Revised Draft Water Resources Management Plan 2024

Annex 4: Drought Vulnerability Assessment

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WATER for LIFE

from Southern Water

Contents

1 Introduction 1

2 Methodology 2

2.1 Data sources 2

2.2 High-level screening 2

2.3 Characterisation of supply system and calculation approach 5

2.4 Selection of 'month ending' attribute 5

2.5 Selection of demand level 6

2.5.1 Demand management and drought permits and orders 7

2.6 Other supply and demand assumptions and failure calculations 7

3 Results 9

3.1 Evaluation of rainfall deficit/probability bands 9

3.2 Drought vulnerability – HSW 10

3.3 Drought vulnerability – HSE 12

3.4 Drought vulnerability – IOW 14

3.5 Drought vulnerability – SNZ 15

3.6 Drought vulnerability – SWZ and SBZ 17

3.7 Drought vulnerability – KME 20

3.8 Drought vulnerability – KMW and SHZ 21

3.9 Drought vulnerability – KTZ 24

4 Key Findings 26

List of Tables

Table 1: Summary of input data used for our drought vulnerability assessment. 2

Table 2: Key supply characteristics by DO proportion of each of our WRZs. 3

Table 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. 4

Table 4: Selection of the two 'month ending' response surfaces for our WRZs. 6

Table 5: Summary of demand side benefits of restrictions applied to DI for failure assessment based on our MDO period. 7

Table 6: Other assumptions in our drought vulnerability assessment. 8

List of Figures

Figure 1: Example rainfall deficit versus return period plots for HSW. 9

Figure 2: Drought response surfaces for HSW. 11

Figure 3: Secondary early drought response surfaces (August) for HSW. 12

Figure 4: Drought response surfaces for HSE. 13
Figure 5: Secondary early drought response surfaces (August) for HSE. 13
Figure 6: Drought response surfaces for IOW. 14
Figure 7: IOW drought response surface for indicator borehole groundwater levels. 15
Figure 8: Drought response surface plots for SNZ. 16
Figure 9: Secondary early drought response surfaces (August) for SNZ. 17
Figure 10: Drought response surface for groundwater level decline (SBZ indicator borehole). 18
Figure 11: Drought response plots for SWZ. 19
Figure 12: Drought response surface plots for SBZ. 19
Figure 13: Drought response surface plots for groundwater level decline (KME indicator borehole). 20
Figure 14: Drought response surface plots for KME. 21
Figure 15: Drought response surface plots for KMW and SHZ. 22
Figure 16: Drought response surface plots for reservoir storage and failures associated with Bewl Reservoir (KMW). 23
Figure 17: ‘Late’ drought response surface plots for KMW and SHZ. 24
Figure 18: Drought response surface plots for KTZ. 25
Figure 19: Drought response surface plots for KTZ including outage. 25

1 Introduction

Our Water Resources Management Plan 2019 (WRMP19) included an assessment of the drought vulnerability of our water resource zones (WRZs) in Annex 3[1]. Our WRMP19 assessment considered rainfall deficits, probabilities and impacts upon the Deployable Output (DO) of our sources during droughts of varying severity (in terms of rainfall deficit) and duration.

We based our WRMP19 drought vulnerability assessment in line with the assessment by the Environment Agency[2]. We completed our assessment as part of our WRMP19 technical work prior to the publication of the Drought Vulnerability Framework (DVF)[3] 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 and the results are presented herein.

[1] Southern Water, 2020. Water Resources Management Plan. Annex 3: Supply Forecast.
[2] Environment Agency, 2015. Understanding the performance of water supply systems during mild to extreme droughts. Report SC120048/R.
[3] UKWIR, 2017. Drought Vulnerability Framework. UK Water Industry Research Limited, London.

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 1.

Table 1: Summary of input data used for our drought vulnerability assessment.

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 (DI) for WRMP19	Modelled DI for 2022 as set out for each WRZ in our water resource planning tables
Demand saving	Estimated impact (in %) of demand restrictions (Temporary Use Bans and Non Essential Use Bans) on WRZ demand	WRMP19 demand savings study[4] 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 resources 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

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.

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.

The amount of water that we can supply to some WRZs is limited either by our abstraction licences or by the amount we can safely treat. These WRZs tend to show a high degree of resilience to drought. 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 to all 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:

[4] Atkins, 2017. Effectiveness of Restrictions Technical Note. Southern Water Drought Plan.

[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 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.[5]

The majority of our WRZs are assessed under the first category. 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 (KME), which although is 100% groundwater, is closely interconnected with the Kent Medway West WRZ (KMW) and our reservoir system in Kent - the River Medway Scheme. The key supply characteristics of each of our WRZs are summarised in Table 2.

Table 2: Key supply characteristics by DO proportion of each of our WRZs[6].

WRZ	Screening Criteria	Groundwater	Run of River	Reservoirs	Transfers
Hampshire Kingsclere (HKZ)	1	100%	0%	0%	0%
Hampshire Andover (HAZ)	1	100%	0%	0%	0%
Hampshire Winchester (HWZ)	1	100%	0%	0%	0%
Hampshire Rural (HRZ)	1	100%	0%	0%	0%
Hampshire Southampton East (HSE)	1	48%	52%	0%	0%
Hampshire Southampton West (HSW)	1	0	100%	0%	0%
Isle of Wight (IOW)	1	47%	23%	0%	30%
Sussex North (SNZ)	1	35%	51%	8%	6%
Sussex Worthing (SWZ)	1	100%	0%	0%	0%
Sussex Brighton (SBZ)	1	100%	0%	0%	0%
Kent Medway West (KMW)	2	44%	56% (river and reservoirs)		0%
Kent Medway East (KMW)	2	100%	0%	0%	0%
Sussex Hastings (SHZ)	2	5%	0%	79%	16%
Kent Thanet (KTZ)	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 (DI) as set out in our WRMP19 planning tables.

[5] Southern Water, 2019, Securing a resilient future for water in the South East Our Water Resources Management Plan for 2020–70
[6] Ibid

Target headroom = Taken to be the WRZ target headroom for 2022-23 as set out in our WRMP19

The results of the high-level screening are presented in Table 3.

Table 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.

	Drought return period	HAZ	HKZ	HWZ	HRZ	HSE	HSW	IOW	SNZ*	SWZ	SBZ	SWZ	KME	KMW	KTZ	SHZ
Minimum or Dry Year Annual	1-in-2 year	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N
	1-in-20 year	N	N	N	N	Y	N	Y	Y	N	N	N	N	N	N	N
	1-in-100 year	N	N	N	N	Y	Y	Y	Y	N	Y	N	N	N	Y	Y
	1-in-200 year	N	N	N	N	Y	Y	Y	Y	N	Y	N	N	N	Y	Y
	1-in-500 year	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
	1-in-1000 year	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Dry Year Critical Period	1-in-2 year	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	1-in-20 year	N	N	N	N	Y	N	Y	N	N	N	N	N	N	Y	N
	1-in-100 year	N	N	N	N	Y	N	Y	Y	N	N	N	N	N	Y	N
	1-in-200 year	N	N	N	N	Y	Y	Y	Y	N	N	N	N	N	Y	N
	1-in-500 year	N	N	N	N	Y	Y	Y	Y	N	Y	N	N	N	Y	N
	1-in-1000 year	N	N	N	N	Y	Y	Y	Y	N	Y	N	N	N	Y	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 HAZ, HKZ, HWZ, HRZ and KME.

The four Hampshire WRZs mentioned above were also not considered in our WRMP19 drought vulnerability assessment[7]. These WRZs are 100% dependant on groundwater and our water resource modelling for WRMP19 indicated that the yield of these groundwater sources is constrained by either licence or infrastructure 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 KMW. KME is relatively drought resilient. Whilst there are some drought sensitive sources, the demand is low compared to the available DO. 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 ignores the effect of transfers considering only the native WRZ DO. This affects some WRZs, which are dependent upon transfers from neighbouring WRZs such as the IOW and KTZ. 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 SHZ, pass the first screening assessment for Dry Year Critical Period (DYCP), but SHZ fails for the Dry Year Annual Average (DYAA) period. When considered against the second screening criteria for WRZs that are

[7] Southern Water, 2020, Water Resources Management Plan, Annex 3: Supply Forecast

more complex, only KMW has sufficient headroom to pass by itself. 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 next considers 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[8]. 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.

Our WRZs are therefore classified under the DVF as being consistent with DVF approach 1a or 1b. For the WRZs being assessed full rainfall deficit/flow analysis were 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 4).

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 WRZs drought vulnerability.

[8] 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.

Table 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, SBZ, SWZ	HSW, HSE, SNZ, KTZ	KMW, SHZ, 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

2.5 Selection of demand level

The DRS is required 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:

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 DVF 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 DRS plots for scenarios equivalent to that under the 'Mild to Extreme Droughts Study'[9] which examines the relationship between rainfall deficits, drought duration and decline in DO. We have also developed 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 in 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 carried out any assessment using DI only (level 1 above).

The data for our demand levels are taken from our WRMP19 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 DI - 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

[9] 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

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

2.5.1 Demand management and drought permits and orders

We have included the beneficial 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 WRMP19 planning tables. The magnitude of demand saving benefits are based on those assumed for WRMP19[10] and are summarised in Table 5.

Table 5: Summary of demand side benefits of restrictions applied to DI for failure assessment based on our MDO period.

Supply area	WRZs	Effectiveness of TUBs and NEUBs (MDO period)
Western	HAZ, HKZ, HRZ, HWZ, HSE, HSW, IOW	3%
Central	SNZ, SBZ, SWZ	3%
Eastern	KMW, KME, KTZ, SHZ	2%

We have excluded the supply-side benefits of demand savings and the benefits associated with any drought permits and orders. This takes account of the fact 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 and 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, we have made a 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 HSW where we recognise the significant risk to the WRZ and its reliance on drought permits and 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 6.

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.

[10] Atkins, 2017. Effectiveness of Restrictions Technical Note. Southern Water Drought Plan.

- 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.

Table 6: Other assumptions in our drought vulnerability assessment.

Supply Demand Element	Assumption
Process losses	Excluded from our assessment. These are generally small and vary with DO. Process losses are not considered in WRMP19 Table 10.
Imports and exports	Net effect on WRZ DO is included in our assessment. Although we have generally excluded transfers from WRMP19 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	As we have adopted a probabilistic climate change modelling approach, 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 our assessment that is based on our baseline DO. Use of the baseline DO is consistent with our population of WRMP19 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 and orders.

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

For the more complex WRZs, where storage in surface water reservoirs is a major component of the supply base, the full 2,000-year stochastic flow sequence was modelled in our behavioural Aquator model for the Eastern area. These WRZs (KMW, KME and SHZ) 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 WRMP19 DO assessments were based on 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 experience of the River Test Drought Permit, we wanted to examine the relationship between river flows and groundwater levels for shorter drought durations (<3 months). As the calculations have been automated, we were 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 were determined by inverse ranking. An example set of deficit versus return period plots for HSW are presented in Figure 1.

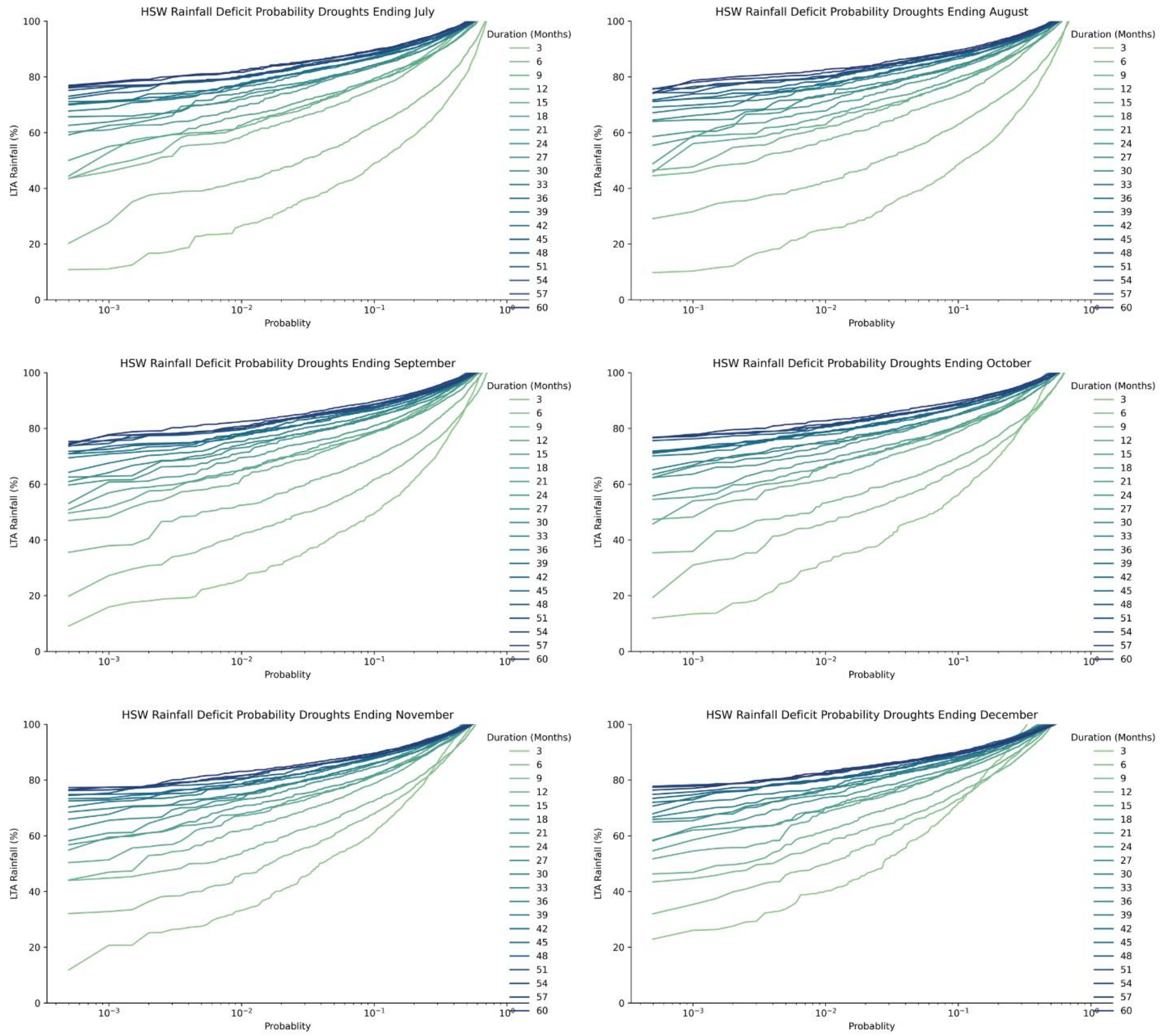


Figure 1: Example rainfall deficit versus return period plots for HSW.

All of the rainfall deficit plots across our region show similar trends. Rainfall accumulations show that variance increases with return period and 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 adding 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 from our assessments.

3.2 Drought vulnerability – HSW

A summary of the key DRS plots for this WRZ are presented in Figure 2. Summary plots like this have been produced for each WRZ that show the following:

- Top left plot 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, 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 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 River Test total flow.
- The lower left plot is the critical DRS 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 in October. Generally, this reflects the timing of groundwater level and river 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 DRS for HSW is similar to that from our WRMP19 preliminary vulnerability assessment. This indicates that in DO in HSW starts to decline for relatively mild droughts (<1-in-10 year) and declines very significantly for droughts of greater than 1-in-20 year 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 plot correlating rainfall deficit to hydrological indicator 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 between September and November when minimum annual flows typically occur.

Failures start to occur for relatively mild droughts (<1-in-20 year). This is consistent with the WRMP19 assessment which showed that HSW faces significant supply-demand deficits following sustainability reductions that occurred in 2019. We are reliant on drought permits and orders to maintain supplies even in moderate droughts until a long-term 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 year and for drought durations between 12 and 24 months. This shows 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.

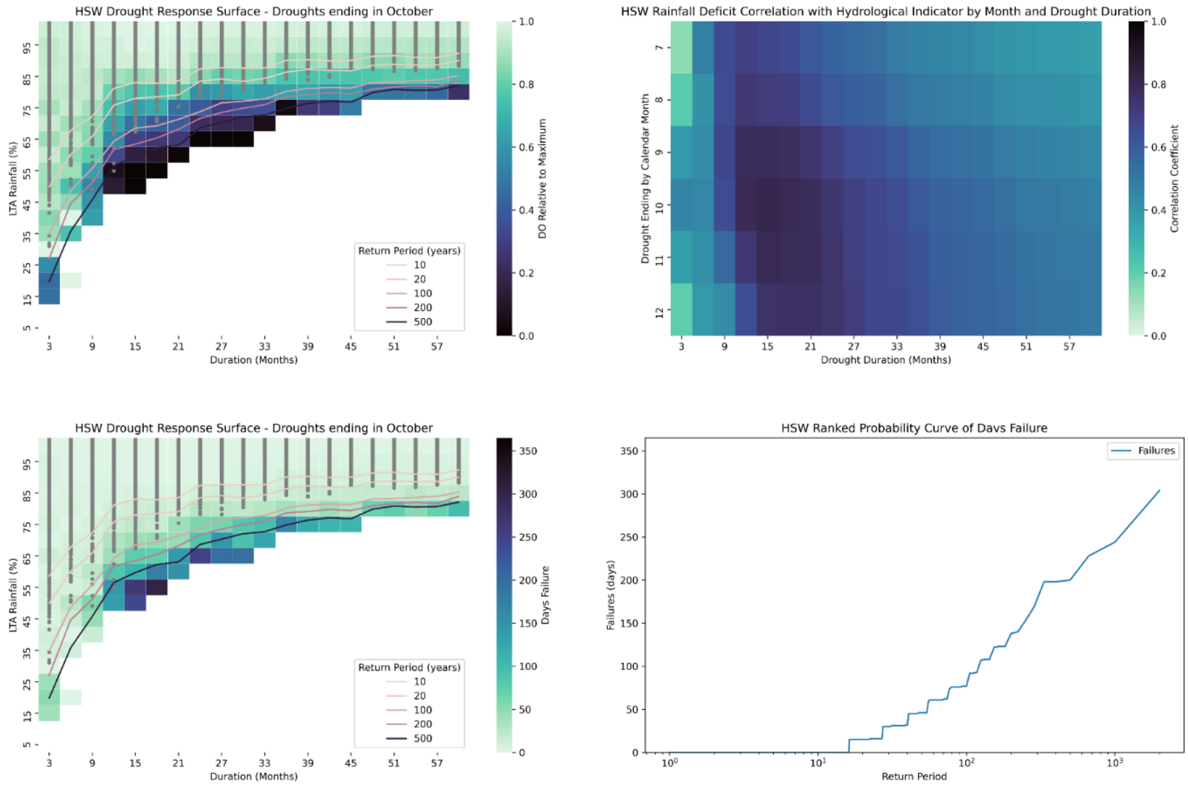


Figure 2: Drought response surfaces for HSW.

We have also considered a secondary ‘early’ response surface for droughts ending August (Figure 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’ duration but again shows vulnerability to relatively mild droughts from around 1-in-20 year return periods.

As 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 and orders to close our supply demand balance. We expect that we will need to implement drought permits and orders on average 1-in-10 year to 1-in-20 year and will need to apply for drought permits much more frequently.

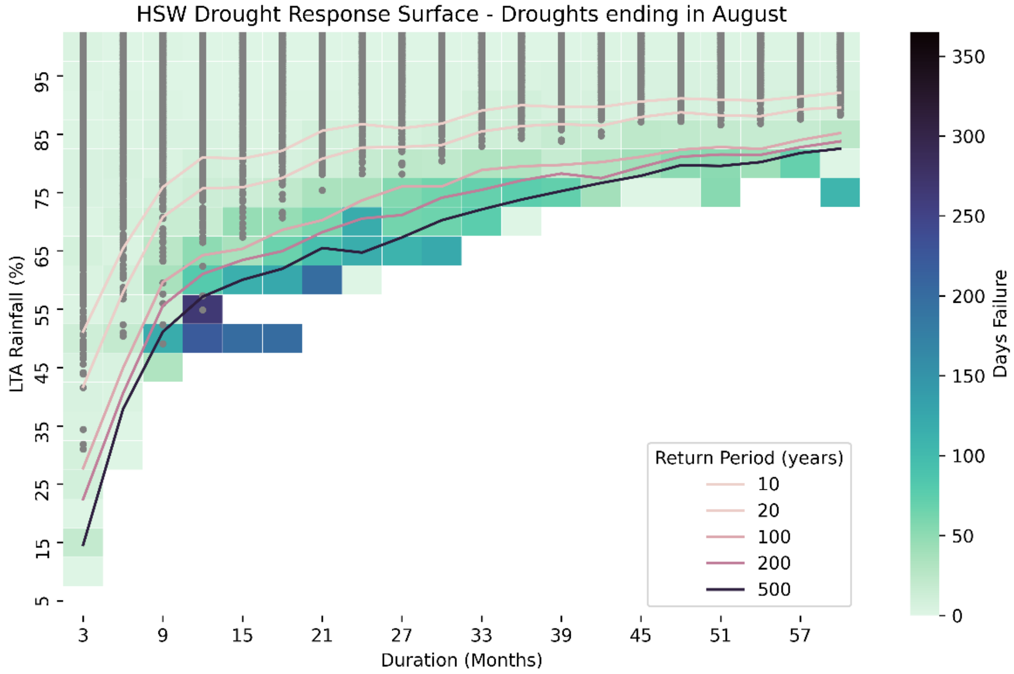


Figure 3: Secondary early drought response surfaces (August) for HSW.

3.3 Drought vulnerability – HSE

Overall, the response surfaces for HSE are very similar to that for HSW (Figure 4) as the River Itchen shares many similarities with the River Test; both being baseflow-dominated chalk rivers and hence the hydrological response to rainfall deficits is very similar.

DO response, failures and hydrological indicators for HSE 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 and 18 months. Failure probabilities are similar to HSW and below our target Levels of Service, reflecting that this WRZ is somewhat reliant on water transferred from HSW. HSE was subjected 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 shows 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' duration. 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).

The secondary 'early' response surface for droughts ending August (Figure 5), which is more reflective of critical period responses, shows a similar pattern to HSW, with a narrower range of failures relating to shorter duration, single winter drought events of 9-18 months' duration but again showing vulnerability to relatively mild droughts from around 1-in-20 year return periods.

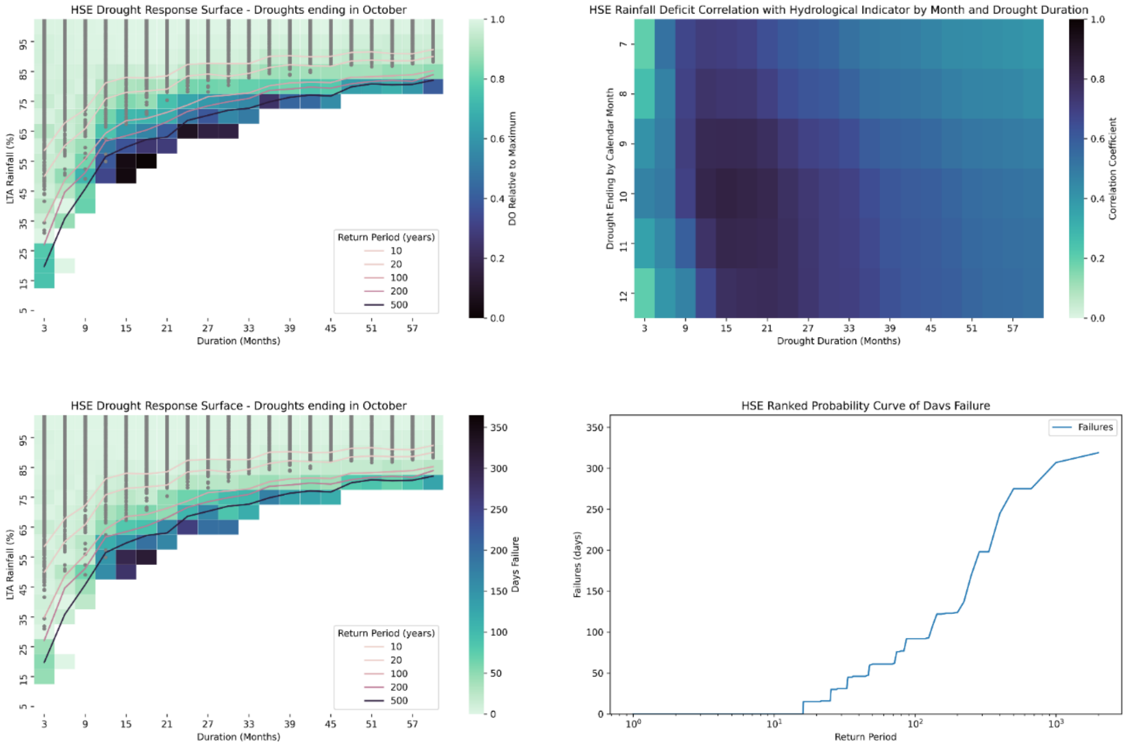


Figure 4: Drought response surfaces for HSE.

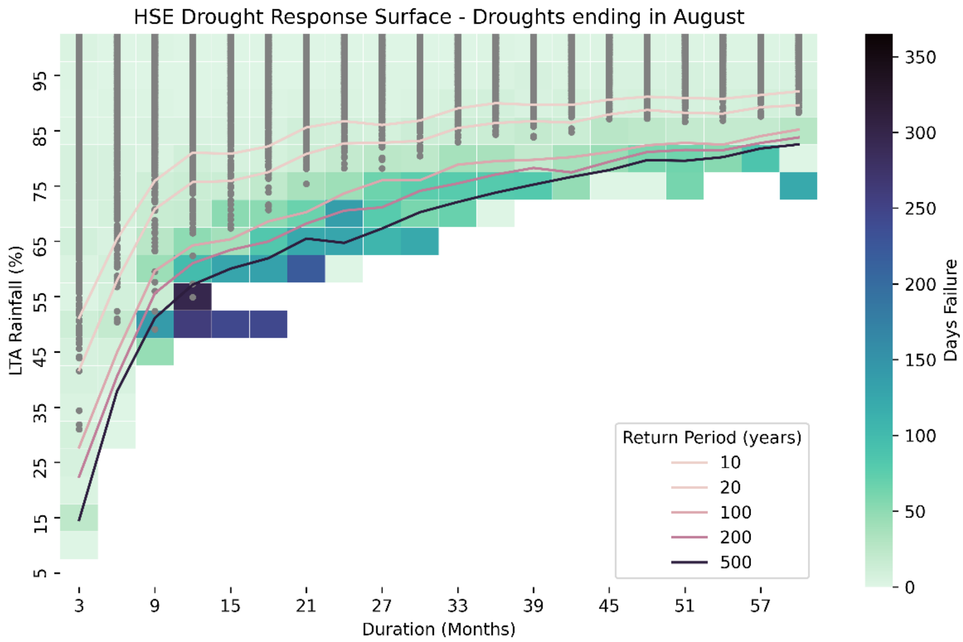


Figure 5: Secondary early drought response surfaces (August) for HSE.

3.4 Drought vulnerability – IOW

The DRS plots for the IOW (Figure 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, DOs are set for severe droughts that maintain Hands-off Flow (HoF) conditions. Our larger groundwater and surface water abstractions are also relatively drought resilient to low groundwater levels and being sustained by a flow augmentation scheme.

However, the apparent drought resilience is primarily due to the transfer from the mainland (HSW) which can maintain supplies on the IOW. This transfer, and by proxy, the WRZ is subject to the same vulnerability as the rest of the HSW and hence actual failures are likely to be much more frequent than shown here.

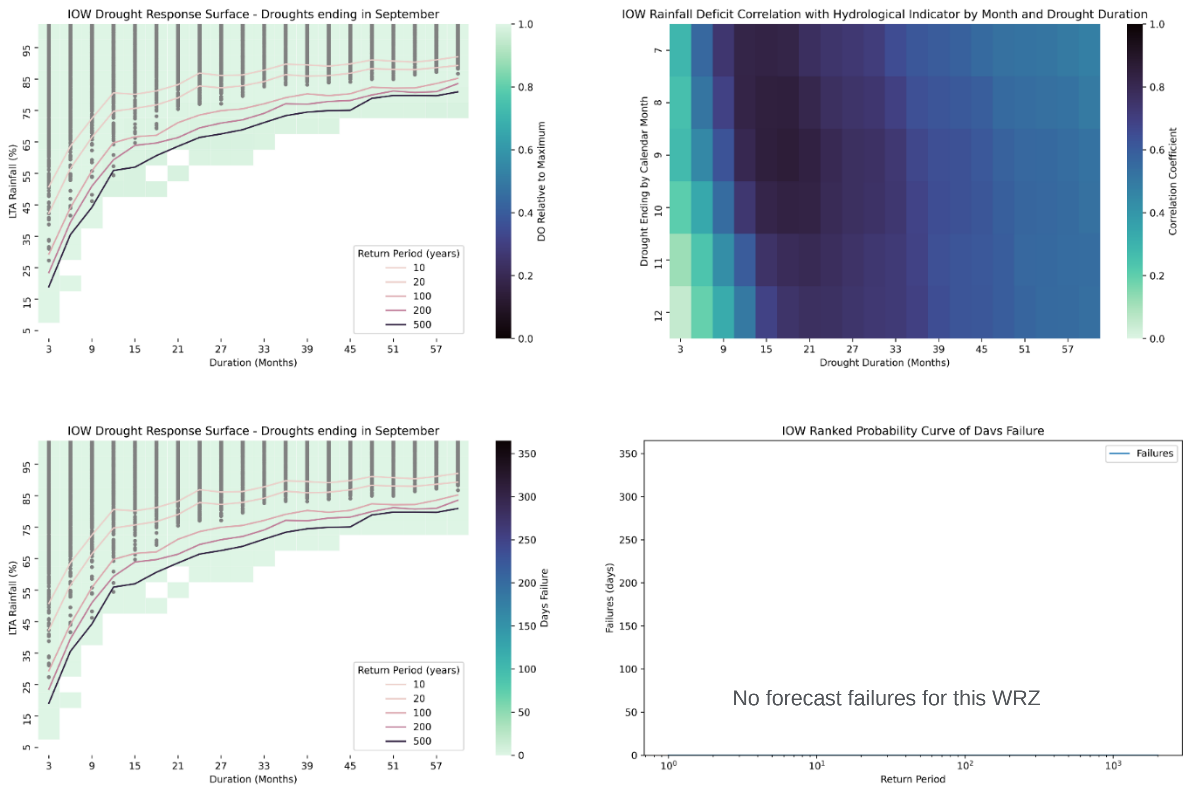


Figure 6: Drought response surfaces for IOW.

Figure 7 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 summer but ending earlier in the year, between August and September. This shows that the chalk aquifer of the IOW has 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.

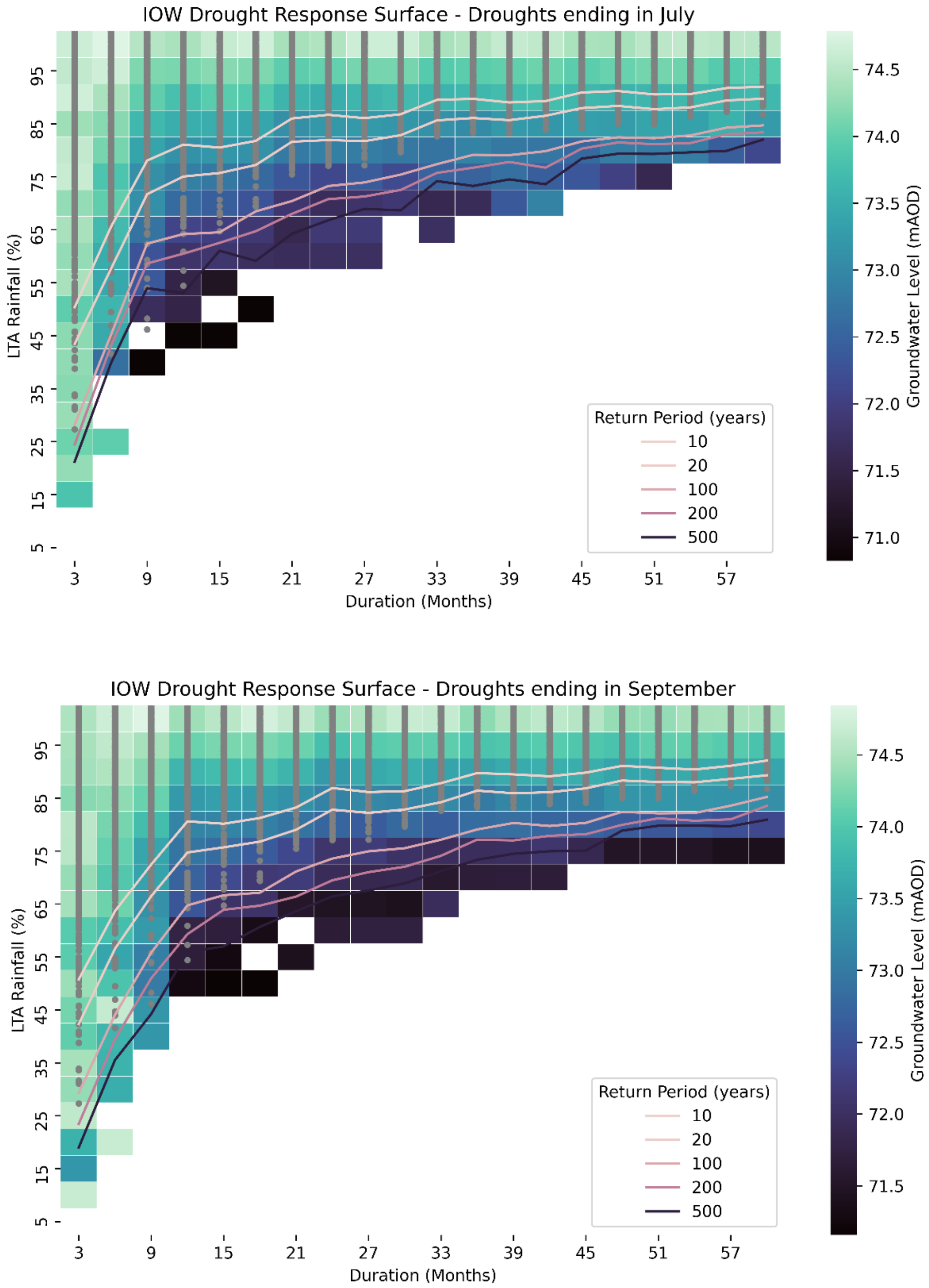


Figure 7: IOW drought response surface for indicator borehole groundwater levels.

3.5 Drought vulnerability – SNZ

Figure 8 shows the summary DRS plots for SNZ. Total DO in SNZ 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.

The DRS 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' duration between 50% and 75% of long-term average rainfall. This is equivalent to a drought worse than around a 1-in-20 year rainfall deficit. A secondary DRS for droughts ending August (Figure 9) shows similar trends but also a response to shorter duration (9 months) events.

As with the Hampshire WRZs, 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 1976 historical drought event.

Due to the link between DO and flow, failures start to accumulate as flows recede in SNZ even for relatively mild droughts. This shows that the WRZ is reliant on drought permits and 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 months' duration droughts ending in October.

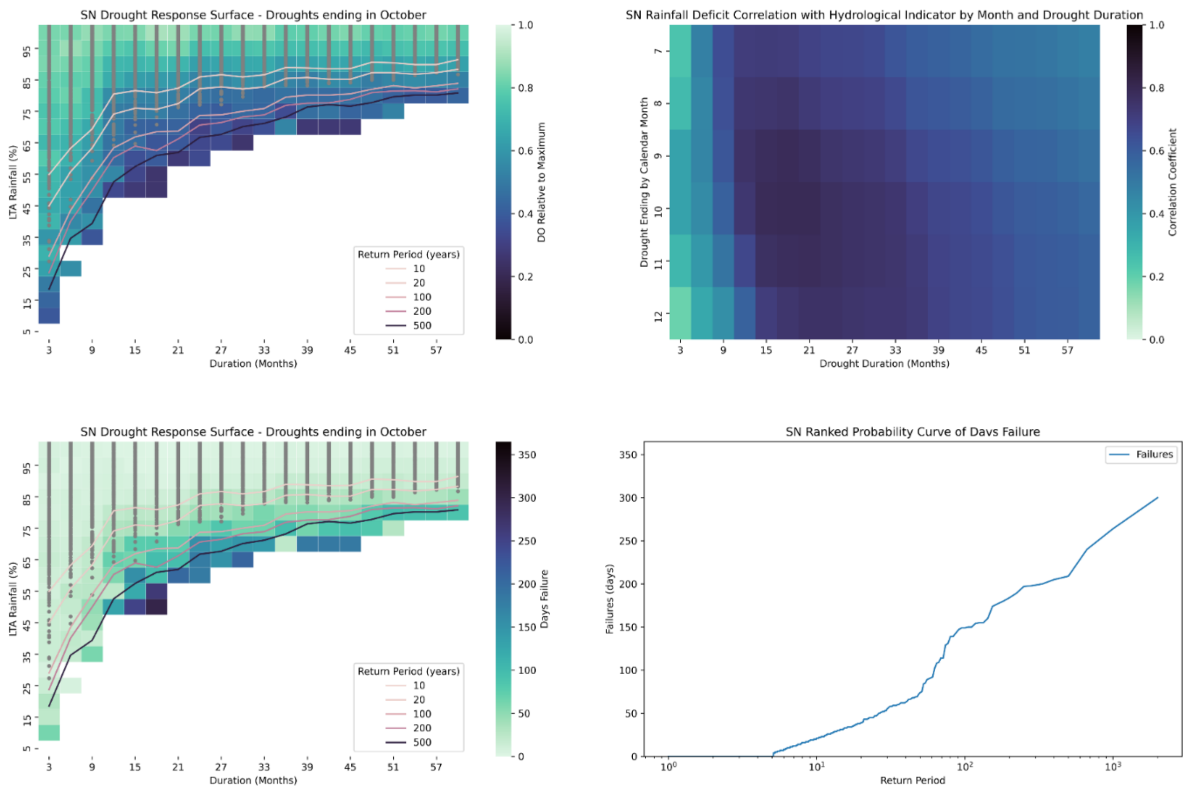


Figure 8: Drought response surface plots for SNZ.

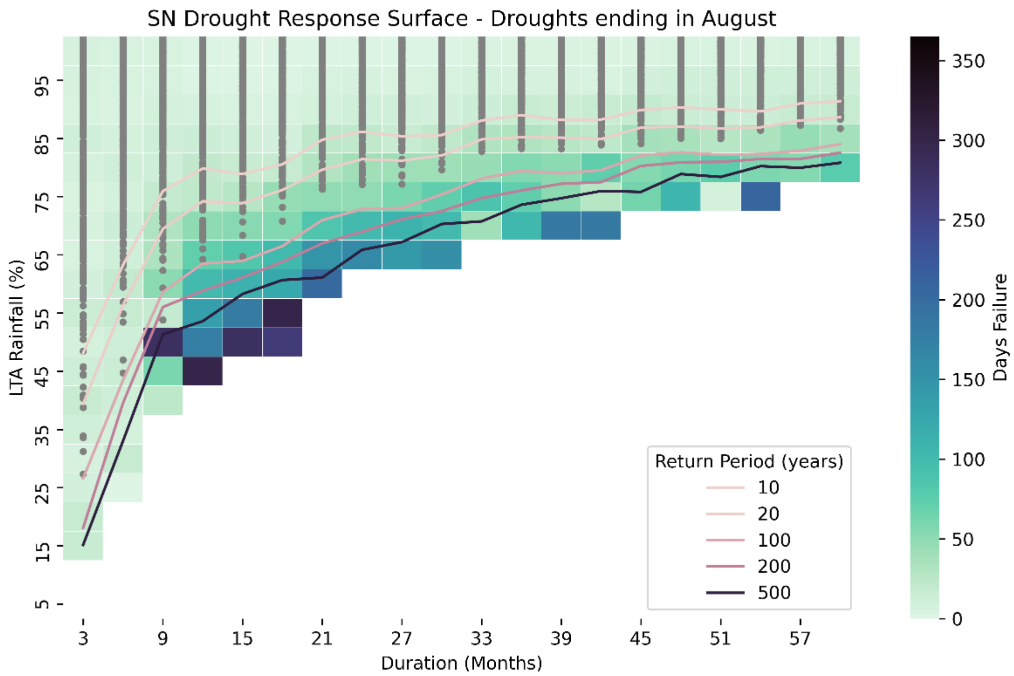


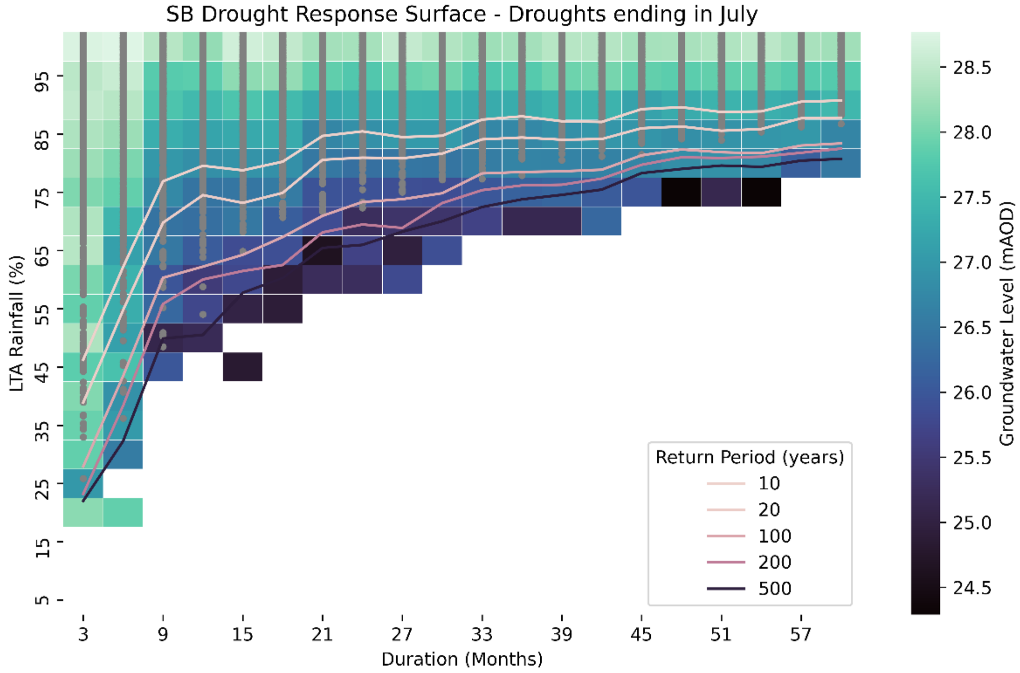
Figure 9: Secondary early drought response surfaces (August) for SNZ.

3.6 Drought vulnerability – SWZ and SBZ

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

Decline in DO during droughts in these WRZs is directly related to groundwater levels (Figure 10) with a common indicator borehole used to determine DO. SBZ has a greater number of drought sensitive sources but as a proportion of lost DO due to rainfall deficits, SWZ is more sensitive. The summary DRS plots for SWZ and SBZ are presented in Figure 11 and Figure 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 these WRZs. DO starts to reduce when rainfall levels fall below 90% of long-term average rainfall for periods of 12 months' duration or more. The greatest DO impacts appear to occur for accumulations of 12-24 months' 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 year to 1-in-500 year). Despite some drought sensitive sources, high yields, the large number of treatment works and interconnected networks provide a degree of drought resilience in these WRZs with failures only occurring in SBZ for extreme droughts. This is consistent with our finding from WRMP19, which indicated the supply-demand deficits in these WRZs were driven by uncertain future abstraction licence changes.



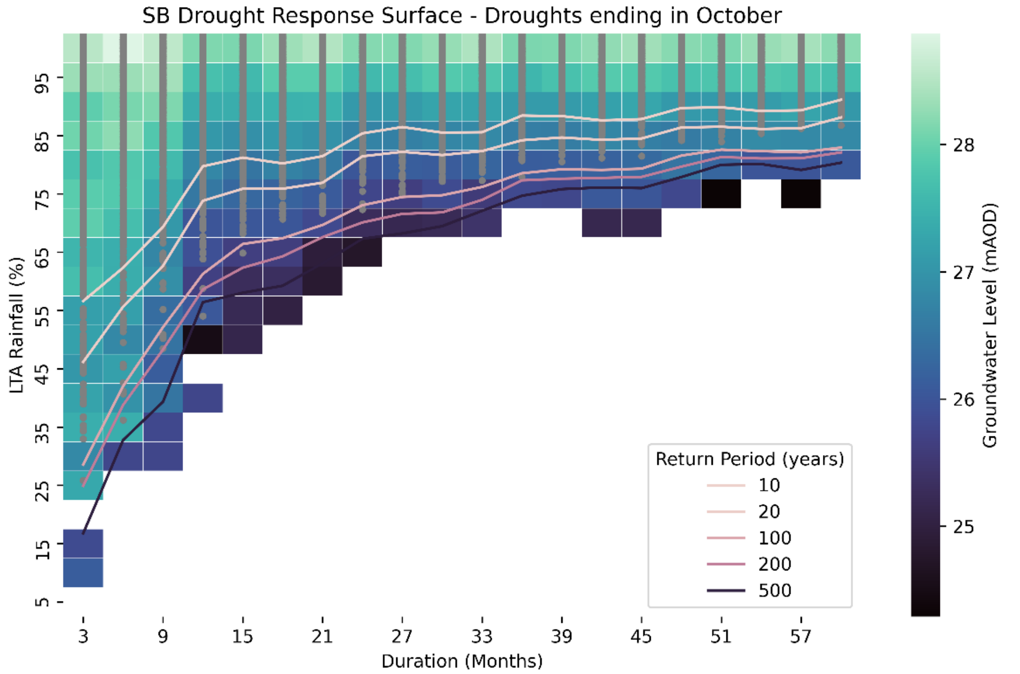


Figure 10: Drought response surface for groundwater level decline (SBZ indicator borehole).

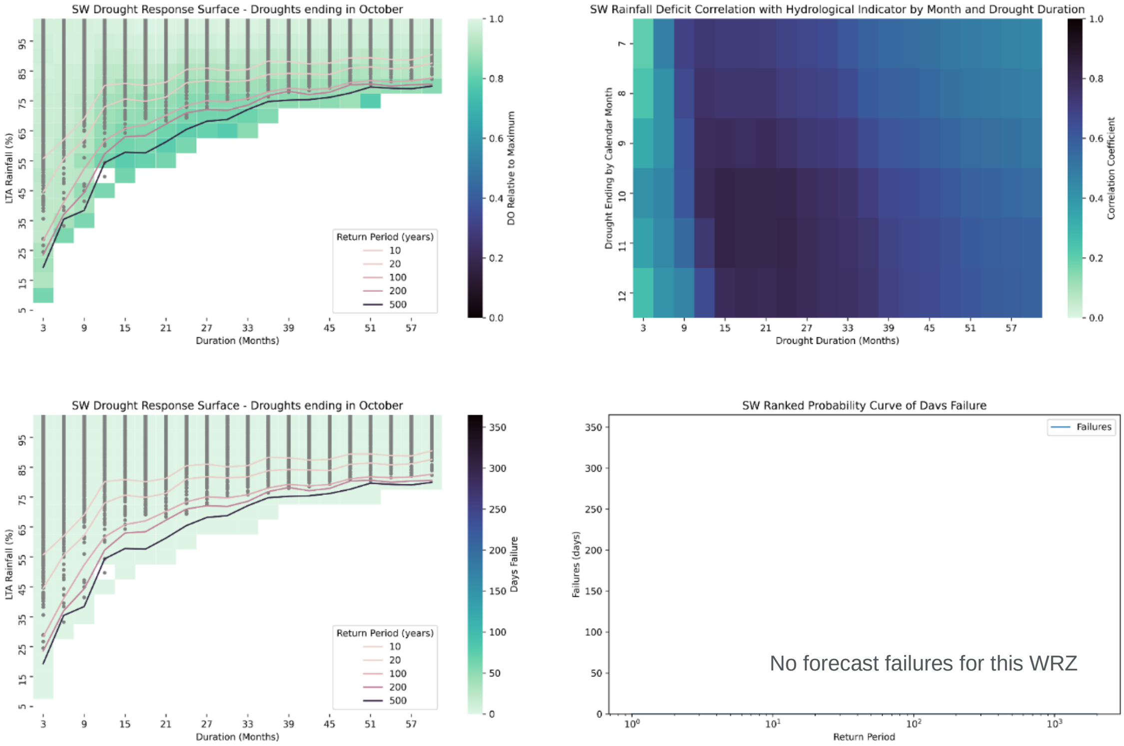


Figure 11: Drought response plots for SWZ.

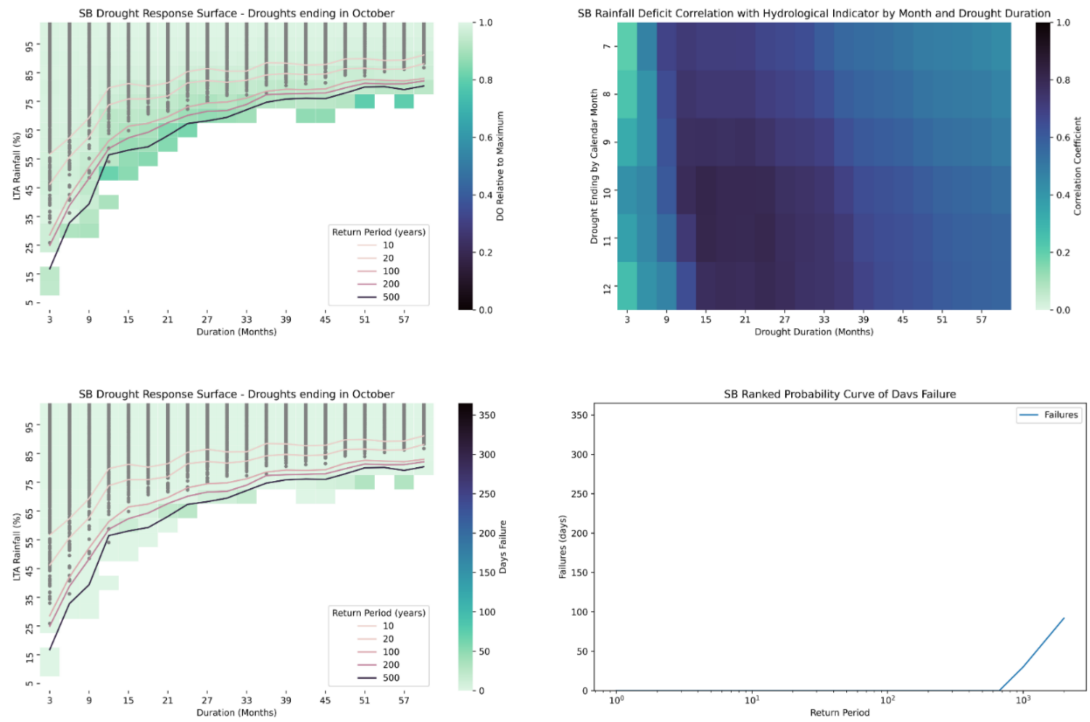


Figure 12: Drought response surface plots for SBZ.

3.7 Drought vulnerability – KME

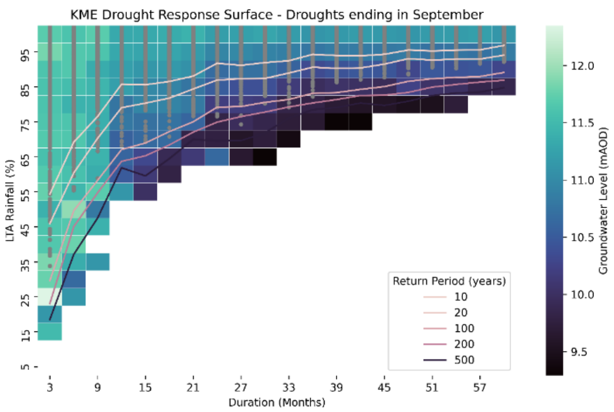
Although high level screening suggested that KME did not require a full assessment, we have nevertheless developed summary DRS plots (Figure 13 and Figure 14) as the groundwater sources in this WRZ do show some drought sensitivity, which is not significant from a failure point of view but is useful to consider in terms of overall resilience and operational flexibility.

As expected from the high-level screening, KME shows only a limited sensitivity of DO to rainfall deficits and no failures. This is consistent with a limited number of groundwater constrained sources in the WRZ. The majority of DO comes from groundwater sources that are constrained by licence or infrastructure. The outputs from these sources are not drought sensitive.

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

This is better illustrated by a groundwater level DRS plots (Figure 13) which shows that the lower groundwater levels are associated with severe to extreme (>1-in-200 year 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 aquifers.



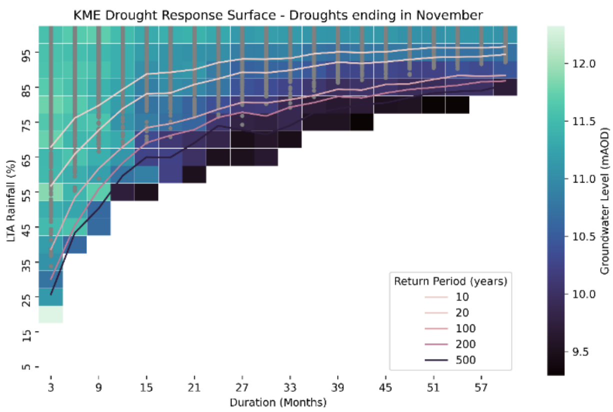


Figure 13: Drought response surface plots for groundwater level decline (KME indicator borehole).

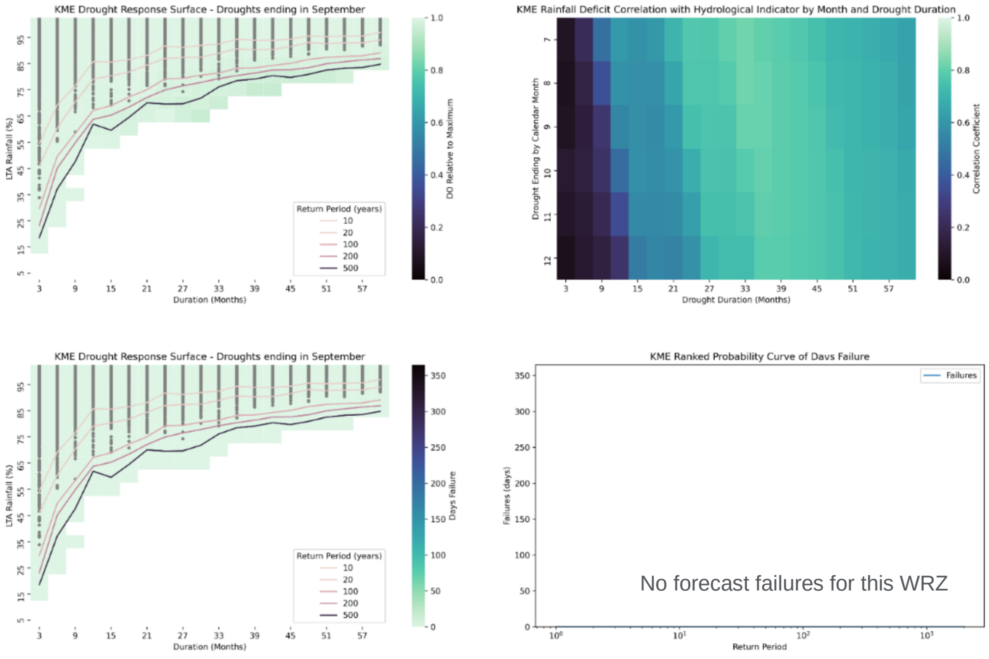


Figure 14: Drought response surface plots for KME.

3.8 Drought vulnerability – KMW and SHZ

We have grouped KMW and SHZ 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 15.

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

The key resource in these WRZs is Bewl Reservoir. It supplies water to both KME and KMW and can be used to transfer water to Darwell Reservoir in SHZ. When KMW/Bewl Reservoir is considered in isolation, it shows a much greater resilience with failures in KMW being much less frequent and only for droughts greater than 1-in-200 year severity (Figure 16). This possibly suggests that use of Powdermill Reservoir emergency storage may not be appropriate.

Reservoir yields begin to decline around a 1-in-50 year drought and the critical drought duration for extreme droughts (>1-in-500 year) appears to be 12-18 months ending in October. There is also a degree of sensitivity to droughts greater than 24 months in duration. The ‘late' DRS plot (Figure 17) shows similar overall trends.

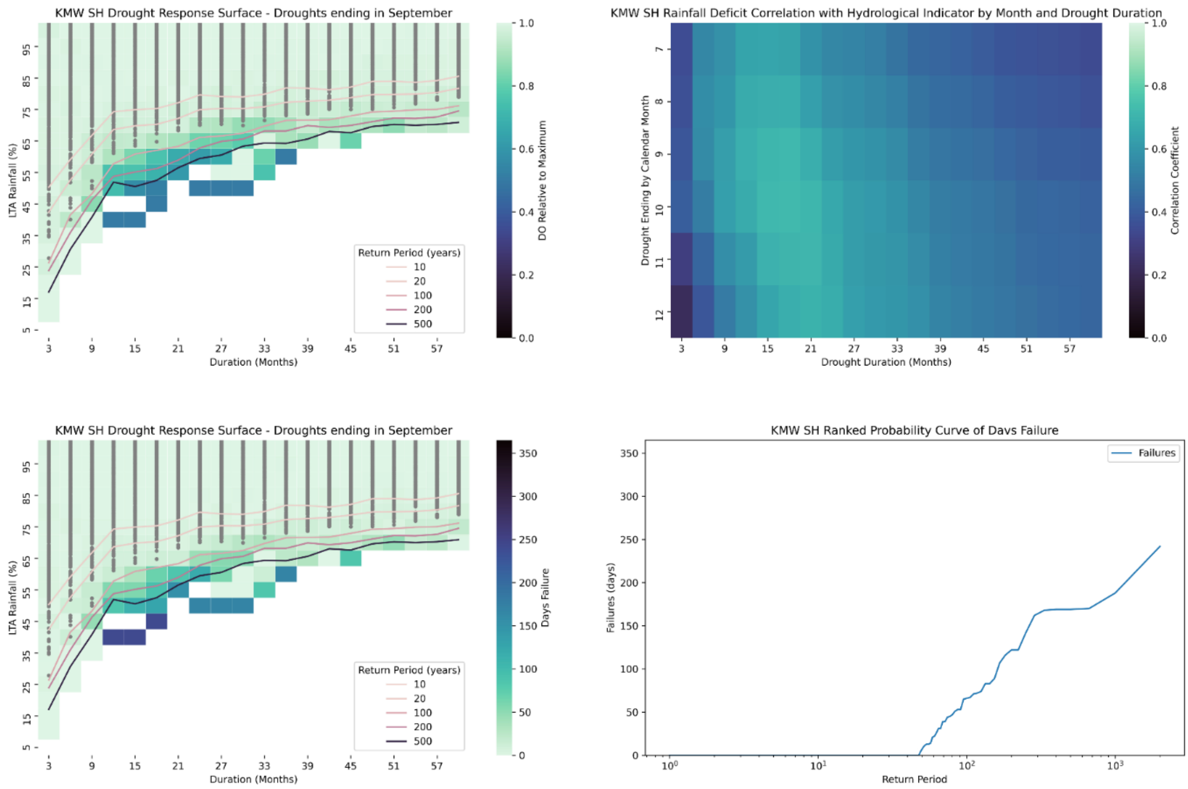


Figure 15: Drought response surface plots for KMW and SHZ.

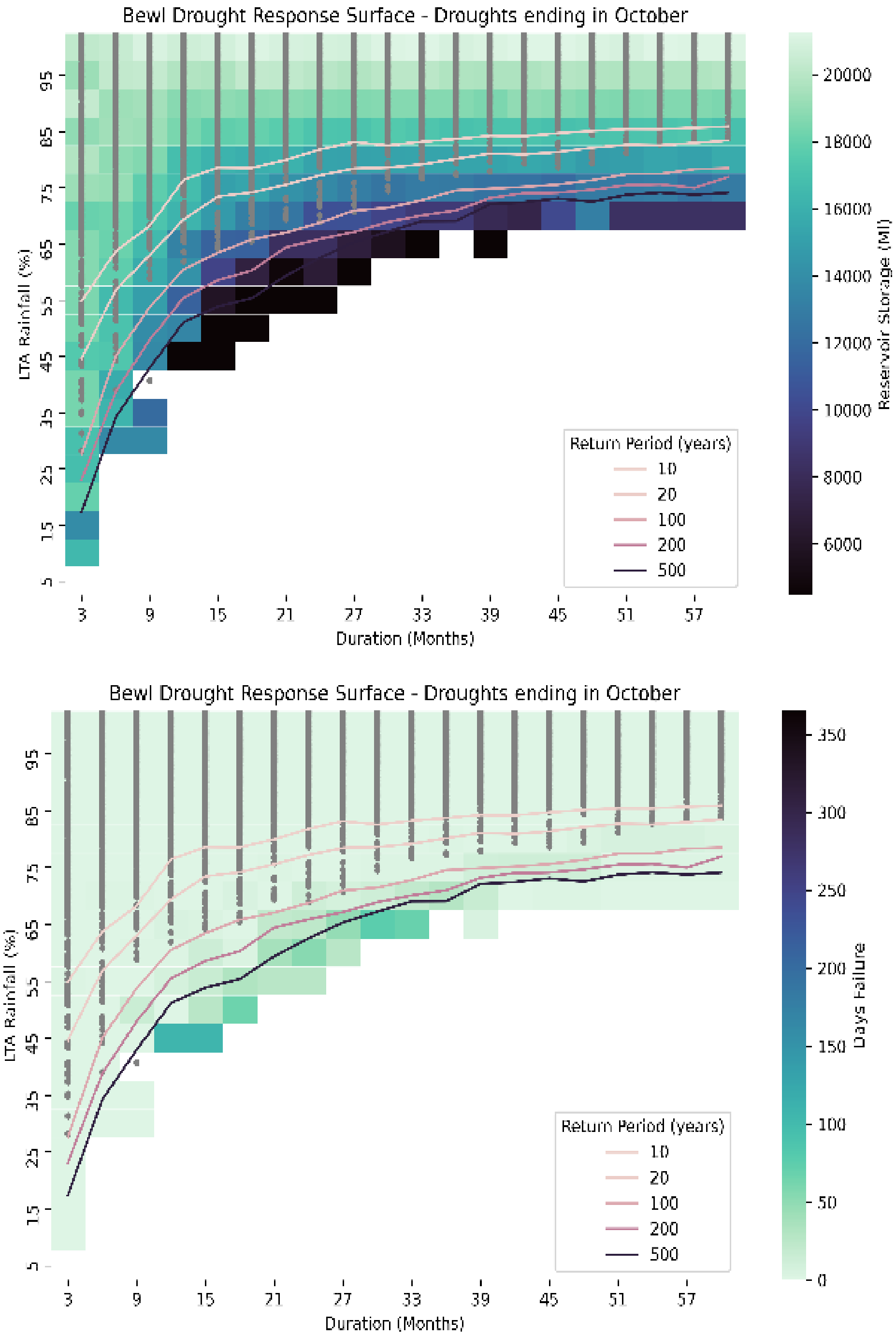


Figure 16: Drought response surface plots for reservoir storage and failures associated with Bewl Reservoir (KMW).

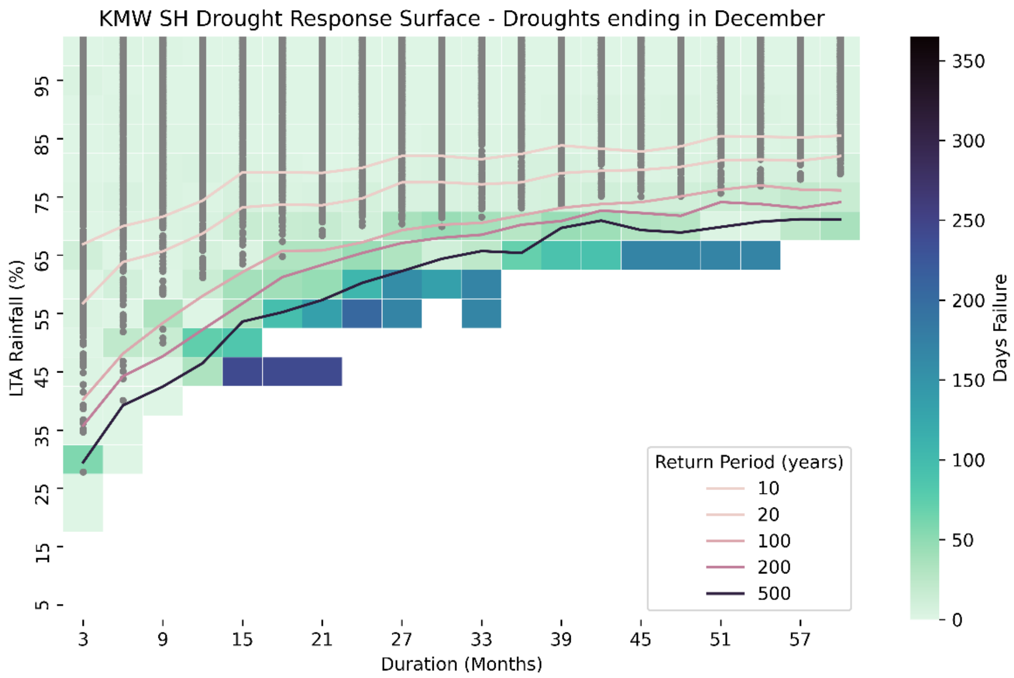


Figure 17: 'Late' drought response surface plots for KMW and SHZ.

3.9 Drought vulnerability – KTZ

Summary DRS plots for KTZ are shown in Figure 18. This WRZ shows many similarities with the neighbouring KME as both get their water from groundwater sources only and are situated in adjacent chalk aquifer blocks that share some characteristics. A greater proportion of groundwater sources shows sensitivity to drought in KTZ and hence the proportional decline in DO with increasing drought severity is greater. Like KMW, the critical droughts in this WRZ are of longer duration than those in the Sussex and Hampshire chalk aquifers reflecting greater storage in the aquifer and slower response to rainfall and recharge. The recharge season also often starts late in the Kent chalk owing to rain shadow effects and higher PET.

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

Although it is more drought sensitive than KME, KTZ exhibits no failures in this assessment owing to an intra-zonal transfer between the two. This helps sustain KTZ 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 19) illustrates the water quality challenges and significantly increases the rate of failure and represents the principal threat to this WRZs resilience. This is presently being addressed through a major network and treatment upgrade and catchment management.

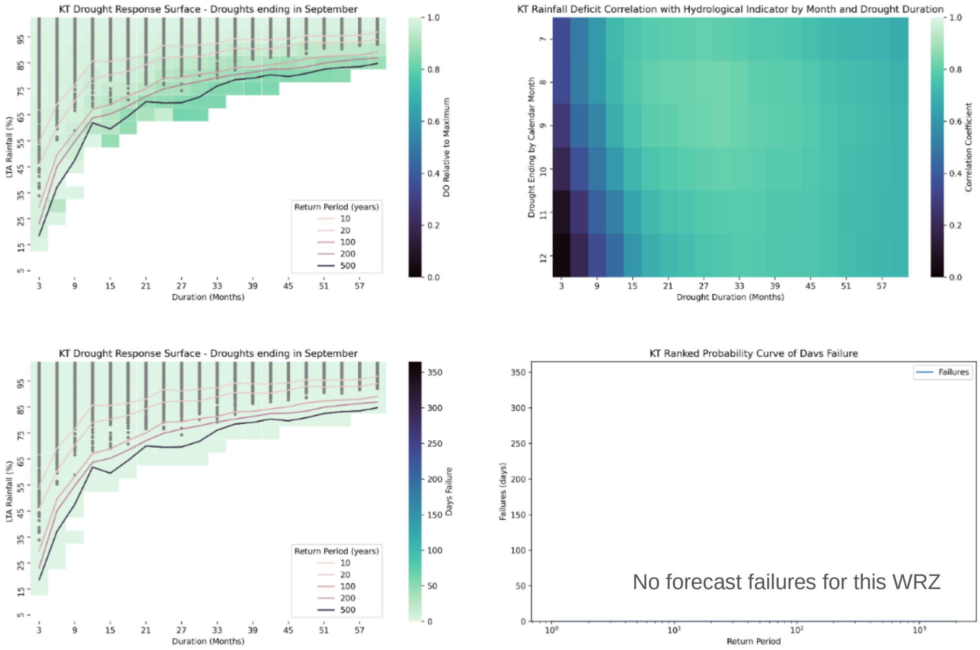


Figure 18: Drought response surface plots for KTZ.

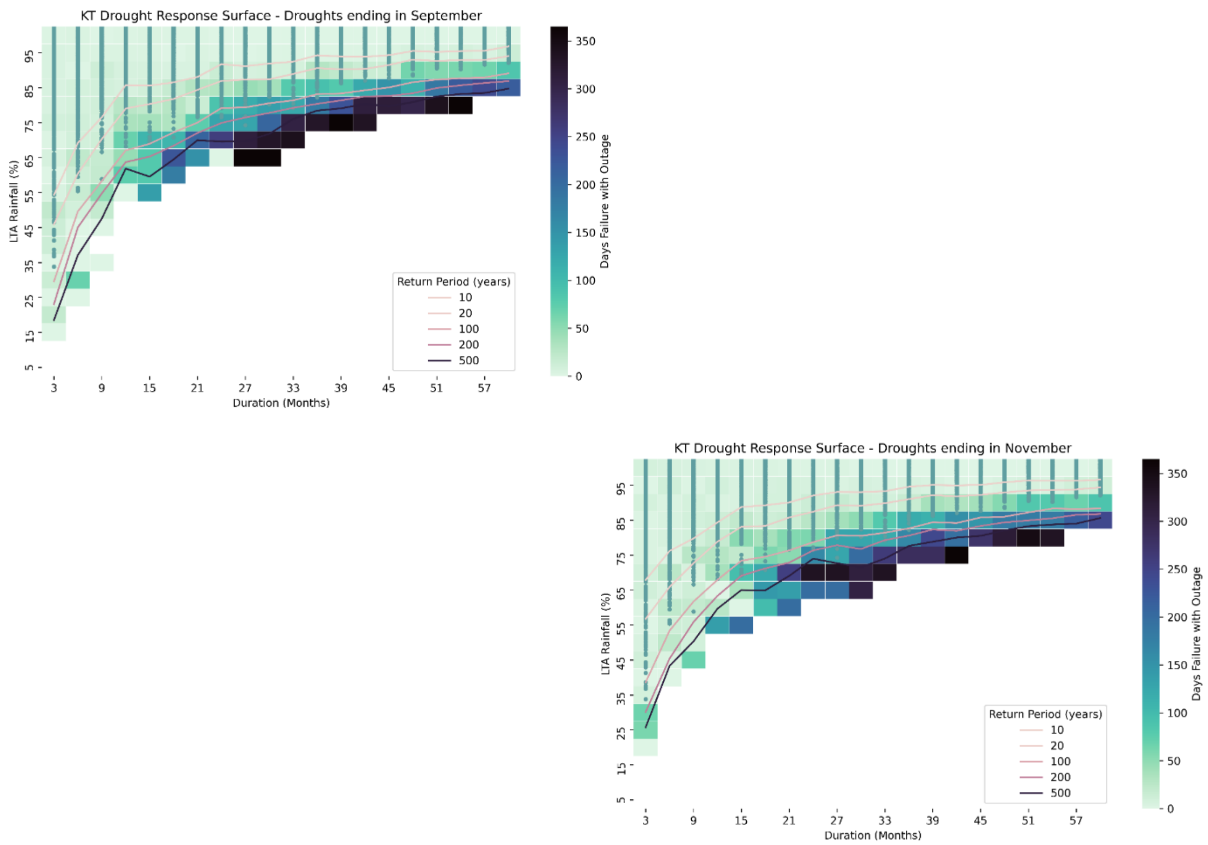


Figure 19: Drought response surface plots for KTZ including outage.

4 Key Findings

A number of trends and findings are evident from the vulnerability assessment for each of our sensitive WRZs.

- Sussex and Hampshire show very similar critical droughts. This largely reflects the characteristics of the chalk aquifer that dominates SBZ and SWZ and provides groundwater baseflow support to the rivers Test and Itchen. Southern Hampshire and the Sussex chalk are most sensitive to 12-21 months' duration 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.
- SNZ 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 HSW, HSE and SNZ are the most drought vulnerable. This is from 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. To an extent this reflects the storage buffering of the large reservoir system that provides a degree of resilience to short drought events.