZ are shown in Figure 2.18.

This WRZ shows many similarities with the neighbouring KME WRZ as both are groundwater only and situated in adjacent chalk aquifer blocks that share some similar characteristics. A greater proportion of groundwater sources show sensitivity to drought in this WRZ hence the greater proportional decline in DO with increasing drought severity. Like KMW, the critical droughts in this WRZ are of longer duration than those in the Sussex and Hampshire Chalk reflecting that this aquifer tend to exhibit greater storage and slower response to rainfall and recharge. Also, the recharge season often starts latest in the Kent Chalk owing to rain shadow effects and higher PET.

The critical drought duration for KT is from 15-33 months with the greatest DO loss and groundwater level decline for droughts of 27-30 months duration ending September.

Although it is more drought sensitive than KME, the KT WRZ exhibits no failures in this assessment owing to an intra-zonal transfer between the two. This helps to sustain KT during dry periods when it would otherwise be in deficit and to offset outages caused by raw water quality (nitrate) challenges within the WRZ.

The inclusion of outages in the assessment (Figure 2.19) illustrates the water quality challenges and significantly increases the rate of failure which forms the principal threat to this WRZs resilience. This is presently being addressed through a major network and treatment upgrade and on the ground catchment management.

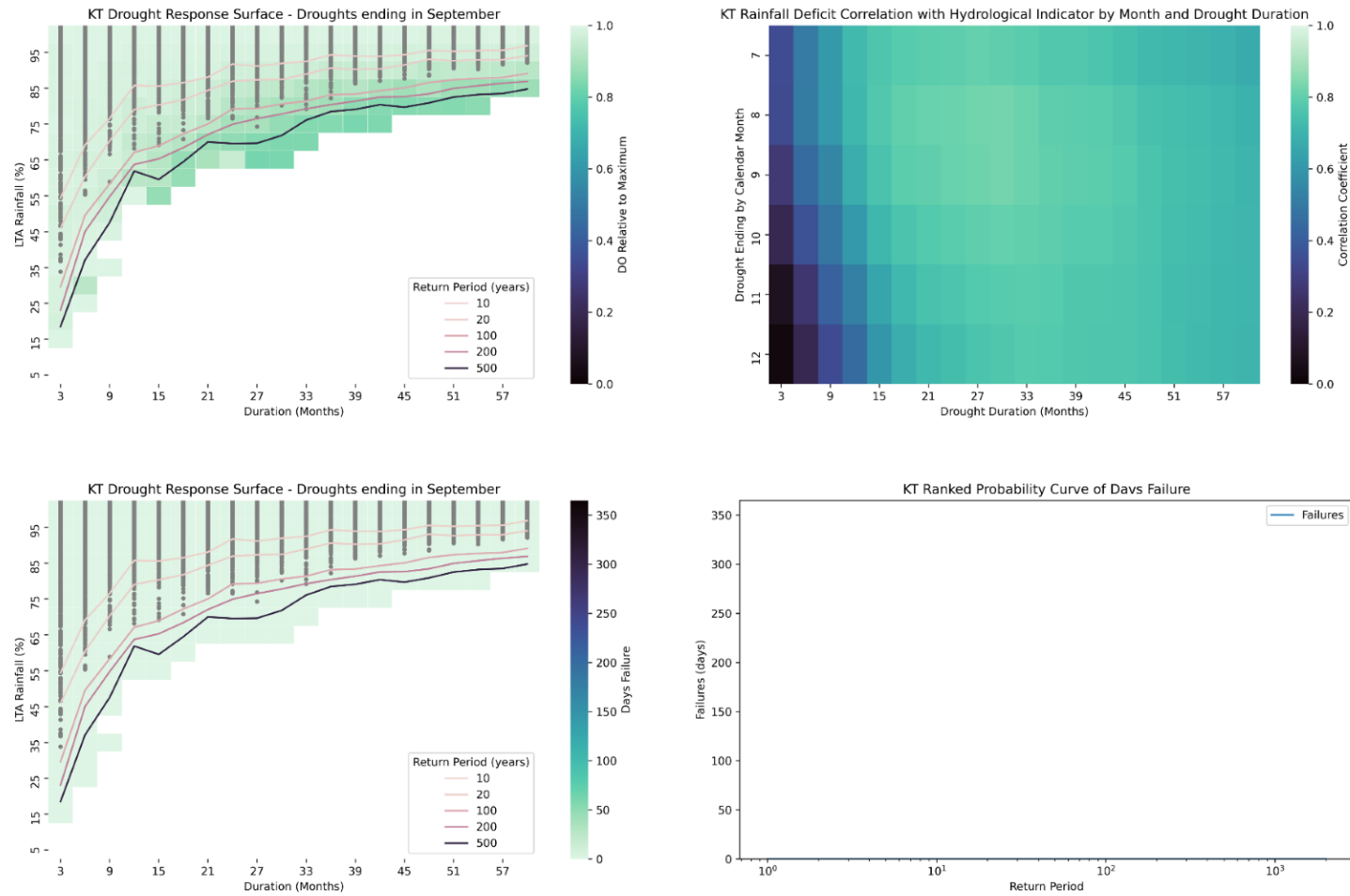
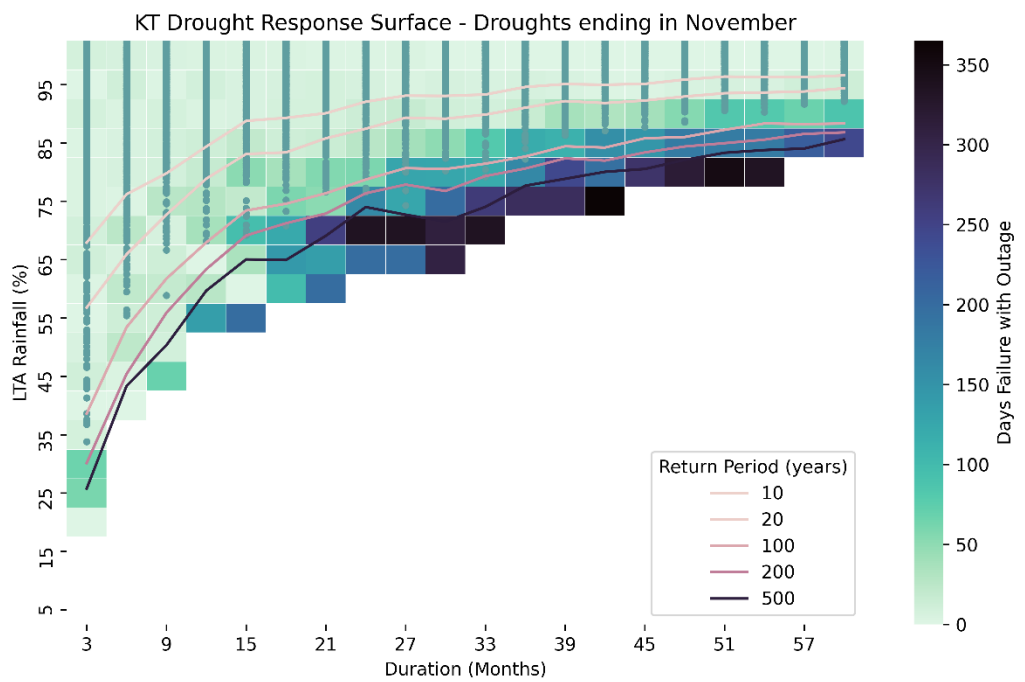
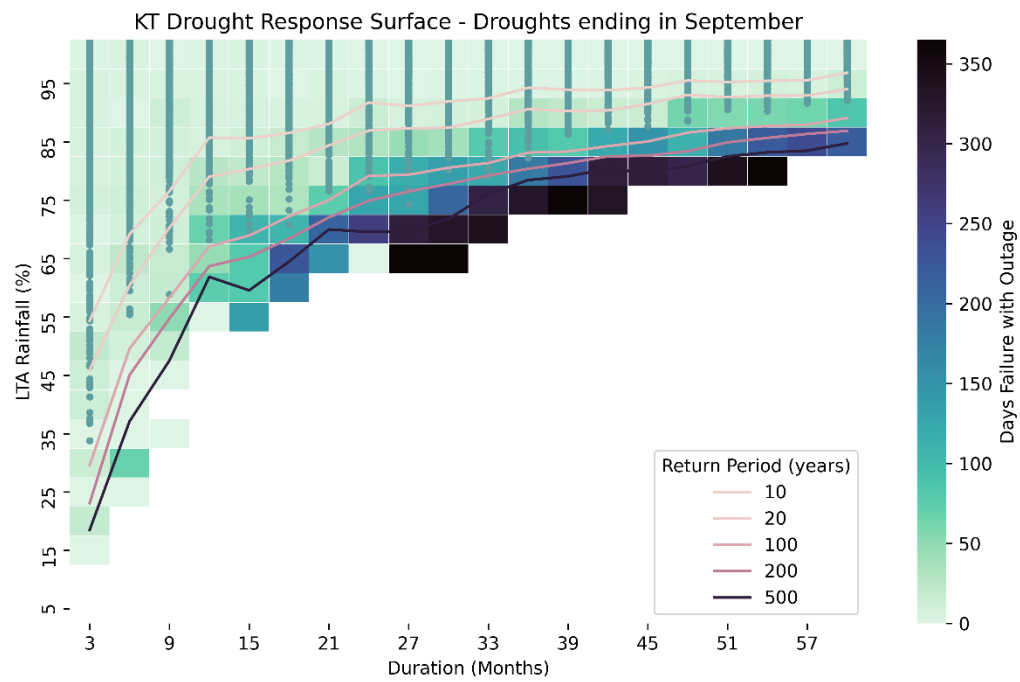


Figure 2.18: DRS plots for Kent Thanet WRZ.



**Figure 2.19: DRS plots for KT including Outage.**

## 4. Drought vulnerability assessment – key findings

Having completed a vulnerability assessment for each of our sensitive water resource zones a number of trends and findings are evident:

- Sussex and Hampshire show very similar critical droughts, largely reflecting the characteristics of the Chalk aquifer that dominates SB and SW and provides groundwater baseflow support to the rivers Test and Itchen. Southern Hampshire and the Sussex Chalk are most sensitive to 12-21 month events ending in October with the most critical event around 15 months in duration. These represent single dry winter events but with multiple dry summers and autumns. Dry autumns are particularly critical reflecting that delayed onset of recharge and groundwater recovery following a dry summer extends groundwater and flow recessions.
- SN shows a similar critical drought response to the adjacent chalk dominated WRZs but the supply mix differs mostly comprising Lower Greensand groundwater and baseflow to the Western Rother.
- The surface water dominated WRZs of HSW, HSE and SN are the most drought vulnerable. This is due to a combination of existing or marginal supply demand deficits, and DO which is dominated by river flows above MRF or HoF conditions.
- The Kent WRZs tend to be more sensitive to longer duration droughts than in Hampshire and Sussex and, to an extent, this reflects the storage buffering of the large reservoir systems that provide a degree of resilience to short drought events.