Drought Plan 2022
Annex 4: Drought triggers and indicators

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WATER for LIFE

from Southern Water

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Abbreviations

ABH	Abstraction borehole
ADO	Average Deployable Output
BFI	Baseflow Index
BFIHOST	Baseflow Index Hydrology of Soil Types
BGS	British Geological Survey
CSMG	Common Standards Monitoring Guidance
DI	Distribution Input
DO	Deployable Output
DP13	Drought Plan 2013
DP19	Drought Plan 2019
DP22	Drought Plan 2022
DRS	Drought Response Surface
DVF	Drought Vulnerability Framework
DYAA	Dry Year Annual Average
DYCP	Dry Year Critical Period
EA	Environment Agency
EFI	Environmental Flow Indicator
ESoR	Exceptional Shortage of Rain
HAZ	Hampshire Andover
HKZ	Hampshire Kingsclere
HoF	Hands-off Flow
HRZ	Hampshire Rural
HSE	Hampshire Southampton East
HSW	Hampshire Southampton West
HWZ	Hampshire Winchester
IOW	Isle of Wight
KME	Kent Medway East
KMW	Kent Medway West
KTZ	Kent Thanet
LoS	Level of Service
MDO	Minimum Deployable Output
MRF	Minimum Residual Flow
NEUB	Non-Essential Use Ban
PET	Potential Evapotranspiration
RMS	River Medway Scheme
RSA	Restoring Sustainable Abstractions
SBZ	Sussex Brighton
SGI	Standardised Groundwater Indices
SHZ	Sussex Hastings
SNZ	Sussex North
SPEI	Standard Precipitation and Evapotranspiration Index
SPI	Standard Precipitation Index
SWS	Southern Water
SWZ	Susses Worthing
TUB	Temporary Use Ban
WFD	Water Framework Directive
WINEP	Water Industry National Environment Programme
WRSE	Water Resources South East

WRZ	Water Resource Zone

1. Introduction

This annex describes our assessment of vulnerability to drought of different durations and severity and the drought triggers we use to identify the development and progression of a drought. Since our consultation in 2021, we have had to make a number of changes to the drought plan and annexes such as this in response to regulatory feedback. We have re-submitted our draft plan to regulators in May 2022, September 2022 and February 2024. Following a letter received from Defra on 21 August 2024 we have made further changes to our draft plan and the annexes. We have also made minor changes to the appendices of this document in response to the letter received from Defra on 9 July 2025.

2. Drought vulnerability assessment

2.1 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[1]. 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[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 (UKWIR, 2017)[4] and the results are presented herein.

2.2 Methodology

2.2.1 Data sources

The input data for our assessment are based on our supply and demand modelling from WRMP19 and are summarised in Table 1.

[1] Southern Water, 2020. Water Resources Management Plan, Annex 3: Supply Forecast
[2] 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.
[3] Counsell, C., Hunt, D., and Ledbetter, R., 2017. Drought Vulnerability Framework, UK Water Industry Research Limited, London.
[4] ibid

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
DO	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 WRMP19 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[5] 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

2.2.2 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.[6]

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[7] 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:

[Available headroom net of outage (DO – demand – target headroom)] / DO

[5] Atkins, 2017. Effectiveness of Restrictions Technical Note, Southern Water Drought Plan.
[6] Counsell, C., Hunt, D., and Ledbetter, R., 2017. Drought Vulnerability Framework, UK Water Industry Research Limited, London.
[7] Ibid

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 the target headroom.

In either case, a supply-demand deficit due to drought is implausible.[8]

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 (KME) WRZ, which although is 100% groundwater, is closely interconnected with the Kent Medway West (KMW) WRZ and our reservoir system in Kent - The River Medway Scheme (RMS). 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[9].

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% (Run of river and reservoirs)		0%
Kent Medway East (KME)	2	100%	0%	0%	0%
Sussex Hastings (SHZ)	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 = DO 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 DI 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.

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

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	IOW*	HWZ*	HSW*	HSE*	HRZ*	HKZ*	HAZ*	SNZ*	SBZ*	SWZ*	KTZ*	KME*	KMW*	SHZ*
Minimum or Dry Year Annual Average	1-in-2 years	Y	N	N	Y	N	N	N	N	N	N	N	N	N	N
	1-in-20 years	Y	N	N	Y	N	N	N	Y	N	N	N	N	N	N
	1-in-100 years	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y
	1-in-200 years	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	Y
	1-in-500 years	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	N	N	Y
	1-in-1000 years	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	N	N	Y
Dry Year Critical Period	1-in-2 years	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	1-in-20 years	Y	N	N	Y	N	N	N	N	N	N	Y	N	N	N
	1-in-100 years	Y	N	N	Y	N	N	N	Y	N	N	Y	N	N	N
	1-in-200 years	Y	N	Y	Y	N	N	N	Y	N	N	Y	N	N	N
	1-in-500 years	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	N
	1-in-1000 years	Y	N	Y	Y	N	N	N	Y	Y	N	Y	N	N	N

*see Table 1 for WRZ names.

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 HWZ, HRZ, HAZ, HKZ (northern Hampshire, Western area) and KME (Eastern area). The four northern Hampshire WRZs were also not considered in our WRMP19 drought vulnerability assessment.[10] 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

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

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 through internal transfers from the neighbouring KMW WRZ. KME is relatively drought resilient, whilst there some drought sensitive sources, the WRZ demand is low compared to the DO available. There are also a 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 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.

2.2.3 Characterisation of supply system and calculation approach

Following the high-level screening, the DVF must next 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[11]. 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.[12] For the WRZs being assessed full rainfall deficit/flow analysis is 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.

[11] 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.
[12] Counsell, C., Hunt, D., and Ledbetter, R., 2017. Drought Vulnerability Framework, UK Water Industry Research Limited, London.

2.2.4 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 low 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 2. Our characterisation is presented in Table 4.

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

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.

2.2.5 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[13]:

1. Total WRZ demand (DI)
2. Total WRZ demand plus target headroom
3. Total WRZ demand plus target headroom and outage
4. Demand equivalent to DO

[13] Counsell, C., Hunt, D., and Ledbetter, R., 2017. Drought Vulnerability Framework, UK Water Industry Research Limited, London.

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 and 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'[14] 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 (WRP) tables for the period 2022-23 which represents the first year of this Drought Plan (DP22). 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 in the WRP tables
- The value for target headroom is the target headroom allowance - line 16FP in WRP tables
- The value for outage is the WRZ outage allowance - line 10BL in WRP tables

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

2.2.6 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 WRP tables. The magnitude of demand saving benefits are based on those assumed for WRMP19[15] 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.[16]

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

[14] 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.
[15] Atkins, 2017. Effectiveness of Restrictions Technical Note, Southern Water Drought Plan.
[16] Ibid

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 (LoS) 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 simplifying assumption that the benefits are always on. Whilst this is inconsistent with our stated LoS for TUBs and NEUBs, we would generally not expect significant supply failures to occur in normal to mild droughts (<1-in-20 years return period) except for HSW where we recognise the significant risk to the WRZ and its reliance on drought permits/orders.

2.2.7 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 WRP tables.
DI is the fixed WRZ DI for 2022-23 from our WRP tables.
Target headroom is the fixed target headroom for 2022-23 from our WRP tables.

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

Table 6: Other assumptions in our drought vulnerability assessment.

Supply-demand element	Assumption
Process losses	Excluded from our assessment, generally 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	As 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 our 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 supply, the full 2000-years stochastic flow sequence has been modelled in our behavioural Aquator model of our 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.

2.3 Results

2.3.1 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 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 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.

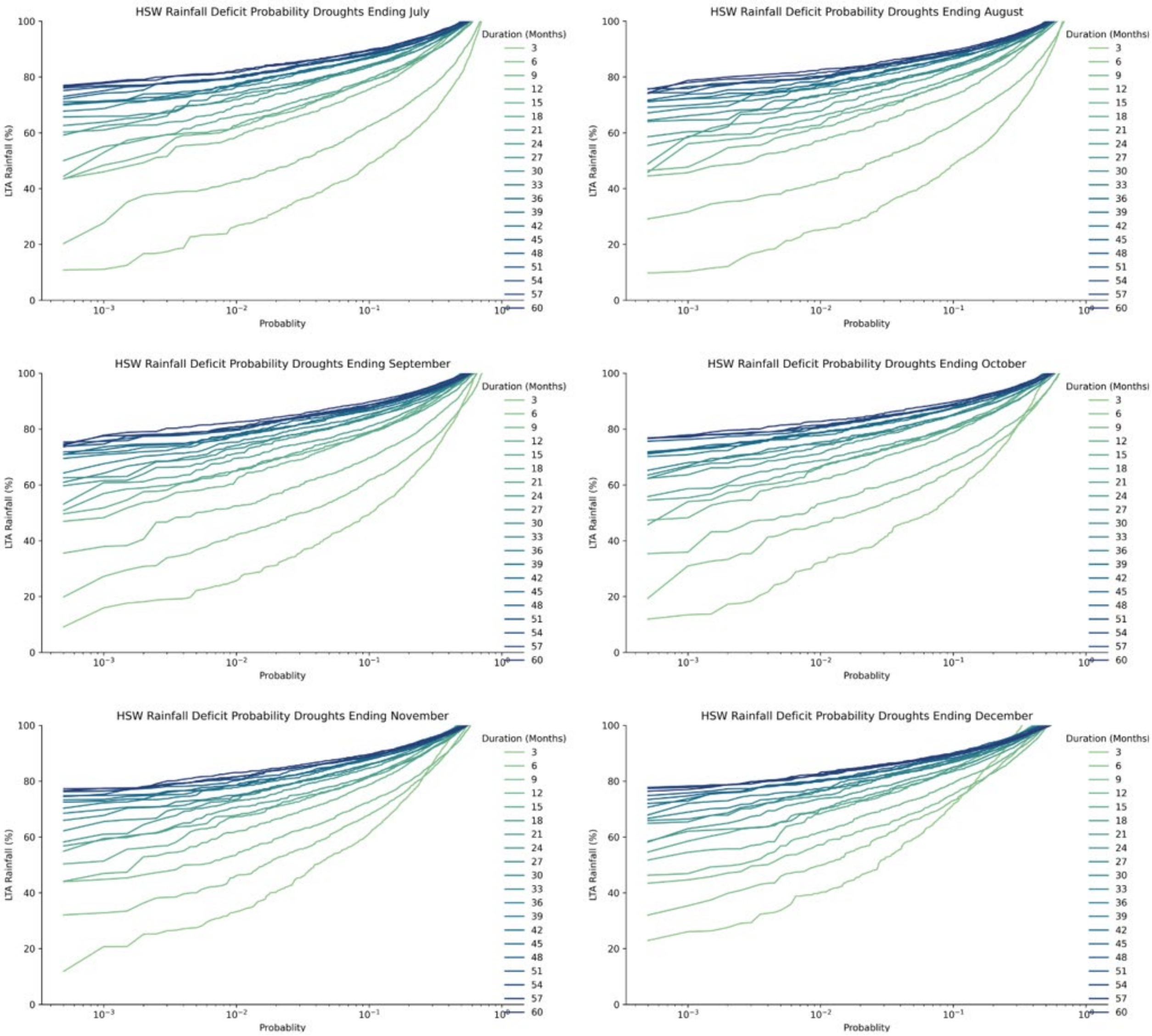


Figure 1: Example rainfall deficit versus return period plots for HSW WRZ.

2.3.2 Drought vulnerability - HSW

A summary of the key DRS plots for this WRZ are presented in Figure 2. The full set of DRS plots for each calendar month is included in Appendix A.

Summary plots like Figure 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.

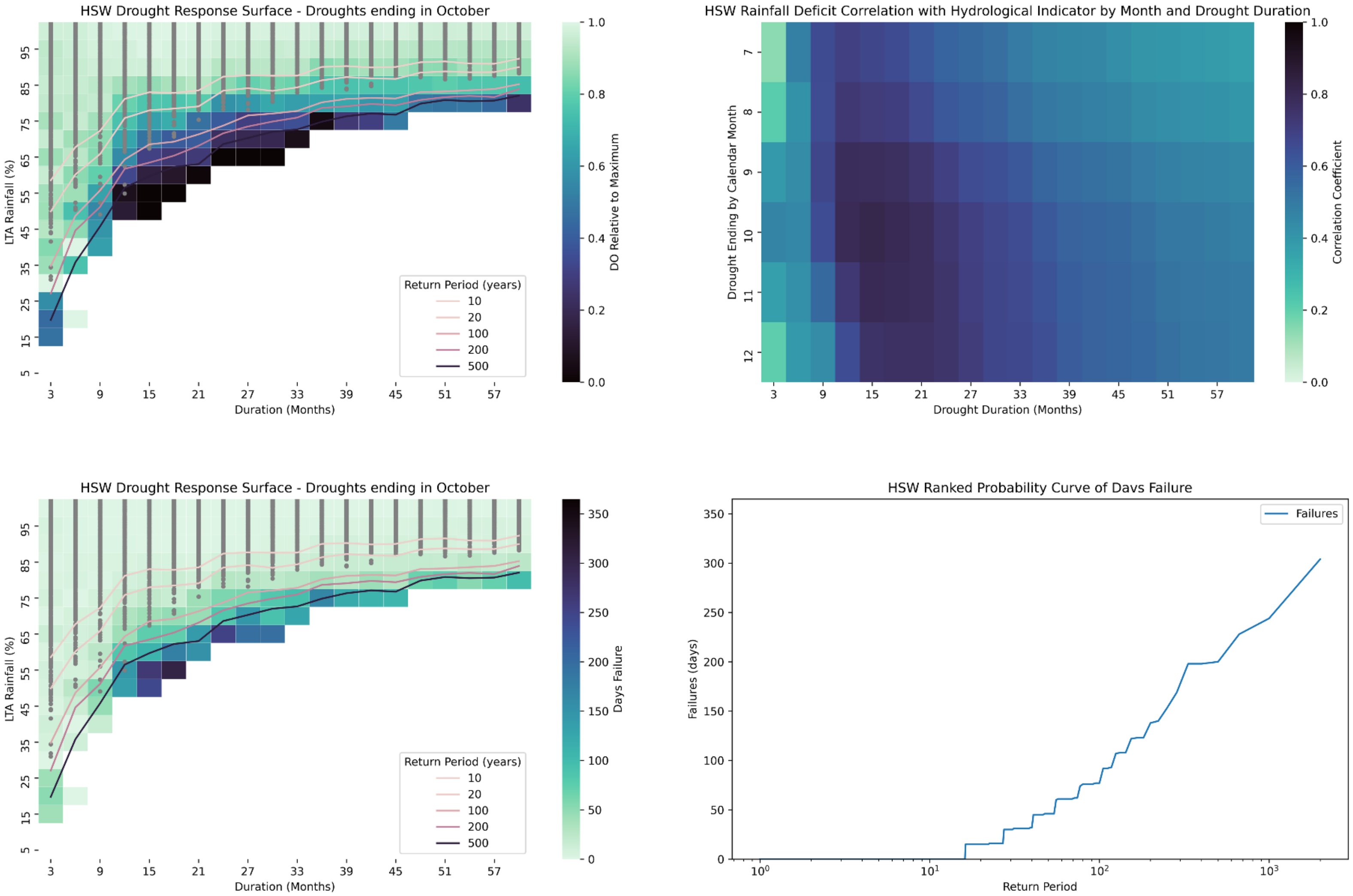


Figure 2: Drought response surfaces for HSW WRZ.

- 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 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 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 LoS and for comparison of our expected failures against our target LoS. This plot is also used to consider if any LoS 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 15-21 months' duration. There is also some sensitivity to short-term rainfall deficits that arises from dry autumn and summer periods leading to extended recession in river flows.

The rainfall deficit – hydrological indicator plot shows similar results, with the greatest correlations between low flows occurring due to rainfall deficits between 12-18 months' duration ending in the autumn month 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 12-24 months. This reflects that single dry winter events combined with dry summer and autumn conditions, similar to the 1976 historical drought, have the most significant impact on this WRZ.

As we recognised in WRMP19, the failure probability curve illustrates that we cannot meet our target LoS 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 1-in-10 to 1-in-20 years and will need to apply for drought permits/orders much more frequently.

2.3.3 Drought vulnerability - HSE

The summary DO response surfaces and associated plots for HSE are presented in Figure 3. 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 are 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 9-24 months' duration ending in October with the largest DO deficits and failures for droughts between 15 and18 months. Failure probabilities are similar to HSW and below our target LoS, reflecting that this WRZ is somewhat reliant on water transferred from HSW. 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).

2.3.4 Drought vulnerability - IOW

The drought response plots for the IOW (Figure 4) show a much greater degree of resilience than the adjacent HSW and HSE WRZs. The full set of plots is in Appendix A. DO varies by only minor amounts with rainfall deficits and this reflects that in our assessment approach the 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 apparent drought resilience most dominantly reflects that the WRZ is supported by transfer from the mainland and can maintain supplies whilst the transfer is active. This transfer, and by proxy, the WRZ is subject to the same vulnerability as the rest of HSW and hence actual failures are likely to be much more frequent than illustrated by this analysis.

Figure 5 shows a DRS for the IOW which relates rainfall deficit and drought duration to decline in groundwater levels at our indicator borehole. 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, 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 earlier than in 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 3: Drought response surfaces for HSE WRZ.

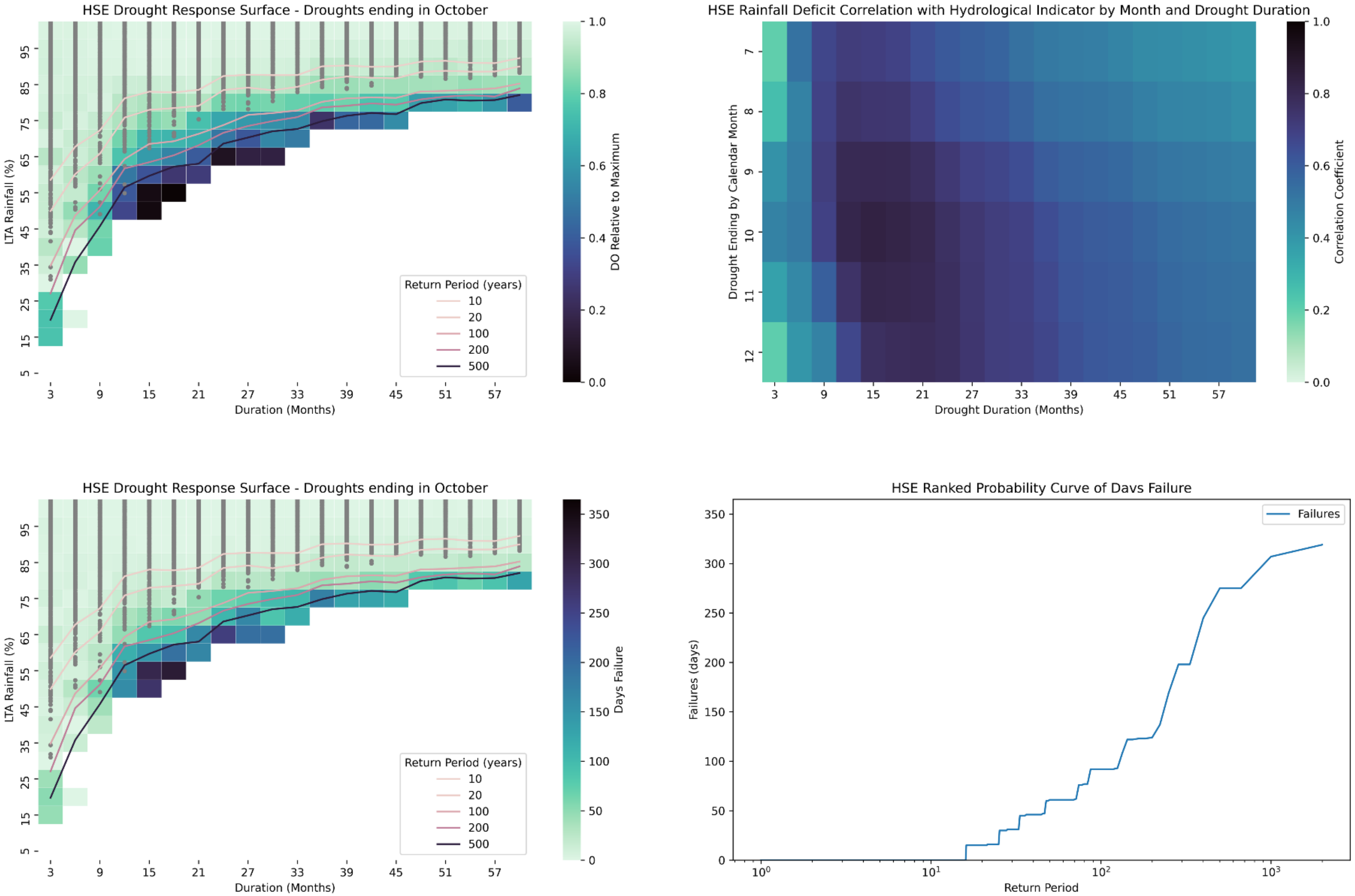
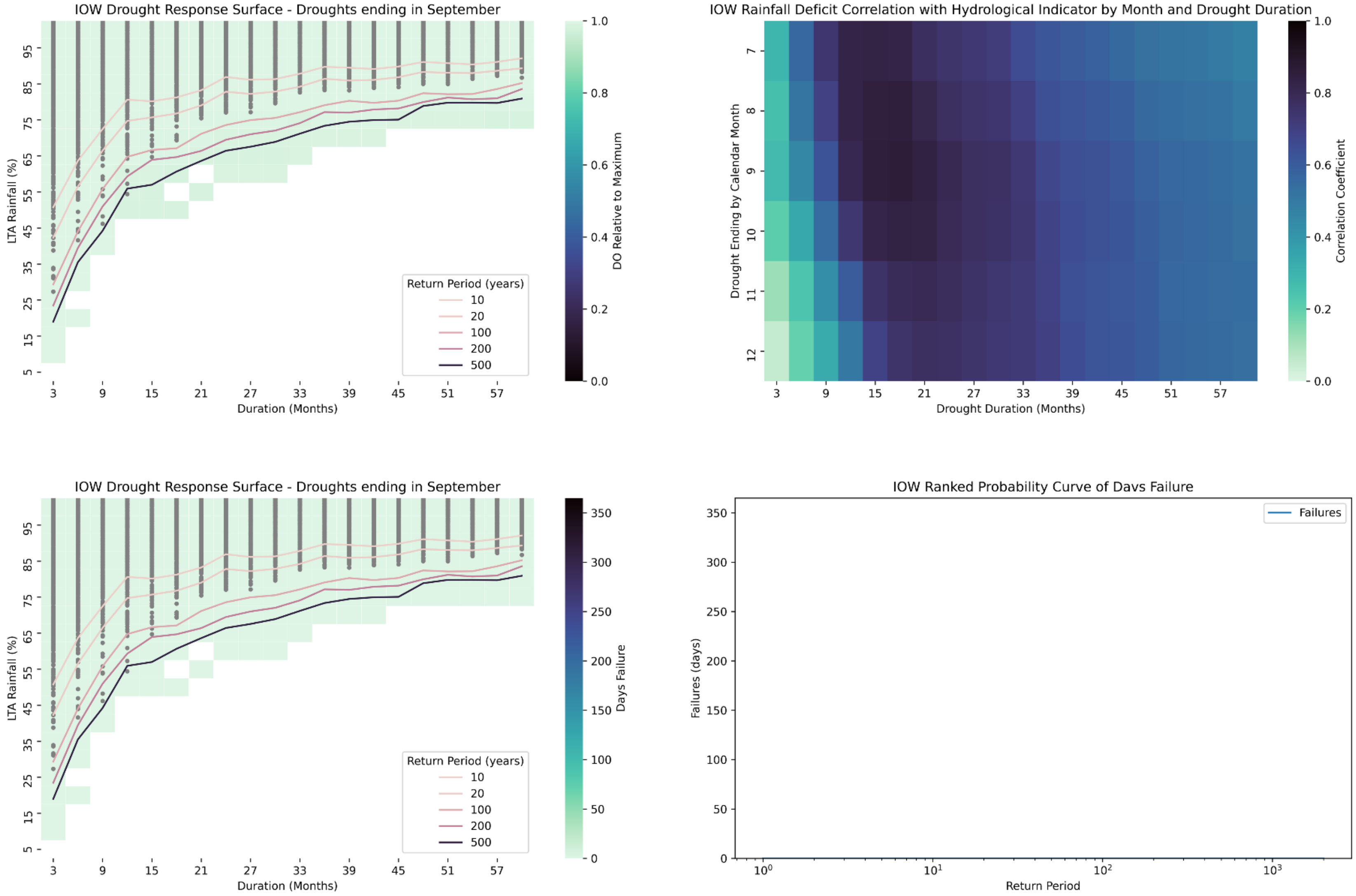


Figure 4: Drought response surfaces for IOW WRZ.



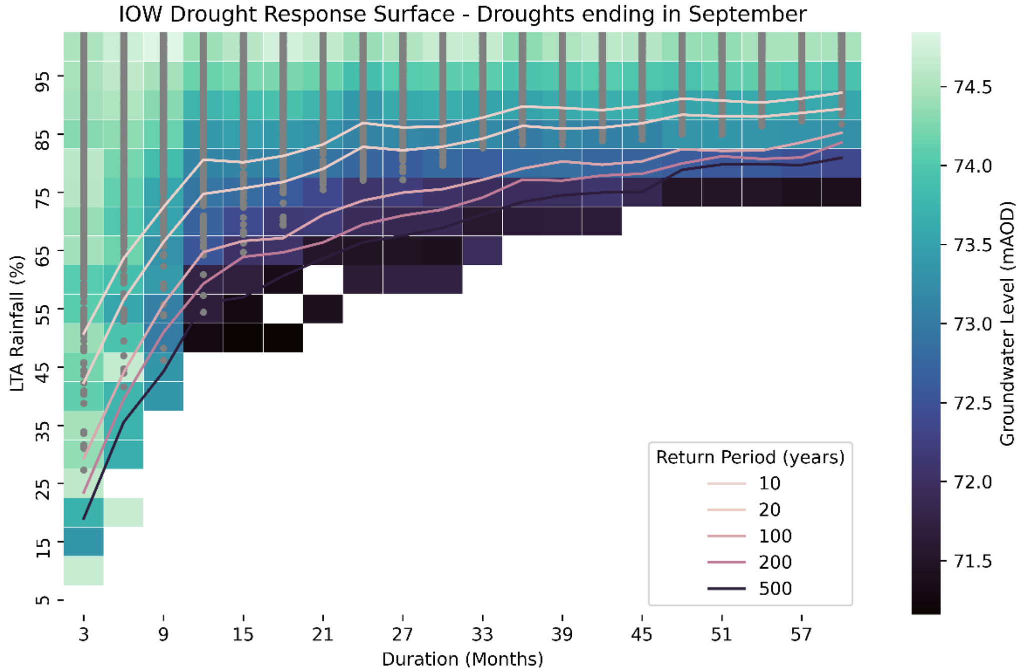


Figure 5: DRS for indicator borehole groundwater levels - IOW

2.3.5 Drought vulnerability – SNZ

Figure 6 shows the summary DRS plots for the SNZ WRZ. The full set of DRS plots is in Appendix A.

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 years rainfall deficit.

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 1976 historical drought event.

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 the WRZ's reliance 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 months duration droughts ending October.

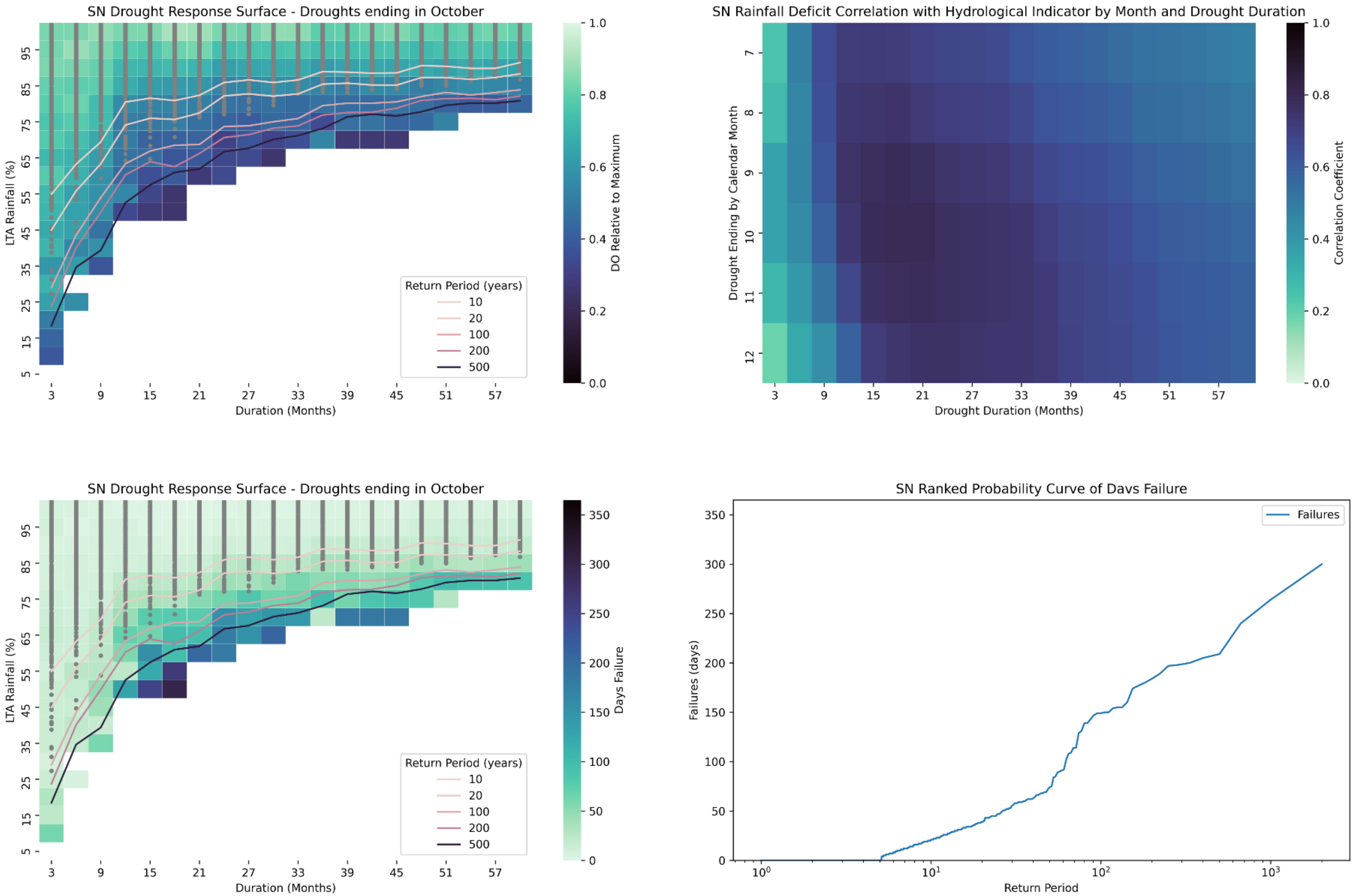


Figure 6: DRS plots for SNZ WRZ.

2.3.6 Drought vulnerability – SBZ and SWZ

These two WRZs are considered together here 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-related decline in DO in these WRZs is directly related to groundwater levels (Figure 7) 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 8 and Figure 9 respectively and the full set is provided in Appendix A.

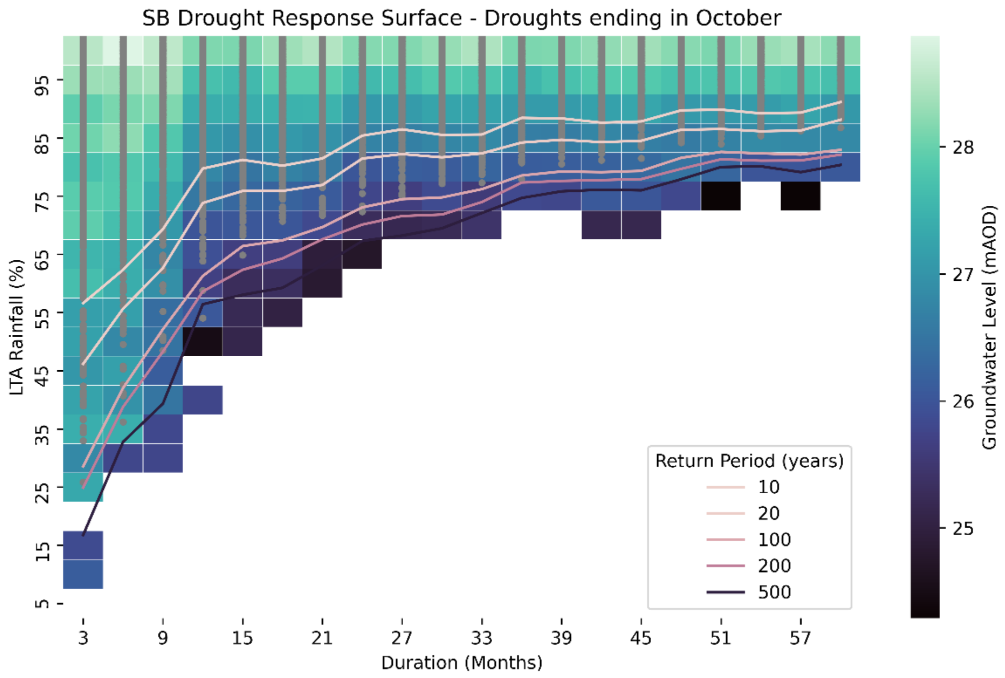


Figure 7: DRS for groundwater level decline, SBZ indicator borehole.

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 to 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 years to 1-in-500 years). 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 that the supply-demand deficits in these WRZs were driven by uncertain future abstraction licence changes.

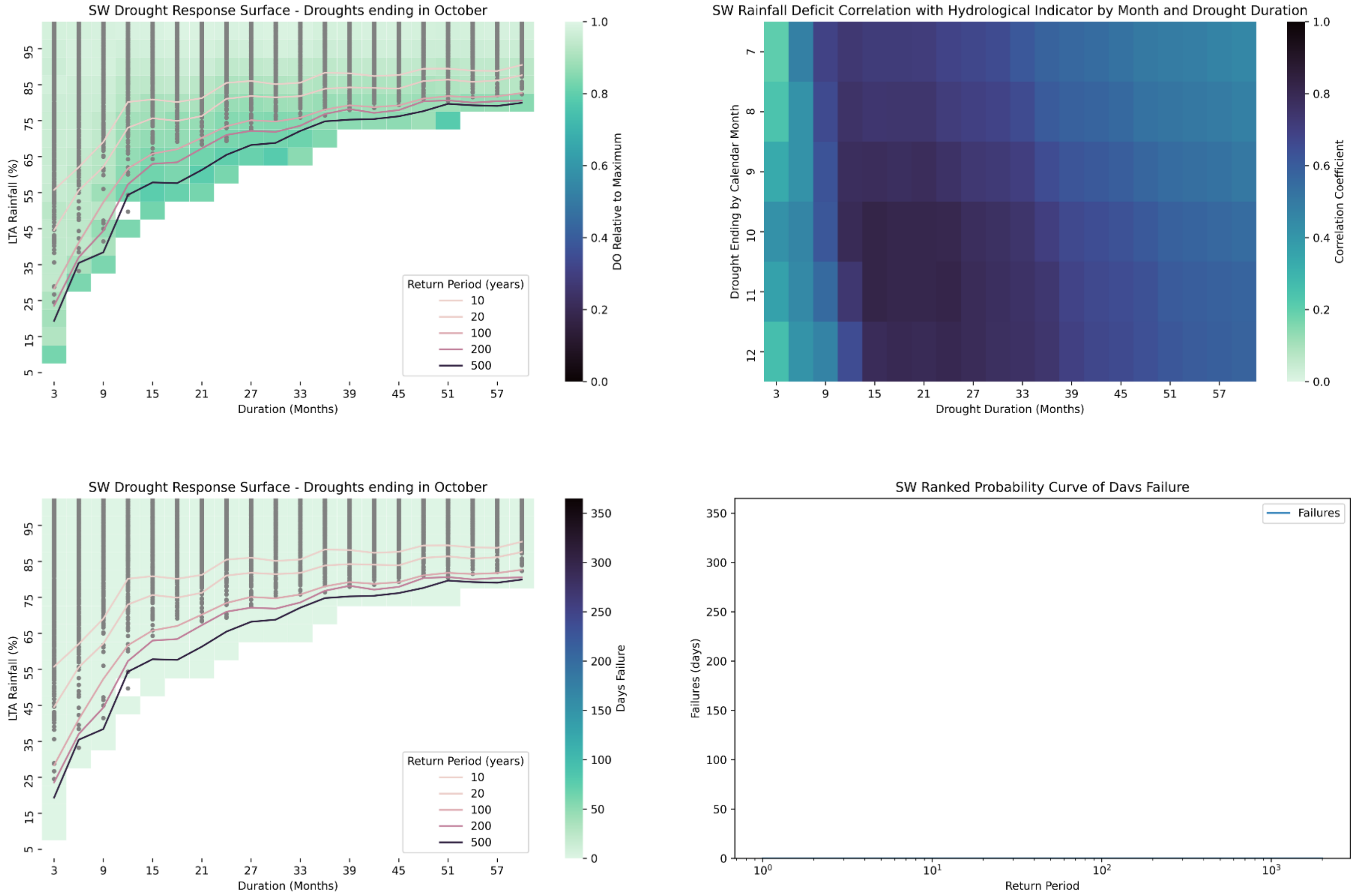


Figure 8: DRS plots for SWZ WRZ.

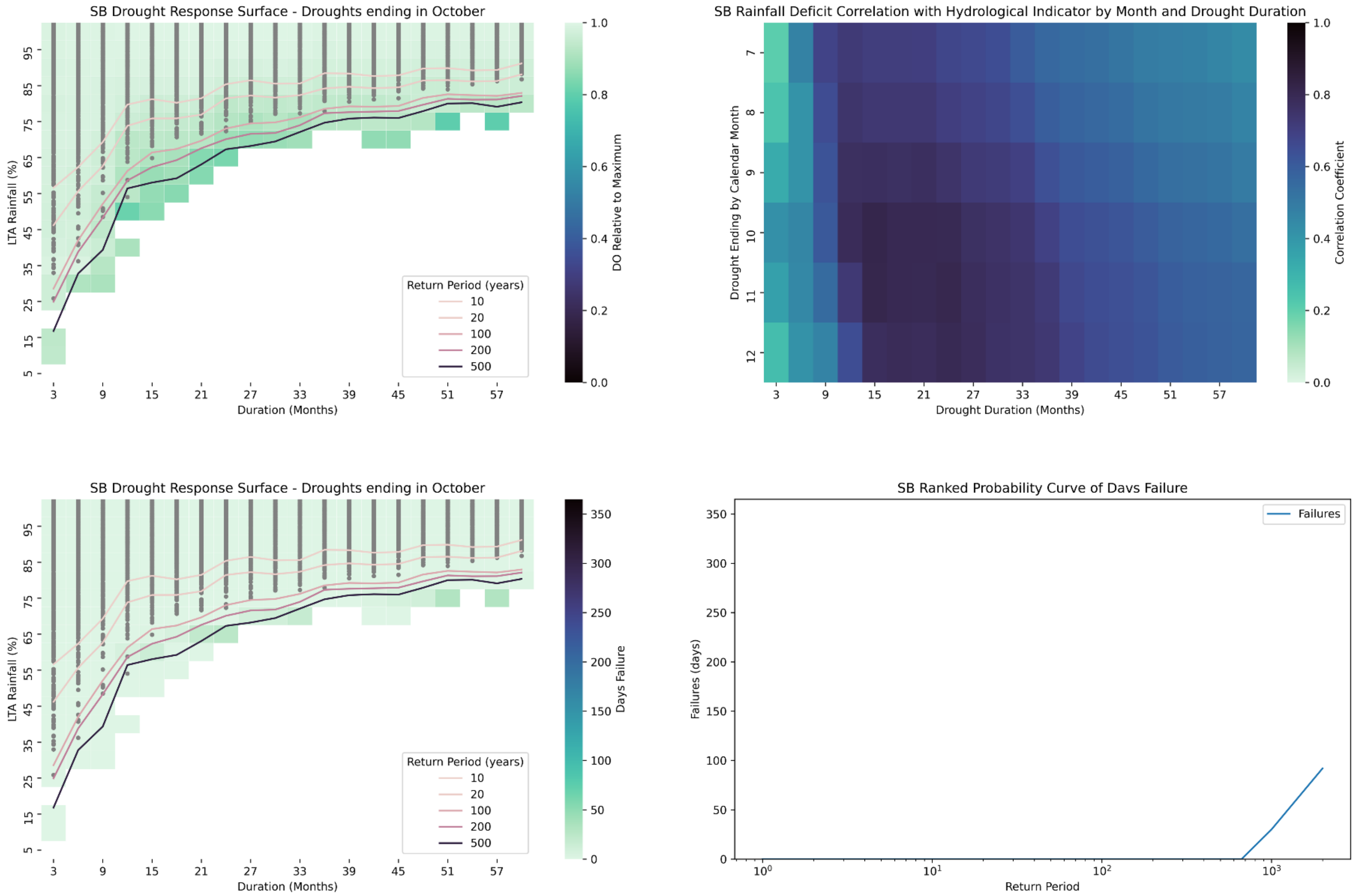


Figure 9: DRS plots for SBZ WRZ.

2.3.7 Drought vulnerability – KMW and SHZ

We have grouped our KMW and SHZ WRZs together for this assessment as they are coupled by the conjunctive use of the reservoirs associated with the RMS. A summary set of drought vulnerability plots are shown in Figure 10 and the full set is presented in Appendix A.

Failure 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 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 key resource in these WRZs is Bewl reservoir. This 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 than SHZ with failures in KMW being much less frequent and only for droughts greater than 1-in-200 years in severity (Figure 11). This possibly suggests that use of Powdermill emergency storage may not be appropriate.

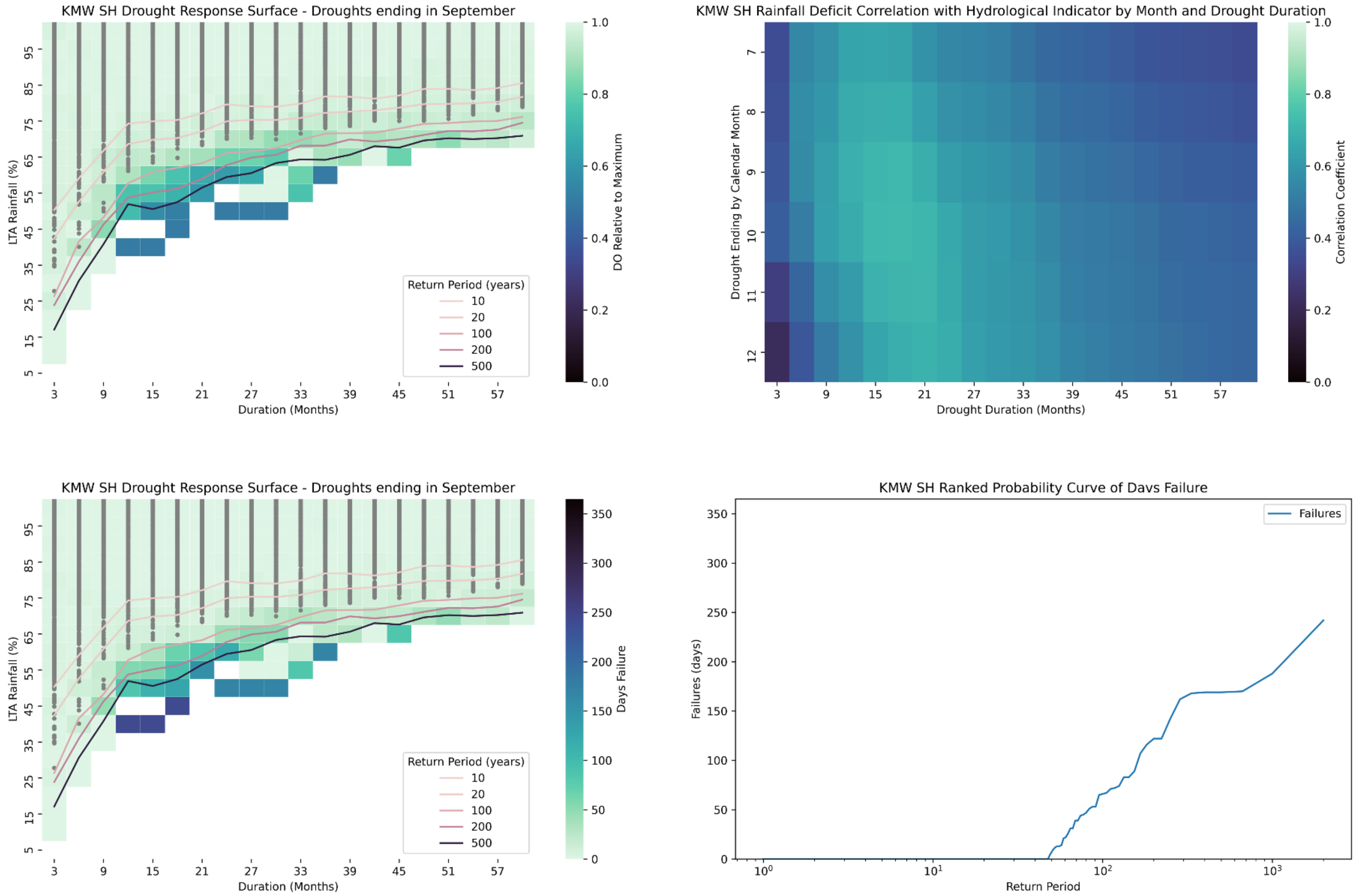


Figure 10: DRS plots for KMW and SHZ WRZs.

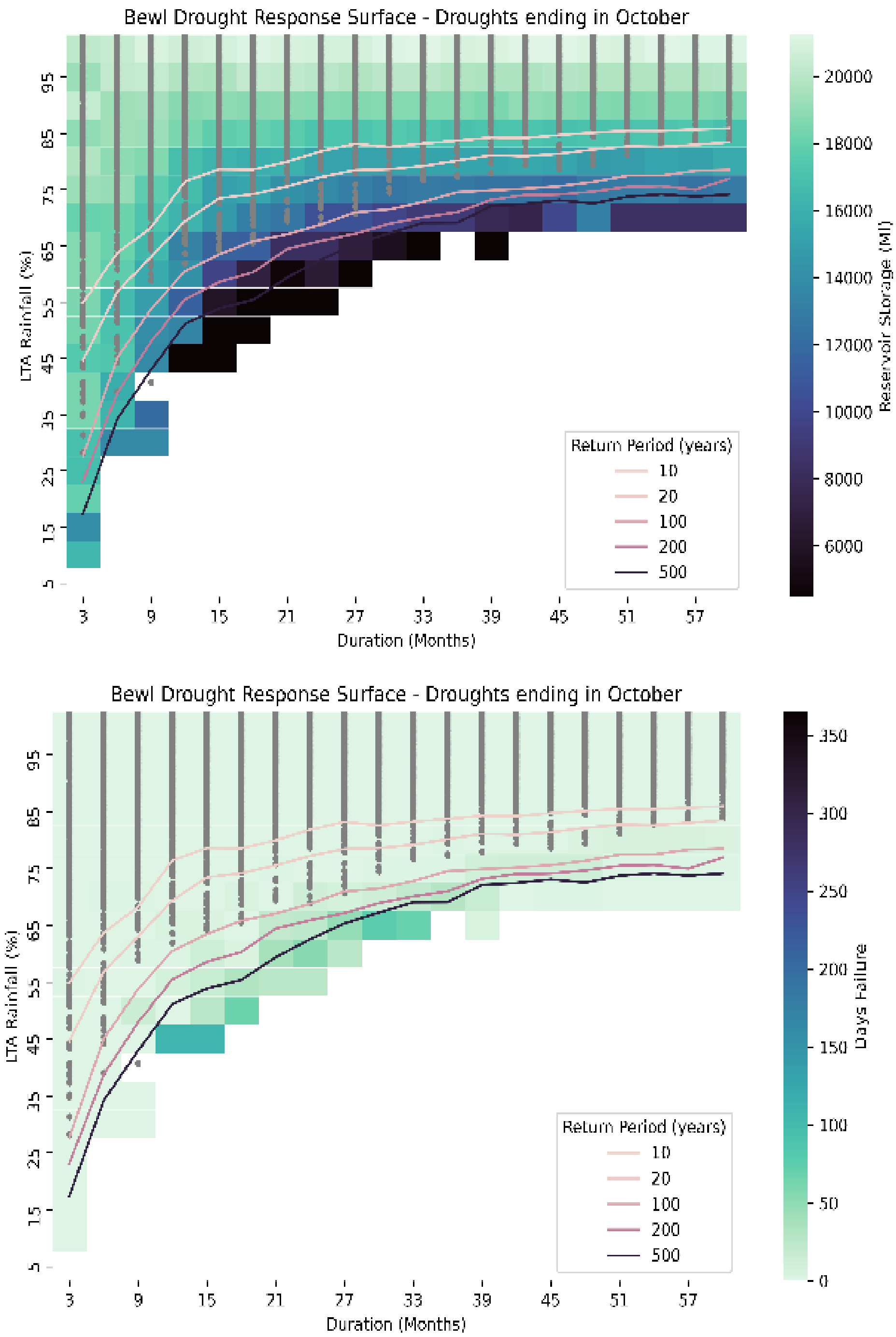


Figure 11: DRS plots for reservoir storage and failures associated with Bewl reservoir – KMW WRZ.

2.3.8 Drought vulnerability – KME

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. The majority of DO in the WRZ is supplied by licence or infrastructure constrained groundwater abstractions and their 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 a groundwater level DRS (Figure 12) which indicates that the lower groundwater levels are associated with severe to extreme (> 1-in-200 years return period) long duration droughts greater than 21 months in duration ending in the late 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 chalk aquifers in Sussex and the IOW.

A suite of summary plots is provided in Figure 13 and the full set in Appendix A.

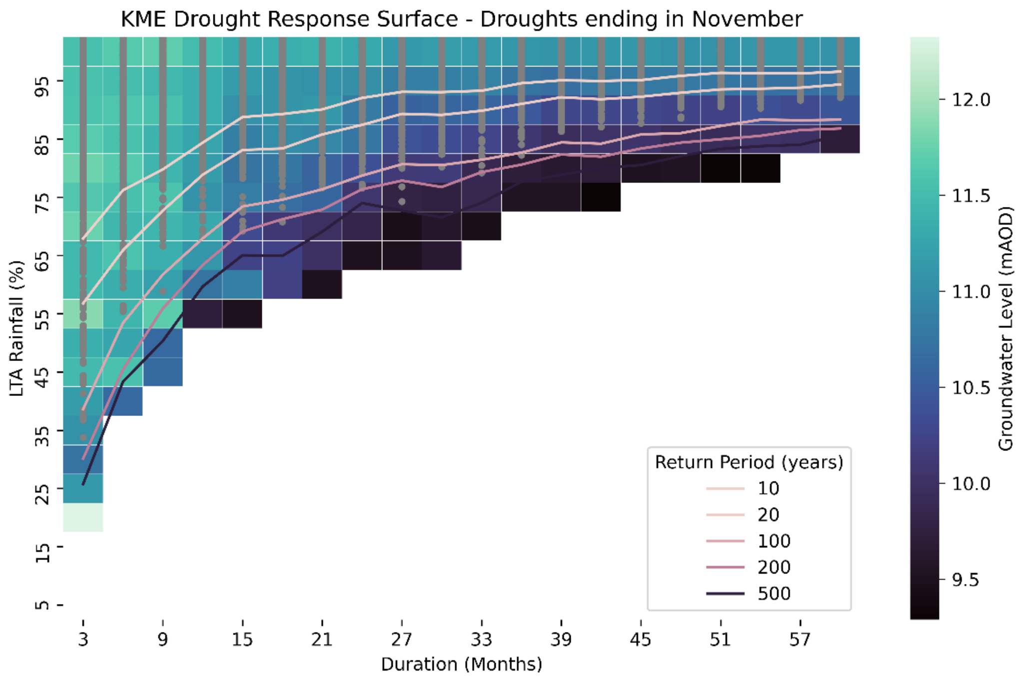


Figure 12: DRS for groundwater level decline in indicator borehole – KME WRZ.

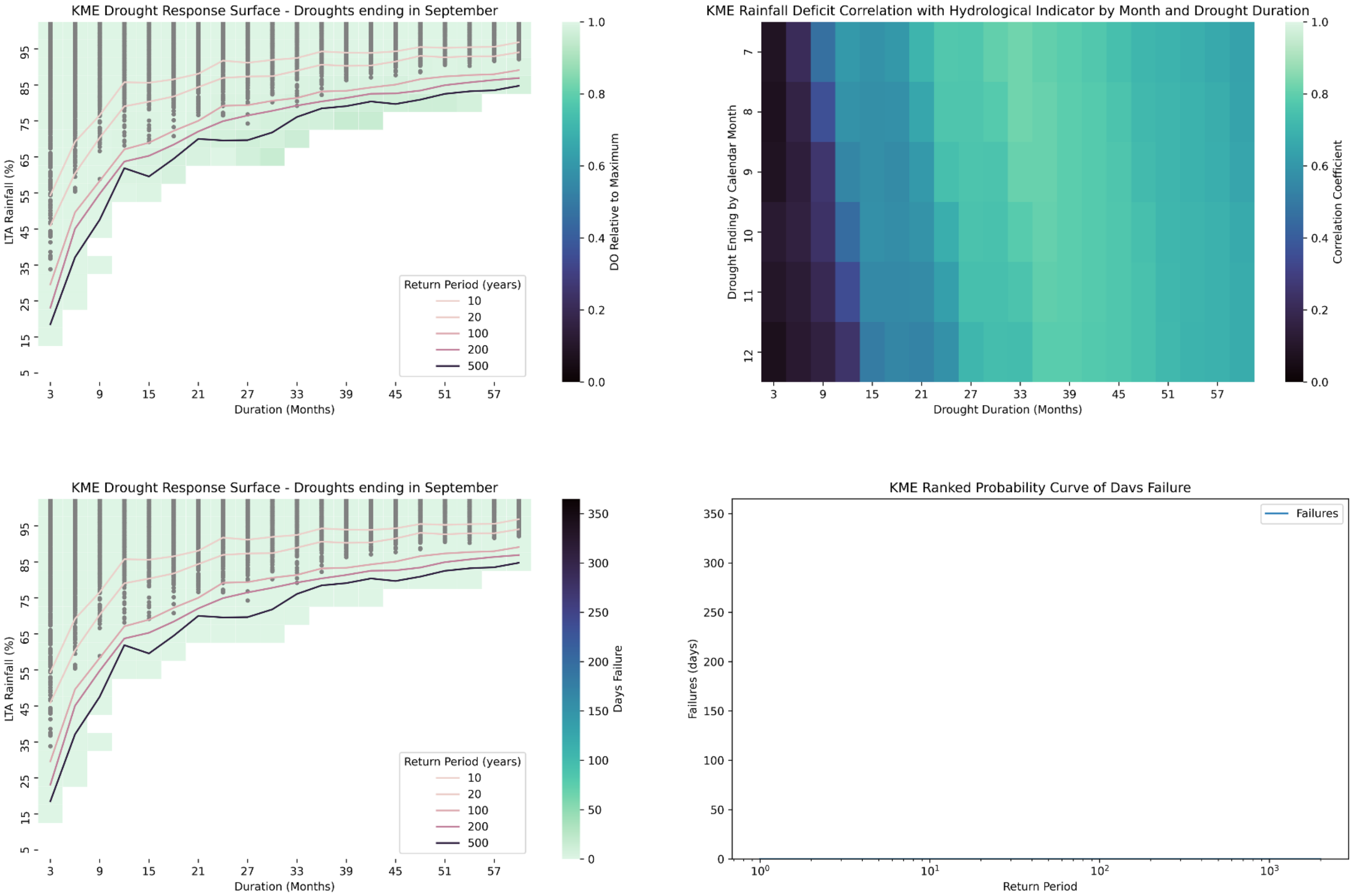


Figure 13: DRS plots for KME WRZ.

2.3.9 Drought vulnerability – KTZ

Summary DRS plots for our KTZ are shown in Figure 14 and the full set of plots is presented in Appendix A.

This WRZ shows many similarities with the neighbouring KME WRZ as both are supplied by 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 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 and slower response of this aquifer to rainfall and recharge. The recharge season also often starts latest 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, the KTZ WRZ exhibits no failures in this assessment owing to an intra-zonal transfer between the two. This helps to 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 15) illustrates the water quality challenges and significantly increases the rate of failure and illustrates the principal threat to this WRZs resilience. This is presently being addressed through a major network and treatment upgrade and catchment management.

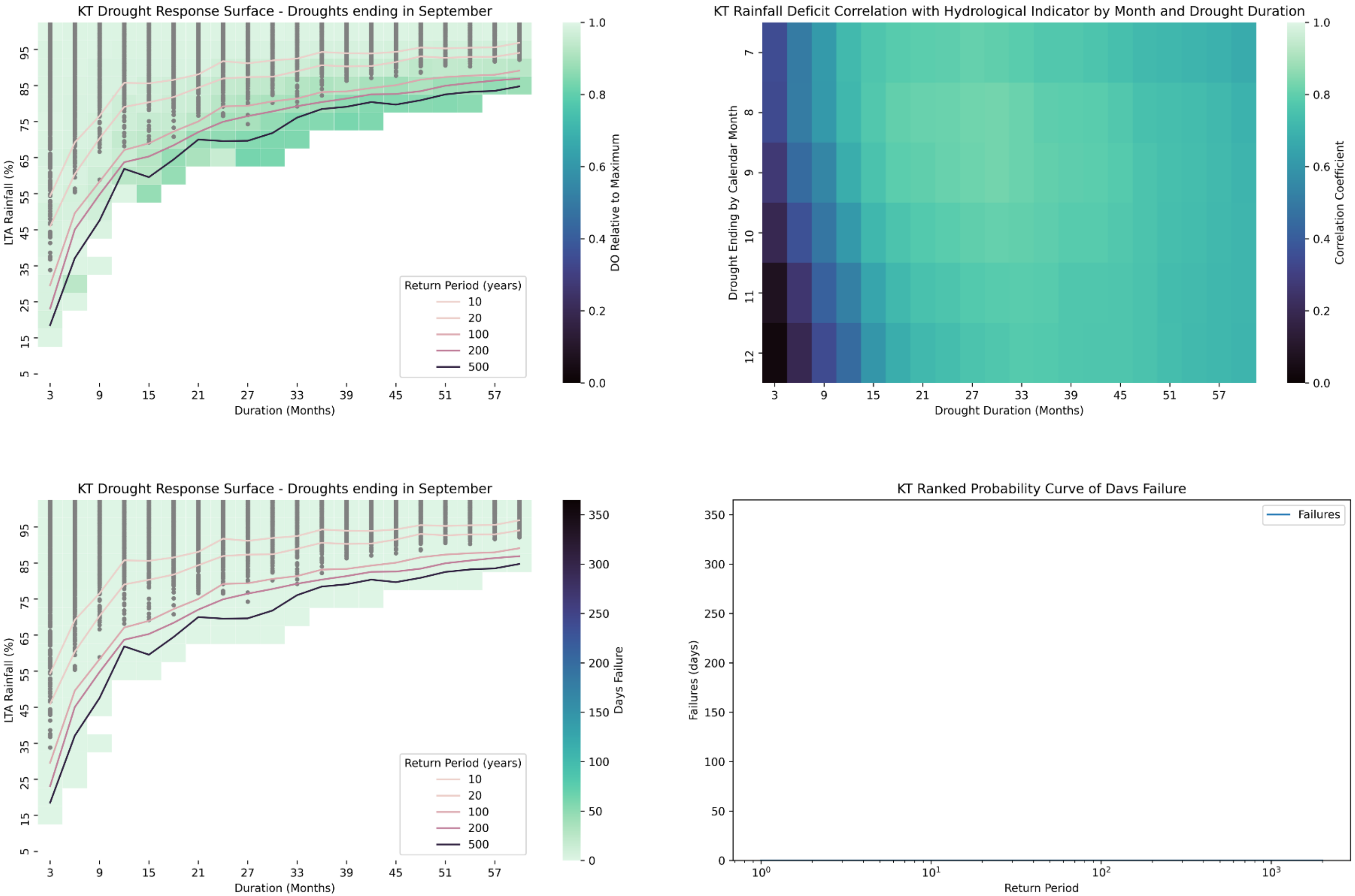


Figure 14: DRS plots for KTZ WRZ.

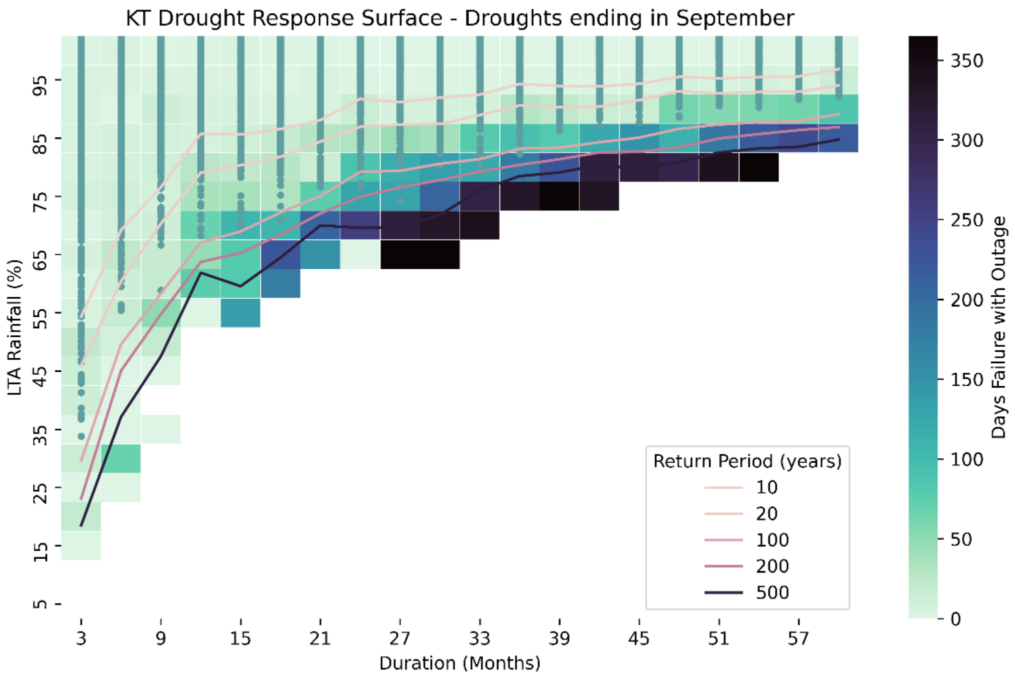


Figure 15: DRS plots for KTZ WRZ including outage.

2.4 Drought vulnerability assessment – key findings

Key findings from vulnerability assessment for each of our sensitive WRZs are as follows.

- 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 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 WRZs (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.
- Our 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.

3. Overview of our drought triggers

Having characterised the drought vulnerability of our supply system, this section sets out the data and trigger levels that we will use to monitor the onset and severity of drought.

The range of trigger levels we employ reflects the diversity and vulnerability of our WRZs and we will base our decision making on a range of factors that will take account of the rainfall deficits, time of year and the status of our water resources (reservoir levels, river flows and groundwater levels). This decision-making is embodied in our multifactorial trigger approach, which will consider the status of several critical triggers in determining our drought response on a WRZ by WRZ basis.

We employ a suite of drought triggers that cover a range of hydrological characteristics and responses relevant to our water supplies:

- Rainfall
- PET
- Groundwater levels
- River flows
- Reservoir storage
- Multifactorial triggers

Drought is characterised by an absence or reduction in rainfall and therefore monitoring of rainfall is critical to establish the onset of drought. Our drought vulnerability assessment has indicated that rainfall deficits of about 12-18 months duration are indicative of critical drought durations that have the greatest impact on supplies. Only a few WRZs, notably HSW and the IOW, show significant drought sensitivity to short duration droughts. We have chosen to monitor rainfall deficits through Standard Precipitation Indices (SPI), which allow easy site-to-site comparison across our supply area.

However, rainfall data alone only provide limited use in understanding the hydrological impact of drought (e.g. on groundwater levels and river flows). The timing of rainfall deficit has a significant effect on drought. To better understand and monitor the hydrological impacts of rainfall deficits, we incorporate PET data to allow us to monitor the amounts and deficits of effective rainfall. These data are captured through a Standard Precipitation and Evapotranspiration Index (SPEI), an extension of the SPI calculation.

Over 70% of our resources are groundwater abstractions from the Chalk and Lower Greensand aquifers and these comprise a large number of drought sensitive sources where yields reduce under conditions of low groundwater levels, as evidenced by our drought vulnerability assessment (e.g. for SBZ and SWZ). Through our operational practice and numerous modelling studies, we have developed a good understanding of the characteristics of each aquifer block and have selected indicator boreholes that provide a reasonable representative indication of the groundwater status of each aquifer block. These boreholes have long observation records, are regularly monitored, and often are reported upon in the EA water situation reporting.

Similar to groundwater levels where we have surface water supplies, we have set triggers on river flow levels to inform the need to take drought actions to maintain supplies, protect the environment and to meet our HoF or MRF licence conditions. In some cases, our river flow triggers are directly linked to our drought actions, for example under the Section 20 Agreement with the EA for the River Test and River Itchen Catchment Drought Permits and Orders.

Similarly, we have set triggers and actions linked to the storage volumes in our reservoirs. These are critical to the supplies in some of our WRZs, particularly in our Eastern area and are based on behavioural modelling of reservoir performance during severe and extreme droughts.

Overlying these individual suites of drought trigger levels, we have set out a series of multifactorial trigger levels that identify the key trigger sequences that reflect the underlying supplies of our supply areas and WRZs.

As set out in the drought plan main report, having validated and gained confidence in the skill of our predictive models we have made a refinement to our approach. We recognise that the triggers themselves are conservative and would lead to more applications than are required. We have learned from dry conditions since 2019 in particular from the River Test drought permit applications in 2019 and 2022. So, we would now only apply for a drought permit or drought order if both the triggers have been reached and our flow forecasting shows that crossing of the hands off flow is likely.

3.1 Environmental stress triggers

The Drought Plan Guidance[17] allows for the development of environmental triggers that would indicate when the environment might become stressed during drought due to a reduction of flows or groundwater levels, but which may not necessarily impact upon water supplies.

Many of our large abstractions have been subject to sustainability investigations under Water Industry National Environment Programme (WINEP), which aims to improve the status of abstraction-impacted water bodies in line with the objectives of the Water Framework Directive (WFD). Many of these sites have since been subject to abstraction licence changes as part of mitigations to improve water body status and prevent deterioration. These have taken the form of annual, monthly or daily quantity reductions and the imposition of HoF or MRF conditions.

In some cases, it is the loss of DO from environmentally driven licence changes that have required us to use drought permit/order options to be able to maintain public water supply in a drought. Such actions may lead to environmental damage, but the drought permit/order process seeks to limit such damage by only enacting these measures when necessary to maintain water supplies and through monitoring and mitigation of the impacts. Environmental stresses will be, to some extent, mitigated within the abstraction licence conditions and our preparations for drought permits/orders.

Development of environmental stress triggers may be more practical, and provide more benefits, for sites where the environmental impacts of our abstractions are less well understood. This is most likely to be the case for our groundwater sources which have not yet been subject to Restoring Sustainable Abstraction (RSA) studies, or which are due to be studied under our ‘No Deterioration’ WINEP objectives. Limited hydroecological data presently exist for such sites and is unlikely to be comprehensive for low-flow periods given that recent years have been relatively wet.

[17] Environment Agency, 2020. Water Company Drought Plan guideline, December 2020 (Version 1.2).

In the absence of regular or live hydroecological monitoring, flow and/or water quality data are likely to provide the best indication of potential for environmental stress. The flow standards for the Environmental Flow Indicator (EFI) thresholds or use of the Common Standards Monitoring Guidance (CSMG) thresholds could be applied as an indicator for establishing environmental stress.

In Table 7 we have proposed a set of provisional environmental stress triggers for several key surface water bodies in our supply area. The triggers are based on the low flow Q_{95} (95th percentile) EFI which provides a good indication or water body stress during drought conditions. subject to environmental investigations. The triggers are based on the low flow Q_{95} (95th percentile) EFI which provides a good indication or water body stress during drought conditions.

We have used our understanding of the specific abstraction reductions likely to be required at the relevant individual sources to meet EFI targets to set target abstraction rates based on the work we have conducted for Sustainability Reductions in WRMP19 and for our draft WRMP24 Environmental Destination.

However, our long term WRMP planning has shown that to achieve these abstraction reduction targets before 2027 would create supply - demand deficits until some of our long term strategic water supply options are available. As these abstractions are currently operating within their abstraction licences any reductions to alleviate environmental stress would have to be made on a best endeavours basis, reflecting the drought severity and supply risk at that time

These trigger locations have been selected as telemetered flow data is available at nearby gauging stations that allows near real-time monitoring of flow conditions compared to the EFI and so could act as a live indicator of environmental stress. Potential mitigations actions are indicated in Table 7; however, there are a number of limitations to this approach that must be recognised.

There are a limited number of actions that we can currently take if the EFI triggers are crossed. The most obvious is to increase water efficiency messaging and to reduce abstraction from affecting sources (e.g. those closest to surface water bodies or groundwater dependent terrestrial ecosystems) and relocate it elsewhere (e.g. from headwater catchments to downstream sources). However, this may not always be practical, particularly in a developing drought and will depend on the nature of the sources (capacity, licence, network arrangement and drought sensitivity) and levels and distribution of demand. Relocation of abstraction also risks just relocating the environmental stress elsewhere.

For sites not yet subject to environmental licence changes, or which are subject to ongoing WINEP studies, flow conditions and abstraction impacts may be such that EFI targets are not met, even under normal conditions, hence the environment may be in a degree of constant stress. This may only be fully understood and appropriate mitigation possible once these studies conclude.

There may be some physical enhancement or management actions we could take (e.g. sluice control) if such environmental stress triggers are crossed, but this would rely on having a good understanding of the hydroecological function of an affected water body to ensure that such actions are appropriate and would not cause damage themselves.

Our current WINEP studies cover a number of our groundwater abstractions. The investigations will require a significant amount of monitoring, modelling and will improve our understanding of abstraction impacts on surface water bodies and groundwater dependent terrestrial ecosystems. This is likely to lead to future licence changes and mitigations which will provide enhanced protection against deterioration of water body status but will also provide us with the data and understanding that we could use to develop more refined environmental stress triggers, and where needed, additional drought actions to provide increased environmental protection.

Table 7: Proposed environmental stress triggers based on Q_{95} EFI.

River name	Q_{95} EFI (Ml/d)	Associated gauging station	Associated source(s)	Best Endeavors Abstraction Target rate	WRZ	Action
Anton	76.42	Fullerton	Andover	5Ml/d	HAZ	Increase water efficiency communications, reduce abstraction at Andover as much as possible to target rate, increase abstraction at near Whitchurch to compensate
Test, conf Dever to conf Anton	223.27	Chilbolton	Whitchurch, Overton	1.55Ml/d 1.6Ml/d	HAZ	Increase water efficiency communications, no other action presently possible, no relcoation option
Test, conf Dun to Tadburn Lake	339.26	Timsbury	Romsey	5.4Ml/d	HRZ	Increase water efficiency communications No other action presently possible, no relcoation option
Test total flow	450.74	Testwood, Conager Bridge, Ower, M27TV1	Test Surface Water	55Ml/d	HSE	Flow already below River Itchen flow triggers, drought actions including monitoring and mitigation set out under our Section 20 Agreement
Candover Brook	17.69	Borough Bridge, Candover Stream	Alresford	0Ml/d	HWZ	Increase water efficiency communications, reduce abstraction at Alresford (relocate to Winchester) but only shifts impacts downstream
Itchen at Easton	195.28	Easton	Winchester	13.3Ml/d	HWZ	Increase water efficiency communications, reduce abstraction at Winchester (relocate to Itchen Surface Water or the Section 20 Agreement measures), shifts impacts downstream
Itchen at Allbrook and Highbridge	283.02	Allbrook and Highbridge	Itchen Surface Water, Itchen Groundwater, Twyford	30Ml/d	HSE	Flow already below River Itchen flow triggers, drought actions including monitoring and mitigation set out under our Section 20 Agreement
Lukely Brook	24.67	Carisbrooke	Newport, Lukely Brook	3.42Ml/d 0.79Ml/d	IOW	Increase water efficiency communications, reduce abstraction at Lukely Brook and, if possible, Newport
Chillerton	12.93	River Medina at Chillerton	Rookley	0.7Ml/d	IOW	Increase water efficiency communications, relocate abstraction to Newport or Sandown (if possible)
Caul Bourne	2.82	Caul Bourne	Caul Bourne	0.8Ml/d	IOW	Increase water efficiency communications, abstraction already limited to protect HoF, no other actions possible
Eastern Yar	13.34	Burnt House	Sandown	8Ml/d	IOW	Increase water efficiency communications, Use Flow Augmentation Scheme, relocate abstraction to Newport if possible, use Cross-Solent main
Upper Rother at Durford	19.86	River Rother at Iping Mill	Rogate	0Ml/d	SNZ	Increase water efficiency communications, associated source is out of service until 2024, no other actions possible
River Lod	4.29	River Lod at Halfway Bridge	Petworth South	1.33Ml/d	SNZ	Increase water efficiency communications, relocate abstraction downstream (to Pulborough)
Western Rother	121.85	Pulborough	Pulborough Surface	40Ml/d	SNZ	Increase water efficiency communications, no other action presently possible, no relocation option
Nailbourne and Little Stour	40.19	Little Stour at Littlebourne	Near Canterbury	5Ml/d	KTZ	Increase water efficiency communications, relocate abstraction from Canterbury to other sources where possible (but may not be due to wider goundwater abstraction impacts)

3.2 Rainfall

As illustrated by our drought vulnerability assessment, rainfall deficit is fundamental to the definition of a drought, which is characterised as a period with lower-than-average precipitation. Prolonged periods of low rainfall can also drive other drought characteristics such as low groundwater levels and low river flows.

Our rainfall triggers are based on SPI. The SPI[18] is an internationally recognised approach to categorising rainfall deficit, which is essentially a comparison of rainfall deviation from average values, normalised according to the natural variability (expressed as a standard deviation) of rainfall at a given site. SPI gives a good indication of the status of rainfall variation from the norm over a given period (e.g. 6, 12, 24 months) and can be assessed probabilistically.

The ability to calculate SPI metrics of different length readily allows comparison with hydrological variables such as flow which respond over similar timescales and which can be identified from our drought vulnerability assessment.

Our rainfall drought triggers are based on the Met Office 'Had UK' monthly rainfall data which provided to us under licence by the EA and which are copyright of the EA and the Met Office[19].

We have developed the following rainfall triggers.

- A Level 1 trigger based on a 20% annual probability (1-in-5 years). This trigger is useful for establishing the start of a drought and is more critically applied in our HSW and HSE WRZs where river flows and recession towards HoF conditions that restrict DO is sensitive to very mild rainfall deficits.
- A Level 2 trigger based on a 10% annual probability (1-in-10 years) consistent with our target LoS for TUBs.
- A Level 3 trigger based on a 5% annual probability (1-in-20 years) consistent with our target LoS for NEUBs and drought permit application (outside of Hampshire).

SPI based trigger thresholds are calculated for accumulation periods covering 3, 6, 12, 18, 24, 30, 36, 42 and 48 months durations for fourteen EA hydrological catchments which are relevant to our WRZs (Table 8).

To derive our rainfall triggers SPI values were calculated for the monthly rainfall time series across a range of accumulations. Trigger levels for SPI were then calculated by applying percentiles of the required probability (0.1 = 1-in-10 years and 0.05 = 1-in-20 years) to the annual minimum SPI values.

The derived trigger levels were then cross-checked against historical rainfall time series to ensure that the frequency at which the trigger curves are crossed is approximately correct based on the historical rainfall record.

[18] McKee, T.B., Doesken, N.J., Kleist, J., 1993. The Relationship of Drought Frequency and Duration to Time Scales, Eight Conference on Applied Climatology, 17-22 January 1993, Anaheim, California.
[19] Dataset name, Monthly Rainfall data for Hydrological Areas used within Water Situation Reports from the Environment Agency Daily Rainfall Tool (DRT)– 3rd Party IP: NRW, SEPA and Met Office.

Table 8: Relation of EA hydrological catchments used for rainfall monitoring to our WRZs.

EA hydrological catchment	Relevant WRZs
River Test (TPD_SE_H23)	HSW, HAZ, HKZ, HRZ
East Hampshire Chalk (TPD_SE_H24)	HSE, HWZ
IOW (TPD_SE_H27)	IOW
Western Rother Greensand (TPD_SE_H33)	SNZ
West Sussex Chalk (TPD_SE_H25)	SWZ
River Adur (TPD_SE_H38)	SNZ
East Sussex Chalk (TPD_SE_H26)	SBZ
River Medway (TPD_SE_H42)	KMW, KME
Eastern Rother (TPD_SE_H43)	SHZ
North West Grain (TPD_SE_H45)	KME, KMW
North Kent Chalk (TPD_SE_H29)	KME, KMW
Stour (TPD_SE_H30)	KTZ
Dover Chalk (TPD_SE_H31)	KTZ
Thanet Chalk (TPD_SE_H32)	KTZ

The duration of the SPI indicator has been analysed and tailored to reflect the vulnerability of resources that are present within each area or WRZ. We may consider the use of alternative duration SPI metrics as necessary to support our Exceptional Shortage of Rain (ESoR) case for any drought permit/order applications. This follows our lessons learned review following the mock River Test Drought Permit in autumn 2018.

The calculated SPI thresholds for each catchment are shown in Table 9 and Table 10. The SPI thresholds can be related to the drought responses and most critical drought periods identified from the drought vulnerability assessment.

Table 9: Summary of SPI trigger thresholds for rainfall (3 - 24 months accumulations).

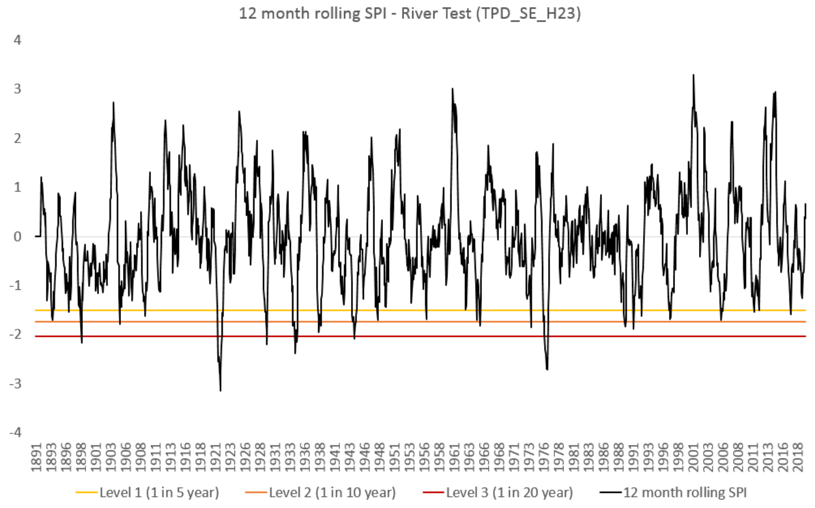
SPI accumulation period (months)	Exceedance*	River Test (TPD_SE_H23)	EHamp Chalk (TPD_SE_H24)	SW IOW (TPD_SE_H27)	WRother Greensand (TPD_SE_H33)	WSussex Chalk (TPD_SE_H25)	River Adur (TPD_SE_H38)	ESussex Chalk (TPD_SE_H26)	River Medway (TPD_SE_H42)	Eastern Rother (TPD_SE_H43)	North West Grain (TPD_SE_H45)	North Kent Chalk (TPD_SE_H29)	Stour (TPD_SE_H30)	Dover Chalk (TPD_SE_H31)	Thanet Chalk (TPD_SE_H32)
3	Level 1	-1.78	-1.82	-1.89	-1.88	-1.95	-1.95	-1.95	-1.97	-2.03	-1.97	-1.94	-1.94	-1.99	-1.84
	Level 2	-1.96	-1.95	-2.01	-2.01	-2.05	-2.01	-2.01	-2.00	-2.08	-2.00	-2.01	-2.02	-2.03	-1.89
	Level 3	-2.04	-2.02	-2.06	-2.03	-2.06	-2.03	-2.02	-2.02	-2.13	-2.06	-2.02	-2.03	-2.07	-1.94
6	Level 1	-1.76	-1.73	-1.72	-1.68	-1.66	-1.65	-1.64	-1.64	-1.65	-1.66	-1.69	-1.65	-1.64	-1.51
	Level 2	-1.96	-1.96	-1.88	-1.91	-1.91	-1.89	-1.81	-2.03	-1.86	-1.95	-1.98	-1.85	-1.87	-1.74
	Level 3	-2.22	-2.19	-2.14	-2.11	-2.06	-2.04	-1.98	-2.20	-2.08	-2.18	-2.14	-2.03	-2.03	-1.94
12	Level 1	-1.50	-1.40	-1.45	-1.34	-1.36	-1.40	-1.41	-1.46	-1.41	-1.42	-1.46	-1.32	-1.39	-1.35
	Level 2	-1.73	-1.70	-1.72	-1.57	-1.63	-1.76	-1.71	-1.73	-1.83	-1.78	-1.79	-1.81	-1.75	-1.67
	Level 3	-2.04	-2.02	-2.02	-2.02	-2.07	-1.96	-1.97	-2.00	-1.97	-1.98	-1.94	-1.95	-1.97	-1.80
18	Level 1	-1.40	-1.40	-1.35	-1.34	-1.43	-1.39	-1.40	-1.44	-1.41	-1.35	-1.42	-1.34	-1.30	-1.24
	Level 2	-1.73	-1.78	-1.67	-1.68	-1.67	-1.75	-1.78	-1.75	-1.82	-1.83	-1.83	-1.75	-1.76	-1.65
	Level 3	-1.97	-1.96	-2.06	-2.03	-2.05	-2.03	-2.01	-1.99	-2.04	-2.00	-1.99	-2.02	-2.01	-1.85
24	Level 1	-1.38	-1.39	-1.34	-1.30	-1.35	-1.40	-1.28	-1.33	-1.35	-1.34	-1.28	-1.28	-1.33	-1.19
	Level 2	-1.66	-1.71	-1.73	-1.66	-1.76	-1.69	-1.67	-1.73	-1.71	-1.68	-1.69	-1.57	-1.71	-1.63
	Level 3	-1.89	-1.77	-1.92	-1.96	-1.96	-2.01	-2.14	-2.00	-2.13	-2.06	-2.02	-2.18	-1.99	-2.03

* Level = 1-in-5 years; Level 2 = 1-in-10 years; Level 3 = 1-in-20 years

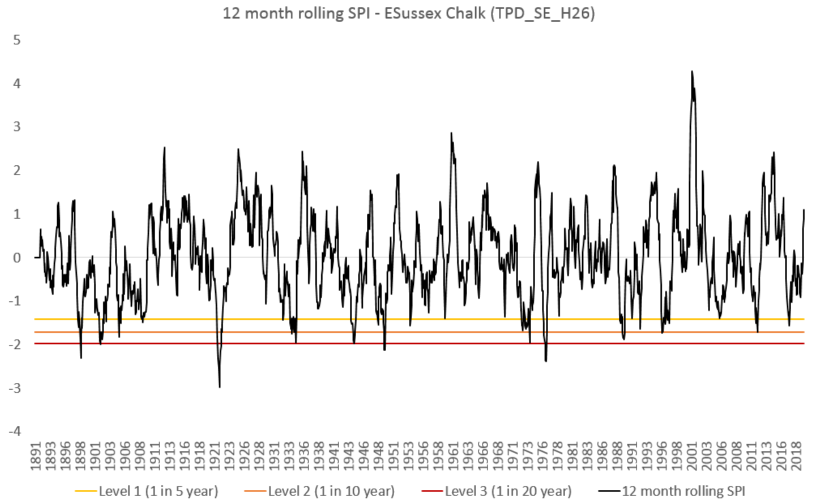
Table 10: Summary of SPI trigger thresholds for rainfall (30 - 48 months accumulations).

SPI accumulation period (months)	Exceedance*	River Test (TPD_SE_H23)	EHamp Chalk (TPD_SE_H24)	SW IOW (TPD_SE_H27)	WRother Greensand (TPD_SE_H33)	WSussex Chalk (TPD_SE_H25)	River Adur (TPD_SE_H38)	ESussex Chalk (TPD_SE_H26)	River Medway (TPD_SE_H42)	Eastern Rother (TPD_SE_H43)	North West Grain (TPD_SE_H45)	North Kent Chalk (TPD_SE_H29)	Stour (TPD_SE_H30)	Dover Chalk (TPD_SE_H31)	Thanet Chalk (TPD_SE_H32)
30	Level 1	-1.37	-1.36	-1.30	-1.28	-1.38	-1.43	-1.39	-1.44	-1.35	-1.25	-1.31	-1.26	-1.16	-1.23
	Level 2	-1.63	-1.73	-1.78	-1.70	-1.80	-1.78	-1.80	-1.76	-1.82	-1.79	-1.80	-1.69	-1.85	-1.58
	Level 3	-1.79	-1.85	-1.90	-1.89	-2.03	-1.96	-2.02	-2.02	-2.15	-1.96	-2.01	-2.02	-2.09	-1.89
36	Level 1	-1.33	-1.38	-1.27	-1.31	-1.38	-1.40	-1.35	-1.32	-1.32	-1.33	-1.38	-1.23	-1.25	-1.08
	Level 2	-1.56	-1.68	-1.70	-1.62	-1.71	-1.70	-1.65	-1.76	-1.67	-1.68	-1.70	-1.75	-1.74	-1.51
	Level 3	-1.71	-1.78	-1.86	-1.80	-1.89	-1.86	-1.89	-1.90	-2.06	-1.97	-1.94	-1.89	-2.07	-1.86
42	Level 1	-1.41	-1.39	-1.30	-1.37	-1.38	-1.20	-1.32	-1.30	-1.21	-1.33	-1.32	-1.23	-1.21	-1.02
	Level 2	-1.59	-1.72	-1.59	-1.61	-1.68	-1.65	-1.65	-1.68	-1.68	-1.70	-1.70	-1.73	-1.78	-1.47
	Level 3	-1.76	-1.83	-1.84	-1.84	-1.82	-1.90	-1.75	-1.87	-1.91	-1.97	-1.85	-1.84	-1.88	-1.72
48	Level 1	-1.29	-1.38	-1.22	-1.23	-1.27	-1.29	-1.23	-1.22	-1.17	-1.24	-1.23	-1.21	-1.25	-0.98
	Level 2	-1.58	-1.64	-1.55	-1.58	-1.63	-1.51	-1.59	-1.62	-1.61	-1.66	-1.61	-1.52	-1.73	-1.38
	Level 3	-1.73	-1.80	-1.68	-1.78	-1.78	-1.79	-1.77	-1.87	-1.90	-1.86	-1.79	-1.84	-1.85	-1.54

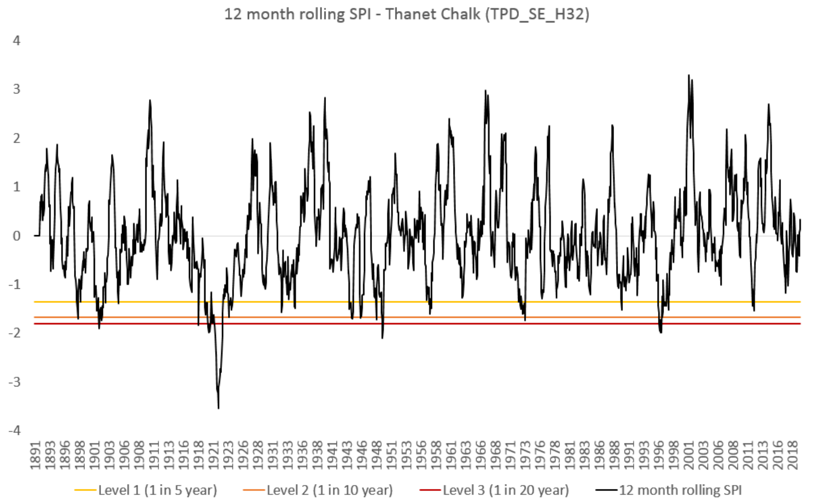
* Level = 1-in-5 years; Level 2 = 1-in-10 years; Level 3 = 1-in-20 years



	Number of annual crossings	Annual crossings frequency
Level 1	26	0.20
Level 2	13	0.10
Level 3	7	0.05



	Number of annual crossings	Annual crossings frequency
Level 1	25	0.20
Level 2	13	0.10
Level 3	7	0.05



	Number of annual crossings	Annual crossings frequency
Level 1	26	0.20
Level 2	13	0.10
Level 3	7	0.05

Figure 16: Example application of our SPI rainfall triggers to historical rainfall time series.

3.3 Standard precipitation and evapotranspiration indices

The SPI is a good measure for meteorological drought, i.e. a metric of the absence of rain. However, it provides only limited information about the how that rainfall deficit may manifest as a hydrological drought characterised by low flows or low groundwater levels.

The timing of rainfall deficits is exceptionally import to how water resources respond. For example, two 12-month drought events may have the same total rainfall and hence 12-month SPI, but in one event the rainfall deficits all accumulated over winter months and in the second the deficits all occurred over the summer months. For most of our water resource systems, the drought event with the greater winter rainfall deficits would have a much greater impact on our water resources at the end of the drought. Summer rainfall provides much less benefit than winter rainfall because higher temperatures, longer daylight hours and increased plant uptake all lead to higher evapotranspiration and reduces the amount of water available to runoff or recharge to groundwater. As illustrated by our drought vulnerability assessment, we are much more vulnerable to autumn, winter and spring drought events. In many of our groundwater dominated WRZs, summer rainfall deficits would not cause a noticeable impact on groundwater levels because we would not normally expect meaningful amounts of groundwater recharge to occur in those months.

The SPEI[20] is based on the same principals as the SPI but attempts to capture this seasonality by accounting for PET and hence provides a better metric of hydrological drought.

We obtained monthly PET data from the EA based on their new dataset[21]. These PET data relate to the same hydrological catchments as the rainfall series used to calculate SPI and thus are directly comparable. We have then determined SPEI triggers following a similar calculation method and the same probability thresholds (1-in-5 years, 1-in-10 years and 1-in-20 years). The corresponding suite of SPEI thresholds are presented in Table 11 and Table 12.

The effect of adopting an SPEI based trigger (compared to SPI trigger) is illustrated by Figure 17, which compares SPI and SPEI responses for the River Test Chalk catchment. Some drought events, which would not by themselves exceed SPI trigger rainfall deficits, for example 2019, do breach trigger thresholds for SPEI thresholds, indicating that the timing of the rainfall deficit led to greater hydrological impact (i.e. reduced recharge). There are also some events, where the opposite is true, for example, in 1965 where rainfall deficits were significant enough to breach the 1-in-10 years trigger, the timing of the rainfall deficit was such that this event would only just have reached the 1-in-5 years level when considered for its SPEI effects.

As it is more closely related to the hydrological water resources response, the SPEI provides a better metric overall when considering the water resource impacts of drought. However, because of the effects discussed above, and in recognition that other water users may be more significantly affected by rainfall deficits alone, for example, the environment or agriculture it is useful to consider both as complementary drought metrics.

[20] Vicente-Serrano S.M., Santiago Beguería, Juan I. López-Moreno, 2010. A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index - SPEI. Journal of Climate 23: 1696-1718.
[21] Environment Agency, 2020. Potential Evapotranspiration datasets, v.1.0 available under the Open Government Licence.

Table 11: Summary of SPEI trigger thresholds (3 - 24 months accumulations).

SPI accumulation period (months)	Exceedance	River Test (TPD_SE_H23)	EHamp Chalk (TPD_SE_H24)	SW IOW (TPD_SE_H27)	WRother Greensand (TPD_SE_H33)	WSussex Chalk (TPD_SE_H25)	River Adur (TPD_SE_H38)	ESussex Chalk (TPD_SE_H26)	River Medway (TPD_SE_H42)	Eastern Rother (TPD_SE_H43)	North West Grain (TPD_SE_H45)	North Kent Chalk (TPD_SE_H29)	Stour (TPD_SE_H30)	Dover Chalk (TPD_SE_H31)	Thanet Chalk (TPD_SE_H32)
3	Level 1	-1.72	-1.74	-1.61	-1.71	-1.69	-1.77	-1.74	-1.64	-1.76	-1.74	-1.79	-1.77	-1.79	-1.85
	Level 2	-1.99	-2.09	-1.80	-2.09	-1.95	-2.01	-1.98	-1.95	-2.02	-2.06	-2.02	-2.02	-2.18	-2.14
	Level 3	-2.15	-2.25	-1.90	-2.30	-2.08	-2.21	-2.11	-2.22	-2.15	-2.15	-2.19	-2.16	-2.31	-2.25
6	Level 1	-1.60	-1.64	-1.49	-1.59	-1.69	-1.74	-1.62	-1.62	-1.64	-1.60	-1.62	-1.68	-1.74	-1.79
	Level 2	-1.89	-1.97	-1.90	-1.94	-1.91	-1.85	-1.97	-1.95	-1.89	-1.88	-1.91	-1.97	-2.08	-1.95
	Level 3	-2.10	-2.21	-2.04	-2.14	-1.99	-2.20	-2.15	-2.11	-2.12	-1.98	-2.18	-2.18	-2.28	-2.26
12	Level 1	-1.48	-1.52	-1.39	-1.43	-1.45	-1.53	-1.58	-1.57	-1.48	-1.53	-1.40	-1.57	-1.61	-1.48
	Level 2	-1.77	-1.72	-1.83	-1.85	-1.65	-1.79	-1.76	-1.78	-1.70	-1.75	-1.73	-1.75	-1.82	-1.78
	Level 3	-1.92	-2.11	-1.97	-1.99	-2.08	-1.87	-2.00	-1.81	-1.93	-1.89	-2.03	-2.07	-2.00	-2.14
18	Level 1	-1.50	-1.43	-1.36	-1.46	-1.34	-1.43	-1.51	-1.33	-1.39	-1.46	-1.46	-1.51	-1.52	-1.38
	Level 2	-1.65	-1.78	-1.56	-1.78	-1.72	-1.79	-1.82	-1.76	-1.83	-1.79	-1.73	-1.81	-1.66	-1.77
	Level 3	-1.78	-1.90	-1.99	-1.93	-1.92	-1.95	-1.93	-2.03	-2.08	-1.91	-2.02	-1.89	-1.87	-1.97
24	Level 1	-1.30	-1.52	-1.18	-1.44	-1.22	-1.47	-1.46	-1.48	-1.42	-1.47	-1.55	-1.47	-1.58	-1.44
	Level 2	-1.75	-1.81	-1.61	-1.75	-1.73	-1.70	-1.70	-1.76	-1.81	-1.74	-1.72	-1.73	-1.94	-1.85
	Level 3	-2.01	-1.98	-2.23	-1.85	-1.87	-1.92	-1.85	-1.87	-1.87	-1.87	-2.09	-1.96	-2.13	-2.11

* Level = 1-in-5 years; Level 2 = 1-in-10 years; Level 3 = 1-in-20 years

Table 12: Summary of SPEI trigger thresholds for rainfall (30 - 48 months accumulations).

SPI accumulation period (months)	Exceedance*	River Test (TPD_SE_H23)	EHamp Chalk (TPD_SE_H24)	SW IOW (TPD_SE_H27)	WRother Greensand (TPD_SE_H33)	WSussex Chalk (TPD_SE_H25)	River Adur (TPD_SE_H38)	ESussex Chalk (TPD_SE_H26)	River Medway (TPD_SE_H42)	Eastern Rother (TPD_SE_H43)	North West Grain (TPD_SE_H45)	North Kent Chalk (TPD_SE_H29)	Stour (TPD_SE_H30)	Dover Chalk (TPD_SE_H31)	Thanet Chalk (TPD_SE_H32)
30	Level 1	-1.16	-1.30	-1.21	-1.32	-1.33	-1.26	-1.38	-1.22	-1.33	-1.27	-1.41	-1.47	-1.53	-1.41
	Level 2	-1.73	-1.85	-1.56	-1.90	-1.60	-1.83	-1.80	-1.80	-1.78	-1.87	-1.66	-1.85	-1.78	-1.71
	Level 3	-2.06	-2.08	-2.11	-2.01	-1.86	-1.87	-1.90	-1.98	-2.15	-2.01	-2.02	-1.97	-1.84	-1.99
36	Level 1	-1.23	-1.42	-1.29	-1.41	-1.26	-1.42	-1.35	-1.42	-1.43	-1.45	-1.48	-1.38	-1.36	-1.51
	Level 2	-1.80	-1.78	-1.54	-1.79	-1.66	-1.73	-1.65	-1.78	-1.76	-1.72	-1.72	-1.73	-1.83	-1.72
	Level 3	-2.00	-1.90	-1.96	-1.86	-1.91	-1.91	-1.85	-1.93	-1.96	-1.90	-1.79	-1.95	-1.92	-1.83
42	Level 1	-1.17	-1.32	-1.20	-1.21	-1.17	-1.19	-1.27	-1.29	-1.42	-1.26	-1.43	-1.29	-1.35	-1.40
	Level 2	-1.64	-1.68	-1.52	-1.57	-1.58	-1.71	-1.67	-1.56	-1.58	-1.65	-1.63	-1.57	-1.69	-1.62
	Level 3	-1.90	-1.77	-1.96	-1.88	-1.87	-1.88	-1.81	-1.82	-1.83	-1.76	-1.71	-1.92	-1.88	-1.80
48	Level 1	-1.22	-1.29	-1.32	-1.25	-1.31	-1.27	-1.16	-1.34	-1.26	-1.31	-1.38	-1.16	-1.27	-1.27
	Level 2	-1.68	-1.69	-1.52	-1.59	-1.57	-1.56	-1.57	-1.65	-1.67	-1.53	-1.50	-1.59	-1.76	-1.68
	Level 3	-1.78	-1.88	-2.15	-1.68	-1.71	-1.86	-1.95	-1.92	-1.89	-1.83	-1.85	-1.90	-1.84	-1.87

* Level = 1-in-5 years; Level 2 = 1-in-10 years; Level 3 = 1-in-20 years

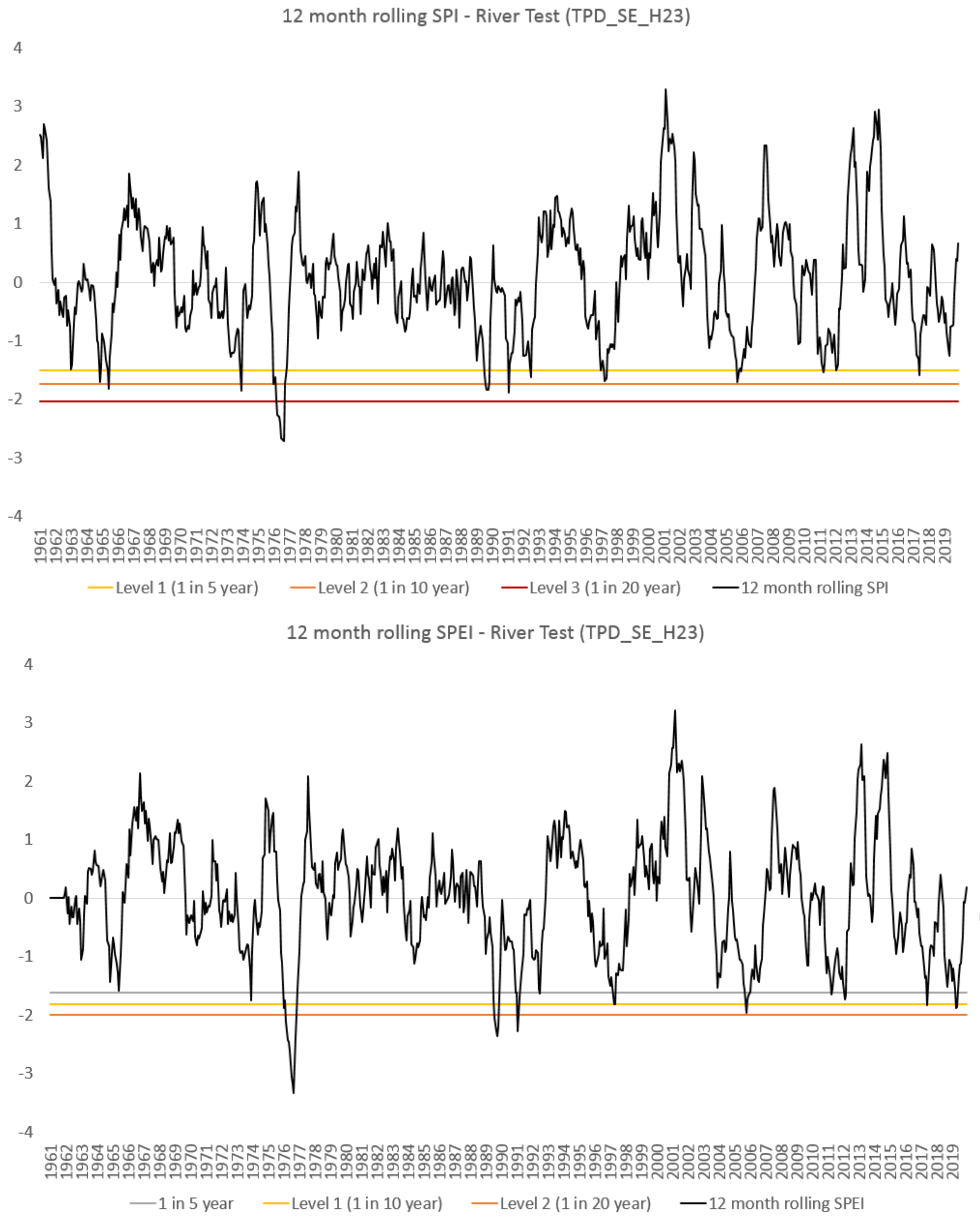


Figure 17: Comparison of historical SPI and SPEI metrics for the River Test Chalk catchment.

3.4 Groundwater levels

Drought trigger curves for groundwater levels have been developed from EA groundwater level data across a suite of key indicator observation boreholes. These boreholes have been selected based on location, aquifer type, monitoring record and currency of monitoring (Table 13).

Table 13: List of key indicator boreholes used for groundwater level and trigger level.

Observation borehole	Aquifer block	Relevant WRZs
Clanville Lodge	River Test Chalk	HKZ, HAZ, HRZ
West Meon	River Itchen Chalk	HSE, HWZ
Carisbrooke	IOW Central Downs Chalk	IOW
Chilgrove	East Hampshire and Chichester Chalk	SWZ
Whitelot Bottom	Brighton Chalk block	SWZ, SBZ
Houndean Bottom	Brighton Chalk block	SBZ
Riddles Lane	North Kent Chalk	KMW, KME
Little Bucket	East Kent Chalk	KTZ

3.4.1 Adoption of standardised groundwater indices

For our 2019 Drought Plan (DP19), groundwater drought triggers were based on month-by-month frequency analysis of groundwater levels with the Level 1 and Level 2 triggers assigned at groundwater elevations equivalent to a 1-in-10 years and 1-in-20 years return period respectively. For this plan, we are proposing to replace our previous percentile-based approach with triggers based on Standardised Groundwater Indices (SGI).

The SGI method was developed by the British Geological Survey (BGS)[22]. The approach has subsequently been applied in several follow up studies[23] [24] [25] [26]. We have discussed the methodology with the BGS and they have kindly shared with us their R code for applying the assessment.

The SGI method follows similar principles to that applied for the widely used SPI to estimate normalised indices for each calendar month by transforming the data via non-parametric normal scores.

Drought triggers of an appropriate frequency can then be estimated from the desired annual probability of a given event (e.g. 10% chance of a 1-in-10 years event) which we can link to our levels of service and

[22] Bloomfield, J. P. and Marchant, B. P., 2013. Analysis of groundwater drought building on the standardised precipitation index approach, Hydrol. Earth Syst. Sci., 17, 4769–4787. https://doi.org/10.5194/hess-17-4769-2013.
[23] Bloomfield, J.P., Marchant, B.P. and Wang, L., 2018. Historic Standardised Groundwater level Index (SGI) for 54 UK boreholes (1891-2015). NERC Environmental Information Data Centre. (Dataset). https://doi.org/10.5285/d92c91ec-2f96-4ab2-8549-37d520dbd5fc
[24] Bloomfield, J. P., Marchant, B. P. and McKenzie, A. A., 2019. Changes in groundwater drought associated with anthropogenic warming, Hydrol. Earth Syst. Sci., 23, 1393–1408. https://doi.org/10.5194/hess-23-1393-2019.
[25] Brauns, B., Cuba, D., Bloomfield, J. P., Hannah, D. M., Jackson, C., Marchant, B. P., Heudorfer, B., Van Loon, A. F., Bessière, H., Thunholm, B. and Schubert, G., 2020. The Groundwater Drought Initiative (GDI): Analysing and understanding groundwater drought across Europe, Proc. IAHS, 383, 297–305. https://doi.org/10.5194/piahs-383-297-2020.
[26] Wendt, D. E., Van Loon, A. F., Bloomfield, J. P. and Hannah, D. M., 2020. Asymmetric impact of groundwater use on groundwater droughts, Hydrol. Earth Syst. Sci., 24, 4853–4868. https://doi.org/10.5194/hess-24-4853-2020.

drought interventions. The associated groundwater level can also be calculated by the inverse transform of the normal score for plotting on standard hydrographs.

We believe this approach offers several advantages compared to our existing groundwater triggers:

- SGI can be readily compared and correlated to rainfall SPIs and SPEIs on the same scale and conventional drought threshold classifications used for SPIs can be applied (e.g. SGI of -1 to -1.5 = Moderate drought, SGI of -1.5 to -2 = severe drought etc.).
- Correlation with SPI and SPEI series.
- Table 14 can be used to identify critical rainfall and recharge accumulations associated with groundwater drought that is an important consideration for our Drought Plan and WRMP drought vulnerability assessment.
- A standardisation approach allows easier site-to-site comparison of groundwater hydrograph responses to drought events where individual borehole hydrographs may have very different groundwater ranges and shapes across the various aquifer blocks from which we abstract.
- The approach has been validated by several peer-reviewed studies across major UK and European aquifers, in particular, the Chalk.
- Published studies show a good correlation of SGI with independently established historical droughts and hence we consider the SGI is a robust indicator of groundwater drought.
- The approach has also been used to identify potential long-term trends of anthropogenic warming.

The SGI approach has been applied to our selected groundwater drought indicator observation boreholes.

Table 14: Proposed drought thresholds for SGI (based on SPI thresholds[27]).

SGI range	Drought definition
SGI > 0	Normal conditions
-1 < SGI < 0	Minor drought
-1.5 < SGI < -1	Moderate drought
-2.0 < SGI < -1.5	Severe drought
SGI <-2	Extreme drought

3.4.2 SGI application methodology

Our calculation of SGI values and derivation of triggers followed these steps:

- Interpolate observed groundwater level series (z_i) to obtain the value on the first day of the month
- Create ranked series of groundwater levels for each month
- Calculate p_i for each groundwater level value (p_i is the probability that a value drawn at random from the fitted distribution is less than or equal to z_i
- Apply an inverse normal cumulative distribution to the p_i values to produce a monthly SGI series

[27] McKee, T.B., Doesken, N.J. and Kleist, J., 1993. The Relationship of Drought Frequency and Duration to Time Scales, Eight Conference on Applied Climatology, 17-22 January 1993, Anaheim, California.

- Calculate the annual minimum SGI values and derive the 10th and 5th percentiles to provide Level 2 and Level 3 'trigger SGI' values respectively.

We can apply the SGI method in reverse to calculate the groundwater levels associated with the trigger SGI and these can be directly compared to observed groundwater levels.

It should be noted that triggers have been developed from 'naturalised' sequences that allow for the fact that there are nearby abstractions that affect groundwater levels. For two of the boreholes, the approach to naturalisation follows the methodology used for DP19. This involved using recharge and borehole level regression modelling that includes the relevant monthly groundwater abstraction rates. For the third (which was not considered in DP19), a newly developed approach to naturalisation has been applied. Drawdown caused by the relevant monthly groundwater abstraction rates is estimated using the Theis equation and Neuman's drawdown equation and used to naturalise groundwater levels.

Our Level 2 trigger curve has been selected to provide exceedance at intervals of about 1-in-10 years. Our Level 3 curve has been selected to provide exceedance at intervals of about 1-in-20 years.

Eastern area

Two boreholes have been selected in the Eastern area, both boreholes are also included in monthly water situation monitoring by the EA.

The first borehole (Figure 18) provides a good indication of the groundwater resource for the North Kent Chalk sources within KME and KMW WRZs. This indicator borehole replaces a previous site, which is no longer regularly monitored. The previous borehole also needed a naturalisation correction applied to account for the impacts of nearby abstraction from one of our Kent Medway groundwater sources on groundwater levels at the observation borehole, which in combination with poor data record added to uncertainty over its use as a suitable indicator borehole. No naturalisation is required for the new borehole and comparisons show that trigger crossing appears consistent with our SPI/SPEI trigger crossings for rainfall sites in the KME WRZ.

However, the EA has expressed some concerns about the reliability of the long-term historic data at this borehole since recent groundwater levels appear to be elevated compared to longer term data providing a potentially distorted picture of the resource situation. Although unconfirmed it is suspected there have possibly been groundwater abstractions affecting the local groundwater levels and that these influences have now ceased or changed resulting in observed GW levels rising reducing confidence in the long-term reliability of the data

We agree with the EA that the record is potentially unreliable, this is evident from recent water situation reports and the current levels with respect to the mapped percentile boundaries. However, that this site is still used in overall Water Resource Situation Reporting by the Agency, and live telemetry is available was a factor in our adoption we adopted the site as a drought indicator borehole.

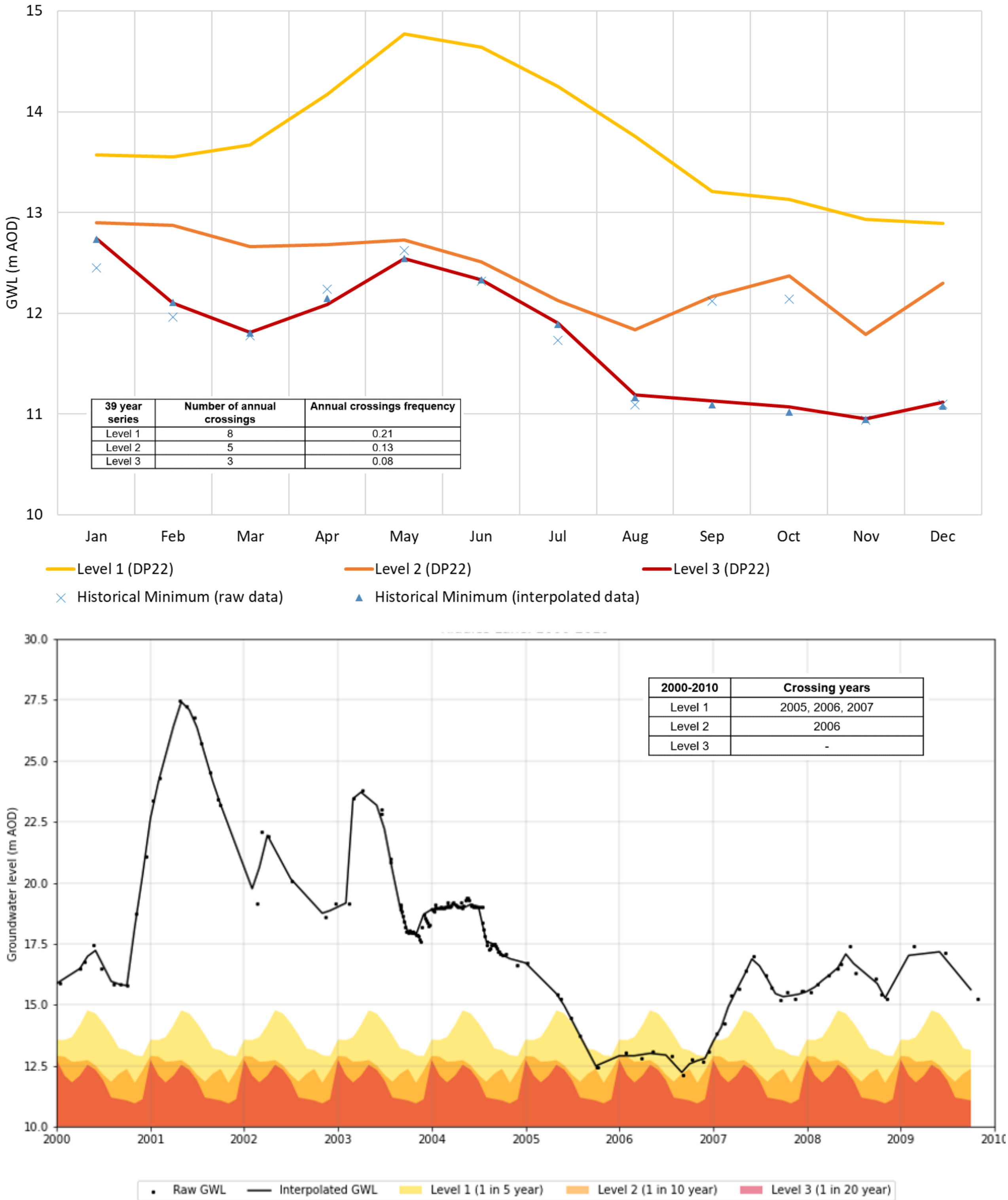
We have considered alternative observation boreholes tell however, there are no other groundwater sites on with live telemetry within 25km of our indicator site in the North Kent Chalk – the closest being Stour Catchment. The next closest site is west of the Darent and outside our area of supply. The length of record and reliability of these boreholes is not presently known.

We have also reviewed our recent North Kent Groundwater modelling report for alternative sites, and have identified two potential sites with long term but as yet neither has available live telemetry via the EA API's and hence would not be possible for 'real time' groundwater level monitoring.

We will keep the performance of our North Kent indicator borehole and, if necessary, update our triggers or incorporate alternative sites

To provide further resilience we have adopted a second borehole, located in East Kent as supporting indicator location for North Kent Groundwater. Drought trigger curves for this borehole (Figure 19) are used also as an indicator borehole for the East Kent and Thanet Chalk aquifer that supplies our KT WRZ. At this site, compared to our 2013 (DP13) and DP19 triggers the SGI derived triggers are slightly lower in elevation with the peak occurring later in the year. However, the overall shape of the trigger curves is similar, especially for the summer recession.

It is also worth noting, that for our Kent Medway Zones most of our groundwater sources are not especially vulnerable to groundwater drought (i.e. many do not have significant groundwater level constraints on Deployable Output) and hence our primary drought triggers for those WRZs are still linked to Rainfall, Effective Rainfall and the Reservoir Storage and we would typically expect those to respond and trigger drought actions in advance of groundwater drought.



39 year series	Number of annual crossings	Annual crossings frequency
Level 1	8	0.21
Level 2	5	0.13
Level 3	3	0.08

2000-2010	Crossing years
Level 1	2005, 2006, 2007
Level 2	2006
Level 3	-

Figure 18: Drought trigger curves based on SGIs for observation borehole in North Kent Chalk showing their historical performance

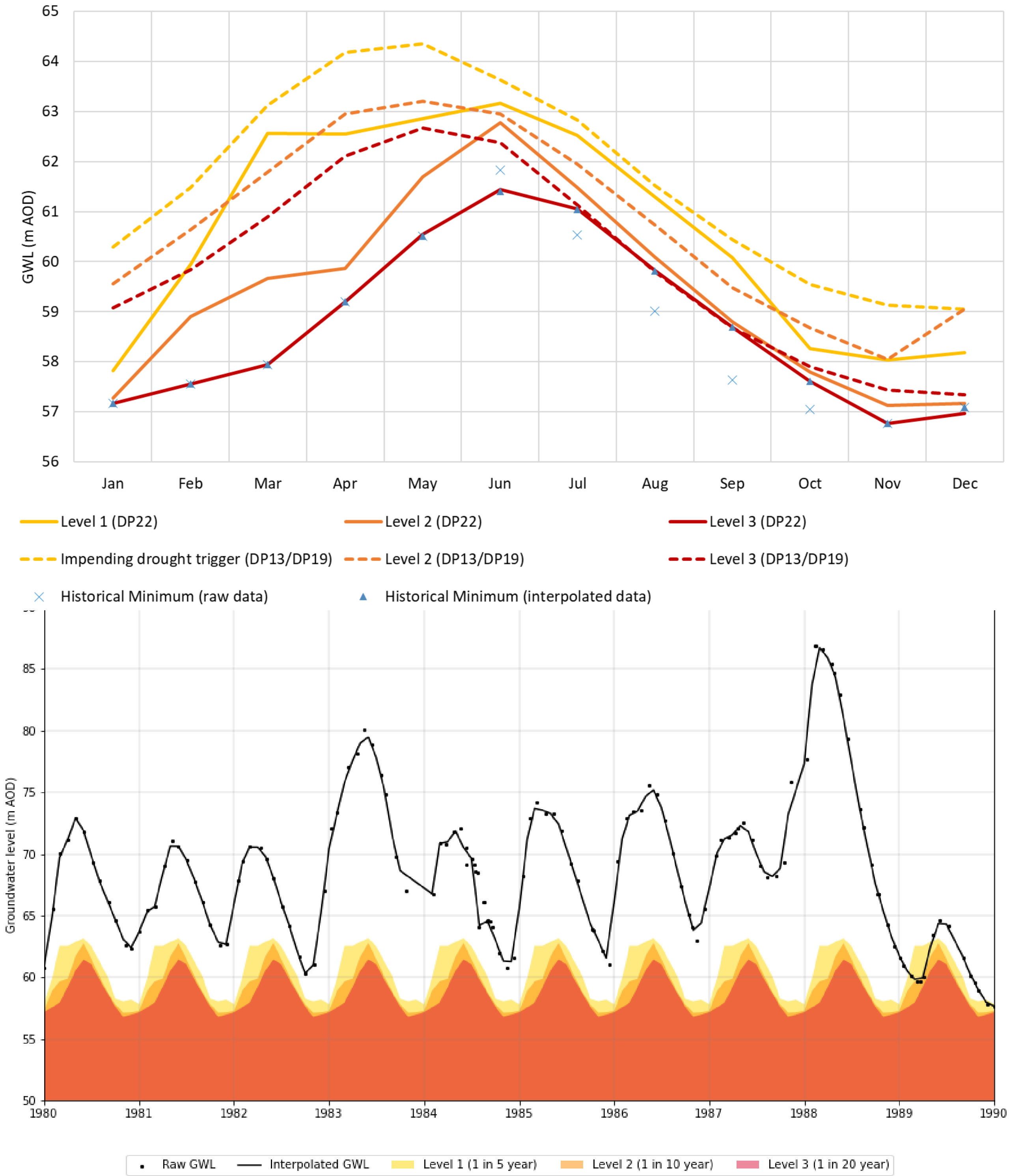


Figure 19: Drought trigger curves based on SGIs for observation borehole for East Kent and Thanet Chalk aquifer showing comparison of our DP13 and DP19 trigger levels and historical performance.

Central area

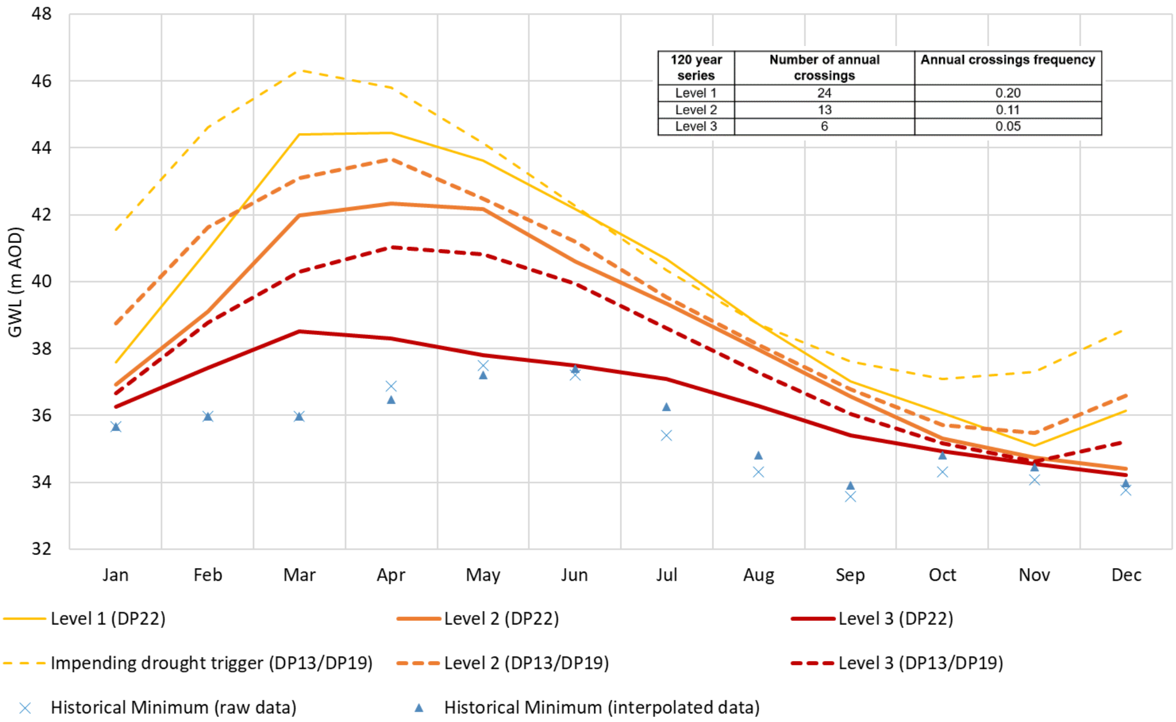
We have included three indicator boreholes for our Central area covering the Chalk aquifer of the Worthing and Brighton Chalk blocks and associated with our SWZ and SBZ WRZs that are completely reliant on groundwater resources.

Three boreholes have been selected as the drought monitoring boreholes in the Central area. The selection is based on good, long-term groundwater level records and the three boreholes provide good spatial spread of coverage from west to east across the relatively narrow coastal aquifer blocks.

The first drought triggers (Figure 20) have been derived using unadjusted SGI calculations and was one of the pilot sites for the original derivation of the SGI methodology[28]. Compared to our previous trigger thresholds the SGI based thresholds are slightly lower in elevation and follow a flatter curve for the Level 3 trigger.

The second borehole is located in the western part of the Brighton Chalk block. This borehole has a long observation record but groundwater levels here are influenced by some of our nearby groundwater abstractions. The groundwater levels have therefore been naturalised to compensate for groundwater abstraction (Figure 21). It has also been used as key indicator borehole for our DO calculations in the SBZ and SWZ WRZs by recharge regression modelling. Overall, this borehole provides a good representation of the central and western part of the Brighton Chalk block and the eastern part of the Worthing Chalk block. However, we do have some concerns over the reliability of the water level data, particularly in recent years, this will need to be addressed with the EA.

[28] Bloomfield, J. P. and Marchant, B. P., 2013. Analysis of groundwater drought building on the standardised precipitation index approach, Hydrol. Earth Syst. Sci., 17, 4769–4787/ https://doi.org/10.5194/hess-17-4769-2013.



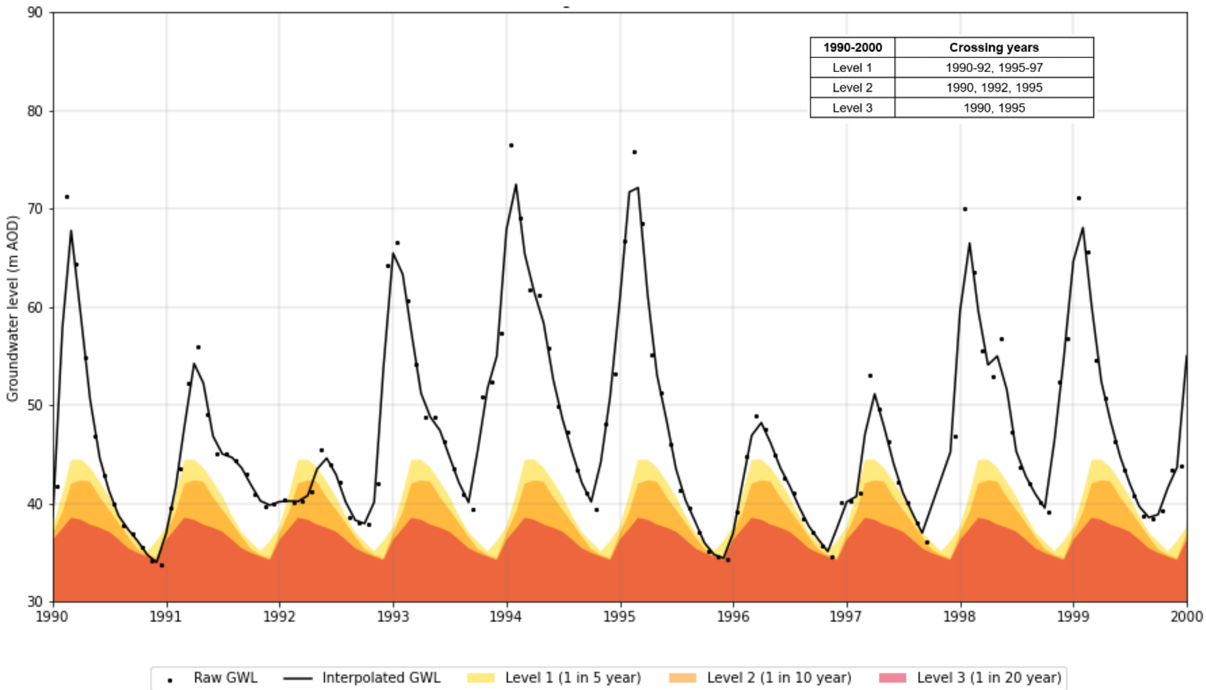
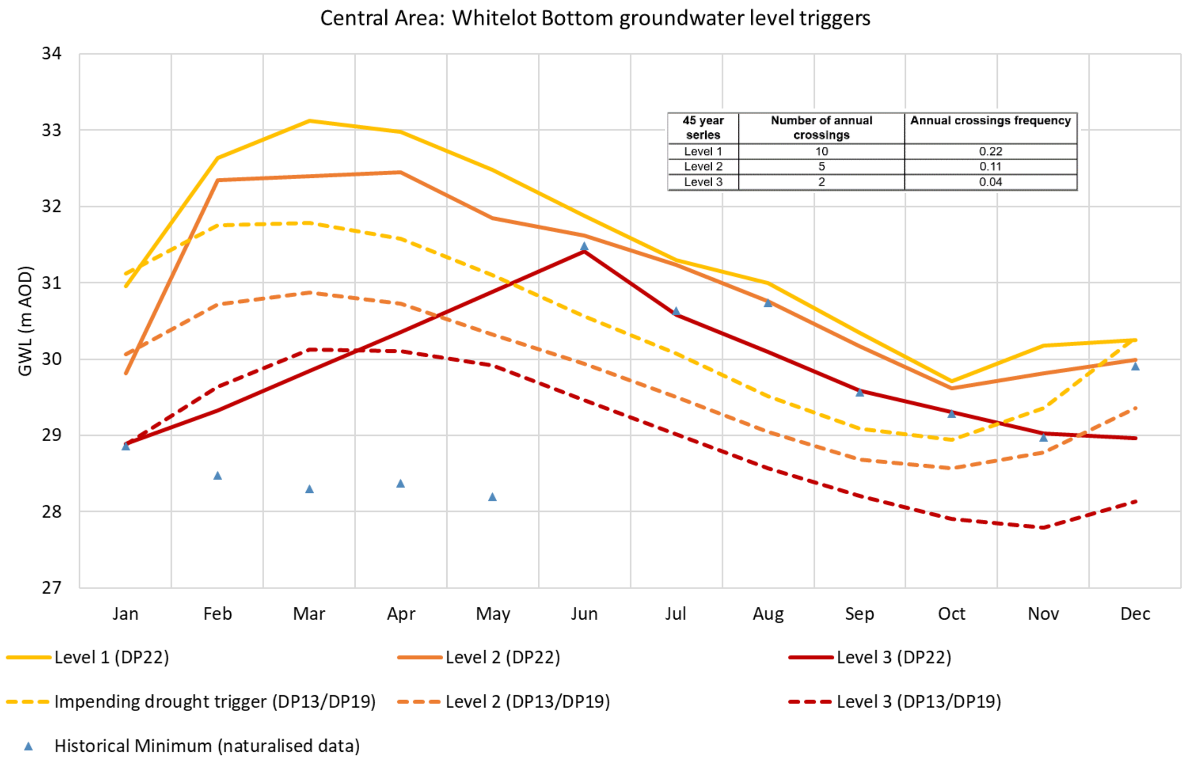


Figure 20: Drought trigger curves for borehole at the SGI methodology pilot site showing comparison of our DP13 and DP19 trigger levels and historical performance.



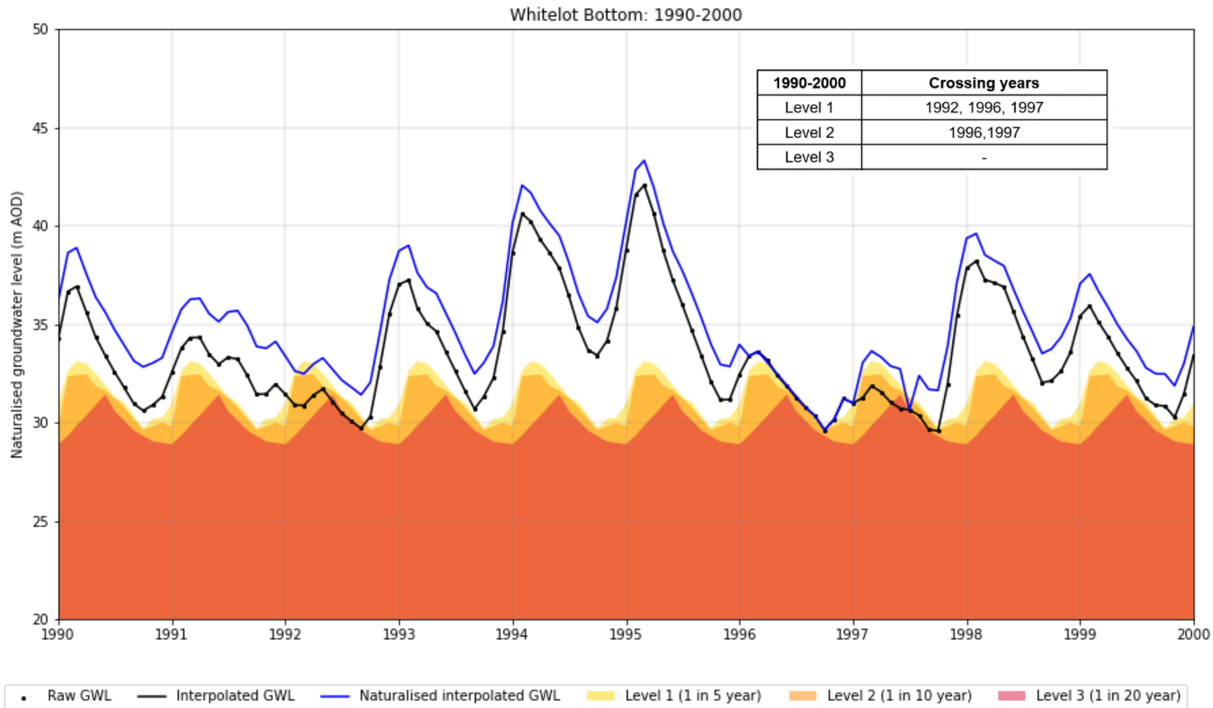
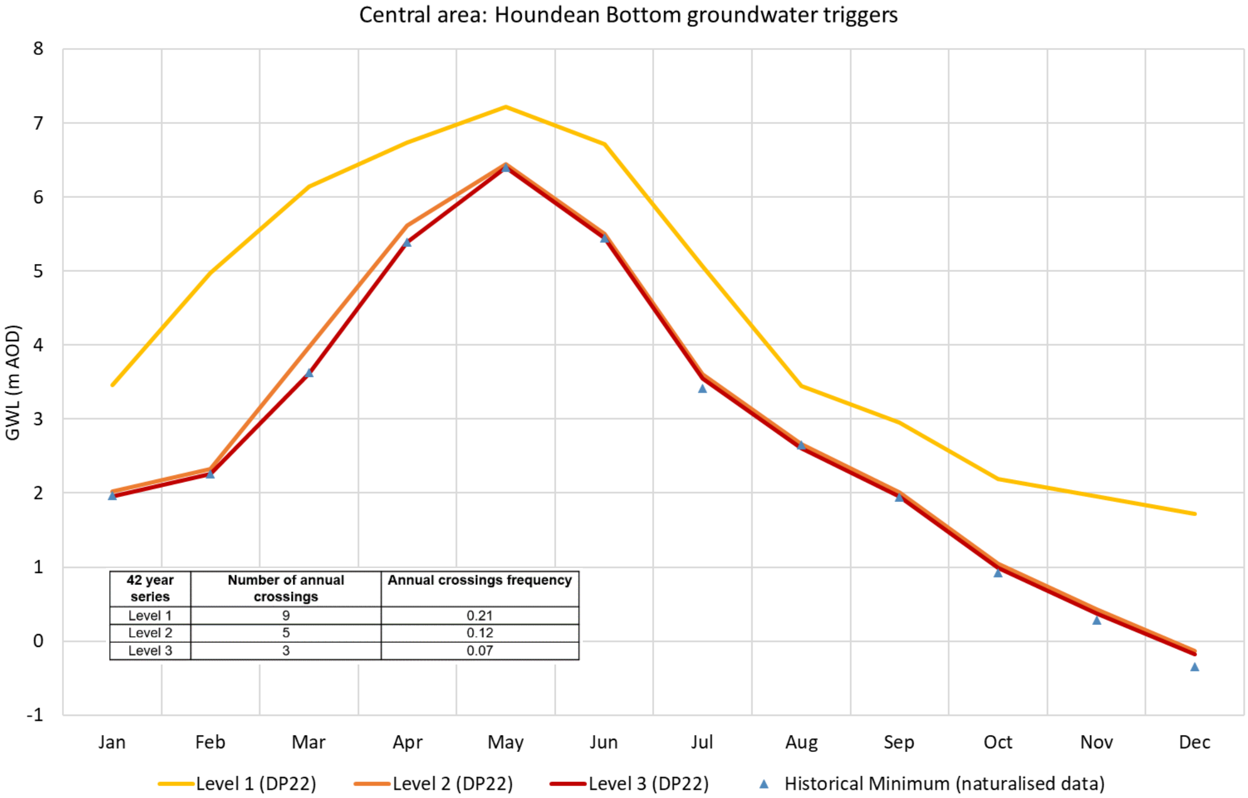


Figure 21: Drought trigger curves for observation borehole in western part of Brighton Chalk block showing comparison of our DP13 and DP19 trigger levels and historical performance.

The shape of the SGI based trigger curve differs from our previous trigger levels with a greater interval between the Level 1 and Level 2 triggers especially in late winter and spring. This groundwater elevation at this time of year is indicative of the winter recharge and in late spring (from April) is a relatively reliable indicator of the potential summer and autumn recession to minimum groundwater levels and hence is critical in determining the potential drought actions we may need to take over the summer. As with many of our SGI derive trigger curves the elevations have also increased in comparison to our DP13 and DP19 trigger levels.

We have included an additional observation borehole for groundwater triggers (Figure 22) in DP22 compared to DP19. This is located in the eastern part of the Brighton Chalk block and shows behaviour characteristic of this area with a large groundwater level range and characteristic recession to similar base levels each year. Consequently, the Level 1, Level 2 triggers and historical minimum groundwater levels are all very close.

We operate several large strategic but drought sensitive sources in this area, all of which show similar groundwater level trends and hence this borehole provides a good proxy indicator for those sites. The site is also included in the EA Water Situation Reporting.



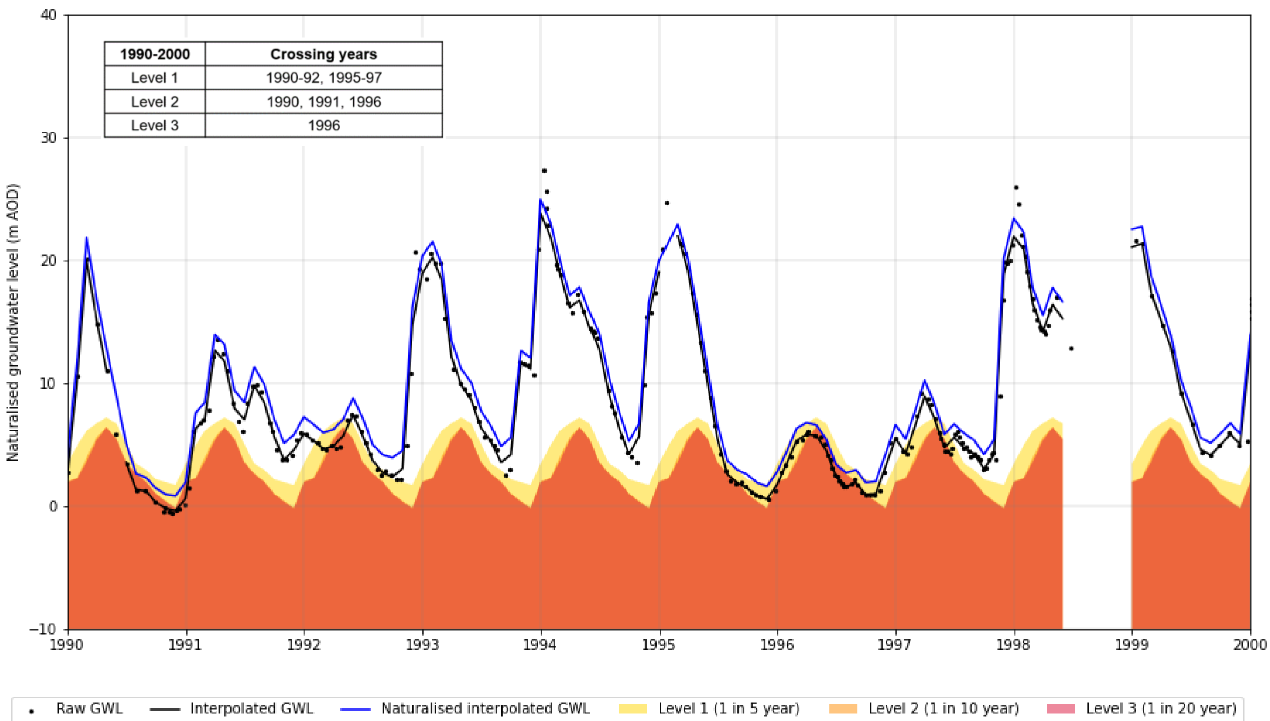


Figure 22: Drought trigger curves for observation borehole in eastern part of Brighton Chalk block showing historical performance.

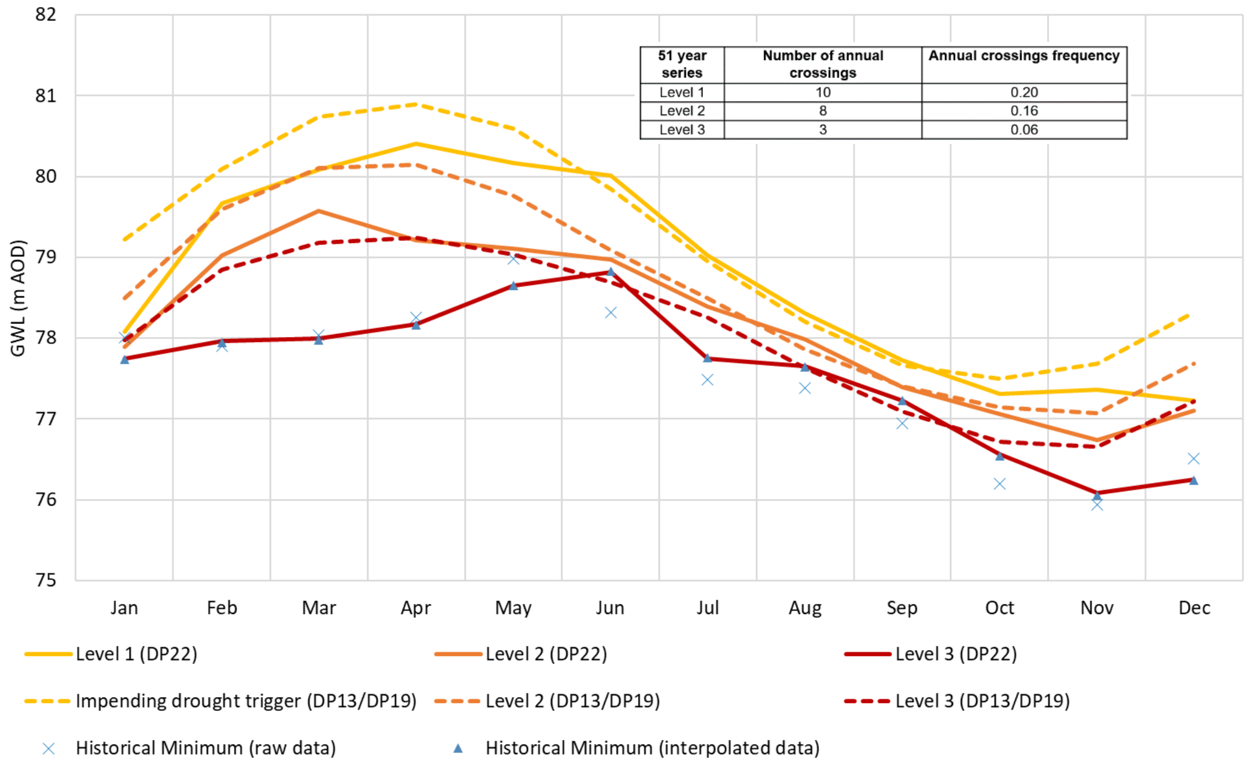
Western area

Water level records from two boreholes are used as drought triggers for Hampshire and have medium-length time series records dating back to the 1970s. The first provides a good indicator borehole for the West Hampshire Chalk and River Test catchment. The second provides a good indicator borehole for the East Hampshire Chalk and River Itchen catchment. Both boreholes are also featured in the EA Water Situation Reporting.

Drought trigger curves for the latter borehole (Figure 23) are slightly higher than in our previous plan except for February. Overall, there is little difference between the recorded minimum historic level and the Level 3 trigger curve as there is limited number of extremely low water level values in the available record.

Drought trigger curves for former borehole (Figure 24) have also been developed using truncated normal distribution analysis. The percentile based trigger curves are relatively close to each other and the historic minimum as there is a limited number of extremely low water level values in the available record.

For the IOW, our triggers are based on another observation borehole (Figure 25). This has a relatively short record (back to 1986). This borehole is affected by nearby abstraction, so the observed groundwater levels have been ‘normalised’ to allow for the impact of the source. The IOW Chalk is characteristically very flashy, responding quickly to recharge and periods of dry weather and the groundwater level record for this site shows very steep/sudden drops due to this high sensitivity to rainfall. This has resulted in very similar profiles for the Level 2 and 3 triggers. In order to better differentiate between the Level 2 and Level 3 triggers, these have been rounded to a greater degree of precision (3 decimal places) compared with triggers at other sites (rounded to 2 decimal places).



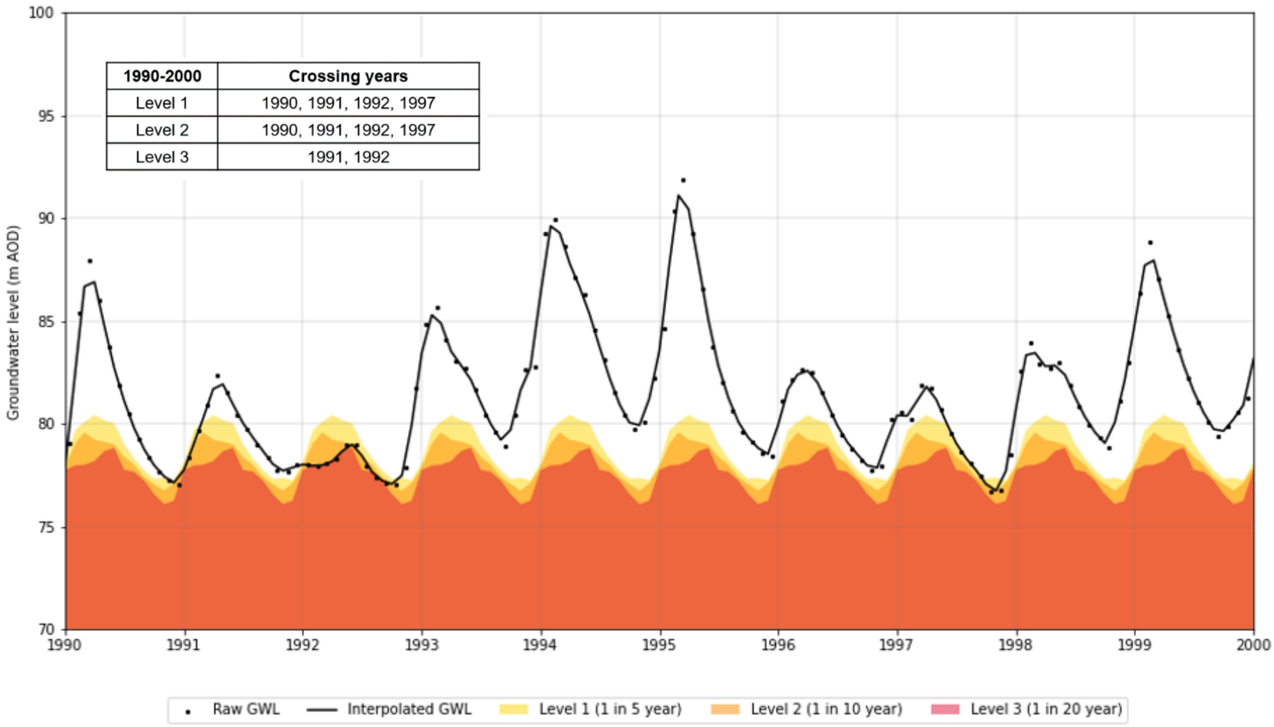
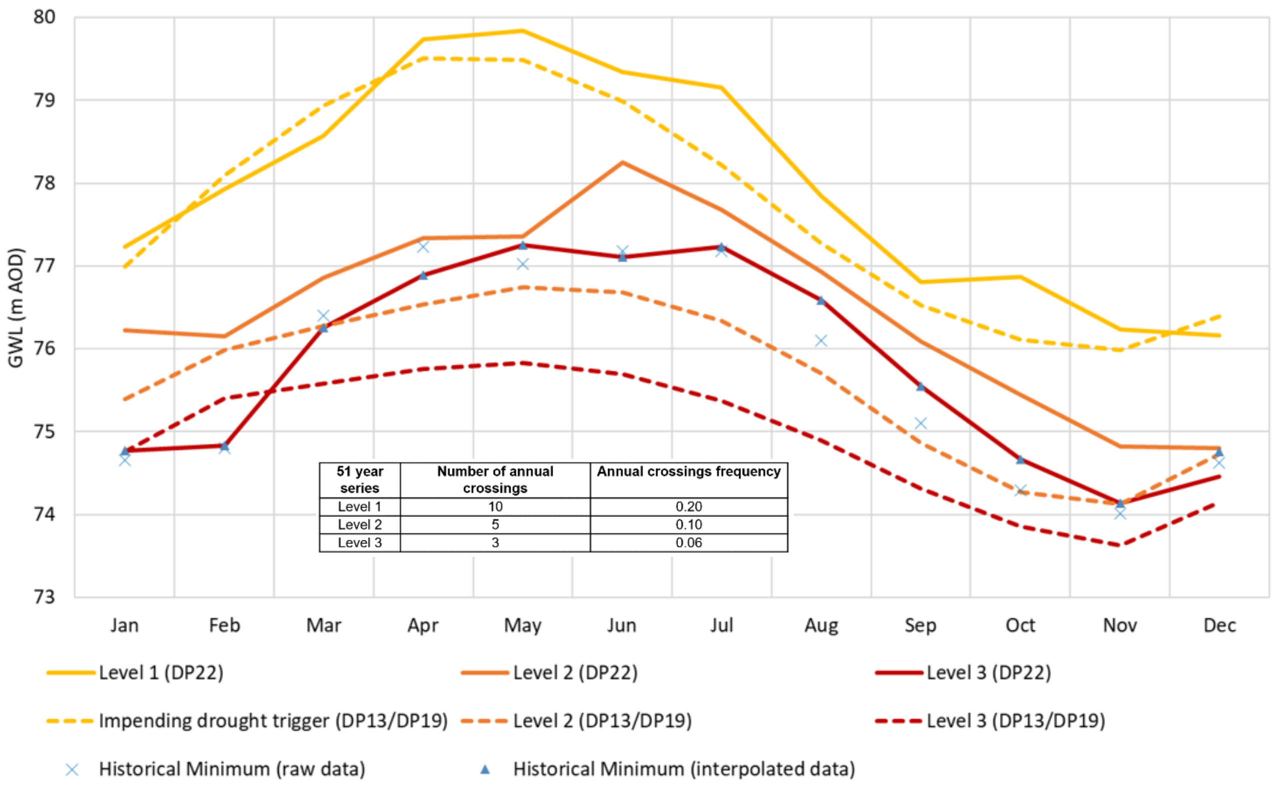


Figure 23: Drought trigger curves for the observation borehole in the East Hampshire and River Itchen catchment showing comparison of our DP13 and DP19 trigger levels and historical performance.



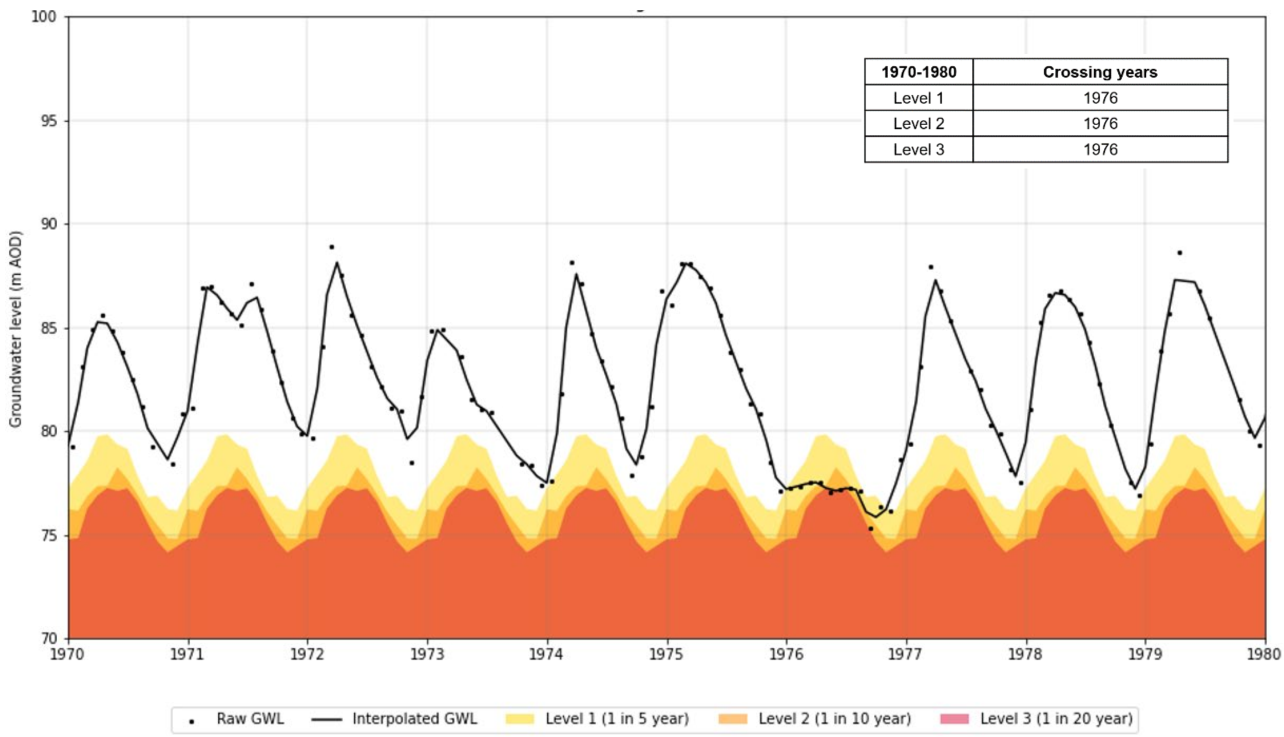
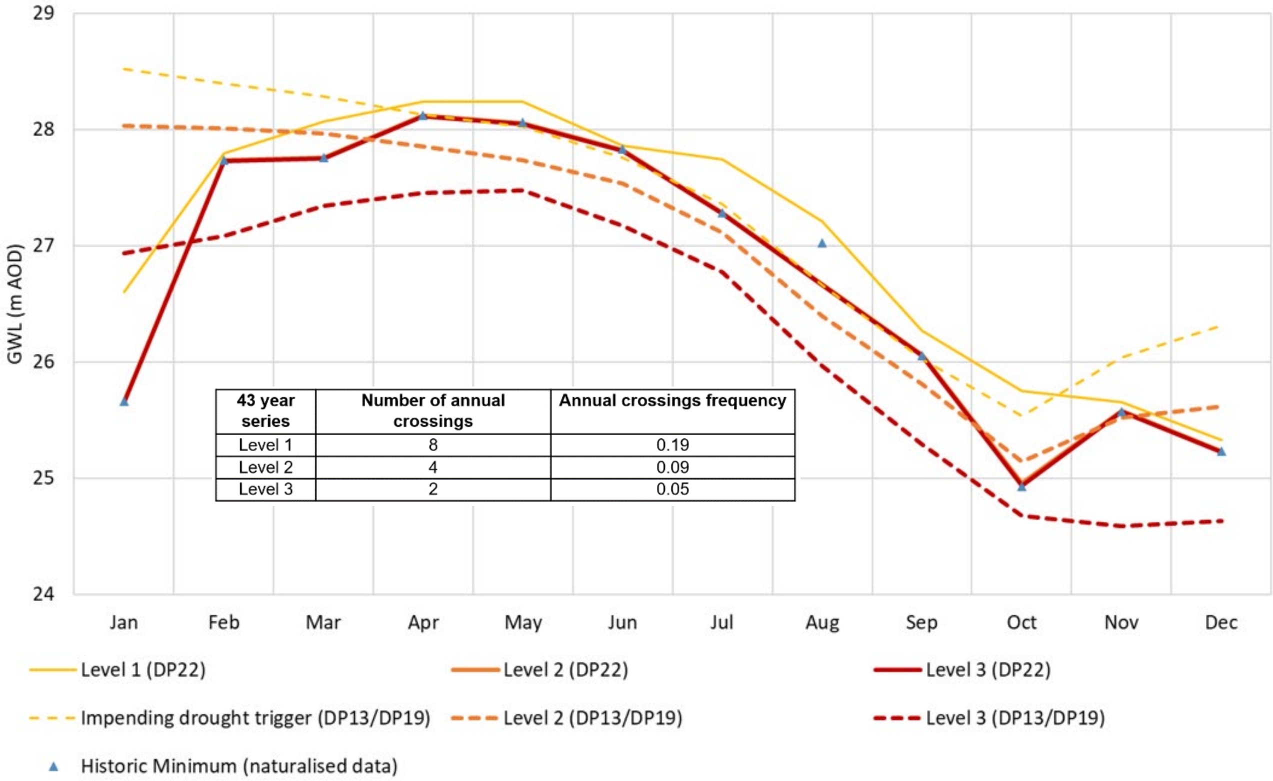
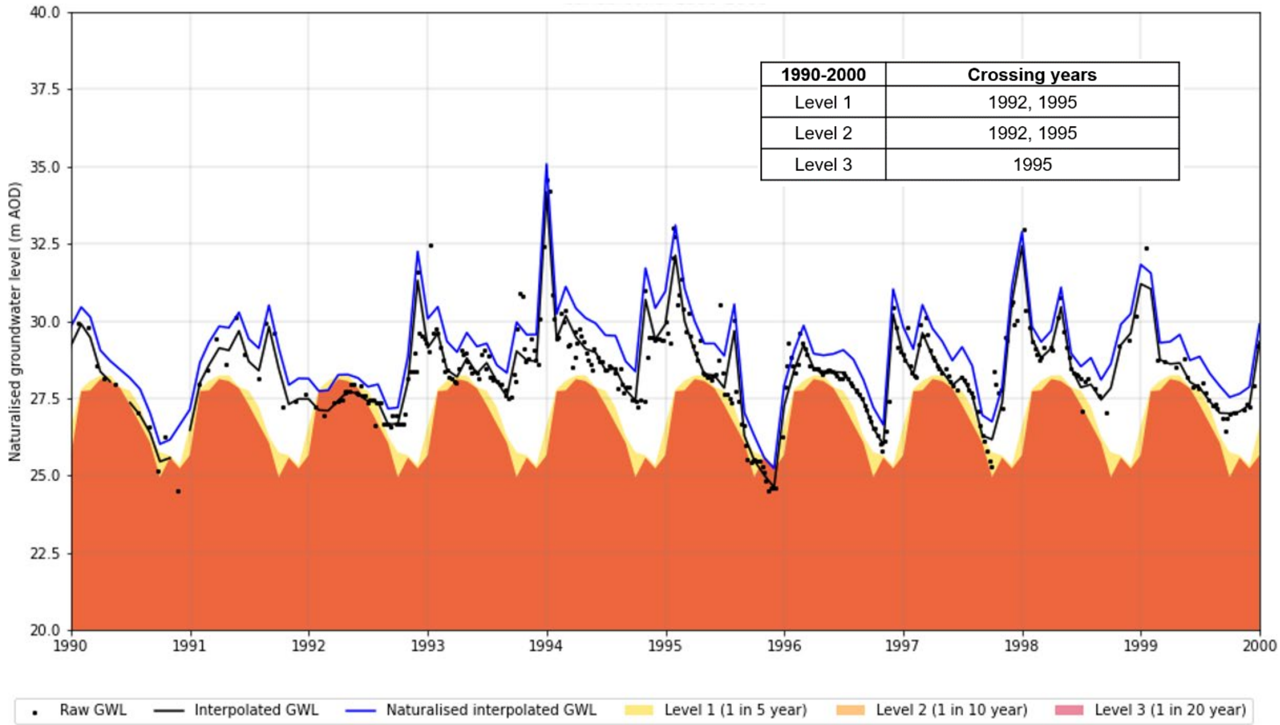


Figure 24: Drought trigger curves for the observation borehole in the West Hampshire and River Test catchment showing comparison of our DP13 and DP19 trigger levels and historical performance.



43 year series	Number of annual crossings	Annual crossings frequency
Level 1	8	0.19
Level 2	4	0.09
Level 3	2	0.05



1990-2000	Crossing years
Level 1	1992, 1995
Level 2	1992, 1995
Level 3	1995

Figure 25: Drought trigger curves for the observation borehole on the IOW showing comparison of our DP13 and DP19 trigger levels and historical performance.

Trigger validation and limitations

To understand the performance of the new triggers against those previously determined we undertook a validation of trigger crossings against historical groundwater levels. Table 15 shows a comparison between the new SGI based triggers and our previous percentile-based groundwater triggers.

Our assessment shows that the DP22 triggers based on the SGI method show consistent triggering frequencies at the required levels of service for all site closely matching the expected triggering frequency: Level 1 triggers 18% of the time (expected 20%), Level 2 triggers 9% of the time (expected 10%) and Level 3 triggers 5% of the time (expected 5%).

In comparison the DP13/DP19 triggers based on the percentile approach show varied triggering frequencies across sites and overall is more frequent than expected. Level 1 triggers are crossed 54% of the time, Level 2 triggers 37% of the time and Level 3 triggers 11% of the time. Notably for two sites, Carisbrooke and Little Bucket, the DP13/19 triggering frequency is much greater than required.

The length of the available observed groundwater level series has a strong influence on the resulting groundwater trigger profiles, and this applies to both percentile-based, and SGI based trigger levels. Shorter groundwater level series result in trigger profiles that can exhibit large variations between months and large/small differences between Level 1, 2 and 3 triggers. Generally, the longer a groundwater level record the more robust the estimates of trigger levels. Unfortunately, because some groundwater sequences are relatively short, they contain few historical drought events and so estimates of low groundwater levels are less robust.

Table 15: Comparison of triggering frequency between the new SGI based triggers with previous percentile-based triggers.

	Percentile Based Triggers (DP13/DP19)			SGI Based Triggers (DP22)		
% of years triggered	20%	10%	5%	20%	10%	5%
Site	**1-in-5 years**	**1-in-10 years**	**1-in20 years**	**1-in-5 years**	**1-in-10 years**	**1-in20 years**
Chilgrove	36%	21%	10%	20%	10%	4%
Whitelot Bottom	13%	4%	2%	22%	11%	4%
Little Bucket	30%	28%	18%	20%	10%	4%
West Meon	25%	22%	12%	20%	12%	6%
Clanville Lodge Gate	22%	4%	2%	20%	10%	6%
Carisbrooke Castle	43%	32%	5%	18%	9%	5%

In addition, there are some specific considerations, we have identified relating to the IOW observation borehole where these issues are most apparent:

- Complex hydrogeological conditions: The behaviour of the groundwater levels (i.e bottoming out) is expected to reflect the hydrogeological behaviour at nearby abstraction sources. Although the DP22 Level 2 and 3 triggers are very close (average difference of 8cm), that is appropriate in this setting.

- A relatively 'short' groundwater level record: DP22 triggers are based on a 44 year GWL series, whilst DP13/19 triggers are based on a 35 year GWL series.
- Uncertainty in naturalisation: Groundwater levels and triggers for DP22 have been naturalised using an updated and longer abstraction series compared with DP13/19. We're more confident in the naturalisation process for the updated triggers and therefore, more confident in the triggers themselves.

Presently we have not yet identified any suitable alternative monitoring locations with high quality groundwater records for the Isle of Wight which could be used in preference. One alternative approach would be to use existing groundwater models, where suitably calibrated to artificially extend groundwater records, either for the historical climate data or through the use of a synthetic drought dataset as used in our long term water resource planning to provide a larger drought dataset, though this itself would be subject to the uncertainty inherent within the modelling.

We have discussed these potential limitations of the approach with the EA and will continue to keep the performance of our groundwater triggers under review and if necessary, consider them alongside our previous DP19 triggers or alterative datasets. Any changes to the triggers will be proposed in our Annual Drought Plan Review.

The limitations to our groundwater data will be mitigated by our adoption of a multi-factor trigger approach to drought monitoring and decision making. Under this hierarchy groundwater levels will be considered alongside other key drought indicators such as SPI and SPEI (sections 3.2 and 3.3) in our decision making all of which are indicative of water resource deficit and hence our initiation of drought actions in not based on a single trigger dataset.

3.5 River flows

We have three major surface water abstractions that are not linked to reservoir systems. These operate on the Lower Test, the Lower Itchen and the Western Rother. The abstractions are large (several 10's of Ml/d) and drought sensitive as at low flows HoF or MRF licence conditions restrict the amount of water we can abstract.

For our Lower Test and Lower Itchen abstractions, the drought actions we take are directly linked to flow thresholds and 'time-before-flow' triggers that have been designed to allow sufficient time for drought permit/order actions, which are necessary to maintain supplies even in moderate droughts, as evidenced from our drought vulnerability assessment for HSW and HSE WRZs.

The Western Rother, which supplies water to our Pulborough supply works, is also critical to the resilience of our SNZ WRZ and at low flows in severe droughts MRF conditions restrict the surface water yield and may limit output from groundwater at this site. As with the River Test and the River Itchen, our drought permits/orders in this WRZ are closely linked to the flows in the Western Rother.

Our drought triggers have been derived from a combination of observed historical flow data and modelled stochastic flow data to test a wide range of drought events. We recognise that each event is different and that a probabilistic approach is required in order to ensure that sufficient time is available following each trigger stage to complete our drought actions without being so conservative that triggers are breached too frequently when drought actions would not actually be required.

To derive the triggers the observed and modelled flow series have been denaturalised (where required) and a baseflow separation performed by applying an Eckhardt Filter[29] to the data. The use of baseflow is an evolution from our DP19.

3.5.1 General approach – River Test and River Itchen

There are three major river flow rivers under consideration in DP22, the Test, Itchen and Rother. The River Stour has been removed from our drought triggers as we no longer operate any surface water sources within the catchment.

Flow triggers are linked to our obligations and drought actions under the Section 20 Agreement. The updated drought triggers have tried to resolve the issues relating the relationship between rapid runoff following rainfall and the baseflow which dominates the recession towards the HoF licence condition (or other set threshold) by deriving the triggers based directly on baseflow-separated data.

This is particularly important for the baseflow dominated River Test and River Itchen. The adopted approach has therefore been based on baseflow separated and de-naturalised modelled flows (Water Resources South East (WRSE) stochastic flow series) for each of the rivers which provides a wide range of dry scenarios to derive the triggers against and increases the confidence in results where the observed record is short. Using the stochastic data meant the approach has been conservative and has resulted in higher trigger levels for the River Test than in DP19, allowing us to cope with extreme future droughts.

Time based triggers, as used for the River Test in DP19, have been adopted for all three rivers with 90-day, 60-day and 35-day lead times. Each trigger level is defined as the minimum time that would ensure a certain probability of reaching the HoF (or other set threshold) in the adopted lead-time for each month of the year. These thresholds have been based on the analysis of stochastic and historic flow recessions.

- The 90-day trigger is an early warning trigger that is linked to internal actions regarding drought plan preparation.
- The 60-day trigger is linked to increasing public awareness (Level 1 actions) and any actions that need to be taken to consider optimisation of source operation, managing strategic transfers and drought permit/order pre-consultation.
- The 35-day trigger should provide enough time for review of the application with the flow threshold for implementation of any drought permit/order being reached by the end of that period.

The requirement for a 60-day and 35-day trigger for the River Test is set out in the Section 20 Agreement and is designed to accommodate the agreed drought permit application process for our Lower Test licence.

Seasonality has been considered for each of the lead-time triggers, presented in the form of profiled trigger levels, highlighting how there is a higher risk of reaching the different flow thresholds in particular months. During active drought management, we would supplement these trigger levels by forecasts of flow recessions based on our existing water resource modelling tools to ensure our actions under the Section 20 Agreement are carried out in sufficient time.

The approach has the following steps.

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[29] Eckhardt, K., 2005. How to construct recursive digital filters for baseflow separation: Hydrological Processes, v. 19, no. 2, 507–515.

- Baseflow separation using the calibrated Eckhardt digital filter
- De-naturalisation using recent actual levels of abstraction
- Calculation of the maximum baseflow drops for the different lead times when the baseflow breaches the HoF (or other thresholds)
- Check performance of trigger levels against historical flows
- Manual adjustments and smoothing to ensure appropriate lead times between the trigger levels

  The focus for the manual adjustments was ensuring that there is always enough time between the 35-day trigger and breaching the HoF in both the stochastic and historic records. The next priority was to ensure enough time between the 90-day and 60-day triggers and the 60-day and 35-day triggers within the historical record. Final consideration was given to the timing between these triggers for the stochastics series. It was accepted that there would not always be enough time between triggers in the stochastic series due to the nature of the modelled series and the requirement to increase the trigger levels substantially to remove the failures.

There have been some adjustments to the methods in the cases of the individual rivers as discussed in Section 3.5.3 (River Test and River Itchen in the Western area) and Section 3.5.4 (River Rother in the Central area).

3.5.2 Baseflow separation method

Baseflow separation needs to be done automatically so that it can be programmed and implemented for real-time monitoring. The Eckhardt digital filer (2008)[30] has demonstrated good performance worldwide producing hydrologically plausible results similar to those obtained with manual separation and can be applied to flow records of any length. The filter has two parameters including a recession constant and maximum baseflow index that are used to derive baseflow with following algorithm:

$$b_k = \frac{(1 - BFI_{max})ab_{k-1} + (1 - a)BFI_{max}Y_k}{1 - aBFI_{max}}$$

Where:

a = recession constant
BFI_{max} = maximum value of the baseflow index that can be modelled by the algorithm
b = baseflow
k = time step number
Y_k = total streamflow

The recession constant can be obtained from the flow record by analysing the recession periods and BFI_{max} is derived iteratively to obtain the gauged Baseflow Index (BFI) obtained from other separation methods or the ungauged BFI Hydrology of Soil Types (BFIHOST). The BFIHOST gives an aggregated assessment of BFIHOST for the catchment based on the relationship between soil typologies and runoff response[31].

[30] Eckhardt, K., 2008. A comparison of baseflow indices, which were calculated with seven different baseflow separation methods, Journal of Hydrology (352), 168-173.
[31] UKCEH, 2021. National River Flow Archive. [Online] Available at: https://nrfa.ceh.ac.uk/data/search

Table 15 shows the calibrated parameters used to run the baseflow separation scripts. They were calibrated against a historical flow series and then used for every stochastic series. For the River Test and River Itchen a lower BFI_{max} was used than that which provides the recorded BFI values. This is because the baseflow was still exhibiting patterns of faster responding baseflow. Using lower values of BFI_{max} helped to leave only the slow responding baseflow on which to complete the analysis. Figure 26 illustrates the baseflow separation used with an example provided for the River Test.

Table 16: Baseflow separation algorithm parameters.

River	Historical flow series	Calibrated alpha	Calibrated BFI_{max}	Calibrated BFI	Observed BFI (NRFA)[32]
Test	Test Total Flow (1963-2019)	0.998	0.75	0.71	0.9
Itchen	Itchen near Eastleigh(1958-2019)	0.9995	0.99	0.93	0.96
Rother	Pulborough nat flow (1890-2014)	0.995	0.6	0.52	0.64

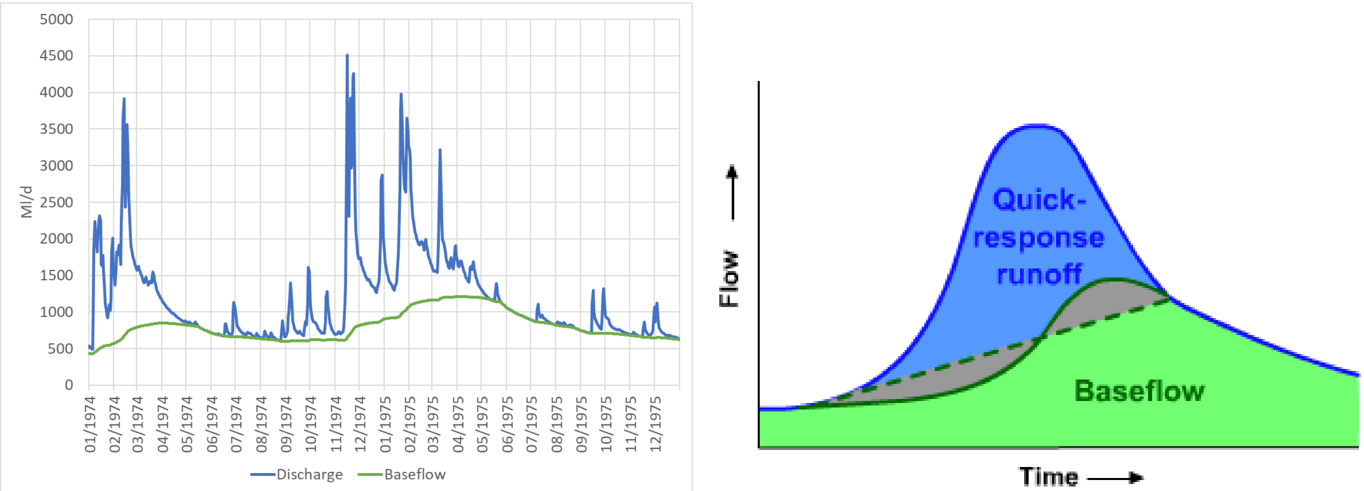


Figure 26: BFI schematic (left) and baseflow separation example (River Test Total Flows) (right).

Since the publication of our draft drought plan we have undertaken some additional work on our River Itchen and River Test Flow Trigger to further refine them and test them. The key workstreams we have pursued are:

- We undertook some further refinement of the River Test and Itchen flow trigger sets which included:
  - Providing the technical basis for an "Alternative" set of Combined Itchen Flow triggers developed after submission of dDP22 and originally presented, we have included this information in our revised draft

[32] UKCEH, 2021. National River Flow Archive. [Online] Available at: https://nrfa.ceh.ac.uk/data/search

- Developing an additional drought order application (35-day trigger level) for the Itchen 198Ml/d threshold for the Candover Drought Order, using the same methodology as for the alternative 205Ml/d trigger set. However, as discussed later in this document we are no longer including a 35-day trigger for the River Itchen and Candover in this plan.

We also undertook a joint modelling study with Portsmouth Water, the aims of which were to:

- Investigate level of service implications for both companies of the proposed triggers
- Examine the coherence of drought events on the River Test and Itchen and to explore the relative timing of drought interventions on both rivers and associated water resource zones
- Carry out full system simulation modelling of our drought interventions to include the effect of demand restrictions and the sequencing of drought actions set out in the section 20 in associated with the trigger levels
- Where required propose or provide updated trigger suites that continue to protect supplies but which reduce risks of unnecessary drought interventions and associated level of service impacts.

The study used a joint system simulation modelling (building on the regional water resources model developed in Pywr) utilising the stochastic time series developed for Water Resources South East (WRSE) to test assumptions around lead times, resultant levels of service (LoS), and coherence of Drought Permit requirements for both companies. The modelling included the full effect of demand restrictions and system simulation modelling so as to provide a realistic assessment of trigger performance.

Following the further work we have undertaken and taking account the conclusions of the modelling study we proposed to adopt the following trigger sets in our revised draft Drought Plan as set out in Table 17.

Table 17 Summary and status of trigger sets we propose to adopt in our final Drought Plan for the River Test and Itchen Flows

Set	Triggers	Included in DP19?	Included or updated in the dDP22?	Included in Joint Pywr modelling?	Adoption in Revised Draft/Final Drought Plan
A	River Test Drought Permit 355Ml/d Trigger Set (90/60/35-day triggers)	Yes	Updated	Yes	Yes – no change from dDP22
B	River Test Drought Order (265Ml/d) (90/60/35-day triggers)	Partially	Yes	Yes	Yes – but relabeled following modelling study Original 90-day trigger is to be dropped 60-day trigger becomes a 90-day trigger and 35-day trigger becomes a 60-day trigger
C	Original Combined River Itchen 205Ml/d Drought Order Trigger set (90/60/35-day triggers)	Partially	Yes	No	Not adopted
D	Combined "Alternative" River Itchen 205Ml/d Drought Order Trigger set (90/60/35-day triggers)	Partially	No	Yes	Yes but relabeled following modelling study Original 90-day trigger is to be dropped 60-day trigger becomes a 90-day trigger and 35-day trigger becomes a 60-day trigger
E	New 35-day River Itchen 198Ml/d Drought Order Trigger	No	No	No	Yes but relabeled as a 60-day trigger based on results of modelling study

All of these trigger sets, except for the revised Combined River Itchen Drought Order triggers (Set D) and the 35-day Trigger for the River Itchen Drought Order (Set E) were included in our draft Drought Plan (dDP) submission. These modifications do not affect the River Test Drought Permit 35-day trigger that is referred to in the Section 20 Agreement. But, because the River Itchen 35-day trigger is relabelled as the 60-day trigger, these modifications mean that this plan no longer contains an Itchen 35-day trigger.

Further detail on each set of triggers is provided in the following section.

3.5.3 River Test Drought Permit (355Ml/d HoF)

Our proposed drought triggers for the River Test have been based on the WRSE stochastic Test total flows series with comparison against the historical Test total flow. Trigger curves have been derived for both the 355Ml/d HoF and 265Ml/d drought permit HoF.

Table 18 and Figure 27 show a comparison of the DP19 and proposed DP22 trigger sets for the River Test Drought Permit. In general, the DP22 triggers are slightly higher in flow and hence provide earlier warning than those for DP19. Our comparative assessment of trigger performance and flow forecasts over the past two years has shown this brings forward lead times to drought interventions by about a week.

Table 18 comparison of DP19 and proposed DP22 flow trigger sets for the River Test Drought Permit (355Ml/d)

	DP19 Trigger Set (Ml/d)			Proposed DP22 Trigger set (Ml/d)		
Month	90-day	60-day	35-day	90-day	60-day	35-day
Jan	660	535	435	660	589	509
Feb	660	535	440	728	589	497
Mar	660	535	440	728	589	486
Apr	660	535	440	728	589	486
May	660	535	465	738	589	486
Jun	660	535	465	738	589	486
Jul	660	535	455	738	589	481
Aug	660	535	455	738	589	476
Sep	660	535	455	738	589	472
Oct	660	535	420	738	589	467

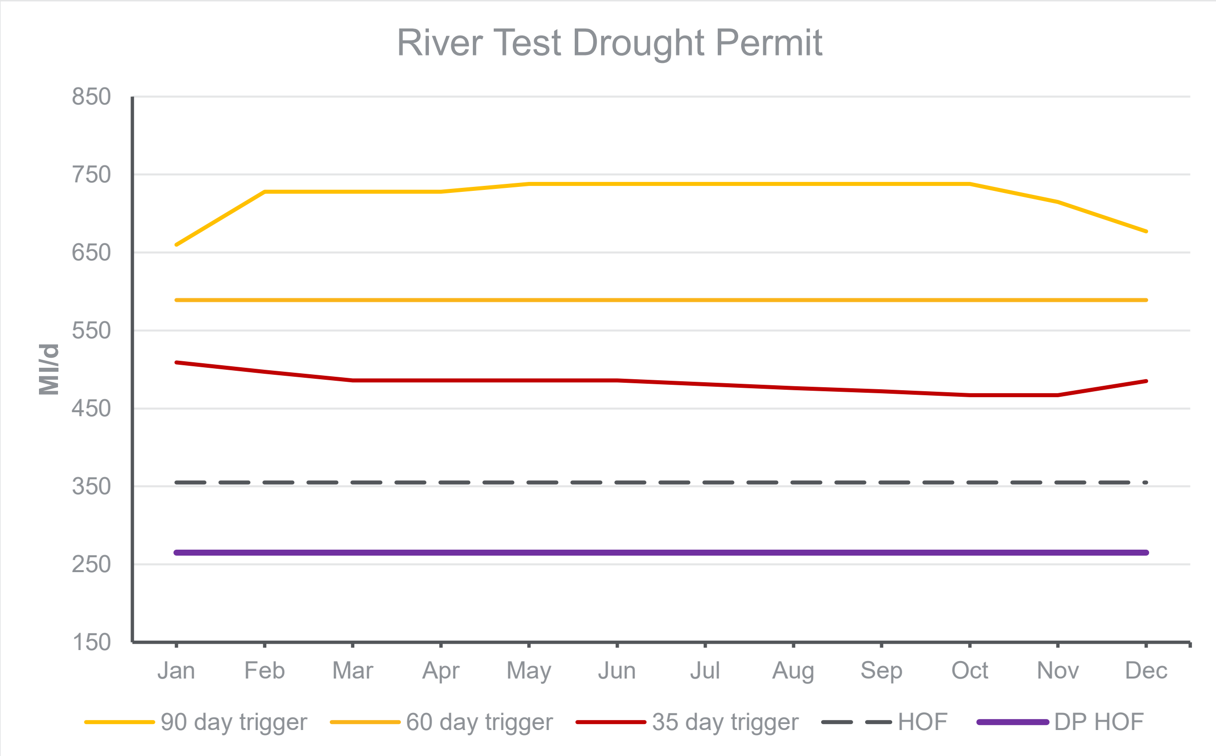


Figure 27: Time based triggers for the River Test Drought Permit

This figure is consistent with that shown in the main drought plan. These triggers are unchanged since the February 2024 submission, but the graph has been simplified so that it no longer shows the 2019 drought plan triggers. The dashed line labelled HOF in the figure above indicates when the flow has reached the Hands Off Flow (HOF). If the EA were to grant a Drought Permit (DP) for the River Test then this is the point when it would be implemented. If this Drought Permit were implemented, the revised HOF would be the flow shown by the purple line i.e. the Drought Permit Hands Off Flow (DP HOF). The DP HOF is 265 Ml/d. The HOF would only be 265Ml/d for the period that the Drought Permit applies. After the Drought Permit expires, the HOF would revert to the previous value of 355 Ml/d.

The joint modelling study showed the River Test Drought Permit flow triggers, as included in our draft Drought Plan and updated compared to our 2019 Drought Plan, was appropriate in terms of timing and alignment with our required Section 20 Agreement actions at 60 and 35-days in advance of River Test 355Ml/d Hands-off-Flow for pre-consultation and application for the River Test Drought Permit.

Testing these triggers against a historical drought suggested that the triggers meet the required timing thresholds set out in the Section 20 agreement for historical droughts and a majority of the synthetic stochastic droughts. A key consideration was ensuring that the 35-day trigger for application and to allow determination of the River Test Drought Permit was always met.

3.5.4 River Test Drought Order (265Ml/d)

Under our previous 2019 drought plan there was only an implementation trigger for the River Test Drought order set at 265Ml/d. Unlike the River Test Drought Permit there are no time-based triggers for pre-consultation and application for this drought order set out in the Section 20 agreement.

Our review showed that the preparation, pre-consultation and application triggers for River Test Drought Order flow triggers, as included in dDP22, were triggered moderate frequently (every 0.5 to 9.1 years on average) but the Drought Order itself was very rarely implemented, the 265Ml/d flow threshold only being reach in extreme droughts (more than 1 in 400 year return period). The study concluded that the time-based triggers could be relabelled, and our interventions adjusted accordingly to better match the modelled recession characteristics.

We therefore propose to make the following modifications to this trigger set from those in the draft Drought Plan:

- The 90-day trigger included in dDP22 will be dropped
- The 60-day trigger included in dDP22 will be relabelled as a 90-day trigger, better matching modelled recession rates and will be linked to actions to begin internal drought order preparation (~1 in 9 year frequency)
- The 35-day trigger included in dDP22 will be relabelled as a 60-day trigger, better matching modelled recession rates and will be linked to actions to begin formal drought order pre-consultation (~1 in 9 year frequency).

The proposed triggers we intend to adopt for the River Test Drought Order are set out in Table 19 and Figure 28. Because of the adjustment to the triggers this means that we will no longer have a dedicated "35-day" application threshold. We propose to develop an application threshold trigger (be that 35-days or otherwise as appropriate) as part of our programme of further work. In the interim period we will use our flow forecasting approach (set out in section 4.4) to forecast the timing and likelihood of flow recession and would intend to submit the application no later than 35-days before we forecast there to be a significant risk with the 265Ml/d flow threshold for implementation of the River Test Drought Order being reached.

Table 19 comparison of DP19 and proposed DP22 flow trigger sets for the River Test Drought Order (355Ml/d)

	DP19 Trigger Set (Ml/d)	Proposed DP22 Trigger set (Ml/d)		
Month	Implementation only	90-day	60-day	35-day
Jan	265	443	367	N/A
Feb	265	443	367	N/A
Mar	265	443	367	N/A
Apr	265	445	369	N/A
May	265	416	360	N/A
Jun	265	415	350	N/A
Jul	265	409	341	N/A
Aug	265	407	341	N/A
Sep	265	400	340	N/A
Oct	265	400	340	N/A
Nov	265	430	340	N/A
Dec	265	445	326	N/A

In lieu of no longer having a 35-day "application" trigger we propose to base the need for a drought order application on our flow forecast modelling and our perceived risk of recession below 265Ml/d in consultation with the Environment Agency noting that by the time of any drought order application (and beyond the 60-day trigger) formal pre-consultation with the Environment Agency under the Section 20 agreement would already have been instigated for the River Test Drought Permit and that permit would already have been applied for.

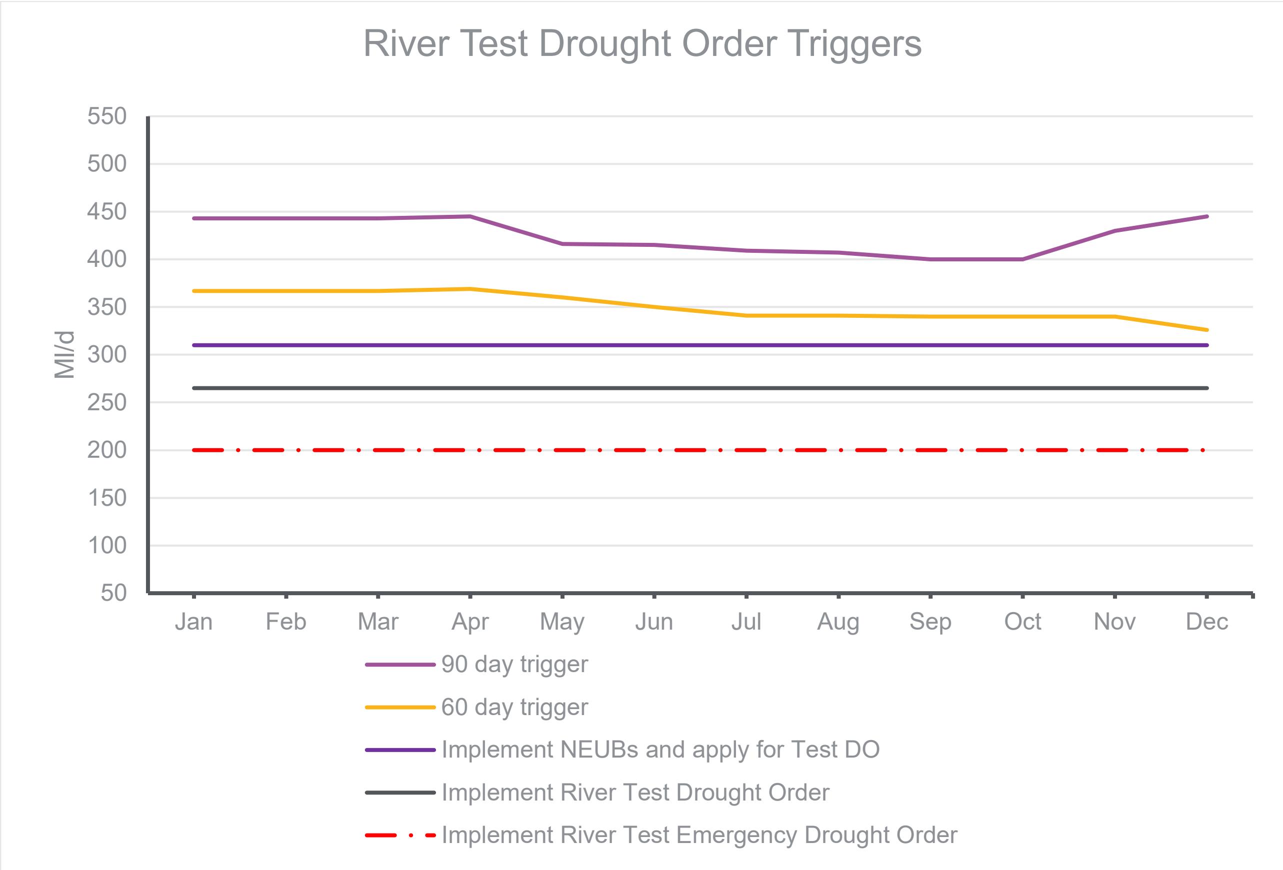


Figure 28 Summary of triggers for the River Test Drought Order

This figure is now consistent with the graphs and tables shown in the main drought plan. The graph no longer contains a 35-day trigger. This is explained below in this section and in the flow forecasting text in section 4.4.

A further outcome of the modelling study to note, irrespective of the trigger levels, is that the examination of the coherence of drought flow recession for the River Test and Itchen showed that, in severe to extreme drought events, the 265 Ml/d River Test Drought Order threshold was only reached ahead of the River Itchen 198 Ml/d Drought Order threshold 2% of the time and so in a severe drought event it is likely that the Candover and/or River Itchen Drought Order implementation would likely be required before the River Test Drought Order. This feature of the flow recession therefore imposes some limitations on sequencing of interventions under the Section 20 Agreement.

3.5.5 River Itchen Drought Orders

Drought triggers for the River Itchen have been based on the WRSE stochastic Itchen near Eastleigh flow series with comparison against the historical observed flows at the gauging station. The triggers have been defined based on the 205Ml/d threshold for the Candover Drought Order. The trigger derivation followed the general approach already outlined but with the following exceptions:

- The WRSE stochastic flow data was not baseflow separated as the dataset is based on an Interpolated groundwater model output which is already more consistent with baseflow.
- The baseflow separated historical series was used for the calculation of the maximum baseflow drops due to the series exhibiting steeper recessions than the stochastic series. A buffer of 20Ml/d was applied to the threshold to include more recessions in the calculation as the historical series has

a limited number of occasions where the original threshold is breached. When calculating the final trigger, the additional 20Ml/d was excluded.

Following the refinements undertaken post submission of dDP22 and the outcomes of the joint modelling study we propose to adopt the "Alternative" combined trigger set for the Candover Drought Order ahead of 205Ml/d (Set D in Table 17) and the new 35-day trigger for the River Itchen Drought Order ahead of 198Ml/d (Set E in Table 17) with the following modifications:

- Set D - 90-day combined River Itchen trigger is to be dropped
- Set D - 60-day combined River Itchen Trigger is to be relabelled as a combined 90-day trigger linked to internal preparation of the Candover and/or River Itchen (Allbrook and Highbridge) Drought Order
- Set D – 35-day combined River Itchen Trigger (for 205Ml/d) is to be relabelled as a combined 60-day trigger linked to formal pre-consultation of the Candover
- Set E – 35-day trigger for the River Itchen Drought order is to be relabelled as a combined 60-day trigger linked to formal pre-consultation of the River Itchen (Allbrook and Highbridge) Drought Order and Portsmouth Water's Lower Itchen abstraction licence Drought Order.

Because the joint modelling with Portsmouth Water suggested that the previous triggers were being crossed too frequently we have adopted the approach set out above. This means that the 35-day trigger is relabelled as the 60-day trigger. These modifications mean that this plan no longer contains an Itchen 35-day trigger. In the main drought plan report we illustrate this in figures 2.9, 3.3, 3.5 and 3.6. Later in this document in section 4.4 on flow forecasting we describe the advantages of using that technique instead of a rigid 35 day trigger.

These modifications do not affect the River Test 35-day trigger that is referred to in the Section 20 Agreement.

Our DP19 included an early warning Level 1 Trigger (set at 1 in 5 year flows) and a Level 2 trigger set at 206Ml/d just in advance of the Candover Augmentation. Comparisons of the DP19 and proposed DP 22 trigger sets are presented in Table 20 and Figure 29.

Table 20 comparison of DP19 triggers and proposed "Alternative" DP22 Triggers for the Candover (Set D) and River Itchen (Set E) Drought Orders

	DP19 Trigger Set (Ml/d)		Proposed DP22 Trigger sets D and E (Ml/d)		
Month	Level 1 Trigger	Level 2 Trigger	90-day (Set D)	60-day to 205Ml/d (Set D Candover)	60-day to 198Ml/d (Set E River Itchen)
Jan	280	206	241	224	218
Feb	355	206	255	237	218
Mar	370	206	273	241	231
Apr	345	206	280	244	237
May	305	206	315	258	249
Jun	270	206	355	278	265
Jul	245	206	315	289	242
Aug	225	206	280	252	242
Sep	220	206	274	252	242
Oct	220	206	274	252	242
Nov	220	206	258	242	237
Dec	220	206	240	233	223

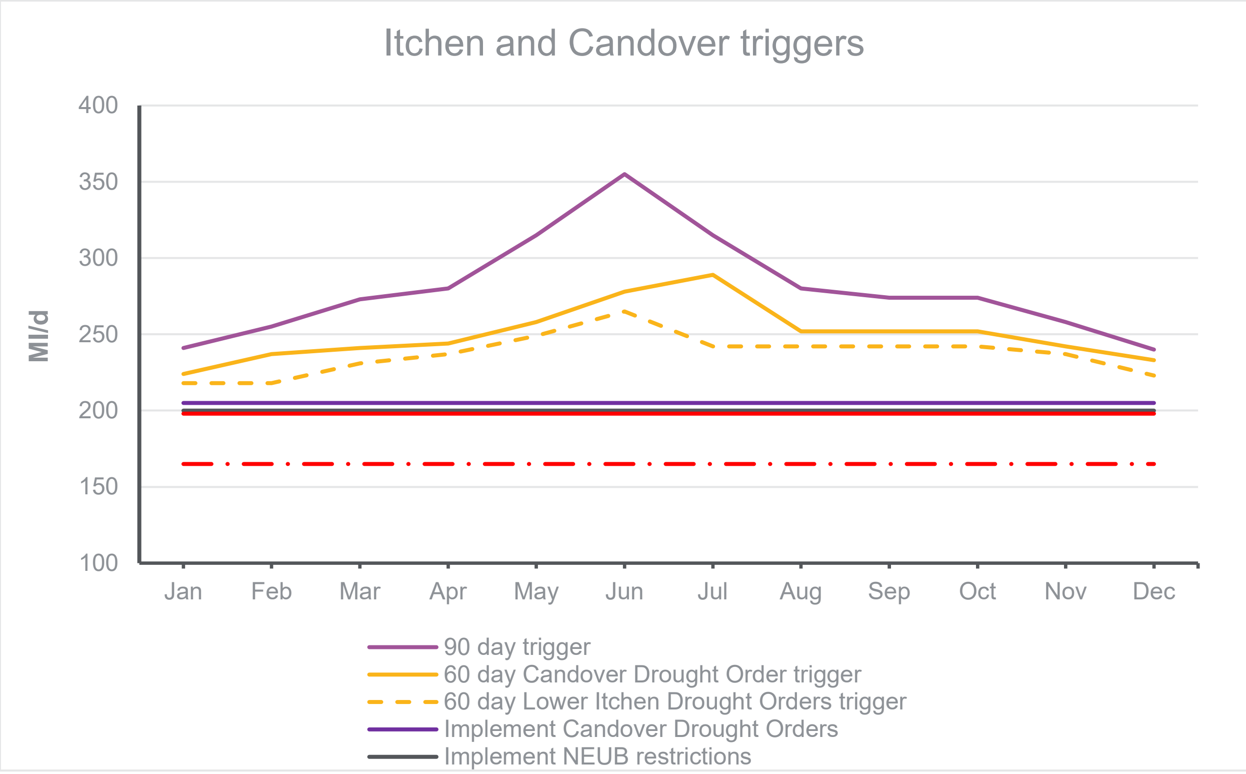


Figure 29 Triggers for the Candover and River Itchen Drought Orders

This figure is now consistent with the graphs and tables shown in the main drought plan. For example, the graph above no longer shows the 2019 drought plan triggers.

The DP19 and DP22 tiggers share different shapes because they differ in how they were derived. The DP19 triggers were based on monthly flow return periods whilst the DP22 triggers were based on the potential time before flow recession to the Hands off Flow or Candover Drought Order threshold. The proposed DP22 triggers are therefore more directly linked to interventions than those for DP19 and their shape varies according to the gradient of the expected flow recession.

As with the River Test Drought Order, it should be noted that the frequency of reaching these triggers is less than for the River Test Drought Permit and hence liaison with regulators regarding that drought permit is likely to have already started prior to any application for this drought option.

3.5.6 Trigger Validation and System Simulation

Because of the complex interactions between the various River Test and River Itchen Drought Interventions and downstream impacts on Portsmouth Water's supplies in the Lower Itchen we undertook a joint modelling and validation exercise with Portsmouth Water to further explore the effectiveness of the Test and Itchen Drought Triggers. The study would also aim to address several representations we received from the Environment Agency

The key findings are summarised below:

- Our stated levels of service for water use restrictions and the frequency of drought permit application and implementation in WRMP19 can be met or exceeded and therefore remain unchanged.

- Use of the Candover Augmentation Scheme Drought Order greatly reduces the frequency of use of the Lower Itchen Drought Order
- The application of demand restrictions up to and including Non-Essential Use Bans only has a minor impact on reducing use of the Candover Augmentation Scheme Drought Order. In severe droughts where these interventions are required the rate of river flow recession below drought order and hands-off-flow conditions outpaces the expected impact of demand restrictions
- The River Test Drought Permit Triggers to the 355Ml/d Hands off Flow condition are set at appropriate thresholds to meet the required timings (60-day, 35-day) set out in the Section 20 Agreement
- The River Test Drought Order Triggers derived from our baseflow separation provide greater warning times than stated in our draft drought plan and hence we have revised warning thresholds downwards from those in our draft drought plan in order to trigger less frequently.
- The draft Candover Drought Order Trigger curves provide greater warning times could be revised downwards to be triggered less frequently and hence we have revised warning thresholds downwards from those in our draft drought plan in order to trigger less frequently.
- Use of the transfer from HSW to HSE is important in reducing the frequency of drought interventions in HSE such as the Candover Augmentation Scheme or the River Itchen Drought Order. If the Environment Agency were to impose similar conditions to our 2019 River Test Drought Permit during a drought event this would necessitate earlier and more frequent drought interventions being required on the River Itchen to maintain supplies to HSE.
- In the context of drought intervention timing for coherent drought events on the River Test and Itchen the Test Drought Permit is utilised most frequently and nearly always in advance of interventions on the River Itchen. However, the need for the River Test Drought Order was found to occur much less frequently than that for the River Itchen Drought Order, even with the Candover Augmentation Scheme Drought Order in operation. The most likely sequencing of drought permit and order interventions in terms of water resources need in our Western Area is therefore likely to be Test Drought Permit > Candover Drought Order > Itchen Drought Order > Test Drought Order. In accordance with the Section 20 agreement, the sequencing of further drought interventions following implementation of the River Test Drought Permit would consider the ecological considerations and impacts and would be discussed with the Environment Agency and Natural England.
- It had been assumed in the Section 20 Agreement that the utilisation of the River Itchen Drought Order would be concurrent with the Portsmouth Water's Lower Itchen abstraction licence order. However, modelling results show that the frequency of implementation of the Portsmouth Water's Lower Itchen abstraction licence Drought Order is much greater than that for the Itchen Drought Order based on the current model setup. This will have implications for the timing of drought interventions set out in the Section 20 Agreement. The use of the Portsmouth Water's Lower Itchen abstraction licence Drought Order is shown to be driven by demand in Southern Water's System rather than Portsmouth Water.

3.5.7 Western Rother (Central area)

A critical resource in the Central area is the combined run-of river and groundwater abstraction located at Pulborough. This resource is used in both the SNZ and the SWZ via a transfer main between the two WRZs.

Drought conditions are monitored based on the semi-naturalised flow over the weir (i.e. flow net of the surface abstraction near Pulborough), and groundwater levels in abstraction borehole (ABH) 10. Flows over Pulborough weir form a key drought trigger for the Central area, and we have developed return period 'breach' curves based on 1-in-10 years and 1-in-20 years flow deficits.

Since Pulborough is a conjunctive use source, the risk to the resource comes from a combination of the magnitude and duration of surface water availability, as longer periods of low river levels mean there is a greater reliance on the groundwater storage. The trigger curves are therefore based on cumulative deviation from the long-term mean, rather than absolute river flows. Catchmod models of both the Western Rother and River Arun are available for resource forecasting at this site.

We have attempted to derive time-before-flow based triggers for the Western Rother similar to those for the River Test and Itchen. However, due to the lower permeability of the catchment, it typically has a much flashier response to rainfall events. Additionally, the actions of upstream abstractors can cause large step changes in flow. This has complicated the development of time-based flow triggers because adoption of appropriate baseflow separation parameters has proven difficult to find a balance between providing sufficient lead-time between trigger breaches and too frequent breaches of trigger levels that would often trigger drought actions unnecessarily. We will continue development of these triggers through the consultation period and will engage with the EA to consider whether it is appropriate to adopt a time-before-flow approach in our final plan for the Western Rother.

The current River Rother trigger curve has been calculated using the following approach:

- The Q_{75} for monthly flows are calculated based on the 1961-1990 period.
- The difference between these and actual in-month totals are calculated and added on a cumulative basis.
- The trigger curves are calculated based on percentages from these deficit profiles.
- Relevant percentiles have been selected to represent a 1-in-5 years (Level 1), 1-in-10 years (Level 2) and 1-in-20 years (Level 3) frequency of exceedance.

This approach addresses and balances all the operational needs for this indicator, namely that:

- It should provide an indicator of how severe the recession is during the spring year so that drought actions for the summer peak and autumn minimum flows can be initiated.
- It should indicate how long river flows have been below the threshold at which abstraction starts to become limited during the summer. This is important as it provides an indicator of the stress that the key groundwater storage site in SNZ has experienced because of abstraction during the drought.
- It should indicate the timing of the recharge period, and in particular, when this is late enough to cause concerns over the next year's recession.

Figure 30 shows the trigger curve for the River Rother. For comparative purposes, cumulative deficit lines for historic drought sequences have been plotted against the trigger curves.

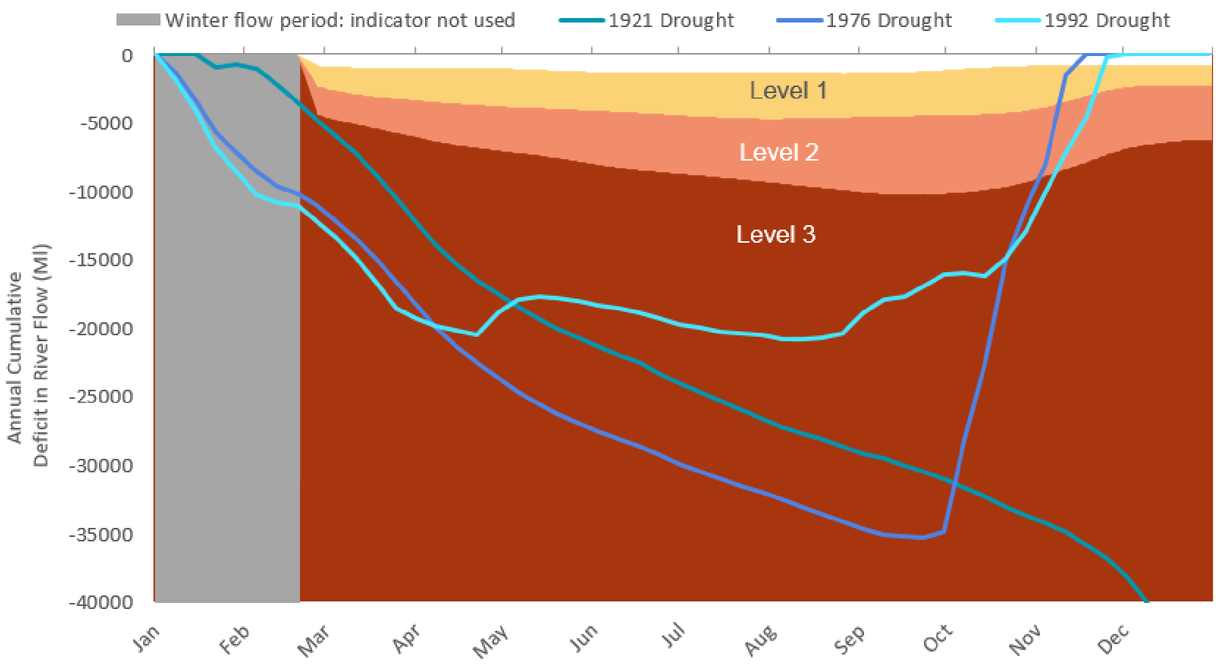


Figure 30: Cumulative flow deficit triggers for the Western Rother.

The dominant influence of abstraction on groundwater levels within the Pulborough groundwater basin source means that ABH10 is used for reference, rather than as a drought trigger.

Drought actions are defined for three different thresholds, the baseline minimum residual flow at 63.64Ml/d, and drought permit/order actions taken at Level 2 and Level 3 that would lower the MRF to 53.64Ml/d and 43.64Ml/d respectively.

3.6 Drought triggers – reservoirs

We have updated our reservoir triggers from DP19 for Bewl, Darwell and Powdermill. As the greatest threat to supplies in SNZ is low flows on the River Rother, our drought actions for this WRZ are primarily driven by our flow triggers. The previous reservoir trigger curves for Weir Wood remain valid but were not updated as they are unlikely to trigger in advance of the primary river triggers.

We have four main reservoirs in our supply area.

- Bewl reservoir (Eastern area)
- Darwell reservoir (Eastern area)
- Powdermill reservoir (Eastern area)
- Weir Wood reservoir (Central area)

Due to the interconnected nature of the RMS and the Bewl-Darwell internal transfer, we have developed a combined resource metric for our Eastern area surface water resources. Therefore, a combined metric for Bewl, Darwell and Powdermill based on the combined storage data has been developed.

Based on the analysis of WRMP19 stochastic reservoir storage data the triggers have been developed for Level 2 (1-in-10 years) and Level 3 (1-in-20 years) thresholds which have been defined by the day of the year from 0 to 365. Although for leap years the 366th day has not fed through into the calculations, it is considered an acceptable approximation to adopt the same value for the 29th February and the 28th February. Manual adjustments have been made to ensure a representative number of years with crossings over the 2000-year stochastic dataset. Some smoothing has been applied using a 61-day average smoothing profile due to the variability evident within the profiles. The trigger levels were checked against the historical observed reservoir levels and available Aquator series.

For the Bewl-Darwell reservoir system, there are also secondary control curves that seek to optimise the transfer of water between the two reservoirs in order to optimise the overall DO of the system. The transfers are started when Darwell levels fall below a certain value but controlled based on remaining levels within Bewl.

The final combined trigger curves are shown in Figure 31, with individual triggers shown in Figure 32 to Figure 35.

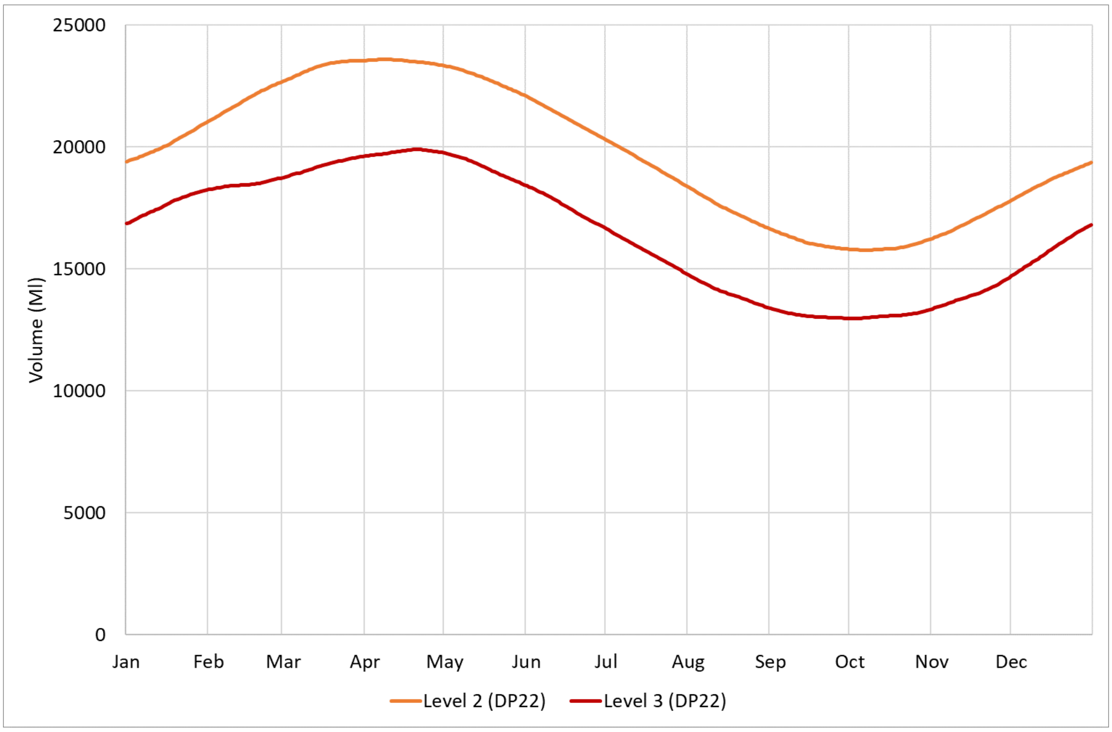


Figure 31: Trigger curves for combined reservoir metric.

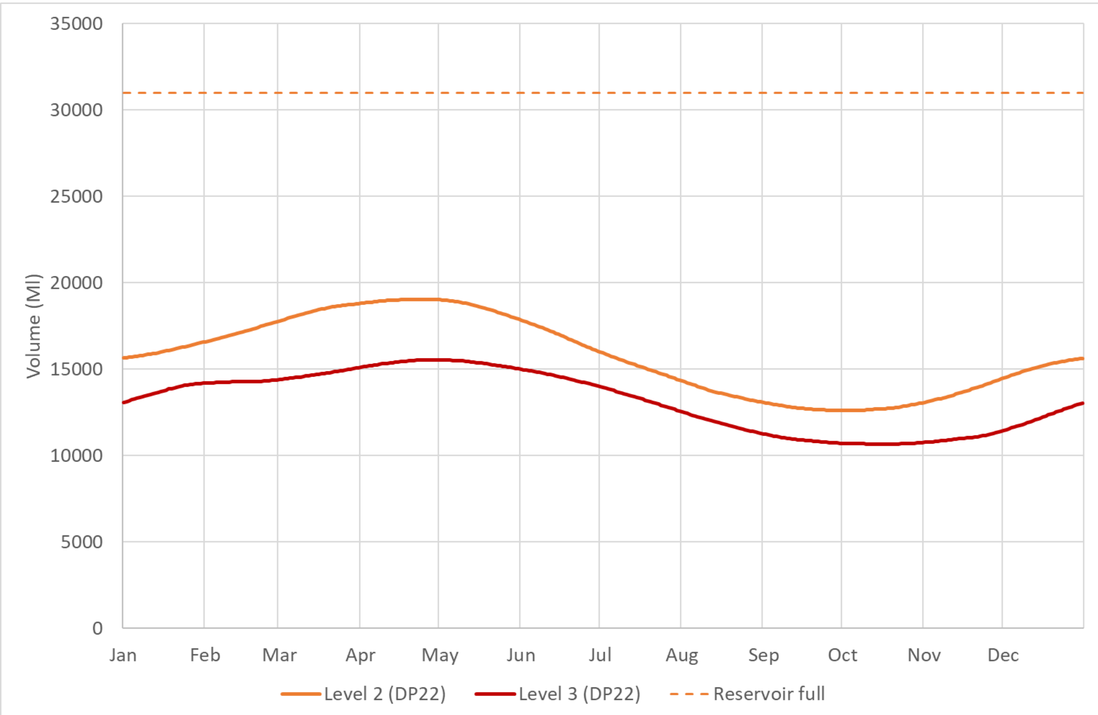


Figure 32 Trigger curves for Bewl reservoir.

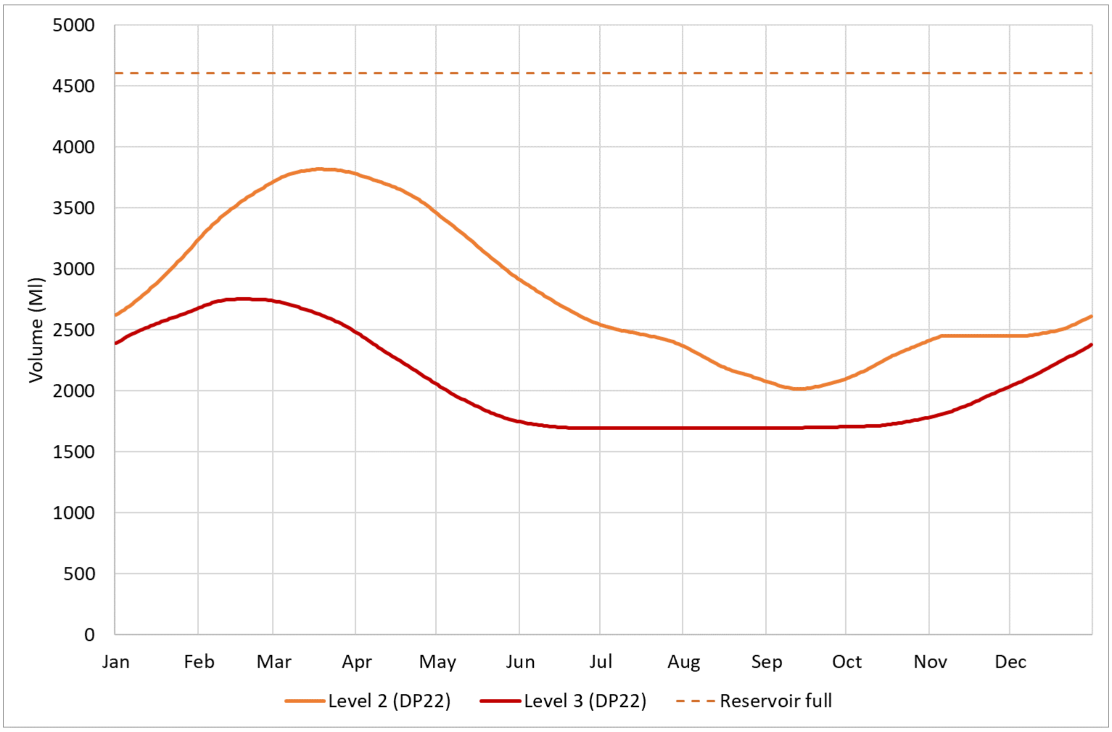


Figure 33: Trigger curves for Darwell reservoir.

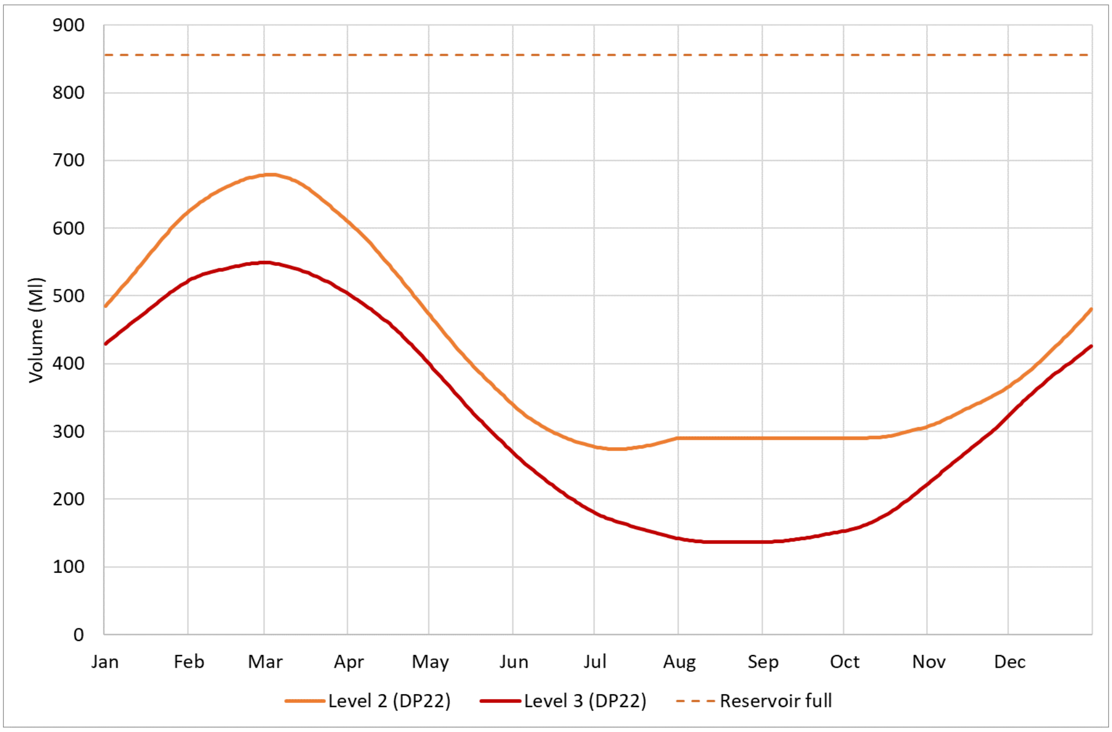


Figure 34: Trigger curves for Powdermill reservoir.

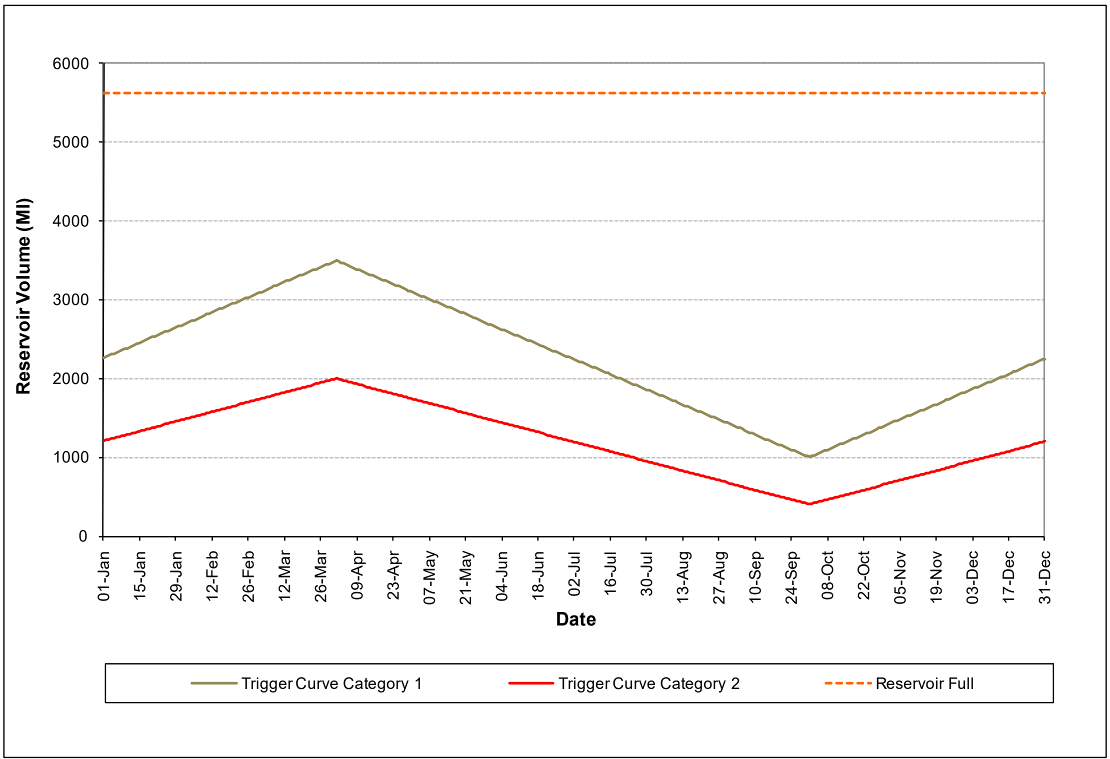


Figure 35: Trigger curves for Weir Wood reservoir.

4. Drought Phasing

We have developed triggers based on our analysis of a wide range of drought events considering a variety of different monitoring data. The triggers are progressive in nature and therefore intended to reflect the increasing severity of a drought event so that measures that are associated with each set of triggers are only introduced when they are required.

In general, for each WRZ, the start of a drought (Level 1), which involves voluntary actions, has been defined as any SPI or SPEI trigger crossing the 1-in-5 years trigger threshold. The exception to this is in relation to the River Test and River Itchen where drought actions are defined under the Section 20 Agreement. For this, the start of drought is defined with a 60-day threshold to start preparation of drought permit and water efficiency measures. An additional 90-day trigger is also defined to provide an internal early warning. This will nearly always be a 90-day threshold triggered for the River Test and it will typically occur in advance of even moderate rainfall deficits developing.

Level 2 and Level 3 actions will tend to be defined with triggers crossing the 1-in-10 years and 1-in-20 years thresholds respectively, except for the River Test and River Itchen where drought actions are defined under the Section 20 Agreement. For each WRZ, primary and supporting triggers have been defined.

Primary triggers include the river flow, reservoir storage or groundwater levels and supporting triggers include SPI and SPEI triggers for associated durations as well as groundwater levels and triggers based on other WRZs. We have defined the associated duration for SPI and SPEI based on a comparison of historic drought occurrence between the primary trigger and different SPI and SPEI durations.

Level 2 or Level 3 actions can be initiated based on the primary trigger or based on the SPI or SPEI trigger if the primary trigger is close to its respective trigger. It is important to note that the trigger levels do not require both SPI and SPEI to initiate the next phase of drought actions.

In the case where due to data availability or recording issues a trigger is not available, actions may be initiated based on primary or supporting triggers alone. In addition to this, we may consider the use of alternative duration SPI and SPEI metrics as necessary to support an ESoR case for any drought permit/order applications. This follows our lessons learned from the Section 20 Agreement process for the River Test Drought Permit in 2019 and 2020.

A drought ends when normal conditions resume and the risk to security of supply and the environment are no greater than they would be in a normal year. Several indicators are used to determine that a drought has ended. This varies for each WRZ but in general consists of the primary trigger (river flow, reservoir storage or groundwater level) exiting the defined trigger thresholds and SPEI reaching a defined threshold. From comparisons for historic droughts (discussed in Section 5.1) we found that SPEI for the associated durations for each WRZ corresponds well to the progression of the primary triggers as it considers not just the significance of the rainfall deficit but also seasonality by accounting for PET and hence providing a better metric of hydrological drought.

Further details on the multifactorial triggers identified for each WRZ are discussed below. The phasing and combination of triggers adopted for each of the defined Level 1 to Level 3 as well as the end of drought conditions are also included specific to each WRZ.

4.1 Eastern area

In the Eastern area, our primary and supporting triggers are defined for each WRZ as follows:

- KTZ: Observation borehole groundwater level.
- KME and KMW: The combined reservoir storage volume for the Bewl, Darwell and Powdermill system with an observation borehole groundwater level as a supporting trigger.
- SHZ: The combined reservoir storage volume for the Bewl, Darwell and Powdermill system.

The relatively long storage times involved in the Bewl-Darwell reservoir system and the KME, KMW and KTZ borehole sources means that the SPI and SPEI indicators that have been chosen are a combination of moderately long and very long-term rainfall and hydrological deficits (12 months and 30 months). A schematic of primary and supporting triggers is shown in Figure 36.

The phasing of triggers is set out in Figure 37. For groundwater level triggers, due to the uncertainty in and closeness of some of the trigger levels, there is greater flexibility to define drought plan actions based on a combination of groundwater level and associated SPI or SPEI duration triggers.

The combined reservoir storage tends to trigger in advance of the associated SPI and SPEI triggers due to the quicker responding nature of the surface water system. As such, the reservoir storage trigger is most likely to initiate the Level 2 and Level 3 phases. However, SPI and SPEI are included in case there is a situation where these provide some advance warning. Although Bewl is located in the KMW WRZ, for simplicity, we use the same combined reservoir storage metric as for the SHZ WRZ.

Drought end thresholds for SPEI have been checked against historic droughts and set at -0.5 for all WRZs.

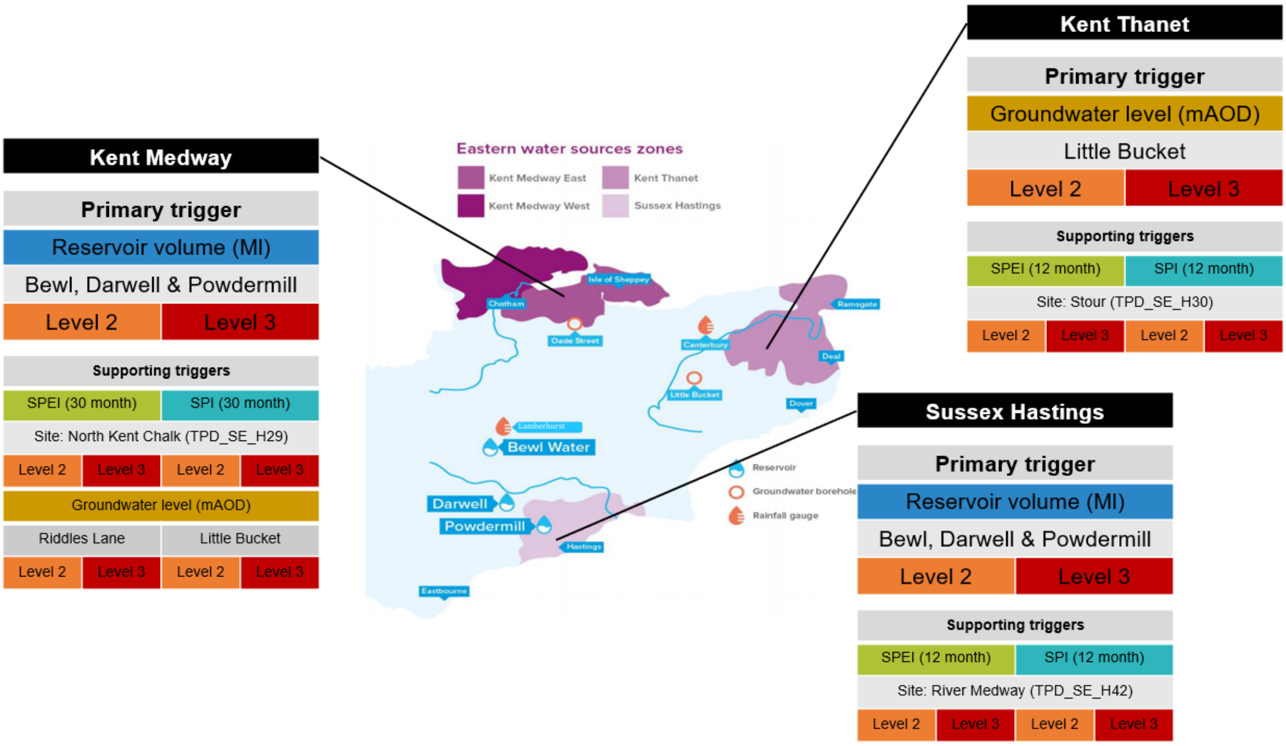


Figure 36: Eastern area primary and supporting triggers.

Zone	Trigger	Level 1	Level 2	Level 3	Drought end
Kent Medway	Reservoir volume: Bewl, Darwell & Powdermill Groundwater level: Riddles Lane Groundwater level: Little Bucket SPI (30 month rolling): North Kent Chalk SPEI (30 month rolling): North Kent Chalk	• SPEI or SPI **below** 1 in 5 year threshold OR • Level 1 conditions triggered in Sussex Hastings zone OR • Either GW level **below** 1 in 5 year threshold	• Reservoir volume **below** 1 in 10 year trigger curve OR • Either GW level **below** 1 in 10 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• Reservoir volume **below** 1 in 20 year trigger curve OR • Either GW level **below** 1 in 20 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	• SPEI **above -0.5** AND • Reservoir storage above 1 in 10 year trigger curve AND • Both GW levels above 1 in 10 year trigger curve
Kent Thanet	Groundwater level: Little Bucket SPI (12 month rolling): Stour SPEI (12 month rolling): Stour	• SPEI or SPI **below** 1 in 5 year threshold OR • GW level **below** 1 in 5 year threshold	• GW level **below** 1 in 10 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• GW level **below** 1 in 20 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	• SPEI **above -0.5** AND • GW level above 1 in 10 year trigger curve
Sussex Hastings	Reservoir volume: Bewl, Darwell & Powdermill SPI (12 month rolling): River Medway SPEI (12 month rolling): River Medway	• SPEI or SPI **below** 1 in 5 year threshold	• Reservoir volume **below** 1 in 10 year trigger curve OR • SPEI / SPI **below** 1 in 10 year trigger curve and reservoir volume **close to** 1 in 10 year trigger curve	• Reservoir volume **below** 1 in 20 year trigger curve OR • SPEI / SPI **below** 1 in 20 year trigger curve and reservoir volume **close to** 1 in 20 year trigger curve	• SPEI **above -0.5** AND • Reservoir storage above 1 in 10 year trigger curve

Note: If due to data availability / recording issues drought plan action levels may be initiated based on primary or supporting triggers alone.

Figure 37: Eastern area trigger phasing.

4.2 Central Area

In the Central area, our primary and supporting triggers are defined for each WRZ as follows:

- SWZ: Observation borehole groundwater level.
- SBZ: Observation borehole groundwater level.
- SNZ: Cumulative flow deficit triggers for the Western Rother at Pulborough.

Groundwater provides an important source in the Central area drawing on abstractions from the SBZ and SWZ groundwater sources. Although Chilgrove is located outside the SWZ WRZ, it serves as an indicator of the groundwater levels in the Chalk block. The Western Rother is an important surface water source for the Pulborough supply works.

Comparison of the primary triggers and supporting SPI and SPEI triggers indicates the Central area sources tend to be vulnerable to relatively short droughts of between 6 and 18 months. SPI and SPEI indicators have therefore been chosen as 12 months for SNZ and SBZ WRZs and 6 months for SWZ to match the historic drought occurrence and provide lead-time against the primary triggers. A schematic of primary and supporting triggers is shown in Figure 37.

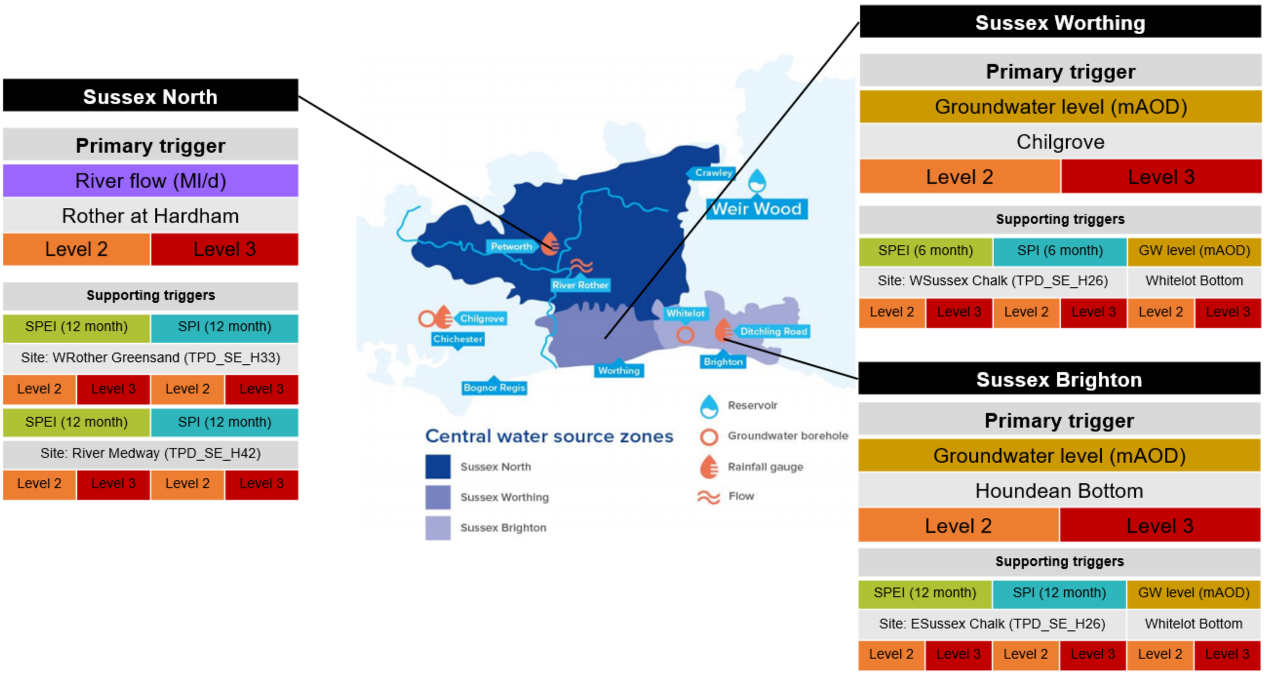


Figure 38: Central area primary and supporting triggers.

The phasing of triggers is set out in Figure 38. For groundwater level triggers, due to the uncertainty in and closeness of some of the trigger levels there is greater flexibility to define drought plan actions based on a combination of groundwater level and associated SPI or SPEI duration triggers.

The cumulative flow deficit trigger for the River Rother tends to trigger in advance of the associated SPI and SPEI triggers due to the quicker responding nature of the surface water system. As such, the cumulative flow deficit is most likely to initiate the Level 2 and Level 3 phases. However, SPI and SPEI are included in case there is a situation where these provide some advance warning.

	Trigger	Level 1	Level 2	Level 3	Drought end
Sussex North	River flow: Rother at Hardham SPI (12 month rolling): W Rother Greensand SPEI (12 month rolling): W Rother Greensand SPI (12 month rolling): River Medway SPEI (12 month rolling): River Medway	• Either series SPEI or SPI **below** 1 in 5 year threshold	• Cumulative flow deficit **below** 1 in 10 year trigger curve OR • Either series SPEI / SPI **below** 1 in 10 year trigger curve and Cumulative flow deficit **close to** 1 in 10 year trigger curve	• Cumulative flow deficit **below** 1 in 20 year trigger curve OR • Either series SPEI / SPI **below** 1 in 20 year trigger curve and Cumulative flow deficit **close to** 1 in 20 year trigger curve	• Both series SPEI **above -0.5** AND • Cumulative flow deficit above 1 in 10 year trigger curve
Sussex Brighton	Groundwater level: Houndean Bottom Groundwater level: Whitelot Bottom SPI (12 month rolling): ESussex Chalk SPEI (12 month rolling): ESussex Chalk	• SPEI or SPI **below** 1 in 5 year threshold OR • Either GW level **below** 1 in 5 year threshold	• Either GW level **below** 1 in 10 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• Either GW level **below** 1 in 20 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	• SPEI **above -0.5** AND • Both GW levels above 1 in 10 year trigger curve
Sussex Worthing	Groundwater level: Chilgrove Groundwater level: Whitelot Bottom SPI (6 month rolling): WSussex Chalk SPEI (6 month rolling): WSussex Chalk	• SPEI or SPI **below** 1 in 5 year threshold OR • Either GW level **below** 1 in 5 year threshold	• Either GW level **below** 1 in 10 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• Either GW level **below** 1 in 20 year trigger curve and SPEI / SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	• SPEI **above -0.5** AND • Both GW level above 1 in 10 year trigger curve

Note: If due to data availability / recording issues drought plan action levels may be initiated based on primary or supporting triggers alone.

Figure 39: Central area trigger phasing.

Drought end thresholds for SPEI have been checked against historic droughts and set at -0.5 for all WRZs.

4.3 Western area

In the Western area, the primary triggers for HSE and HSW relate to the River Test and Itchen flows and are subject to a specific set of thresholds and actions as defined in the Section 20 Agreement. In addition to this the groundwater observation boreholes for the Northern Hampshire WRZs and HSE and HSW are also included though these are more drought resilient than the surface water sources.

Separate triggers have been defined for the IOW based on the indigenous groundwater resources. Given the need for supplies from the cross-Solent main, the IOW is dependent on supplies from Hampshire. As such, this WRZ drought phasing is also linked to that for Hampshire South (HSE and HSW).

The response of resources to rainfall is markedly different for the high storage, persistent, chalk fed sources of the mainland and the low storage, constrained sources of the IOW. The Test and Itchen resources are more likely to be affected by a combination of both long-term drought (up to 24 months duration), which reduces groundwater storage and baseflow, and shorter-term drought events (12 months). Given the relative importance of the river flow indicators a single 12-month duration indicator has been adopted for the SPI and SPEI. For the IOW, the quicker responding groundwater is linked to a 6-month duration SPI and SPEI. These timescales are consistent with the critical drought durations identified by our drought vulnerability assessment. A schematic of primary and supporting triggers is shown in Figure 40.

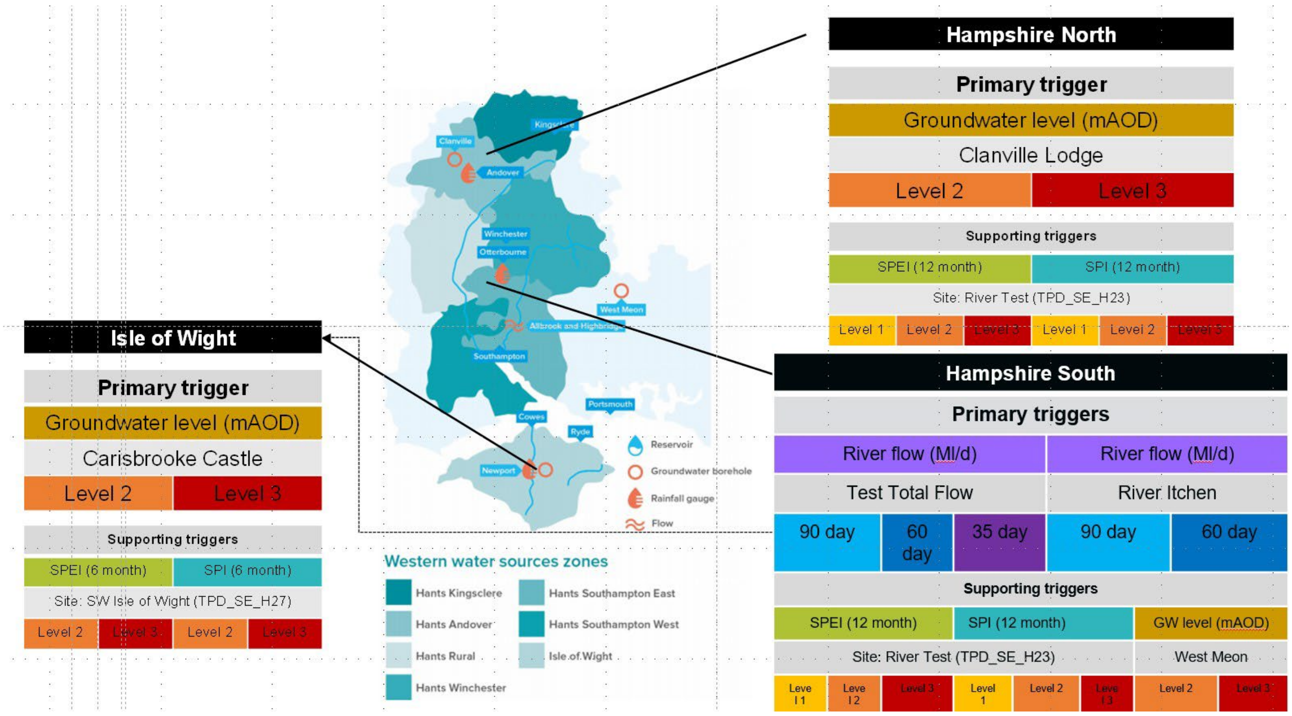


Figure 40: Western area primary and supporting triggers.

Note that this figure has had the River Itchen 35-day trigger removed from it. For more details on this refer to section 3.5.5.

The phasing of triggers is set out in Figure 40 incorporating the current trigger thresholds we use for the Test and Itchen. Both the Test and Itchen also have 90-day early warning triggers that provide additional lead-time to the Level 1 stage. It is expected that for Hampshire South in line with the Section 20 Agreement the river flow triggers will drive the drought plan actions. However, groundwater levels as well as the SPI and SPEI triggers will provide supporting information on the drought progression and can be used to initiate drought plan actions in addition to the river flow triggers. It is unlikely that these supporting triggers will provide any advance warning ahead of the time-based river flow triggers for the rivers Test and Itchen.

For Hampshire North, due to the uncertainty in and closeness of some of the trigger levels there is greater flexibility to define drought plan actions based on a combination of groundwater level and associated SPI or SPEI duration triggers, particularly as SPI and SPEI can provide some advance warning of drought conditions.

A similar principle applies for the IOW triggers where SPI and SPEI can also provide some advance warning of drought conditions. Since there is reliance on the cross-Solent main in this case, a linking trigger has been included to allow for alignment in drought conditions with the Hampshire South WRZs.

Drought end thresholds for SPEI have been checked against historic droughts and set at -0.5 for all WRZs with the exception of HSE and HSW WRZs where it has been set at 0.0.

Figure 41: Western area trigger phasing.

Area	Trigger	Level 1	Level 2	Level 3	Drought end
Isle of Wight	Groundwater level: Carisbrooke Castle SPI (6 month rolling): Stour SPEI (6 month rolling): Sour Hampshire South zone conditions	• SPEI or SPI **below** 1 in 5 year threshold OR • Level 1 conditions triggered in Hampshire South zone OR • GW level **below** 1 in 5 year threshold	• GW level **below** 1 in 10 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve OR • Level 2 conditions triggered in Hampshire South zone	• GW level **below** 1 in 20 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve OR • Level 3 conditions triggered in Hampshire South zone	• SPEI **above -0.5** AND • GW level above 1 in 10 year trigger curve AND • Drought end conditions met in Hampshire South zone
Note: If due to data availability / recording issues drought plan action levels may be initiated based on primary or supporting triggers alone.					
Hampshire North	Groundwater level: Clanville Lodge SPI (24 month rolling): River Test SPEI (24 month rolling): River Test	• SPEI or SPI **below** 1 in 5 year threshold OR • GW level **below** 1 in 5 year threshold	• GW level **below** 1 in 10 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• GW level **below** 1 in 20 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • **SPEI / SPI below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	• **SPEI above -0.5** AND • GW level above 1 in 10 year trigger curve
Note: If due to data availability / recording issues drought plan action levels may be initiated based on primary or supporting triggers alone. Note: 90-day trigger thresholds also exist for the Test and Itchen to provide additional internal lead time prior to the Level 1.					
Hampshire South	River flow: Test Total Flow (TTF)	TTF below 60-day to HoF 335Ml/d Subsequent triggers through Level 1: • TTF below 35-day to HoF 355Ml/d (DP application) • TTF below 90-day, 60 day, 35-day to DP HoF 265Ml/d	TTF below 356Ml/d Subsequent triggers through Level 2: • TTF below 35-day to DP HoF 265Ml/d	TTF below 310Ml/d	• **SPEI above 0.0** AND • TTF **above** 60-day HoF 355Ml/d threshold AND • Itchen above 60-day to 205Ml/d threshold AND • GW level above 1 in 10 year trigger curve
Hampshire South	River flow: Itchen – Highbridge & Allbrook	Itchen below 60-day to HoF 205Ml/d*	Application threshold determined by flow forecasting and in agreement with EA*	River Itchen Flows < 205 Ml/d* River Itchen Flows < 200 Ml/d* River Itchen Flows < 198 Ml/d*	
Hampshire South	Groundwater level: Carisbrooke Castle SPI (6 month rolling): Stour SPEI (6 month rolling): Sour	• SPEI or SPI **below** 1 in 5 year threshold OR • GW level **below** 1 in 5 year threshold	• GW level **below** 1 in 10 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 10 year trigger curve and GW level **close to** 1 in 10 year trigger curve	• GW level **below** 1 in 20 year trigger curve and SPEI/ SPI **below** 1 in 5 year threshold OR • SPEI / SPI **below** 1 in 20 year trigger curve and GW level **close to** 1 in 20 year trigger curve	

*Levels 1, 2 and 3 for the Itchen have been updated. For Level 1, 'subsequent triggers' have been removed; for Level 2, 'subsequent triggers' have been removed and the statement of 'Itchen below 206Ml/d' has been removed and replaced with 'application threshold determined by flow forecasting and in agreement with EA'. For Level 3, the statement 'Itchen below 205Ml/d' has been removed and divided into 3 categories for River Itchen Flows.

We have included the drought triggers for the Test, Itchen and Candover in figure 3.4, 3.5 and 3.6 of the main drought plan.

4.4 Flow forecasting

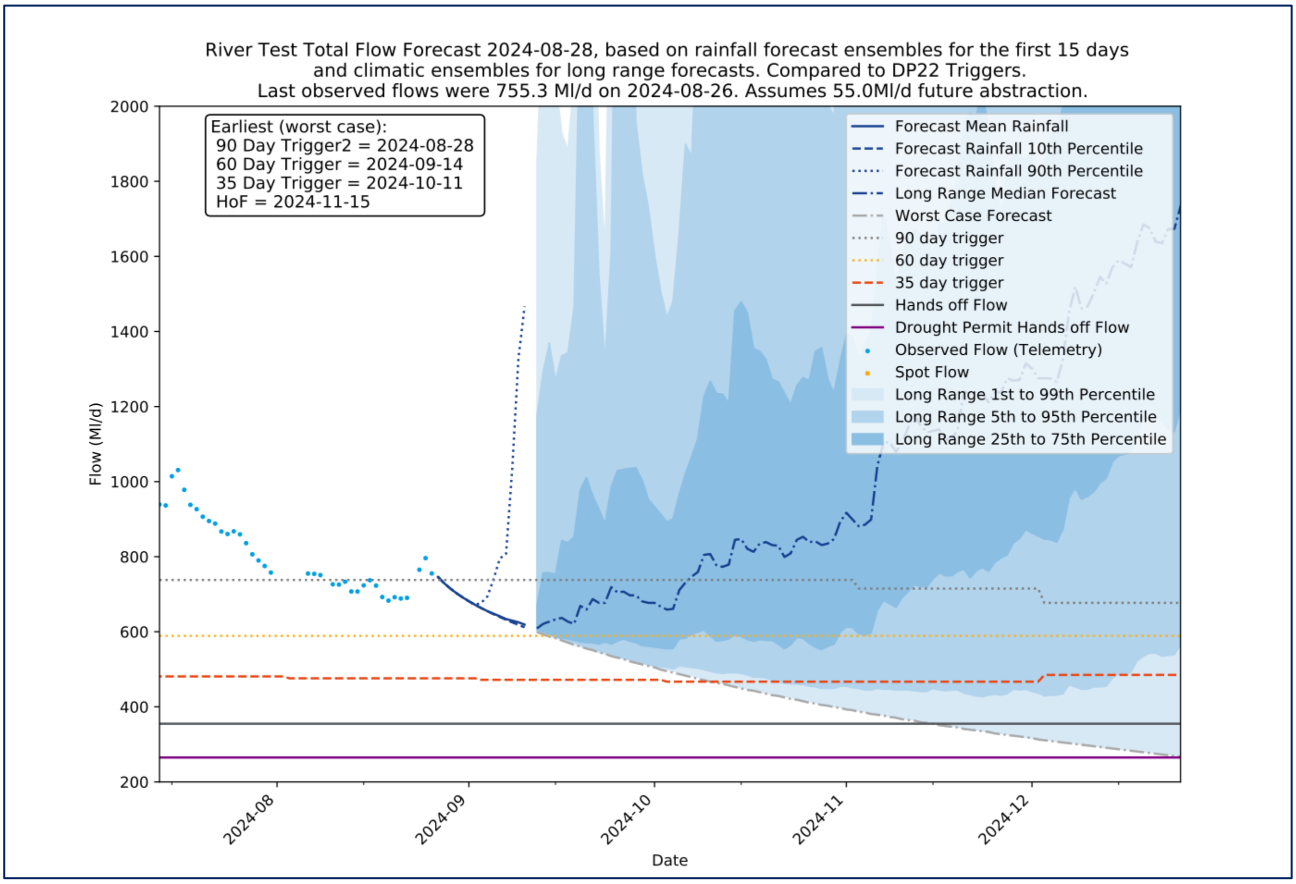
We use 'Catchmod' rainfall-runoff models to forecast potential river flows on both the River Itchen and the River Test. These models were parameterised and calibrated by the EA, and we have several years of experience of successfully using the models.

The models are configured to start at the latest observed flows and are then run into the future to provide an assessment of how flows might occur under a range of potential scenarios. The forecasts are based on actual forecast weather data for the first 15 days of the forecast. These weather forecasts take the form of outputs from ensemble weather forecasts as provided by our weather forecast provider, and comprise three outputs - the 90th percentile, 50th percentile and 10th percentile of these ensemble forecasts. The outcomes of the 15-day forecasts are then spliced with the 19,200 year synthetic climatic weather sequence as was developed for WRSE for the development of the Regional Plan and WRMP24. The outputs are then presented on charts, which present the resulting flows, separated (from the driest up) as the worst case, 1 percentile, 5 percentile, 25 percentile and average flows (see the figure below).

Whenever a forecast is run, it is straightforward to calculate the number of days until the hands off flow (HoF) may be breached. This can be done in relation to potential risk, i.e. the example in the figure below indicates that when that model was run, the chance of needing a Drought Permit (i.e. for flows to fall below the HoF) in around 65 days was >1%, but the overall risk of needing a Drought Permit was <5%.

We are of the view that using flow forecasts to assess the potential lead-in times to needing drought interventions provide a more sensitive, flexible and accurate approach than relying on trigger lines on their own. This is because the forecasts account for any potential forecast rainfall events in the near term and provide an indication of the timing and likelihood of interventions being required in the longer term. Moreover, our forecast system is ensemble based which allows us to predict a wider range of potential future streamflow realizations, which is crucial for contingency planning. The forecasts and related information can be readily shared with regulators and allow for informed decision making based on the most up-to-date understanding of the current situation and potential drought risks. As referred to in section 3.5.5, flow forecasting will provide a more flexible approach than the 35 day trigger for the River Itchen. However, as the Section 20 Agreement specifies a 35-day trigger for the River Test Drought Permit we retain that trigger. Although, as illustrated below, it is used within the flow forecasting tool.

Figure 42 - Illustration of flow forecasting tool used for River Test



5. Testing our plan

5.1 Historical droughts

There are several historical drought events that we recognise as being severe to extreme drought events. Depending on the metric adopted, the 1976 event is estimated to have been between a 1-in-200 years and 1-in-500 years event in terms of rainfall deficits across our region.[33] Similarly, the 1921-22 drought event is the worst historical groundwater drought that we are aware of in our Western and Central areas.

Consideration of the phasing of the triggers and drought end criteria for historical droughts has focused on periods when data for the primary trigger is available. As such, this has meant that generally this comparison has been made for events post 1970s, though in the case of the Eastern area this has been post 1990s.

5.1.1 Eastern area: KTZ

Based on a comparison of historic drought occurrence (Figure 42) the groundwater droughts are most closely associated with the 12-month duration SPI and SPEI. This is notable through 2012 only triggering in the 12-month accumulations. There is also correspondence in 1976, 1989 and 1996.

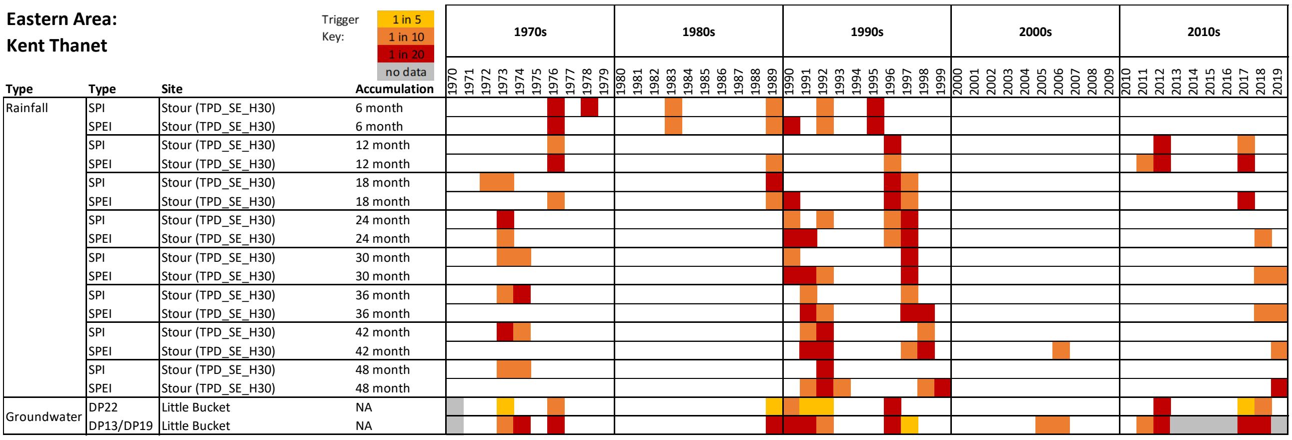


Figure 43: KTZ historical drought occurrence.

Taking the 1996 drought as an example, the progression of drought phases is shown in Figure 42. Both SPI and SPEI are providing advance lead times of the impending drought.

The drought sequence begins with SPEI crossing the level 1 threshold in December 1995. SPEI continues to drop down through the Level 2 trigger at the same time the SPI trigger and the groundwater levels cross the DP22 Level 1 trigger in February 1996. Whilst the SPEI Level 3 is not triggered, the SPI Level 2 is triggered in March 1996 and SPI Level 3 is triggered in April 1996. Groundwater levels cross the DP22 Level 2 and Level 3 triggers later in June 1996.

[33] Met Office, 2016. Southern Water – Planning for 'reasonable droughts' in the South East of England.

Comparatively, groundwater levels cross the DP13/DP19 Level 2 and 3 in January and February 1996. As such, it noted that the DP13/DP19 Level 2 trigger provides a closer match to the SPI and SPEI trigger timing. For Level 1 and 3, the DP22 and DP13/19 triggers seem approximately similar. Overall, there is greater confidence in the DP22 triggers as the triggering frequency of the DP22 triggers is generally better.

The groundwater levels exit DP22 Level 1 in October 1996, around the same time as the SPI and SPEI exit Level 1. Groundwater levels exit DP13/DP19 Level 1 much later in October 1997, around the same time as SPI is at -0.5 (in December 1997) and SPEI is at -0.5 (in January 1998).

5.1.2 Eastern area: Kent Medway (KME and KMW)

Based on a comparison of historic drought occurrence (Figure 43) the groundwater droughts are not always coincident with the surface water droughts as reflected by 1997-98 featuring as a significant groundwater drought and 2011-12 featuring as a significant surface water drought. Groundwater levels at Riddles Lane are most closely associated with the 30-month duration SPI and SPEI. This is notable through the coincidence of 1997 and 2006 and the absence of events in the 2010s. Bewl is most closely associated with the 12-month duration SPI and SPEI for the River Medway (TPD_SE_H42) that is discussed further in Section 5.1.3 for the SHZ WRZ.

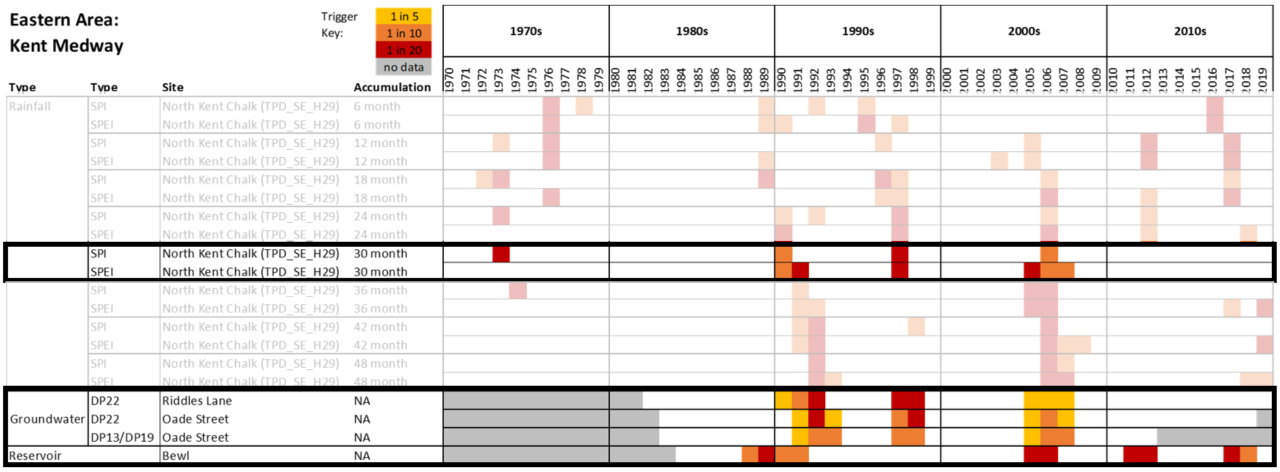


Figure 44: Kent Medway historical drought occurrence.

Taking the 1990-91 drought as an example the progression of drought phases is shown in Figure 45.

SPI and SPEI begin by dropping into the Level 1 trigger in July 1990, whilst groundwater levels cross the Level 1 trigger later in December 1990. Both the reservoir trigger and SPI trigger the level 2 in September 1990 followed by SPEI in December 1990. The reservoir trigger never reaches level 3 and the groundwater does not cross the Level 2 or Level 3 triggers around these dates. The reservoir levels then seem to recover; however, the SPEI levels continue to dop into level 2 through 1990.

For a couple of months all of the triggers are out of their respective levels until October 1991 when SPEI drops through the level 1 trigger and the groundwater levels drop below the level 2 trigger. In September 1990, SPI falls below the level 1 trigger again followed by the groundwater levels hitting the level 3 trigger in March 1992. During this time the reservoir levels are still above the level 2 and level 3 triggers.
The end of the drought is set when SPEI = -0.5 which does not occur until May 1993

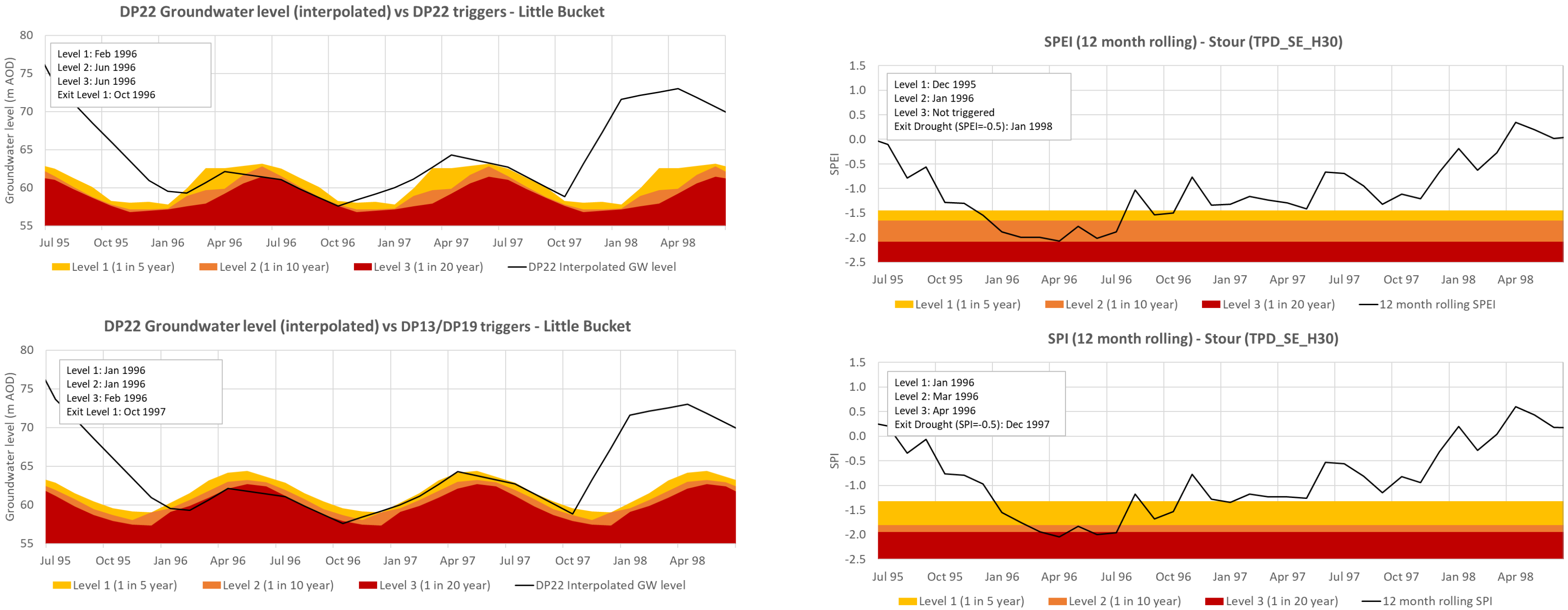


Figure 45: KTZ 1996 drought phasing

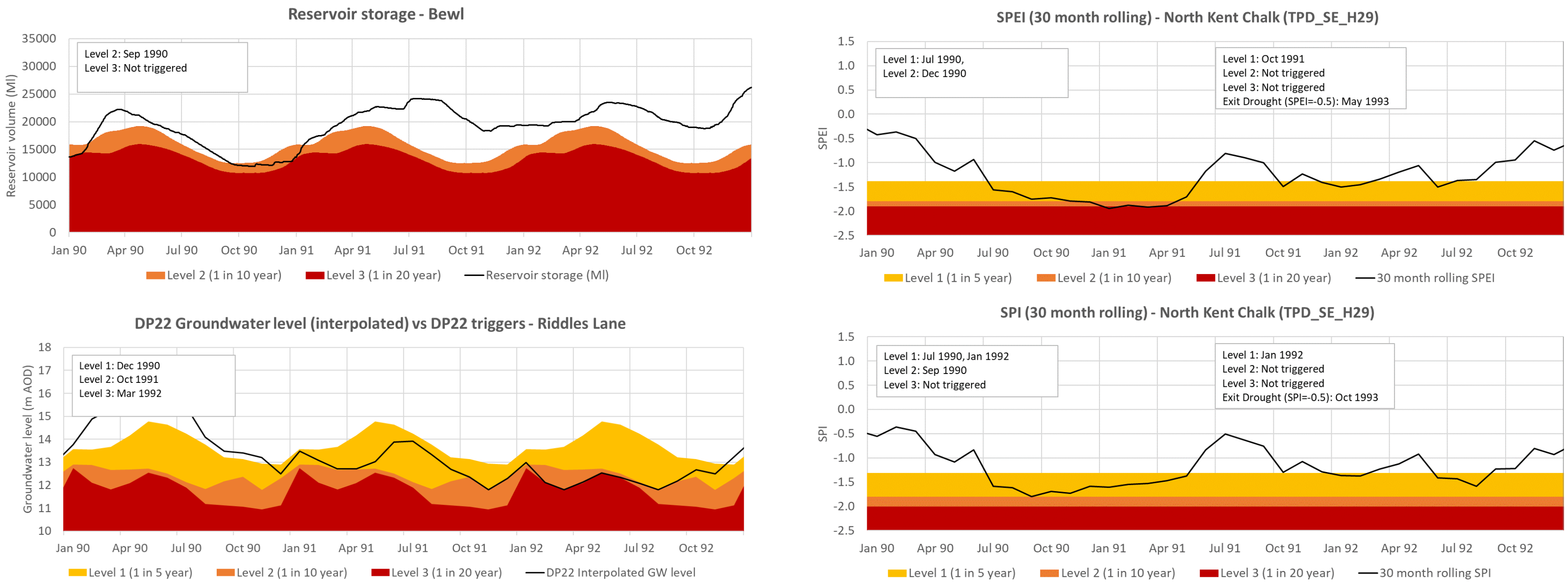


Figure 46: Kent Medway 1990-91 drought phasing.

5.1.3 Eastern area: SHZ

Due to the availability of data, Bewl storage data has been used as the basis for comparison and is considered to well represent the combined reservoir storage of Bewl, Darwell and Powdermill. Based on a comparison of historic drought occurrence (Figure 46), the surface water droughts reflected in the reservoir storage records are most closely associated with the 12-month duration SPI and SPEI. This is notable through the coincidence of 2005-06, 2011-12 and 2017 and the absence of events in the late 1990s.

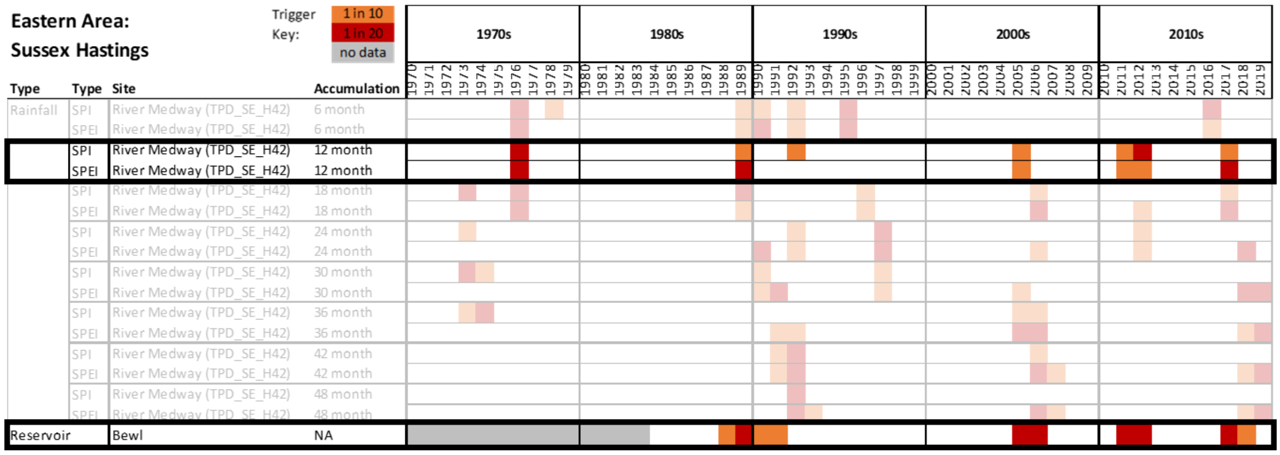
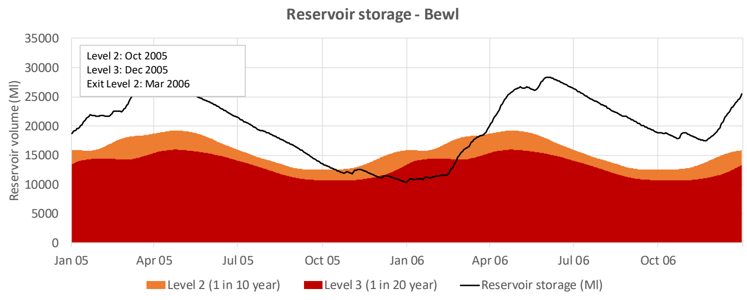
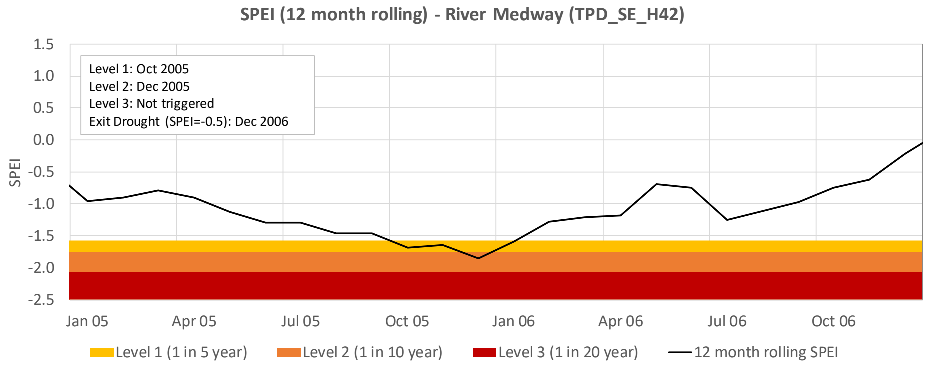


Figure 47: SHZ historical drought occurrence.

Taking the 2005-06 drought as an example, the progression of drought phases is shown in Figure 47. Neither SPI nor SPEI are providing advance lead times of the impending drought and trigger at a similar time to the reservoir triggers. Adoption of an SPEI of -0.5 to indicate a drought end (December 2006) shows that this would trigger later in the year a while after the reservoir storage has recovered (March 2006). A similar pattern has been observed in the other considered droughts of 2011-12 and 2017-18 though the recovery in SPEI is quicker.





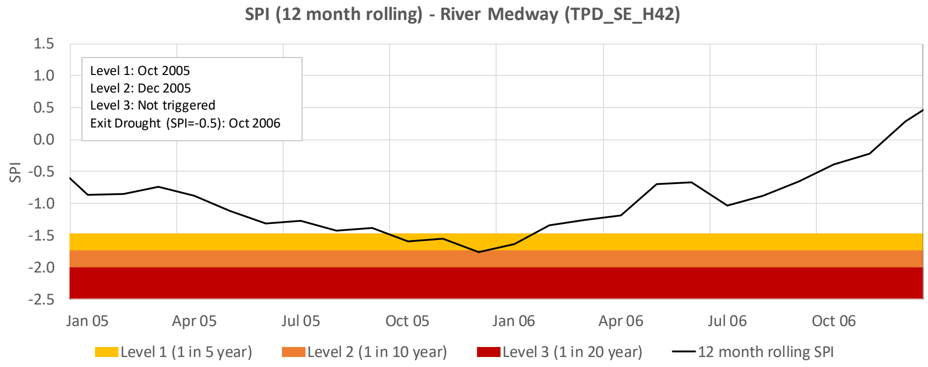


Figure 48: SHZ 2005-06 drought phasing.

5.1.4 Central area: SBZ

Based on a comparison of historic drought occurrence (Figure 47) the droughts are most closely associated with the 12-month duration SPI and SPEI. This is notable as the only rainfall duration that identifies 1989 as a 1-in-20 years event. Despite this, there are indications that longer droughts also affect Houndean Bottom with correspondence with the 30-month duration SPI and SPEI in 1990, 1991 and 2005.

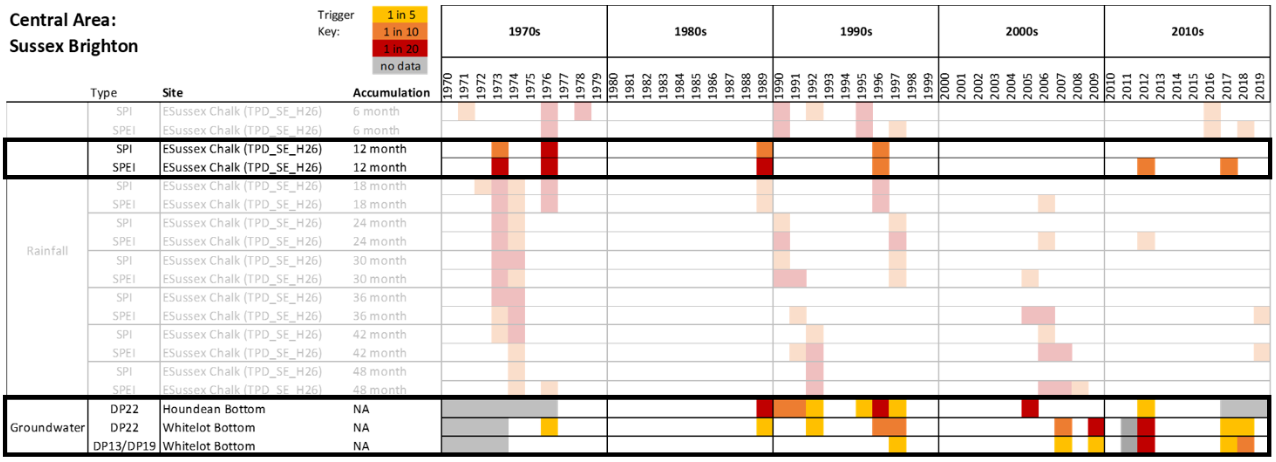
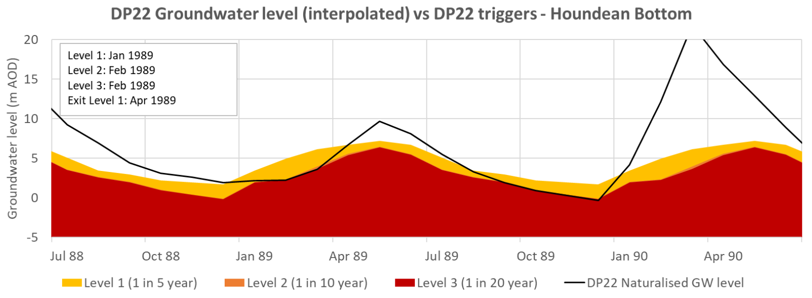
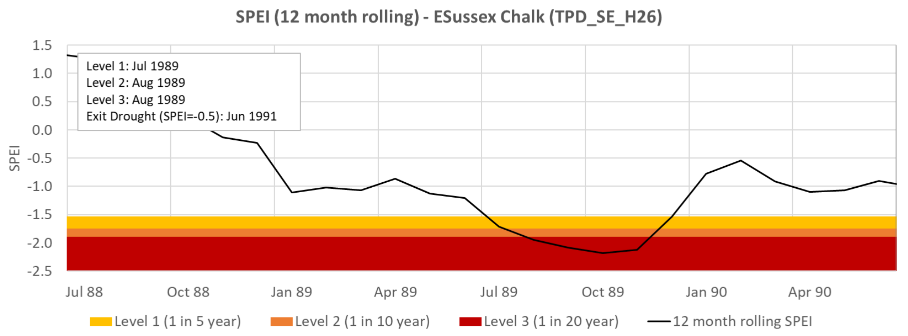


Figure 49: SBZ historical drought occurrence.

Taking the 1989 drought as an example, the progression of drought phases is shown in Figure 50.

For Sussex Brighton, the drought sequencing begins with SPI crossing Level 1 and groundwater levels crossing Level 1 in January 1989. However, the SPEI series remains quite high. In February 1989, the groundwater levels cross the Level 2 and Level 3 threshold. Whilst the groundwater shows some recovery SPEI begins to deteriorate, crossing the level 1 threshold in July 1989 followed closely by the level 2 and level 3 thresholds in August 1989. By August 1989, the groundwater levels are receding again and cross the level 3 triggers in September 1989. Towards the end of the year all three metrics are beginning to recover starting with groundwater, then SPEI and then SPI. The end of the drought is signified by SPEI reaching -0.5 which occurs in June 1991.





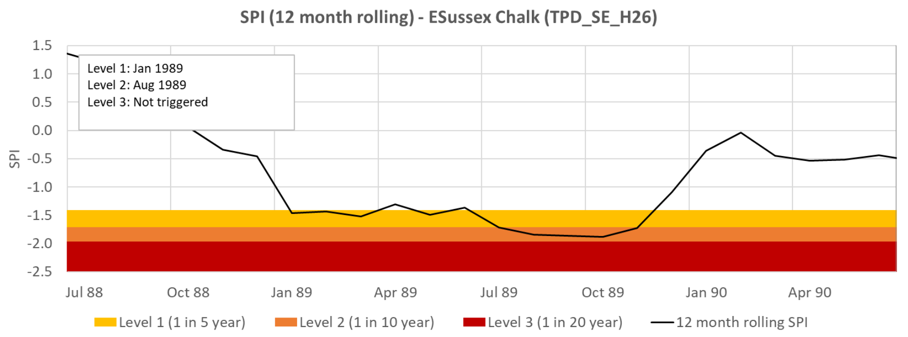


Figure 50: SBZ 1989 drought phasing.

5.1.5 Central area: SWZ

Based on a comparison of historic drought occurrence (Figure 50) the droughts for Chilgrove are most closely associated with the 6-month duration SPI and SPEI particularly due to the pattern of drought years between 1989 and the late 1990s with 1995 only being flagged in the 6-month duration SPI and SPEI.

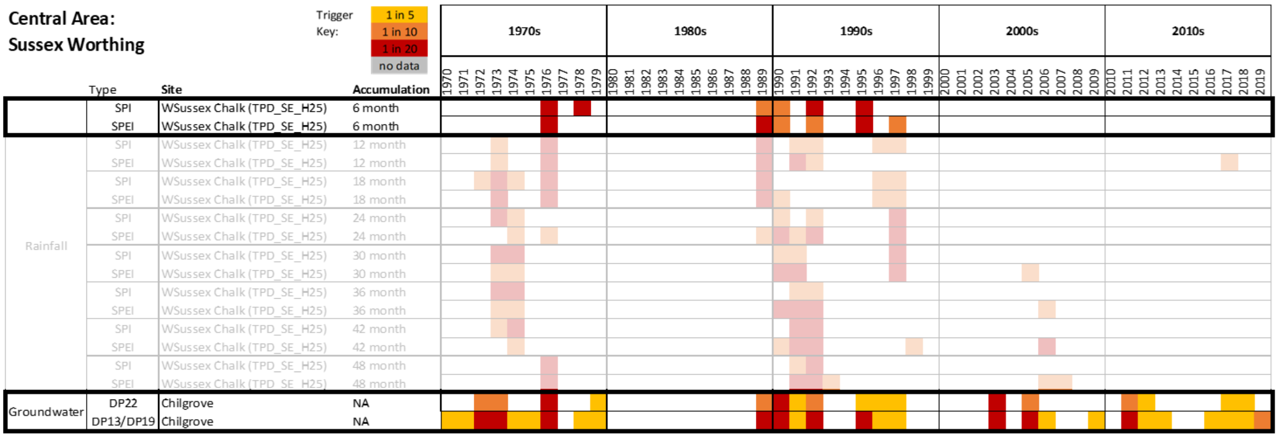


Figure 51: Sussex Worthing (Central area) historical drought occurrence.

Given the long records at Chilgrove, it is possible to consider the 1976 drought, the progression of which is shown in Figure 51. In this case, SPI and SPEI trigger shortly after the groundwater levels cross the Level 2 threshold, reflecting the quick responding nature of the Chalk. Groundwater levels exit the triggers in November 1976, the same month that the SPEI increases above the drought end threshold of -0.5. Although not reproduced below the trigger phasing and SPEI threshold were also checked against the 1990-91 and 1995-96 droughts.

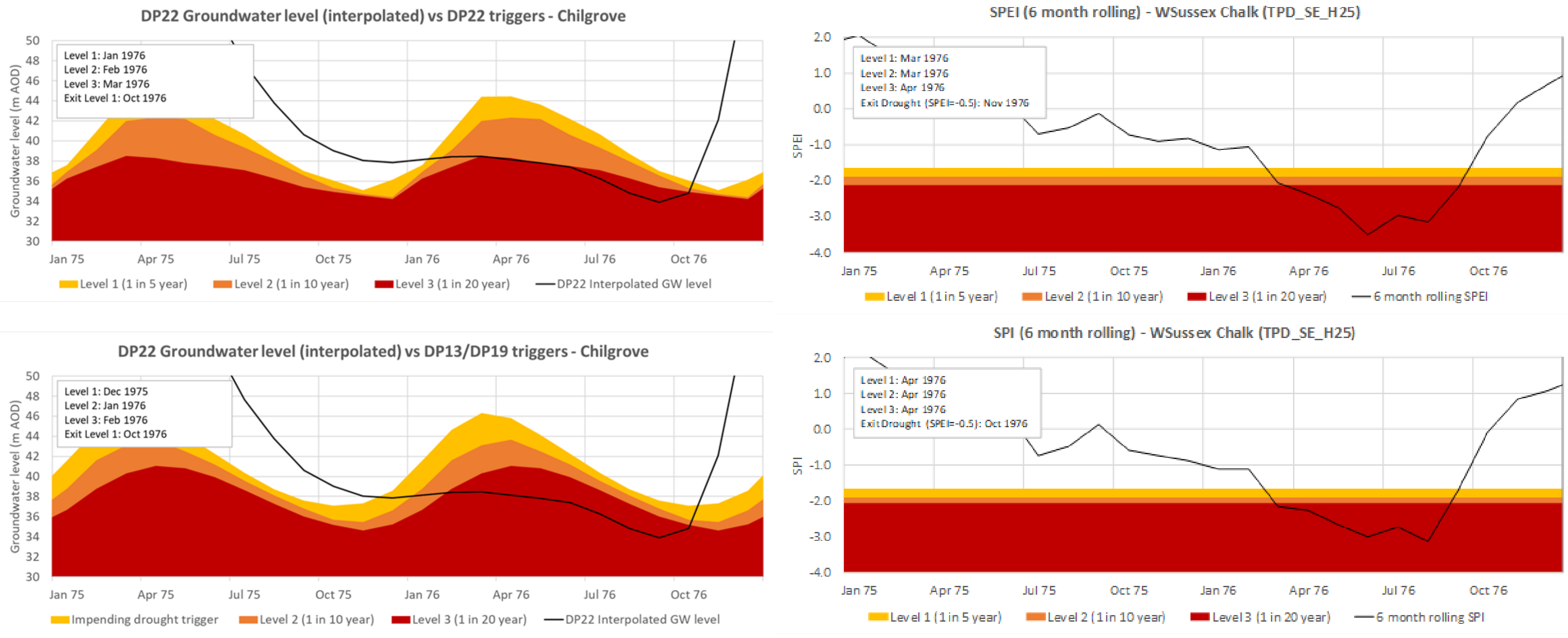


Figure 52: SWZ 1976 drought phasing.

5.1.6 Central area: SNZ

Based on a comparison of historic drought occurrence (Figure 52), the droughts for the Western Rother are most closely associated with the 12-month duration SPI and SPEI due to the correspondence of drought years in 1976, 1989 and 1992.

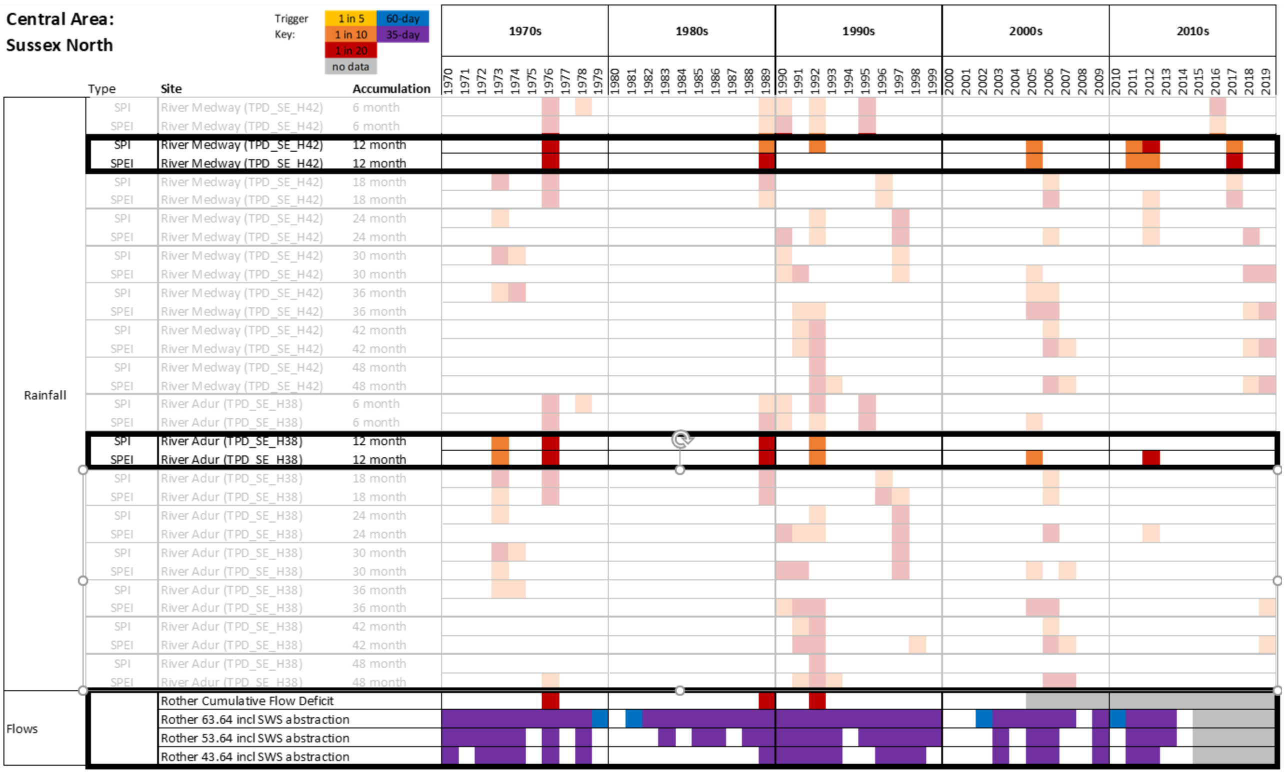


Figure 53: SNZ historical drought occurrence.

Considering the 1976 drought, the progression of this event is shown in Figure 54.

For Sussex North the flow triggers are crossed first. The Level 1 trigger has been set as the 60-day trigger for the 63.64Ml/d. This is crossed in April 1975 before some flow recovery and crossing again in January 1976. This is followed by the 35-day for the 63.64Ml/d and the 35-day for the 53.64Ml/d being crossed in January 1976 and February 1976 respectively. During this time both SPI and SPEI are on a decline. SPI then crosses the level 1 trigger in March 1976. In April 1976, the flows cross both the 35-day for the 43.64Ml/d and the Level 2 threshold, SPI enters level 2 and SPI drops all the way into level 3. This is followed in May 1976 by both the Rother flows and SPEI entering their respective Level 3 triggers. Finally, the 43.64Ml/d MRF is crossed by the Rother flows in July 1976.

In the months following July 1976 the river flows, SPI and SPEI all reach their lowest points and begin to recover. The river flows are fastest to recover and exits all triggers in October 1976. SPI and SPEI have a slower recovery. The end of a drought is set at when SPEI recovers to -0.5 which occurs in February 1977.

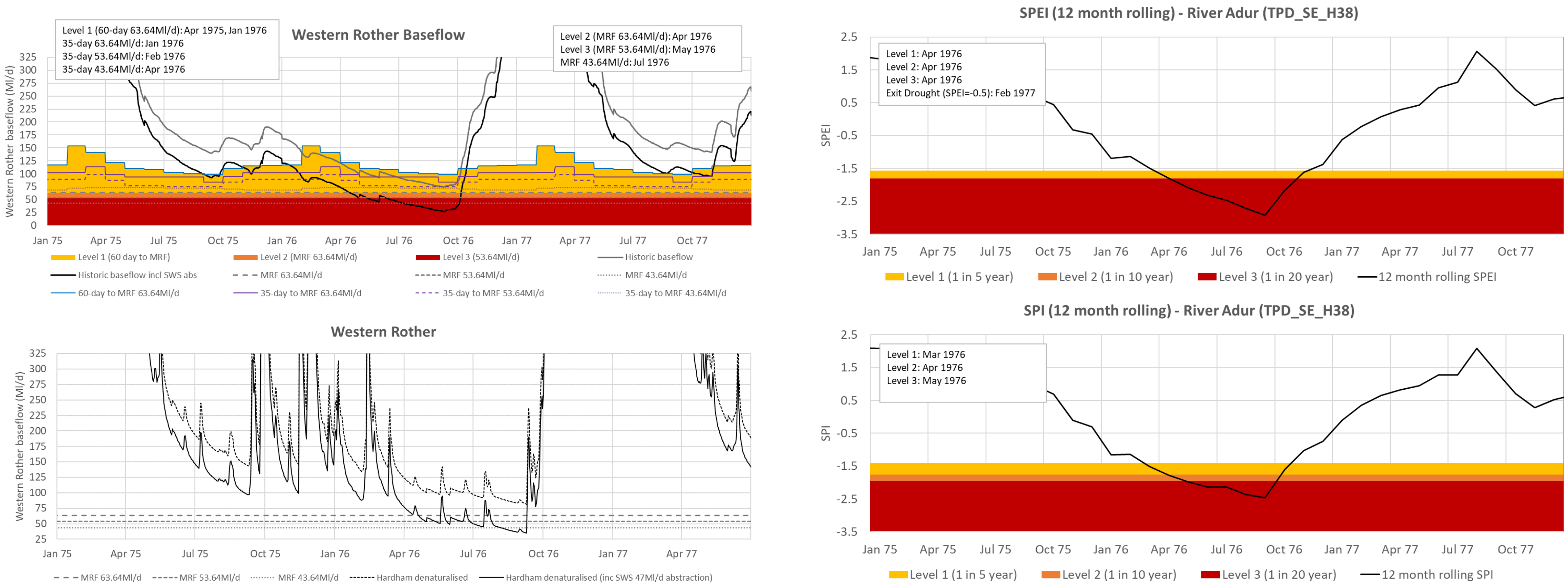


Figure 54: SNZ 1976 drought phasing.

5.1.7 Western area: Hampshire North (HAZ, HKZ, HWZ and HRZ)

Based on a comparison of historic drought occurrence (Figure 55) the droughts most closely associated with Clanville Lodge are in the range of 12-30 months duration SPI and SPEI. Based on the 1976 drought and the relatively rapid nature of the drought event, a 12-month duration SPI and SPEI has been taken forward. This does means that some droughts highlighted in the SPI and SPEI series in 2005, 2017 and 2019 do not trigger based on the groundwater level record (though levels get very close to the trigger curves in 2005).

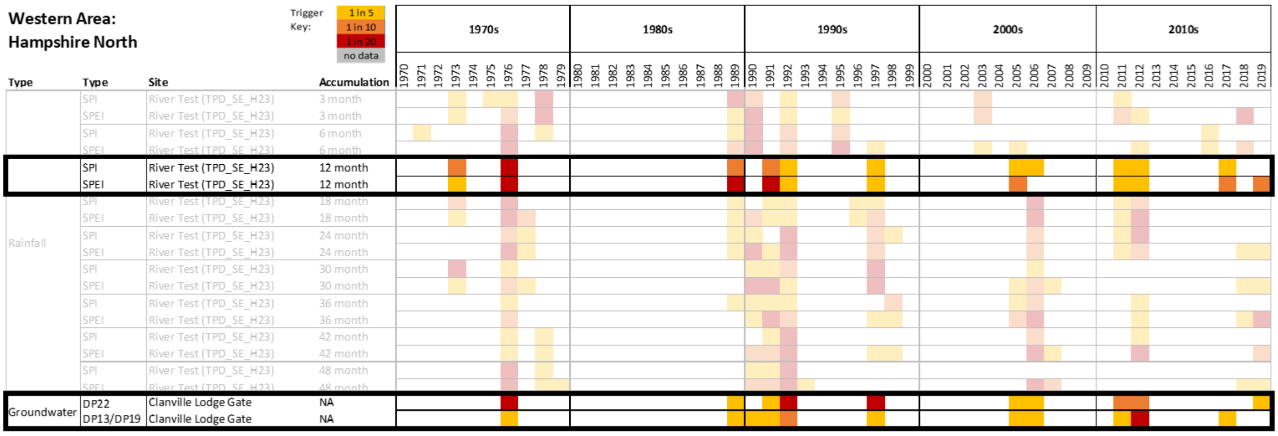


Figure 55: Hampshire North historical drought occurrence.

With groundwater level records, extending back to the 1970s for Clanville Lodge, it is possible to consider the progression of drought phases for 1976 (Figure 56). Both SPI and SPEI provide advanced warning of a drought.

Level 1 is triggered in January 1976 for both SPEI and SPI, level 2 is triggered in January 1976 for SPEI and March 1976 for SPI. Level 3 is triggered in Mar 1976 for SPI and April 1976 for SPI. Following this both SPI and SPEI continue to decrease. It is not until May 1976 that the groundwater levels then trigger both the DP22 Level 2 and the Level 3 triggers.

The groundwater levels are the first to leave the triggers in November 1976, followed by SPI and SPEI. The drought is over when SPEI is more than 0.0 which occurs in March 1976.

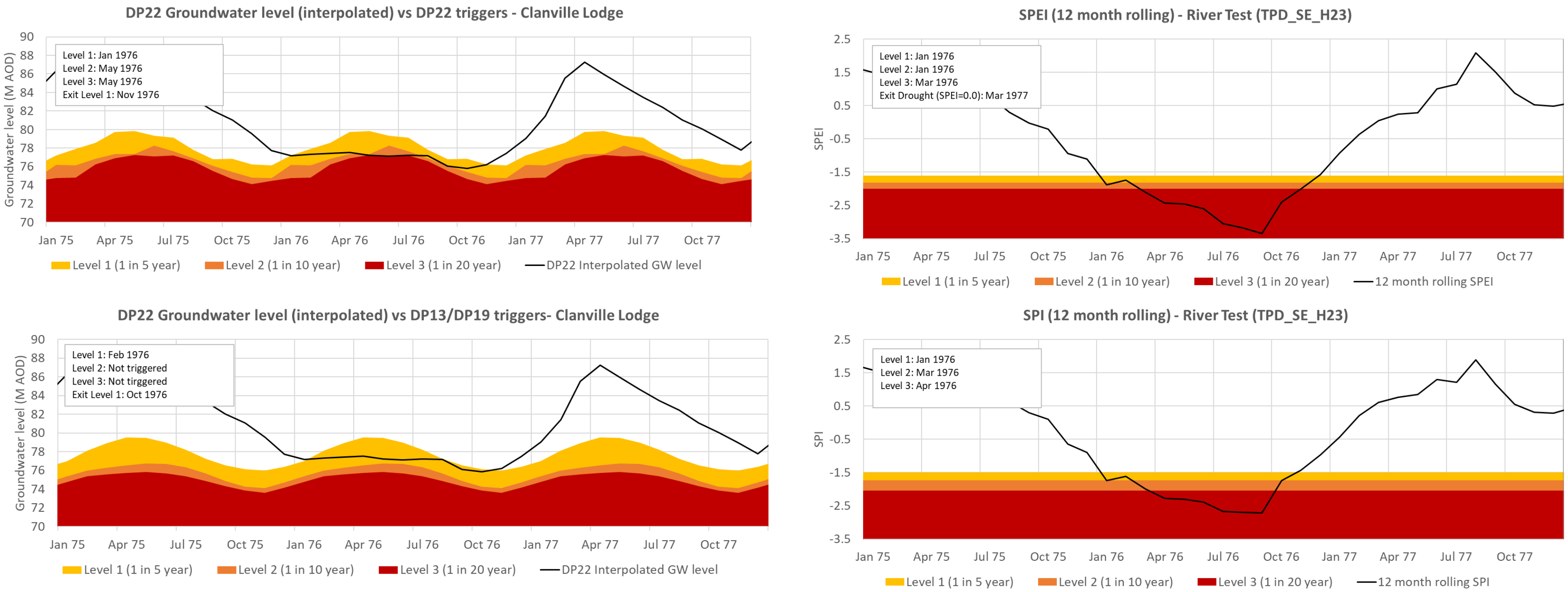


Figure 56: Hampshire North 1976 drought phasing.

5.1.8 Western area: Hampshire South (HSE and HSW)

Comparing the time-based flow triggers with the SPI and SPEI durations triggers is more challenging due to the frequency with which the time-based flow triggers are initiated (the 90-day for the Test total flow 355Ml/d HoF and the 90-day for the Itchen 205Ml/d threshold being triggered in the majority of years). However, examination of the Test total flow series indicates that 1976, 1992, 1996-97 and 2005 have the lowest flows over the period of record that breaches the HoF of 355Ml/d. These coincide with the worst droughts for the River Itchen and groundwater droughts for West Meon. Comparison against the SPI and SPEI triggers suggests these events are most closely matched with 12-24 months durations.

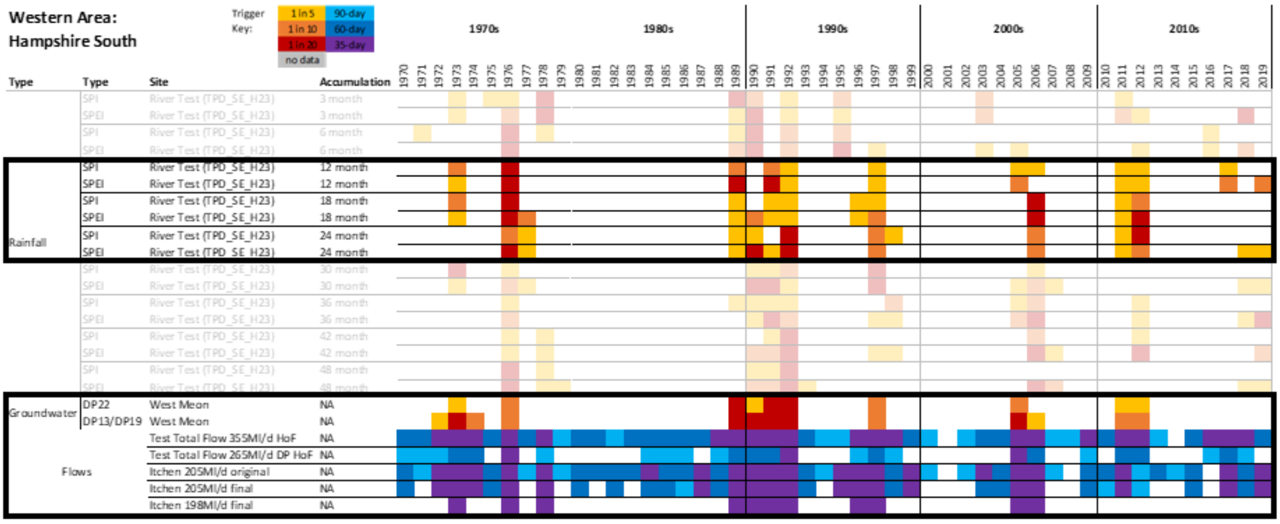


Figure 57: Hampshire South historical drought occurrence.

Taking the extreme drought available on the record, 1976 flows have been compared between the River Test and the River Itchen and with the groundwater levels for West Meon (Figure 58). SPI and SPEI triggers are the same as for Hampshire North and can be found in Figure 56 for the 1976 drought.

The first indication of the impending drought is when baseflow drops below the 90-day and 60-day (Level 1) triggers for the Itchen in June and July 1975 respectively. Whilst the Test passes the 90-day trigger in August 1975, flows in the Itchen start to recover and exit the triggers in October 1975 over the winter period. Baseflow in the Test continues to drop leading to the 60-day (Level 1) trigger being passed in November 1975. The 35-day trigger (for DP application) is passed in February 1976 (along with the 90-day trigger to the drought permit HoF of 265Ml/d), shortly after SPI and SPEI pass the 1 in 5-year threshold in January 1976.

By April 1976, the 12-month duration SPI and SPEI have triggered 1 in 20 year events, the Test has passed the 60-day to the drought permit HoF of 265Ml/d and the Itchen has re-entered the triggers and passed the 60-day (Level 1) trigger again. In May 1976, the Itchen passes the 35-day[34] to 205Ml/d threshold. In June 1976, the Test followed shortly after by the Itchen enters Level 2 with flows dropping below their respective

[34] The analysis described here used the 35-day Itchen trigger but as described in section 3.5.5, this drought plan no longer includes that trigger for the Itchen or Candover.

thresholds. Level 3 is triggered almost immediately for the Itchen in June 1976 with the Level 3 following for the Test in July 1976. Flows start to recover first on the Itchen with the Level 2 and 3 being exited in September 1976 followed by the Level 1 in October 1976. For the Test, recovery is slower with Level 3 being exited in November 1976, Level 2 in December 1976 and Level 1 in January 1977. SPEI recovers to its threshold of 0.0 in March 1977. Groundwater levels at West Meon are not critical in this drought but track close to the trigger curves from March to November 1976 and briefly enter Level 2 in June 1976 before recovering sharply.

Although not reproduced below, other drought years (1990-1992 and 2005-06) have been considered, and all demonstrate similar patterns that the Itchen is quicker to trigger initially but that it also exits the triggers over the winter periods before re-entering again. Aside from a couple of months the Test remains within the Level 1 trigger throughout and it tends to breach the HoF earlier and more frequently than for the Itchen. Recovery for the Itchen is quicker with the Level 1 being exited approximately 2 months before the Test.

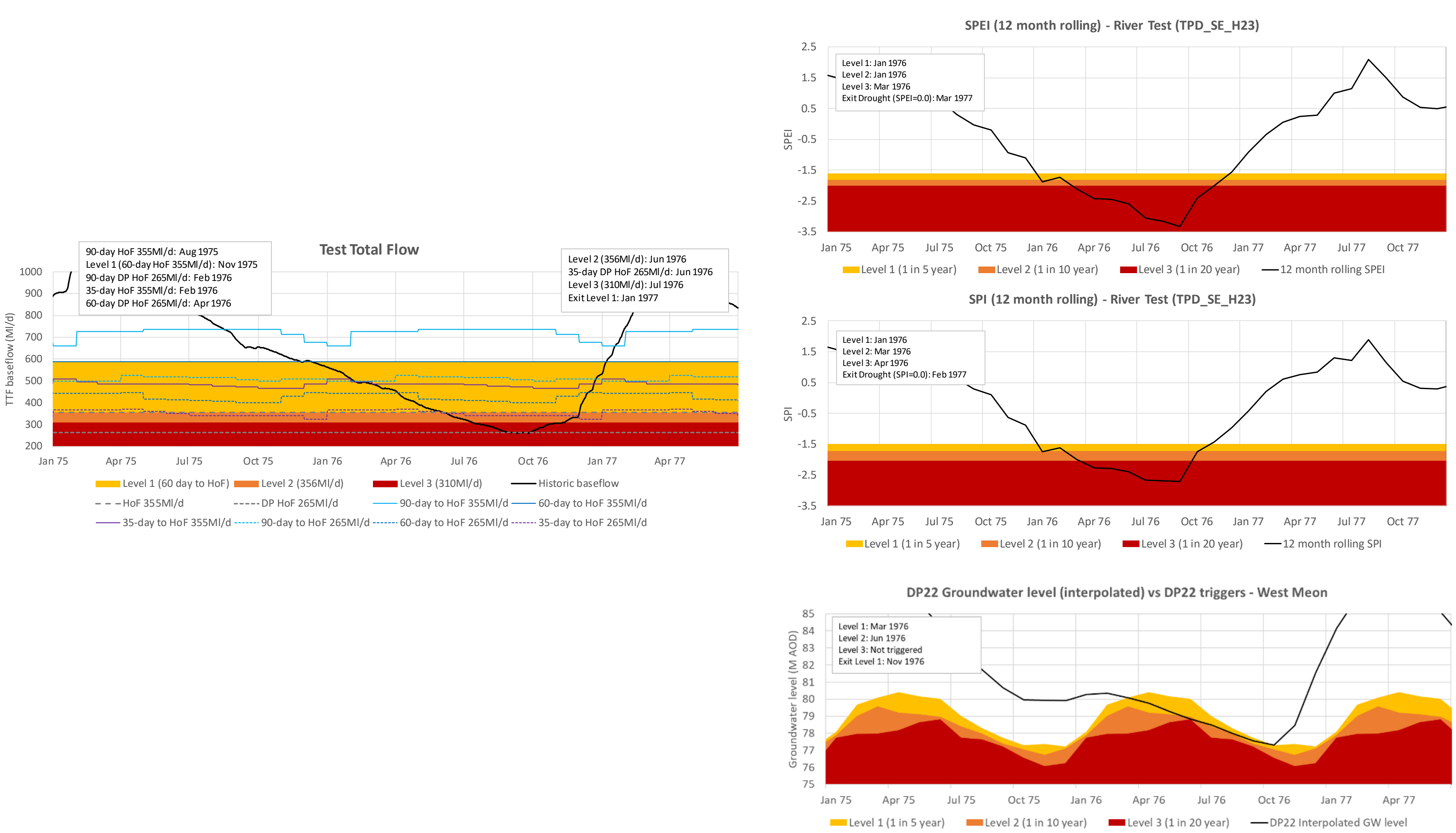


Figure 58: Hampshire South 1976 drought phasing

In order to illustrate how the flow forecasting approach could work we have included a worked example for the River Itchen below. In the figure below we show the observed flows in the River Itchen in 2022 plotted against the drought triggers.

It is worth noting that, as occurred in 2022, we expect that the HOF licence condition on the River Test licence would be approached well in advance of the HOF on the River Itchen. We would therefore expect to already be in regular consultation with regulators and stakeholders and undertaking drought management actions for Southampton and Hampshire (including TUBs) in advance of any requirements in relation to the River Itchen drought orders.

For this illustration we have considered two scenarios:

a) Observed flows (blue trace) - by late summer the flows had dropped beneath the 90-day trigger and discussions with the EA and other key stakeholders had already begun. These discussions had already begun as a result of low flows on the River Test and that is why a TUB was implemented. However, had the flows in the River Itchen fallen to drought level 2 (the area marked by the blue rectangle) we would have raised this with the EA and others. Flow forecasting at the time showed that the flows were unlikely to recede (fall) further. This would have been communicated to the EA and others as the reason for not implementing any other level 2 actions because they were not expected to be required.
b) Synthetic scenario (dashed black trace) - an illustrative synthetic drought scenario that is shown by the dashed black line. In this synthetic scenario flows again fell into the blue rectangle zone. We have used a very extreme[35] drought scenario to show what could happen if flows continued to recede, falling past all of the drought triggers. In this highly unlikely event the flow forecasting would have shown a greater probability of flow recession. This would be communicated to the EA and further level 2 measures would be discussed and implemented. This decision would rely on the latest ecological information, demand forecasts and other data specific to the particular drought.

[35] To put this in context, flows have never fallen below 165Ml/d in the gauged recorded that stretches back to 1958. The lowest gauged flow in this record was 187Ml/d in 1976, which is still significantly higher than the flows shown by this synthetic scenario. This synthetic scenario was produced purely to inform this worked example so does not have a return period.

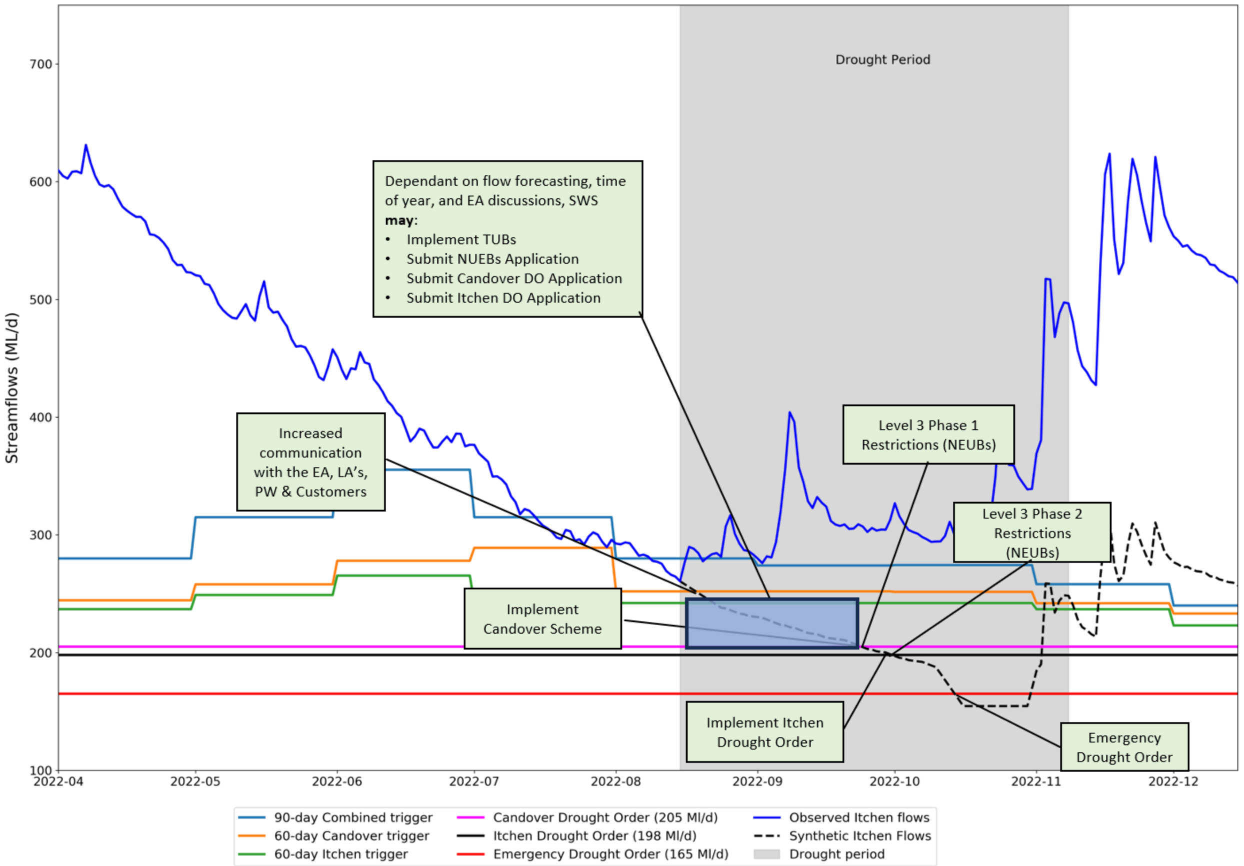


Figure 59 - Worked example of River Itchen drought triggers

5.1.9 Western area: IOW

Based on a comparison of historic drought occurrence (Figure 57) it is clear that the IOW is most impacted by short and sharp drought events with the Carisbrooke Castle record being most closely associated with the 6-month duration SPI and SPEI. Only the 6-month duration identifies the 1995 drought event.

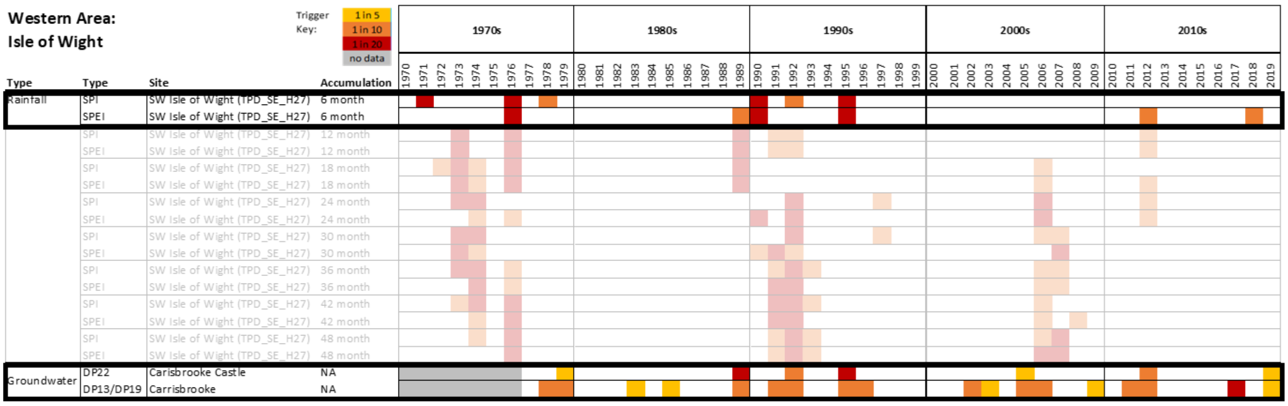
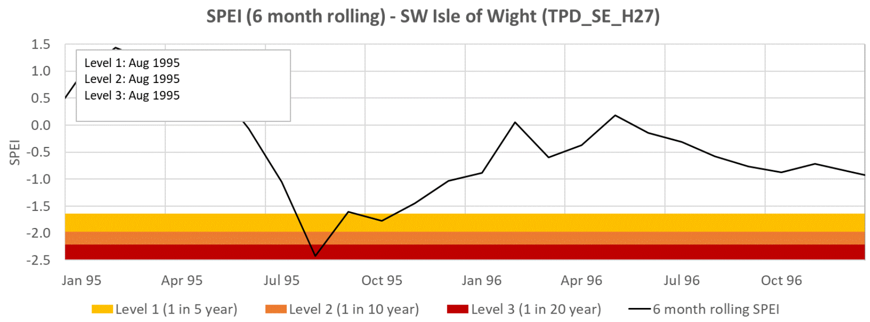
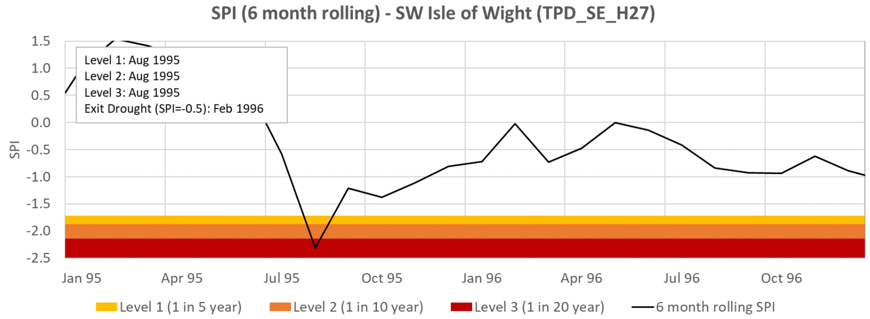


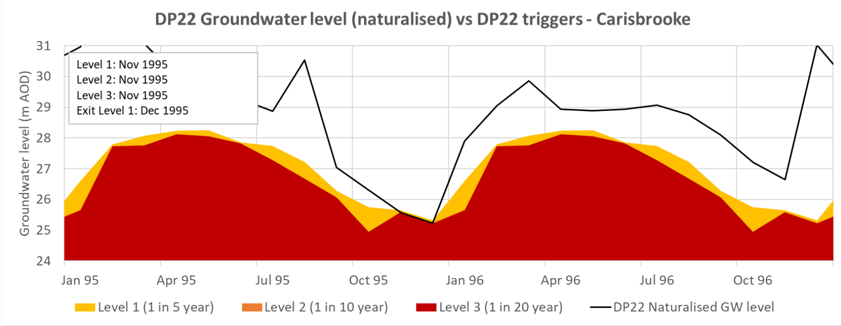
Figure 60: IOW historical drought occurrence.

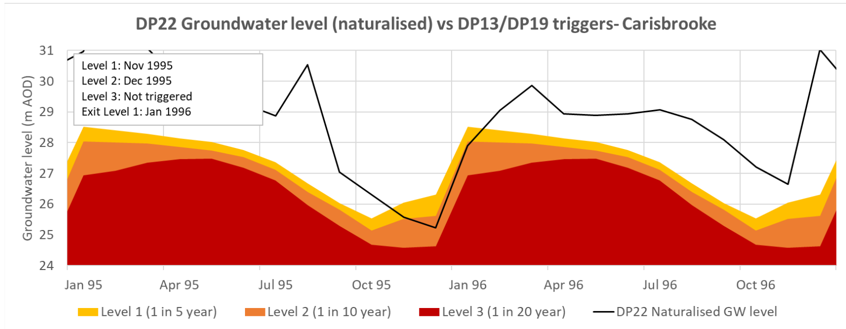
Taking the 1995 drought as an example, the progression of drought phases has been considered (Figure 59). SPI and SPEI both provide a few months lead times of the impending drought drop through all three trigger levels in August 1995. This is in advance of the groundwater levels triggering both level 1 and level 2 in November 1995.

The groundwater levels exit DP22 Level 1 first in December 1995, followed by SPI and SPEI, which begin to recover before exiting the drought in February 1996 when SPI = -0.5. Additional comparison with the DP13/DP19 groundwater triggers shows that DP13/DP19 Level 3 is not triggered.









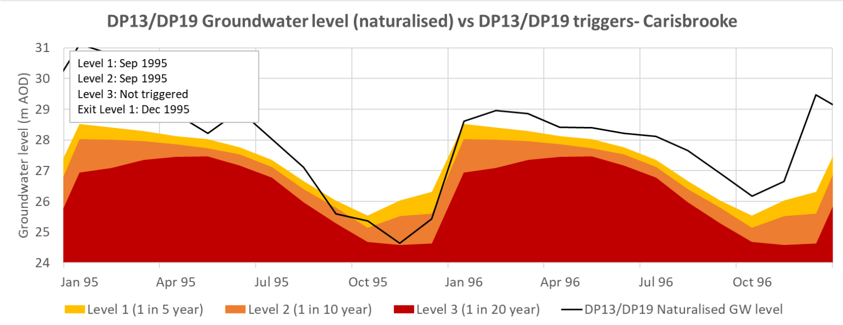


Figure 61: IOW 1976 drought phasing.

5.2 Severe to extreme droughts outside the historical record

Our DO assessments for WRMP19 were based on the use of stochastic climate sequences via long time series in order to examine the resilience of our sources against droughts more severe than those that have occurred in the historical record.

In accordance with our target LoS, we expect to maintain supplies in a 1-in-200 years drought event without drought permits/orders in place and we may be able to provide resilience against Level 4 restrictions for a 1-in-500 years event with our drought permits/orders in place.

At this level of resilience, we expected a less than 10% chance that we will have to resort to restrictions such as rota cuts or standpipes over the 50-year planning period of the WRMP.

The adoption of the Section 20 Agreement between SWS and the EA means that we may need to implement TUBs more frequently in the Western area. To ensure resilient supplies we will also be more reliant on drought permits/orders in this area.

In addition to historical droughts, we have, where possible, tested our drought triggers and presented the actions we would take in a series of 'What if' drought scenarios against our WRMP19 stochastic data.

However, there are a number of complications with testing all of our drought triggers for such events.

- Not all of our drought trigger sites can be simulated by our water resource models. There are multiple reasons for this including the purpose or type of the water resource model, or different model input and output data.
- Even where a trigger site is simulated, the nature of modelling is such that historical data which are used to derive the majority of our triggers will not be perfectly reproduced by the model. Some uncertainty will remain and bias correction may be required.
- Our WRMP19 water resource modelling was based upon stochastic rainfall generated from point rain gauge data. Our new rainfall SPI and SPEI triggers are based on gridded catchment averaged rainfall and different PET data. These two datasets are therefore not directly comparable without further bias correction and even that would introduce additional uncertainty.
- Some of our triggers are based on naturalised or denaturalised flows. These assumptions may not necessarily be consistent with our stochastic drought modelling assumptions for WRMP19.

The greatest limitation lies in the application of our new SPI and SPEI trigger thresholds to our stochastic droughts as the datasets fundamentally differ. It is more practical to compare other drought triggers for example, flows, groundwater or reservoir levels where these can be simulated. However, it must be acknowledged that model performance will not perfectly replicate historic behaviour and that uncertainty increases for droughts outside of the historical model calibration.

We have therefore considered the following eight scenarios that are equivalent to our WRMP19 baseline planning scenarios (for 1-in-200 years droughts) and include more extreme 1-in-500 years return period droughts. SPI and SPEI data are not presented but rainfall deficits compared to long-term average are shown for illustrative purposes.

- Example 1-in-200 years and 1-in-500 years coherent drought events for our HSW and HSE WRZs, under the Section 20 Agreement, require that these WRZs need to be considered in parallel, particularly for such drought events where HoF conditions on both the rivers Itchen and Test are constrained.
- Example 1-in-200 years and 1-in-500 years for our SNZ WRZ illustrating the sequencing of drought permits/orders for the Western Rother.

- Example 1-in-200 years and 1-in-500 years groundwater drought for our SBZ and SWZ WRZs based on modelled groundwater levels for an indicator borehole.
- Example 1-in-200 years and 1-in-500 years drought for our River Medway reservoir scheme showing progression through reservoir triggers and drought permit/order actions for the Eastern area reservoirs.

Return periods are approximate and based on inverse ranking of outturn drought DO and hence is typically related to flow, groundwater or reservoir level but will vary depending on the metric used.

The scenarios are expressed against the respective flow, groundwater level and reservoir storage triggers and time series are presented of simplified supply-demand balances that compare the available yield or DO for a given drought event against forecast demand with and without our supply and demand interventions. These scenarios are based upon data from our WRMP19 and consider the following inputs:

- Modelled river flows, groundwater levels or reservoir storage from our WRMP19 dynamic DO assessments generated using stochastic climate data and our water resource models.
- Modelled DO derived from outputs of the above modelling and our understanding of source constraints. Where relevant these have then been adjusted to account for the benefits of supply side interventions, for example additional yield from drought permits/orders
- Forecast 2022 DI from WRMP19. The DYAA demand is applied for most of the year but in the peak summer months (July and August), our DYCP demand scenario is applied. This provides a stress test against peak demand and allows the seasonal variation in the effectiveness of demand restrictions to be represented.
- WRZ imports and exports are represented as fixed volumes based on our WRP tables for 2022. Exports are considered as an additional demand, imports as additional DO.
- Our WRMP19 target headroom volumes are also included as an additional demand component to address both uncertainty and as a further stress test.
- Our WRMP19 outage allowance for 2022 is included as a reduction in DO.

Incorporation of high demand, outage and heat waves

Our transient supply demand balances in our drought test consider both the effects of high demand, though use of our Dry Year Critical Period Demand in summer months and the effects of outage though the loss of deployable output through outage allowances.

The additional demand (which is correlated with Temperature and behaviour) from high temperatures will be implicitly included in our Dry Year Critical Period demand assessment which reflects the annual summer peak in demand. We have also Incorporating Target Headroom as an additional demand component provides a further stress test of our drought measures and could account for some of the potential additional demand impacts of a heatwave.

Outside of drought conditions, because our supplies are dominated by on groundwater and high baseflow dominated rivers, we tend experience only very limited supply side impacts of heatwaves with the majority of additional stress on the supply network instead being caused due to additional demand.

As part of our routine summer supply-demand planning we form a summer supply and demand to build a strong supply and demand event response outside of the standby rota in line with our incident management model. This allows us to review network risk including summer headroom analysis, outage recovers, incident trigger and escalation levels and DMA level demand analysis. We can also review resilience, alternate responses, and communications for customers both household and retail.

Typically, when a Heatwave or high demand period is anticipated or forecast, for example in long range weather forecasts, we adjust our production scheduling to ensure that, where sites can, they run for longer each day to maintain levels and supplies in service reservoirs. Under normal conditions some sites are also throttled below asset and yield capacity to meet normal demand patterns more efficiently and these sources can be manually increased to provide greater outputs over short spikes in demand if required.

To examine such a scenario, we have also compared some of our drought interventions against a historical high demand scenario, the August 2020 heatwave. The August 2020 heatwave was a record-breaking event, particularly for South East England, with more than six days of sustained temperatures of above 32°C.[36] During the 2020-21 year there were no risks to customers and no need to implement TUBs or NEUBs as there was not a recognised drought.

To examine the potential effect of Heatwaves we have constructed some simplified supply demands balances following a similar approach to that of 'Table 10' in the WRMP19 Water Resource Planning Tables

The Supply Demand Balances include the following supply side components:

- August 2020 peak heatwave Actual Abstractions
- Actual August 2020 Water Resource Zone bulk imports from other zones or water companies
- Other supply side benefits including a 2% uplift in DO to account for optimised source management, outage recovery, recommissioning of unused sources, leakage and network management. Also included are any other supply side benefits from median WRMP19 climate change scenario and our risk-based modelling.

The demand side components include:

- Dry year critical period (peak) demands
- Observed August 2020 Demand
- WRZ bulk exports to other WRZs or water companies
- Other losses including our outage allowance, process losses and climate change based on our WRMP19 assumptions
- Target Headroom is included as an additional demand side component to account of additional uncertainty

The scenario therefore represents a partially artificial worst case scenario in the absence of many of the key drought interventions we might be able to implement. The supply components are shown in Figure 62 and the demand components in Figure 63.

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[36] Met Office, 2020. Met Office: The UK's record-breaking August 2020 heatwave, https://www.carbonbrief.org/met-office-the-uks-august-2020-heatwave. Accessed March 2021.

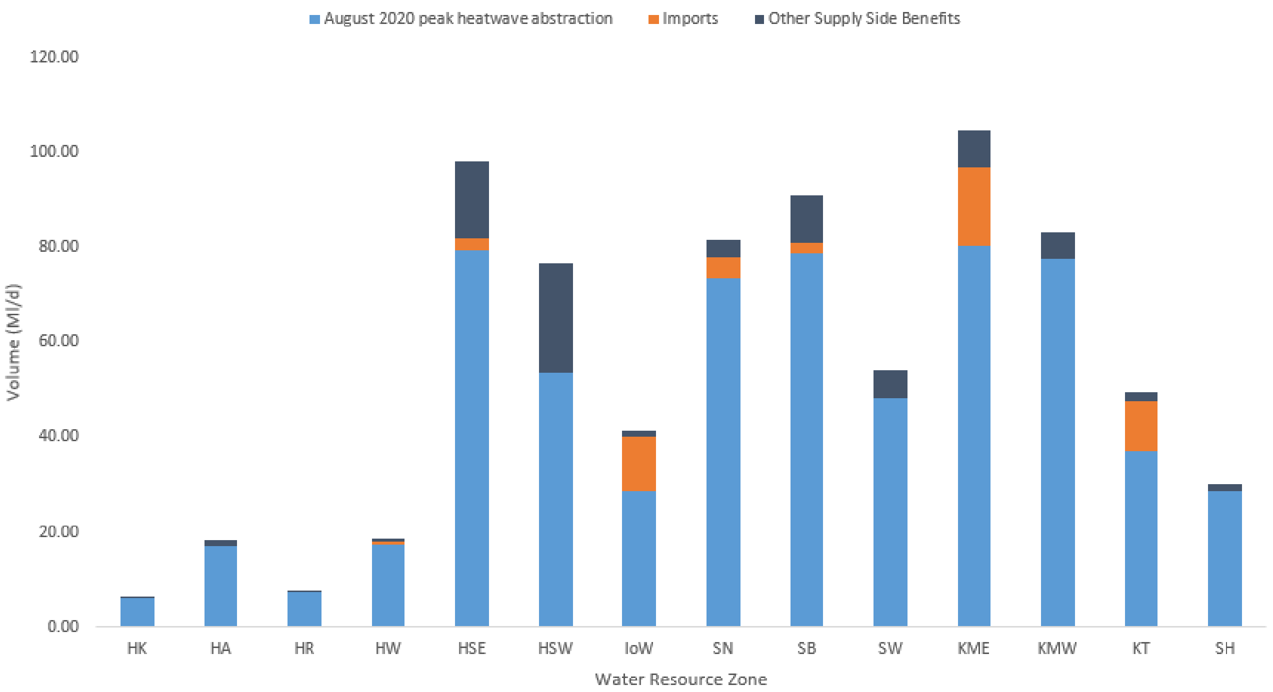


Figure 62: Supply-side components for simplified high demand scenarios.

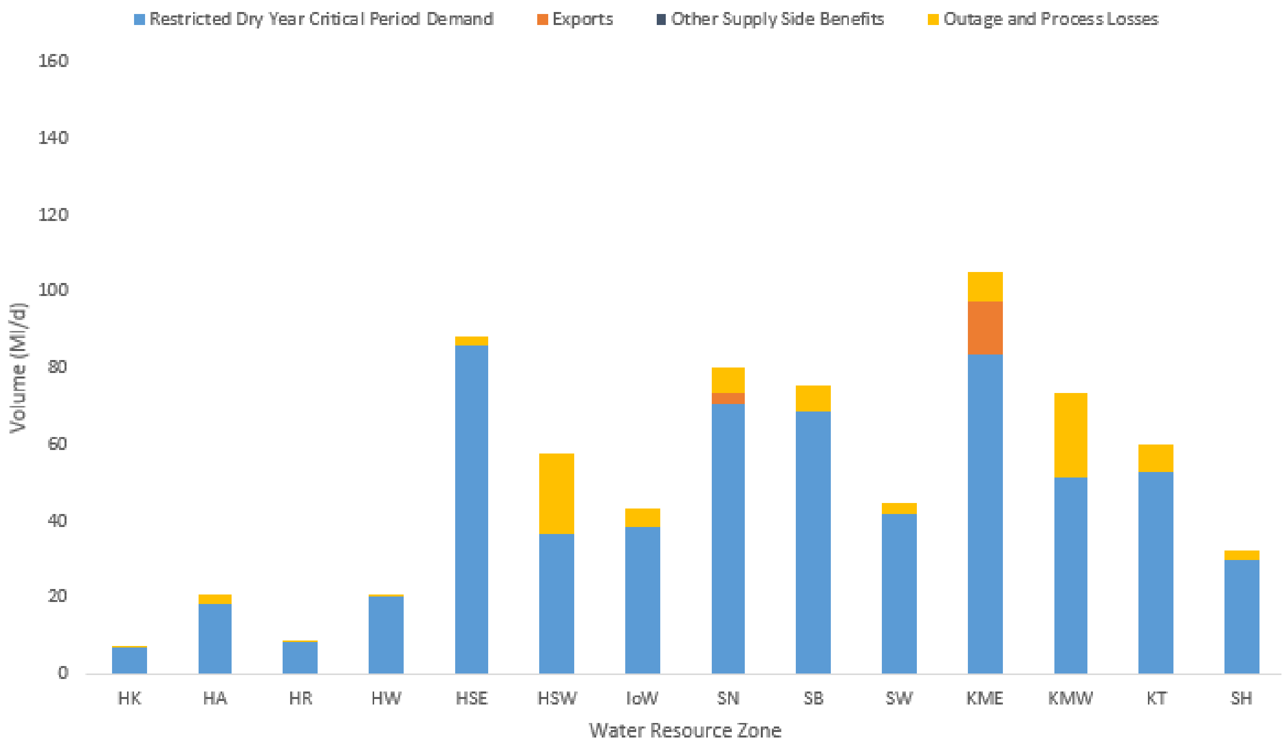


Figure 63: Demand-side components for simplified high demand scenarios.

A comparison of the supply and demand components is shown in Figure 62. In all cases, the forecast peak supply, with our drought interventions, exceeds the DYCP 1-in-200 years drought scenario. Only in KME does the 2020 peak COVID-19 heatwave demand exceed the 1-in-200 years supply forecast. In this example, the assumed import to KME from KMW is zero, consistent with our WRMP19 WRP tables. However, water can be normally moved from KMW to KME, even during drought, and there is sufficient supply headroom in this scenario to resolve the apparent deficit.

Where necessary (for example due to network restrictions) we will use tankers to move additional water to supply areas where demand may exceed network capacity. Key risk areas identified during the 2020 heatwave include:

- Turners Hill and East Crawley in Sussex North Water Resource Zone
- Nurstead and Pitfield in Kent Medway West Water Resource Zone

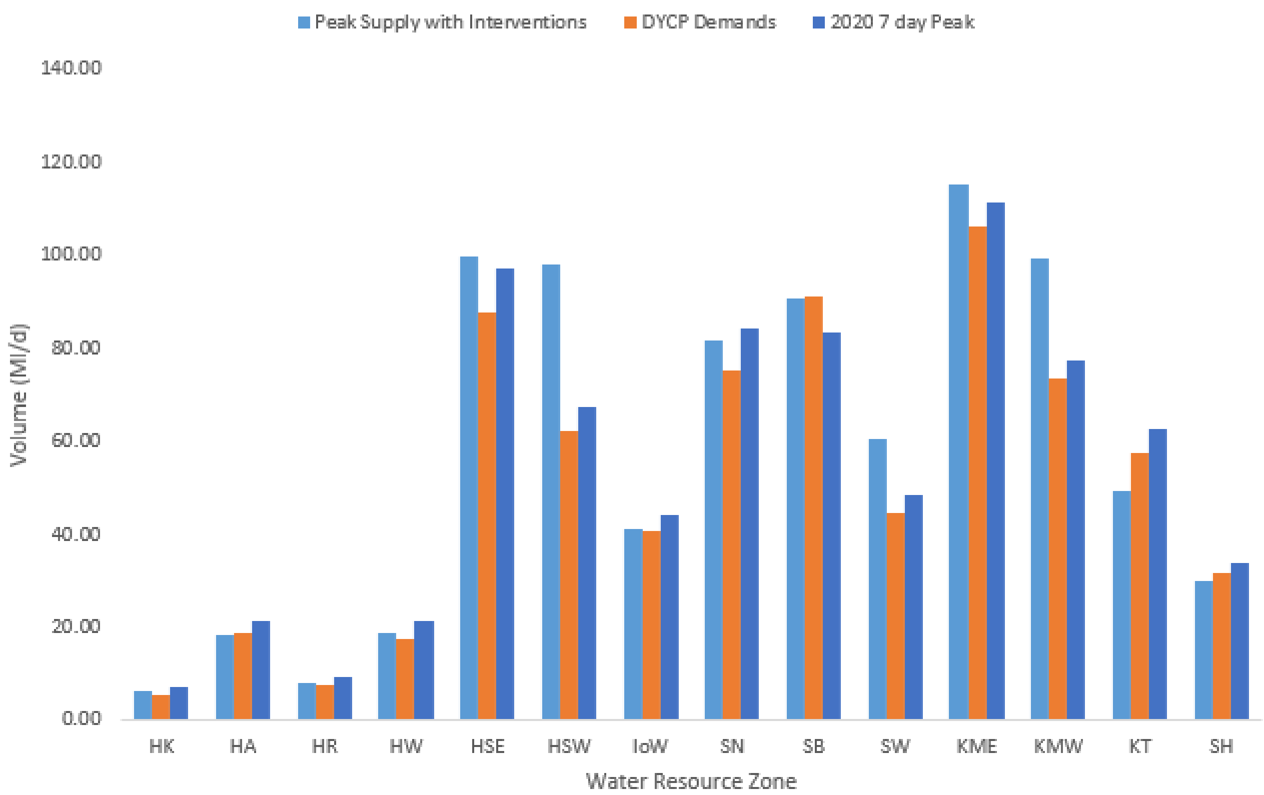


Figure 64: Comparison of supply and demand components for peak demand scenario compared to the August 2020 heatwave peak distribution input including the effect of drought interventions.

This demonstrates that the drought interventions provide a high degree of resilience against conservative supply and demand scenarios that include the effects of outage, heatwaves, target headroom and a pandemic. The COVID-19 pandemic is ongoing and the extent to which the change in household demand will represent a permanent and long-term shift (e.g. due to increased home working) is presently uncertain but will need to be considered as additional scenarios within our future WRMPs.

Incorporation of drought supply and demand measures

For each of the drought scenarios the phasing of supply and demand measures has been applied consistently with our stated approach in DP22 at each drought level. This favours early application of demand-side measures and non-environmentally impacting supply measures early, before resorting to higher impact measures such as drought permits/orders.

Overall, the magnitude of supply-demand balance benefits from demand-side measures is small, especially when compared with the supply-side benefits of drought permits/orders and it is unlikely that demand-side measures alone will be sufficient to maintain supplies during drought, especially for the severe to extreme drought scenarios. The magnitude of demand savings, either through TUBs or NEUBs vary by area and seasonally, consistent with our effectiveness of demand restrictions study.[37]

For some supply and demand measures, we expect that the benefits will be limited or highly uncertain, these measures include:

- Media campaigns to promote water efficiency
- Enhanced leakage control
- Mains pressure reduction and management
- Changing operation of sources and enhancing abstraction
- Distribution network modifications
- Tankering.

For these measures, no supply-demand benefit has been assigned in our simplified supply demand balances, however the sequencing and timing of when these measures should be enacted (primarily at Level 1) in an actual drought is shown.

Drought permits/orders are implemented when required to ensure that the supply-demand balance remains positive. The benefits are expressed as gains in DO. We would generally expect to need to start development and pre-consultation on most of our drought permits/orders but would not implement them until Level 2 or Level 3 drought. Some drought permits/orders, for example those for the River Test and River Itchen have dedicated triggers.

One particular concern in testing the plan was whether our triggers provided sufficient time to develop, consult and implement the drought permit/order before it is required. Table 21 summarises the time available for each of the drought events between the trigger that indicates development of the drought permit/order and the earliest implementation.

[37] Atkins, 2020. SWS Demand Analysis Update, Effectiveness of drought restrictions: Technical Report update, Southern Water, 5200065/DG/001

Table 21: Summary of drought permit/order lead-in times from initiating trigger to implementation for severe and extreme drought scenarios.

Drought permit/order	Time to implement from	1-in-200 years drought	1-in-500 years drought
Test Drought Permit	90-day trigger	107 days (Year 1) 153 days (Year 2)	243 days
	60-day trigger	92 days (Year 1) 107 days (Year 2)	212 days
	35-day trigger	61 days (Year 1) 45 days (Year 2)	151 days
Test Drought Order	90-day trigger	Not required	288 days
	60-day Trigger	Not required	242 days
	35-day Trigger	Not required	137 days
Candover Drought Order	90-day trigger	122 days	335-days
	60-day Trigger	107 days	304 days
	35-day Trigger	76 days	228 days
Itchen Drought Order	90-day trigger	168 days	274 days
	60-day Trigger	153 days	243 days
	35-day Trigger	122 days	228 days
Rother Drought Order	Level 1 trigger	33 days	332 days
East Worthing Drought Permit	Level 2 trigger	91 days	305 days
North Arundel Drought Permit	Level 2 trigger	184 days	91 days
Bewl Drought Orders	Level 2 trigger	170 days	133 days

5.2.1 Severe 1-in-200 years drought – HSE and HSW

Our drought vulnerability assessment has shown that the HSE and HSW WRZs are amongst the most drought sensitive due to due to licence conditions linked to HoF constraints on the Lower River Test and Lower River Itchen that restrict the amount of water we can abstract from the rivers even in relatively minor droughts. Owing to this sensitivity and as set out in the Section 20 Agreement, we are reliant on drought permits/orders to maintain secure supplies in severe to extreme droughts.

The first test is against a 1-in-200 years drought from our WRMP19 stochastic sequences. This drought (named Drought Rafael) is close to the design drought event for Southern Hampshire. The evolution of rainfall deficits for this drought event are shown in Figure 62.

This event represents a compound drought event, comprising an early part which is relatively moderate (~1-in-20 years based on rainfall deficits) which then partially recovers before a severe rainfall dry winter occurs during the second and third year of the event leading to significant flow and rainfall deficits in year 3. The peak rainfall deficit is around 55% of long-term average over 12-18 months accumulations (ending September) and is consistent with a slightly greater than 1-in-200 years rainfall deficit as indicated from our drought vulnerability assessment.

Although we do not have consistent SPI data to compare against our rainfall triggers, a 1-in-5 years rainfall deficit is consistent with around an 85% of long-term average rainfall deficit for 12-18 months rainfall accumulation. The rainfall deficit is actually reached before the start of the event and would have occurred well in advance of the flow triggers being reached. For Southern Hampshire, the primary trigger is actually the 60-day flow trigger although the rainfall trigger is a supporting trigger. The emerging rainfall deficit, particularly over the dry winter, would lead us to start early preparation of drought measures (e.g. permit preparation for the River Test) in anticipation of being required the following summer and autumn. This requirement would likely have been evident from any forecast modelling undertaken in that spring.

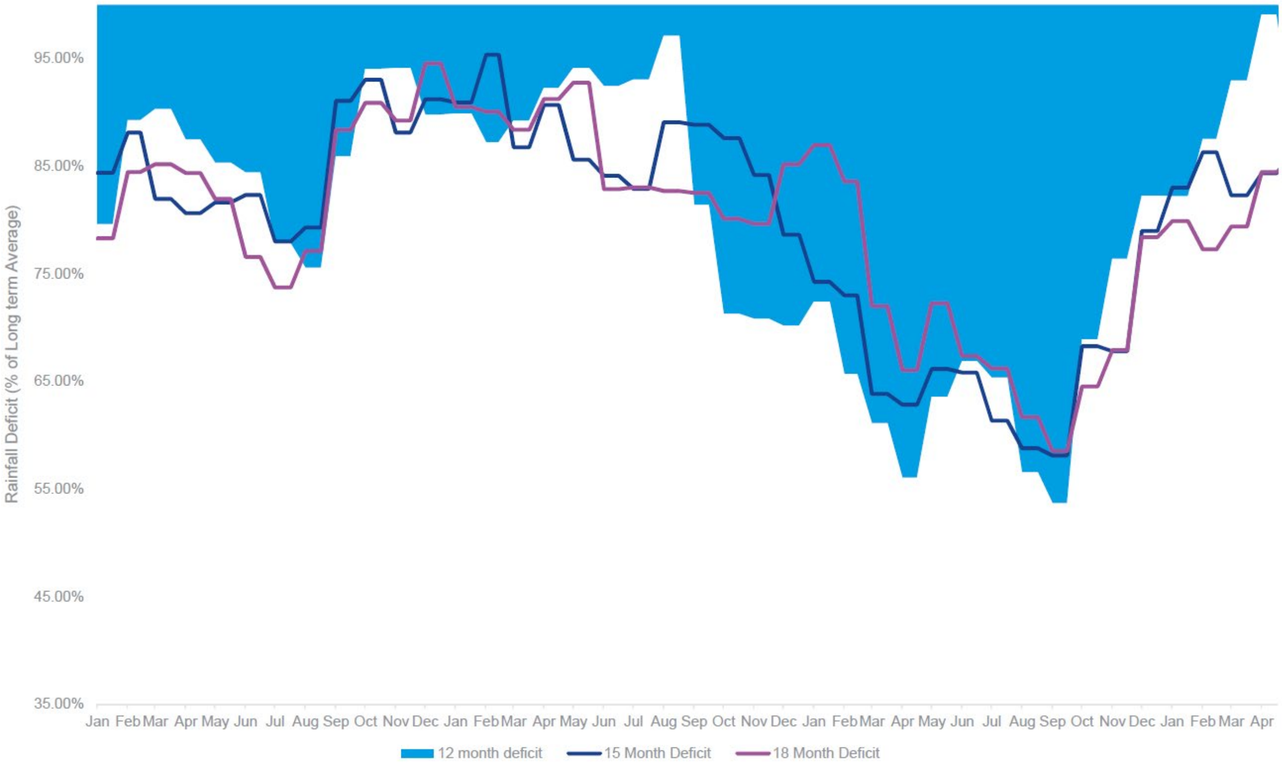


Figure 65: Development of rainfall deficits for a 1-in-200 years drought event in Southern Hampshire

Figure 66 and Figure 67 are drought control charts for the River Test and River Itchen respectively, which show the evolution of flows and our drought responses. The majority of key actions for this event are driven by the flow recession on the River Itchen that is much steeper than the River Test.

In Year 1, the 90-day flow trigger that initiates internal drought permit/order preparation is reached for the Itchen slightly in advance of that for the Test, but we would be undertaking preparation for both options simultaneously.

The 60-day drought permit/order pre-consultation flow trigger is reached at a similar time on both rivers and would initiate the wider Level 1 actions. These include increase efficiency messaging and any other supporting supply and demand measures we can take such as resolving outage, optimising abstraction, leakage and network modifications.

The 35-day trigger[38] for submission of both the Test Drought Permit and the Candover Drought Order is also reached at a similar time and given the observed recession, it is likely we would submit both applications.

[38] This analysis considered a 35-day trigger for the Candover but as described in section 3.5.5, this drought plan no longer includes that trigger for the Itchen and Candover.

This recognises that the outturn impact of the event would not be known, and forecasting would indicate potential risk that both HoF conditions could be reached. This submission would initiate TUBs in line with drought permit/order guidance and leads to some minor, but important demand reductions. In combination with other measures, this is sufficient to allow abstraction to reduce so that the 205Ml/d Candover Drought Order flow trigger is not reached on the River Itchen.

The flow recession does continue on the River Test and the HoF is reached in August of Year 1 and would require a short period of implementation of the River Test Drought Permit to avoid supply deficits. Flows recover in the early autumn and both the rainfall and flows are likely to exit our Level 1 triggers in the winter (by December of Year 1).

Year 2 of the event is very similar to Year 1, with drought permit/order actions being initiated by recession of the River Itchen and again TUBS would be implemented at the time of application for the Candover Drought Order, which in this instance occurs in advance of the River Test Drought Permit 35-day submission trigger. As in Year 1, demand suppression is sufficient to avoid requiring the Candover Drought Order in Year 2 (but this would not be known in advance). Similarly, a short period of drought permit implementation in the late autumn of Year 2 would be required. This reflects that, although the winter rainfall between Year 1 and Year 2 is only slightly below average, the autumn of Year 2 becomes exceptionally dry, delaying recovery of flows in the river and leading to recession below the HoF

Between Year 2 and Year 3, significant rainfall deficits develop and although flows recover above both Test and Itchen 90-day triggers, the SPI or SPEI triggers would be unlikely to recover (both would show increasing deficit). Flow recovery overall is well below average. We would recognise this in our routine monitoring and would maintain Level 1 actions and planning through that winter in anticipation of requiring further interventions in Year 3. Given the severity of rainfall deficits, we would expect to be in constant consultation with the EA, major customers, the National Drought Group and neighbouring water companies throughout that winter.

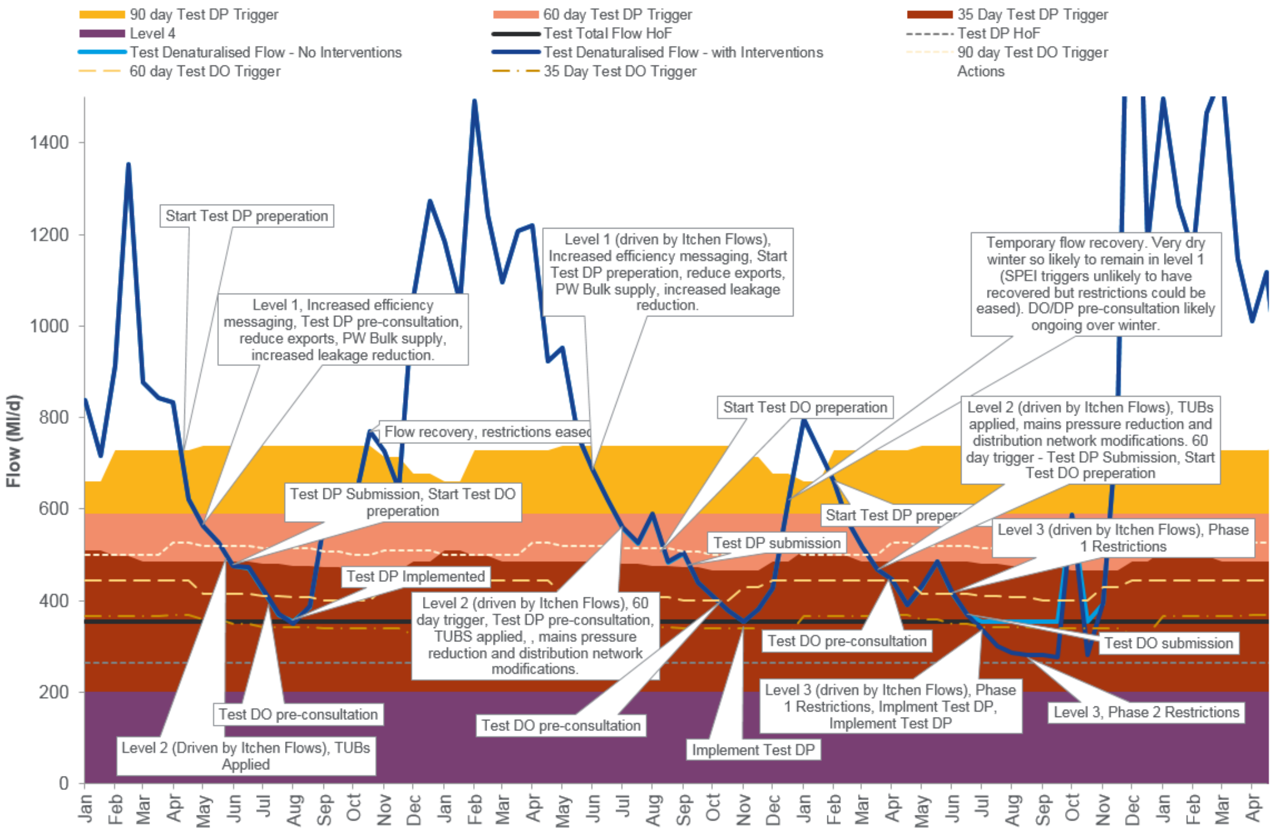
Year 3 represents the peak of the drought event, the rainfall deficits and low-flow recovery over the winter lead to rapid recession of flows through the spring with the 60-day trigger being reached in March. Flow forecasts would indicate a high risk of HoF conditions being reached and we would submit the Test Drought Permit as well as Candover and Itchen drought orders in April and apply TUBs. This would likely result in marginal demand reductions given the time of year. We would also start pre-consultation for the River Test Drought Order.

Both the Test Drought Permit and Candover Drought Order would be required by early summer and prior to implementation we would initiate Phase 1 level 3 restrictions ahead of the summer peak in demand though these would be insufficient to suppress demand enough to avoid drought permits/orders being required. Level 3 Phase 2 Drought orders to restrict water use would be implemented later in the summer.

Use of the Candover Drought Order to augment flow delays the recession of the River Itchen, and thereby requirement for the Itchen Drought Order by approximately 1 month but as net gains reduce the Itchen HoF would again be reached and the Itchen Drought Order would be required through the summer.

An alternative strategy could be to implement the River Test Drought Order and to maximise abstraction from the River Test via both the drought permit and drought order during the summer but there still may not be sufficient headroom in the daily licence limit, or Test surface treatment capacity to meet demand.

Rainfall deficits and flows rapidly recover in the autumn of Year 3.



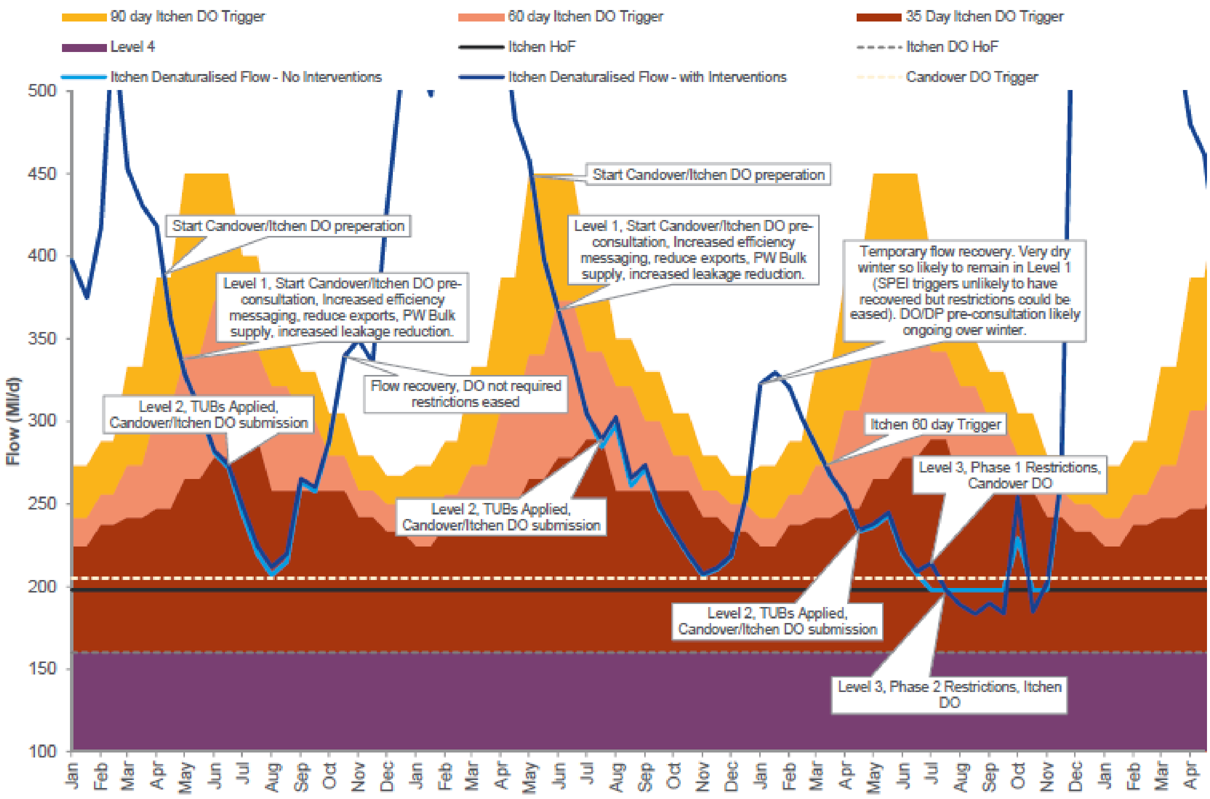


Figure 66: Drought control chart for 1-in-200 years drought on the River Test.

Figure 67: Drought control chart for 1-in-200 years drought on the River Itchen.

The analysis shown in figure 67 included a 35-day trigger for the Itchen but as described in section 3.5.5, this drought plan no longer includes that trigger for the Itchen.

The benefits of the supply and demand interventions across HSE and HSW for this drought are shown in Figure 68. This shows that by application of the measures we have put forward, supplies are maintained through the drought with no deficits. Without these interventions, significant deficit and Level 4 conditions with emergency restrictions would occur in Year 3 of the drought.

Although the use of low environmental impact supply options and demand-side measures is prioritised, the marginal gains in supply are small and are insufficient by themselves to avoid the use of supply-side drought permits/orders in these WRZs although the demand-side measures do slightly delay their implementation.

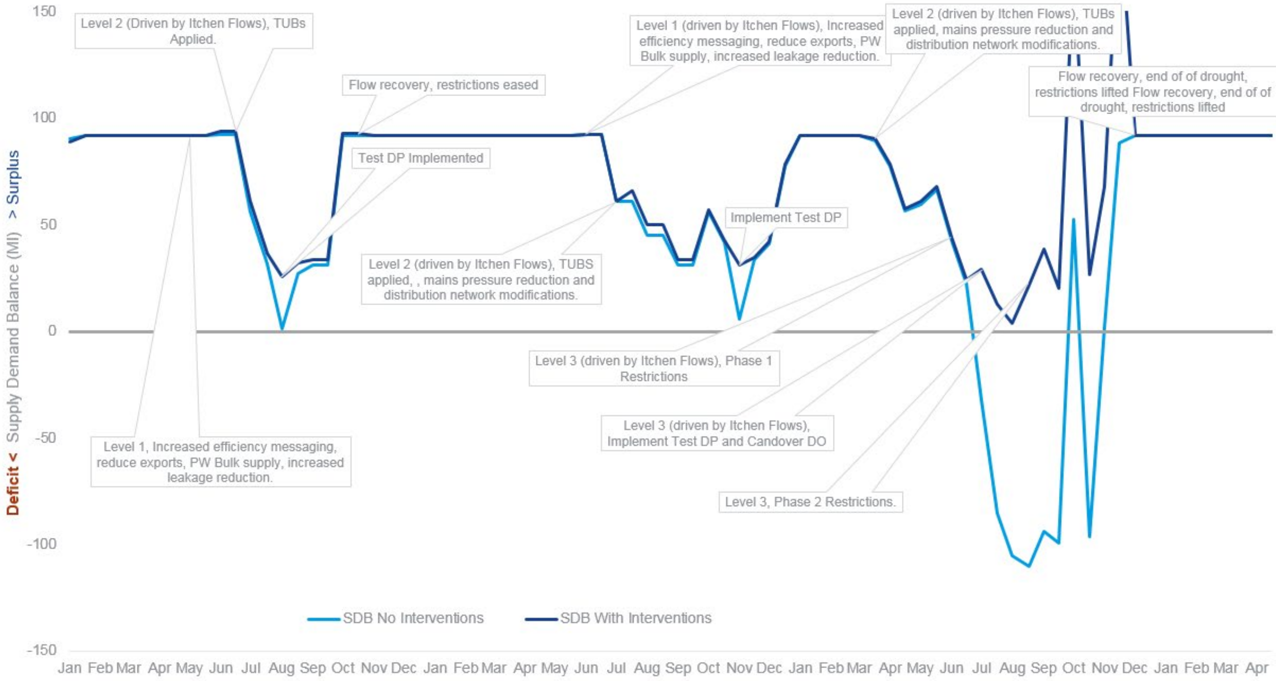


Figure 68 Supply-demand balance for 1-in-200 years drought in Hampshire.

5.2.2 Extreme 1-in-500 years drought – HSE and HSW

This event, again taken from our WRMP19 scenarios (Drought Michael), is a much more severe drought than the 1-in-200 year event but in some ways is a less complex event. The evolution of rainfall deficits is shown in Figure 67. Like the 1-in-200 years event, this represents a compound drought. The first with more moderate rainfall deficits, which largely develop over the summer and autumn of around 65% of long-term average rainfall over 12-18 months accumulations (approximately a 1-in-50 years event) which, after a short recovery, is followed by an extremely dry winter peaking at around 45% of long-term average. The outrun rainfall probabilities are slightly more severe than the drought DO probability.

Drought control charts are shown for the River Test in Figure 70, for the River Itchen in Figure 71 and a supply-demand balance showing the impact of interventions is shown in Figure 72.

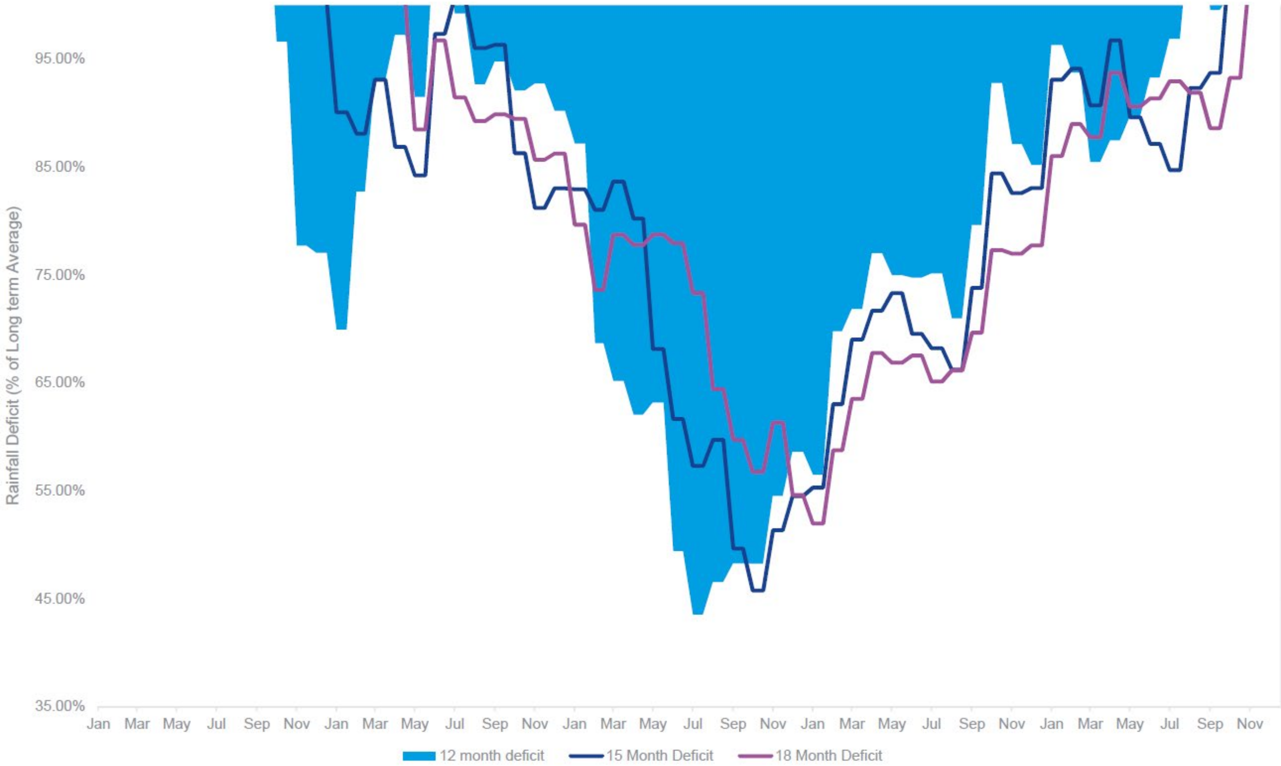


Figure 69: Evolution of rainfall deficits for a 1-in-500 years drought in Southern Hampshire.

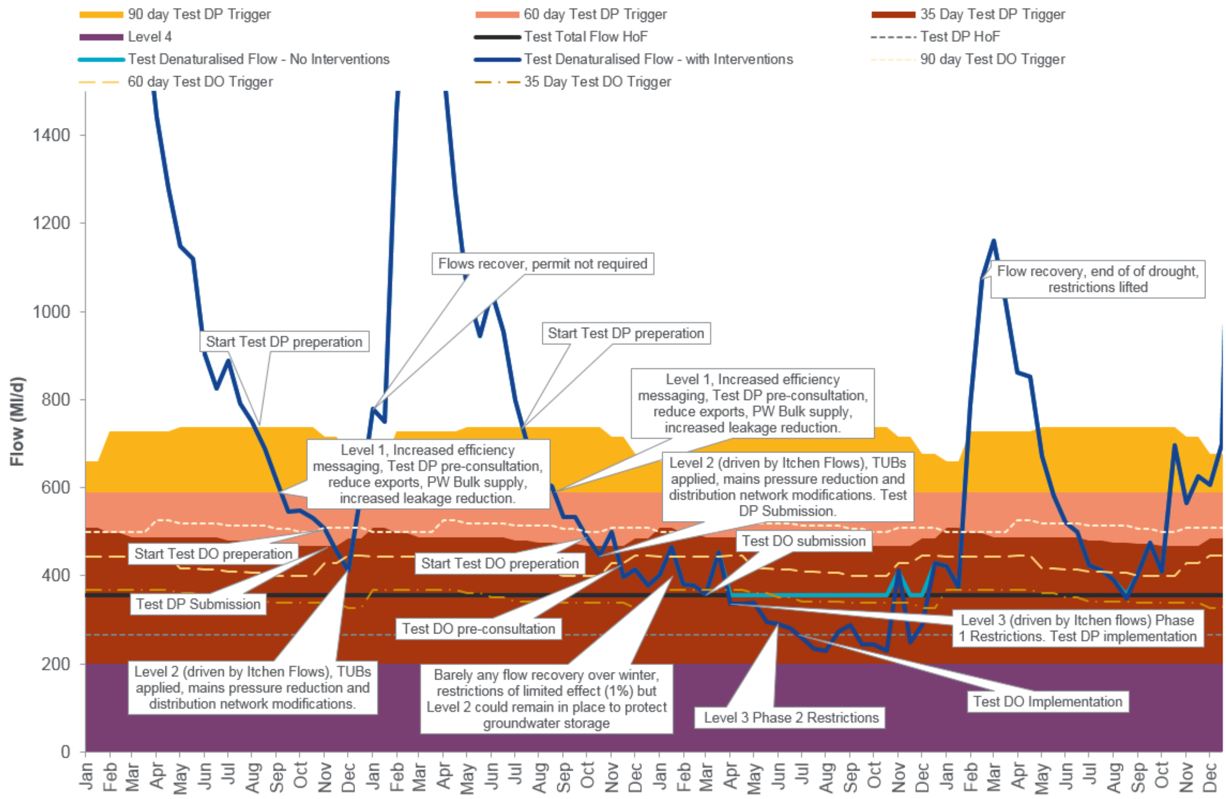


Figure 70: Drought control chart for 1-in-500 years drought on the River Test.

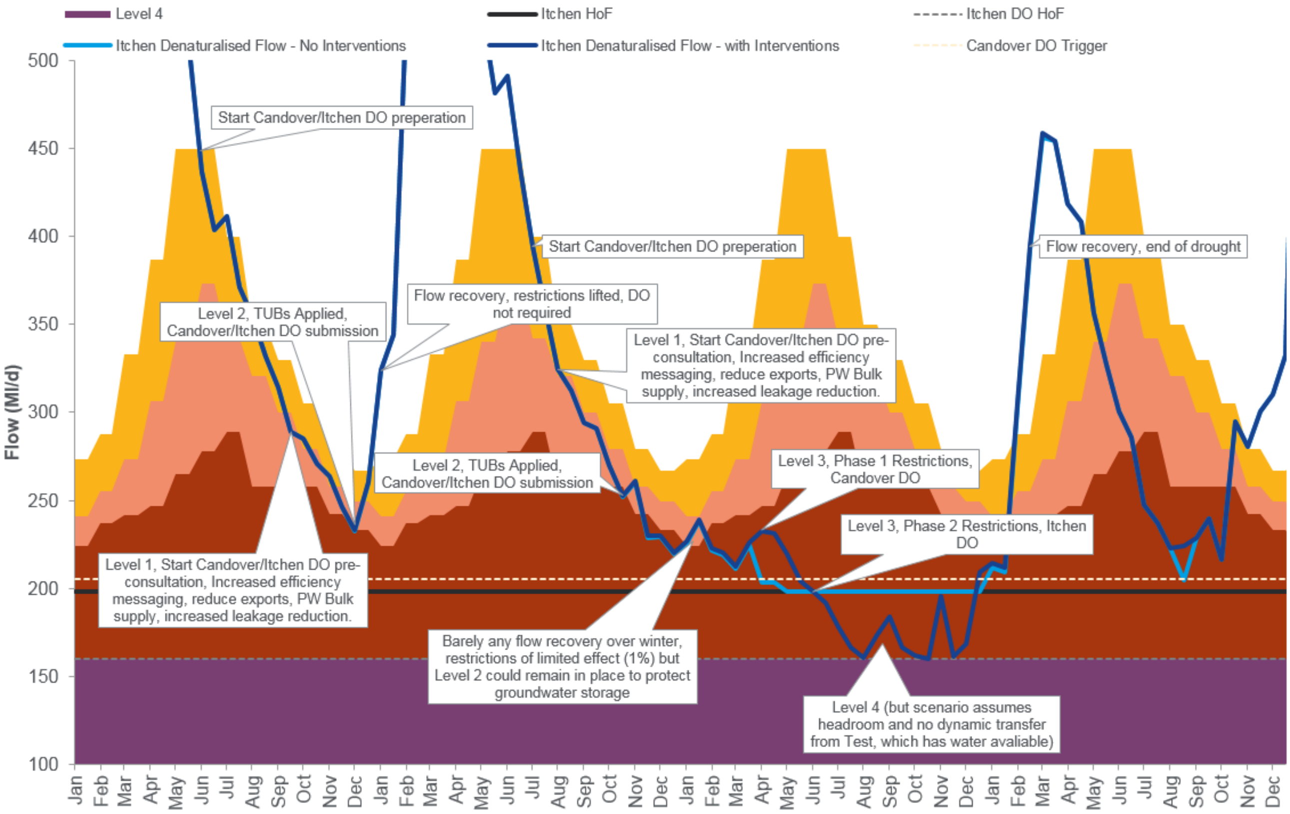


Figure 71: Drought control chart for 1-in-500 years drought on the River Itchen.

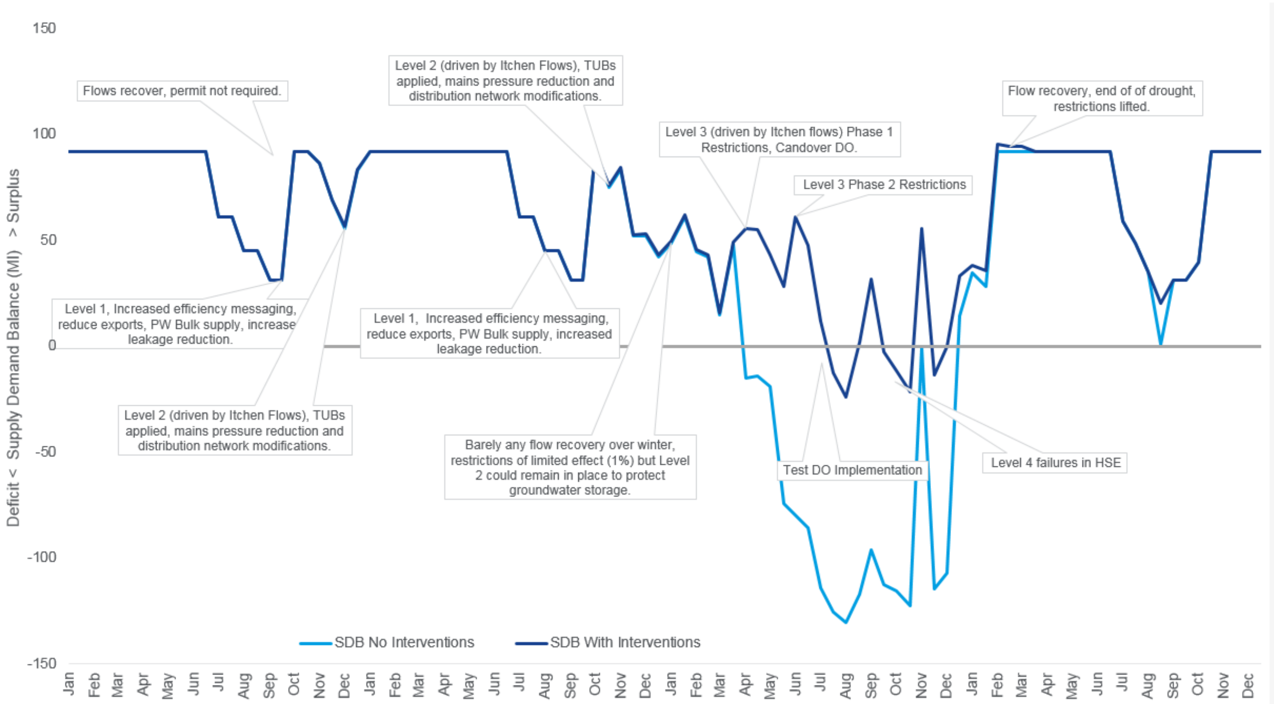


Figure 72: Supply-demand balance for 1-in-500 years drought in Hampshire.

During Year 1 of the drought, rainfall deficits begin to accumulate, and flows recede through the 90, 60 and 35-day flow triggers on both the River Test and the River Itchen[39]. After a short period of TUBs (associated with application for the Candover Drought Order), flow recovery occurs shortly afterwards. At the end of Year 1, both flow and rainfall positions are close to normal.

Year 2 is a relatively normal year until the autumn. Due to the flow recession, the standard progression through the flow triggers occurs through the summer months with applications for both the Candover and Itchen drought orders and River Test Drought Permit being triggered by late summer. However, due to the relatively normal preceding winter, the flow recession slows and although flows approach both the Test and Itchen HoF conditions, neither is reached in Year 2. Instead, a period of much attenuated flow recovery occurs, and winter recharge begins. This is sufficient to maintain flows above the HoF through the winter but insufficient to cause flow recovery above the 35-day flow trigger. Rainfall deficits, and by proxy SPI and SPEI, would continue to show emergence of an extremely dry winter drought during this period and we would remain on a state of high drought alert, potentially with TUBs in place through the winter. This accounts for the long lead-in times between permit/order application and implementation identified in Table 21.

As with the 1-in-200 years event and in recognition of the low flows, we would maintain Level 1 actions and planning through that winter in anticipation of requiring further interventions In Year 3. Given the severity of rainfall deficits, we would expect to be in constant consultation with the EA, major customers, the National Drought Group and neighbouring water companies to co-ordinate our response throughout that winter and into the following summer and autumn. The drought permits/orders would likely remain in a state of continual review and consultation throughout this period in anticipation that they would likely be required early in Year 3. Level 3 Phase 1 drought orders to restrict water use would be applied in the spring of Year 3 as the flow begins to recede.

Once the spring flow recession begins, flows fall quickly below the River Test HoF and then the Itchen HoF with both the Test Drought Permit and Candover Drought Order being implemented. The use of the Candover scheme early in the year causes a reasonable flow recovery although the net-gain diminishes with time as the river continues to naturally recede. Towards the summer peak Level 3 Phase 2 restrictions are applied and by mid-summer, the River Test Drought Order will be required to maintain supplies in HSW. However, the Itchen continues to recede towards the Drought Order HoF and it is possible that some Level 4 failures in HSE could occur. However, it is important to note that this is a simplified model and does not fully take account of conjunctive use benefits between both WRZs and there is some headroom left on the Test Drought Order that could eliminate such deficits.

Restrictions, drought permits/orders would be required throughout the summer of Year 3, as significant flow recovery does not take place until the start of Year 4.

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[39] The analysis described here included a 35-day trigger for the Itchen but as described in section 3.5.5, this drought plan no longer includes that trigger for the Itchen.

5.2.3 Severe 1-in-200 years drought for the Western Rother

This scenario is the same drought event (Drought Rafael) as considered for the 1-in-200 years scenario for our Western area. It develops in a similar fashion though Year 1 of this drought corresponds with Year 2 of the Hampshire drought with a mild (1-in-5 years) preceding drought event which recovers to normal but then is followed by emergence of large rainfall deficits (55% of long-term average 12-18 months accumulations) through the winter and into the following autumn before recovering. The pattern of rainfall deficits in shown in Figure 73.

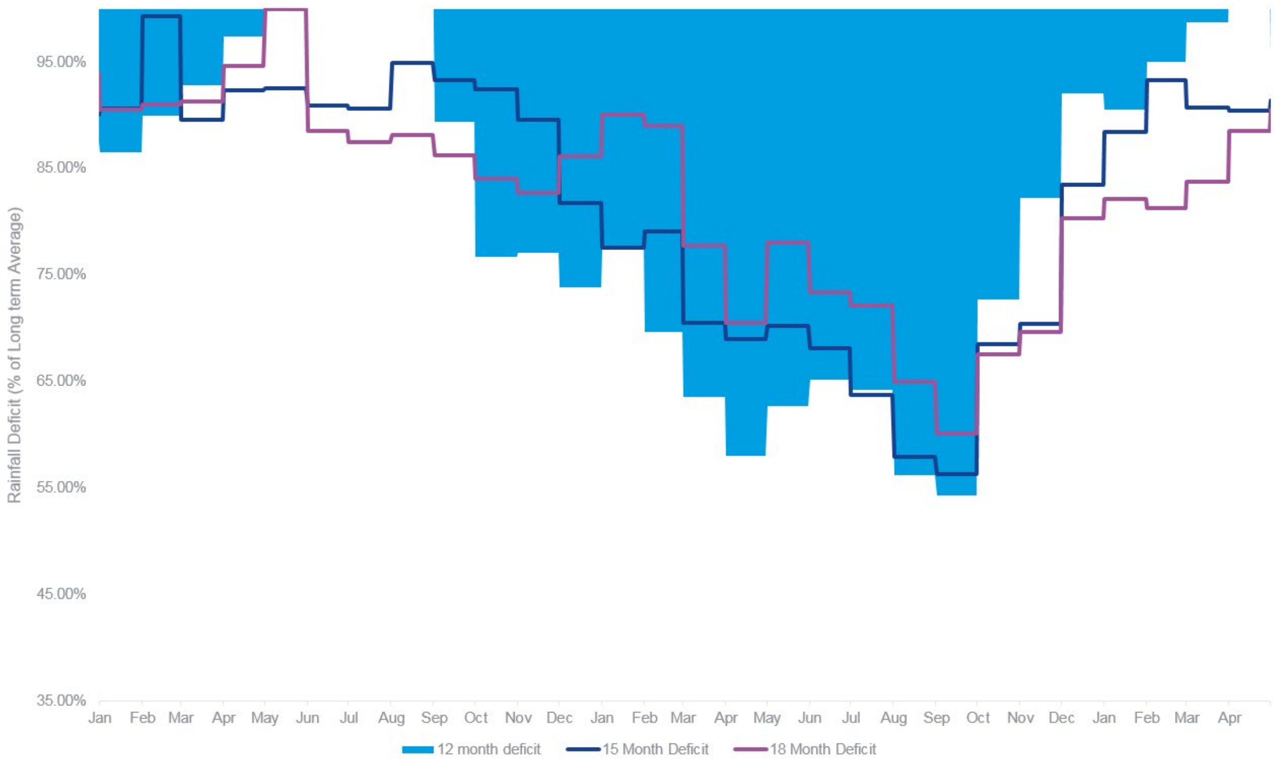


Figure 73: Evolution of rainfall deficits for a 1-in-200 years drought in SNZ.

The drought control curve (Figure 74) shows the progressive evolution of the drought through the cumulative flow deficit triggers. The Level 1 trigger is first reached in the autumn of Year 1 and would initiate our Level 1 actions around water efficiency messaging, drought permit preparation and other supply-side actions such as resolving outage and network and leakage management.

Owing to the rainfall deficits that emerge in the autumn, flow recession continues longer than normal and use of the Pulborough Stage 1 Drought Permit would be required through the winter. This drought develops very quickly and the time available for the drought permit process in such an event would be both difficult to forecast (since a dry autumn could occur in any given year) and only allow limited time for consultation and implementation. It is therefore vital that the Stage 1 drought permit is application ready in case it is required in such an event. Level 2 restrictions (TUBs) would be imposed throughout the winter, although their effectiveness would be limited.

Rainfall deficits continue to worsen throughout the winter and the situation would remain at Level 1 even though there is a short-lived period of flow recovery alleviating need for the Stage 1 drought permit. Once flow recession resumes in the spring it rapidly progresses through the Level 2 trigger in April with the Stage 2 Pulborough Drought Permit and Level 3 restrictions applied in May.

There are some wet summer months between June and July that lead to temporarily higher flows back above the HoF. However, flow continues to recede through August and September with the Stage 1 and 2 Pulborough drought permits being required.

The supply-demand balance (Figure 75) shows that supplies can be maintained by our interventions through this drought, though as in the western area, the demand-side interventions provide only limited benefit compared to supply side measures.

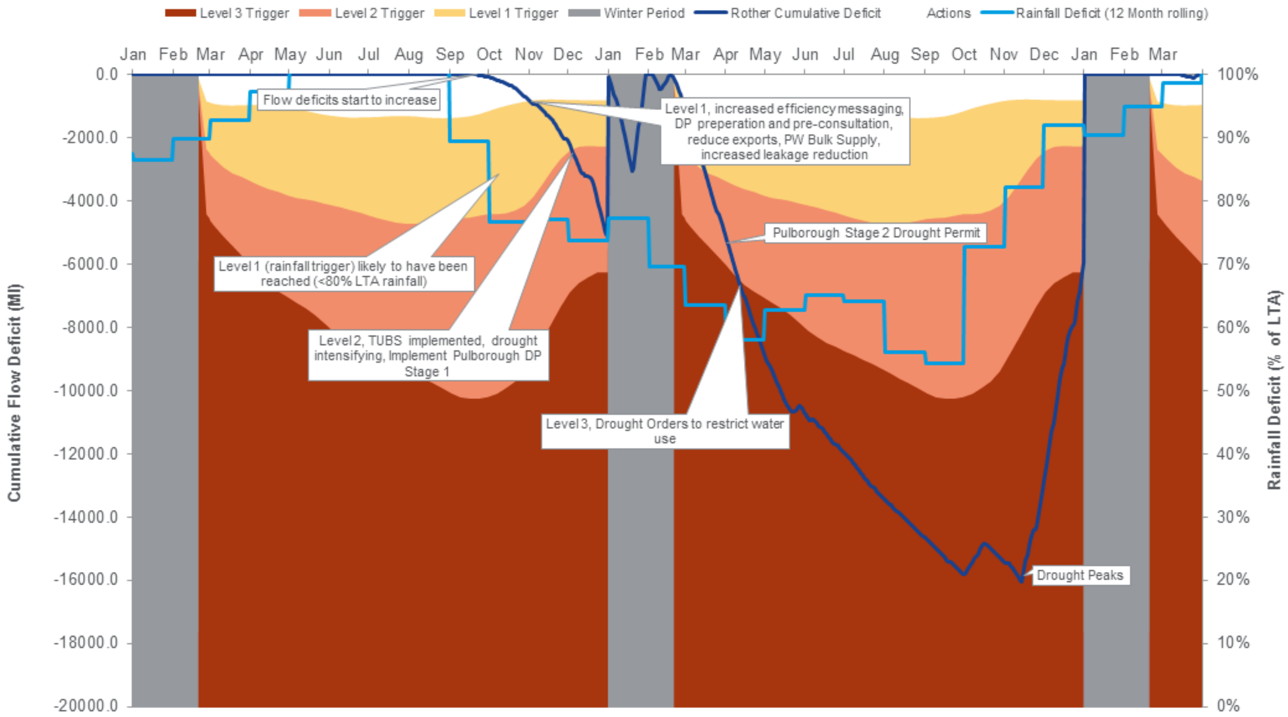


Figure 74: Drought control chart for 1-in-200 years drought on the Western Rother.

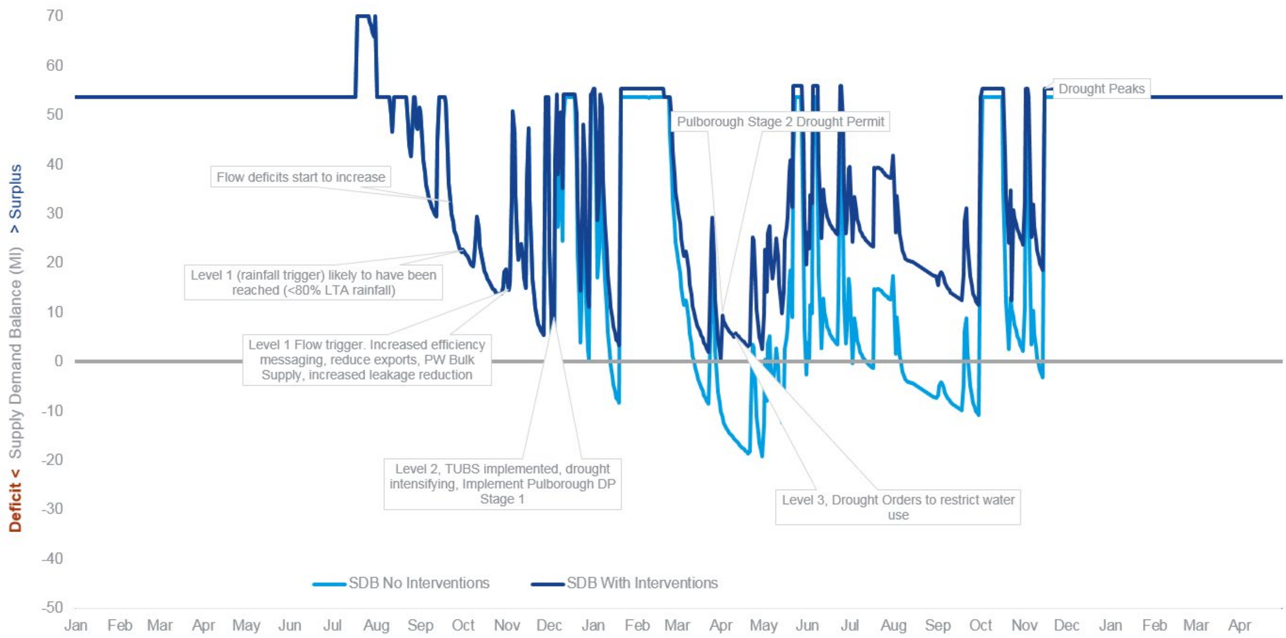


Figure 75: Supply-demand balance for SNZ in a 1-in-200 years drought showing the impact of interventions.

5.2.4 Extreme 1-in-500 years drought – Western Rother

We have also considered a more extreme approximately 1-in-500 years drought for the Western Rother. This scenario (Drought Melissa) provides a further stress test of our triggers and measures.

The rainfall deficit plot (Figure 76) shows that this drought is characterised by rapid emergence of large rainfall deficits (around 60% of long-term average over 12-18 months accumulations) and that these rainfall deficits are sustained for over a year. The emerging rainfall deficits trigger at Level 1 relatively early in this drought in mid-winter of Year 1 before significant flow deficits start to emerge.

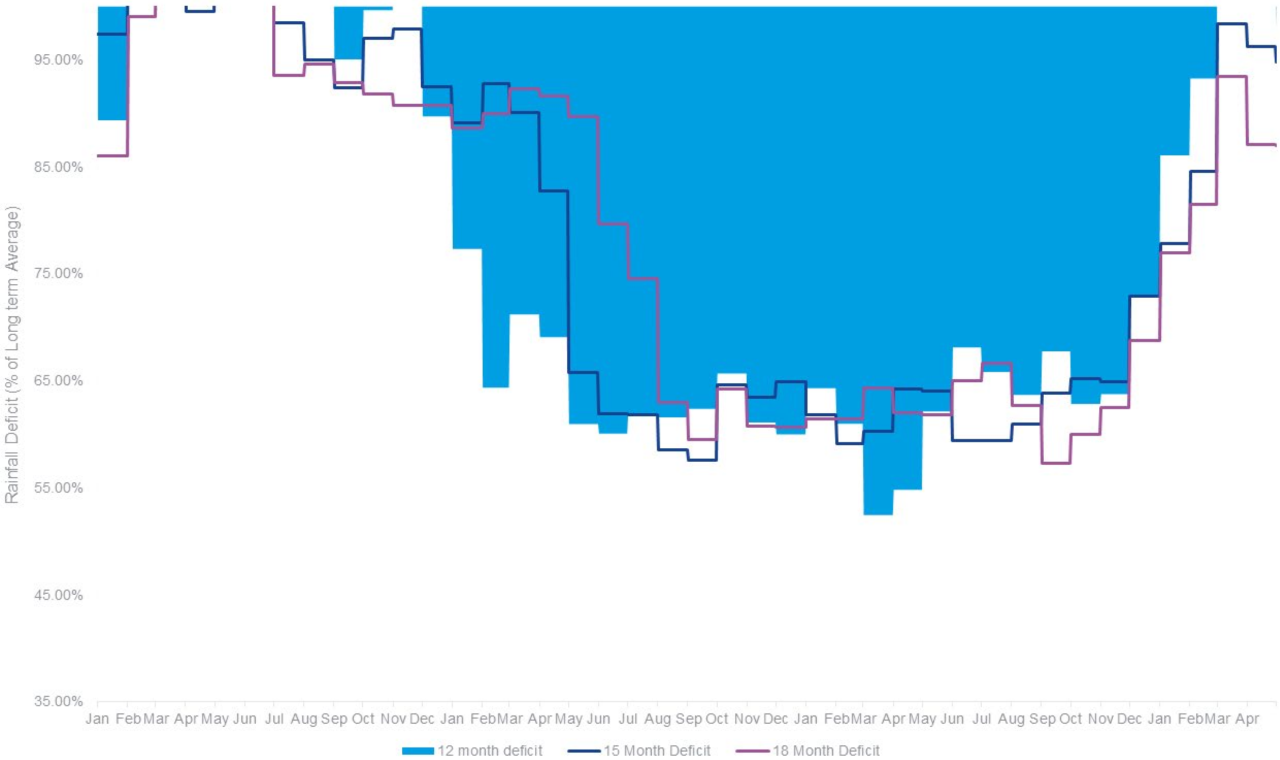


Figure 76: Evolution of rainfall deficits for a 1-in-500 years drought in SNZ

The drought control chart for this event is shown in Figure 77, the accompanying supply-demand balance is shown in Figure 76. The rainfall deficits through the winter would be sufficient for us to start taking Level 1 actions and implement enhanced planning for the year ahead, particularly focused around the summer peak and the autumn minimum flows. We would informally start to consider and prepare drought permit/order options for submission in the spring. In late spring, there is a degree of flow recovery back to normal flow conditions but under the growing rainfall, deficits Level 1 activates would remain in place.

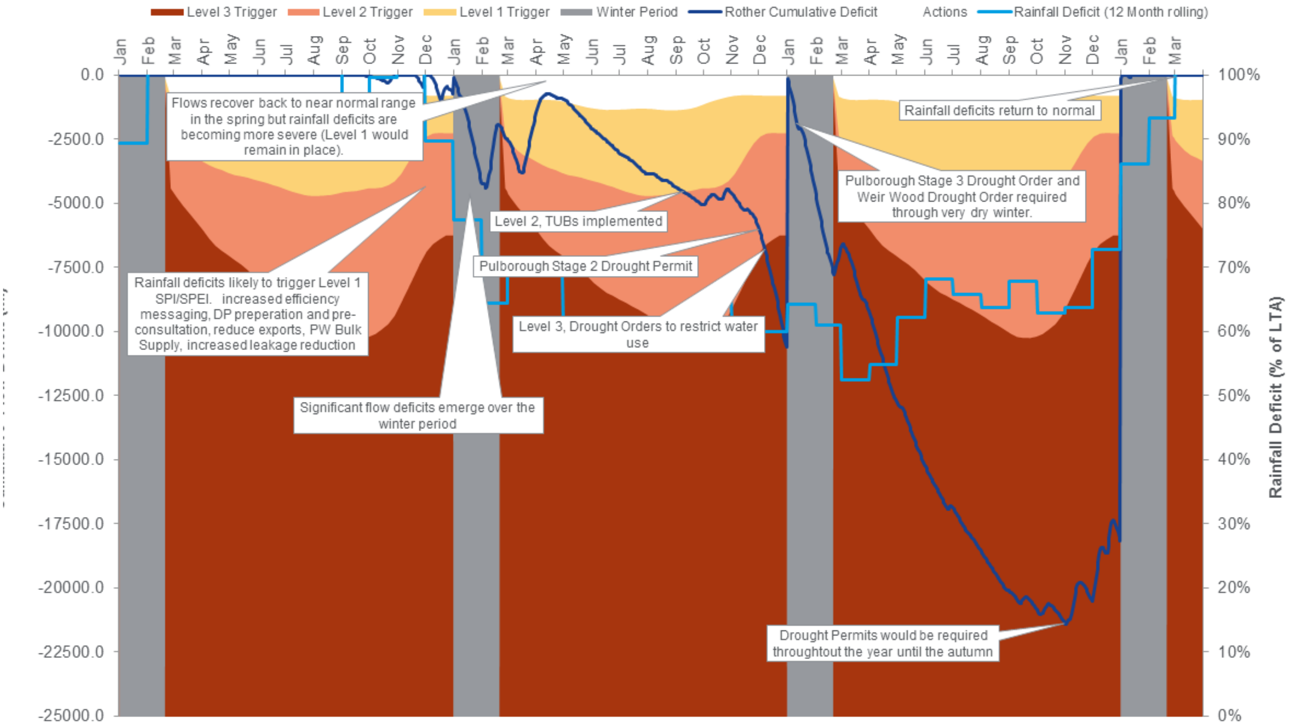


Figure 77: Drought control chart for 1-in-500 years drought on the Western Rother.

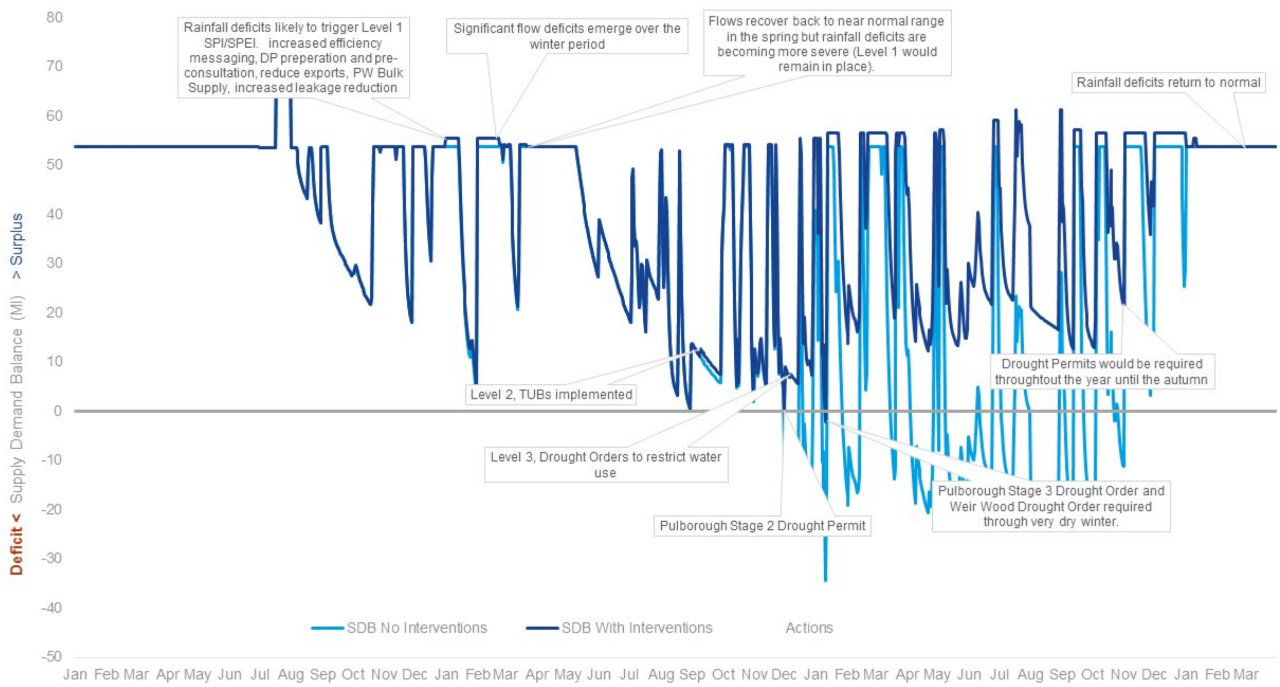


Figure 78: Supply-demand balance for 1-in-500 years drought on the Western Rother.

The Level 2 trigger is reached by August and TUBs would be enacted but drought permit/order interventions would not yet be required though applications would be submitted. The weather remains dry and by late autumn into November and December flow recession is very extended and Level 3 trigger is reached in early December. As well as imposition of drought orders to restrict water use, the Stage 2 Pulborough Drought Permit would be required in December to maintain supplies.

The Stage 3 Pulborough Drought Order and Weir Wood Drought Order would be required in January and would need to remain in place throughout most of the year to maintain supplies until flows eventually start to recover in the autumn of Year 3.

5.2.5 Severe 1-in-200 years groundwater drought – SBZ and SWZ

This drought represents a severe groundwater drought for SBZ and SWZ WRZs, which are both completely reliant on groundwater for their baseline supplies. As evidence by our drought vulnerability assessment, there is a high degree of drought resilience in these WRZs compared to the surface water dominated WRZs such as SNZ, HSE and HSW where yields are much more variable due to river flows. Conversely, there are also fewer large drought interventions possible with only two low-yield drought permits

The rainfall pattern of this drought (Drought Aisha) in Figure 79 shows two moderately dry winters, each of around 75-80% of long-term average rainfall (around a 1-in-20 years return period) followed by a dry summer and winter with a very extended groundwater level recession. Peak rainfall deficits for this drought are around 50-55% of long-term average over 12-15 months accumulations.

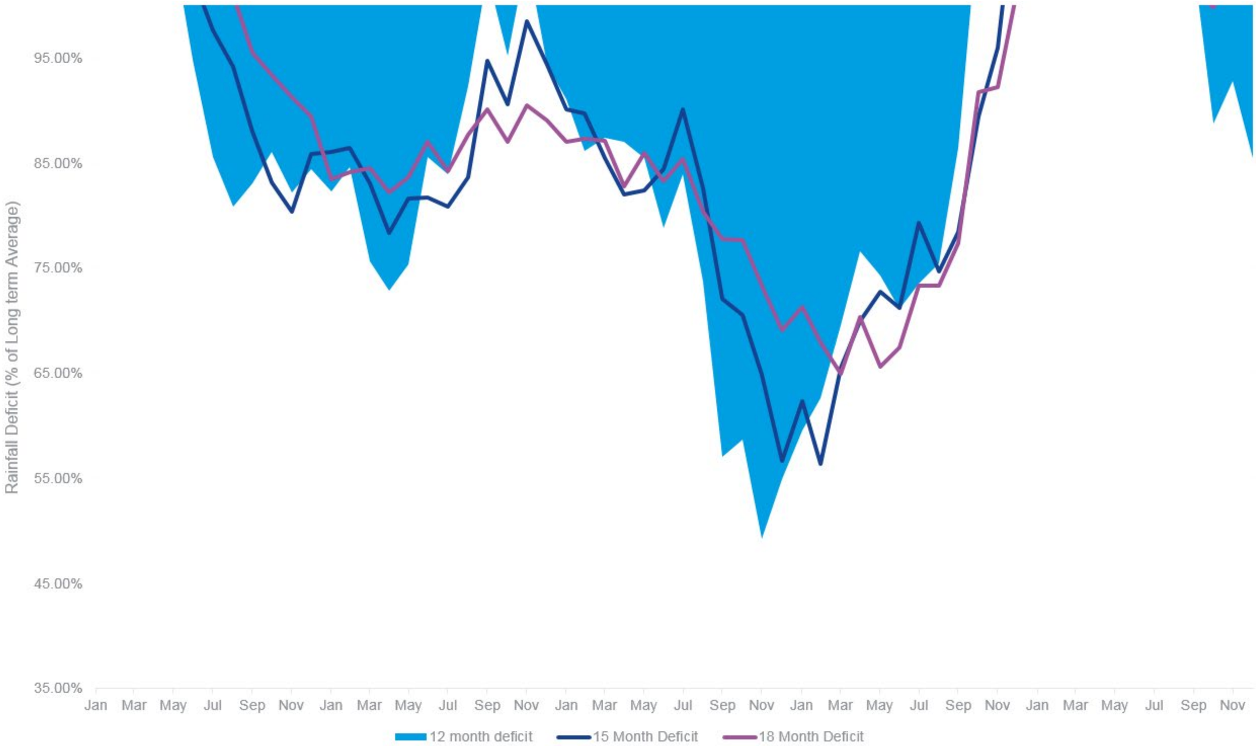


Figure 79: Evolution of rainfall deficits for 1-in-200 years groundwater drought in SBZ and SWZ WRZs.

The drought control chart (Figure 80) illustrates that the Level 1 rainfall trigger would likely be reached relatively early in the early summer of Year 1. However, through most of Year 1 groundwater levels remain above the Level 2 trigger and actions would be relatively limited, for example increased water efficiency messaging and optimisation of source operations to protect groundwater storage.

The winter of Year 1 is dry leading to reduced groundwater recharge and only very limited groundwater level recovery. This leads to the Level 2 trigger being reached in January, which coupled with the low rainfall, would lead to imposition of TUBs early in the year. Level 3 restrictions would be in place through the critical summer peak in demand.

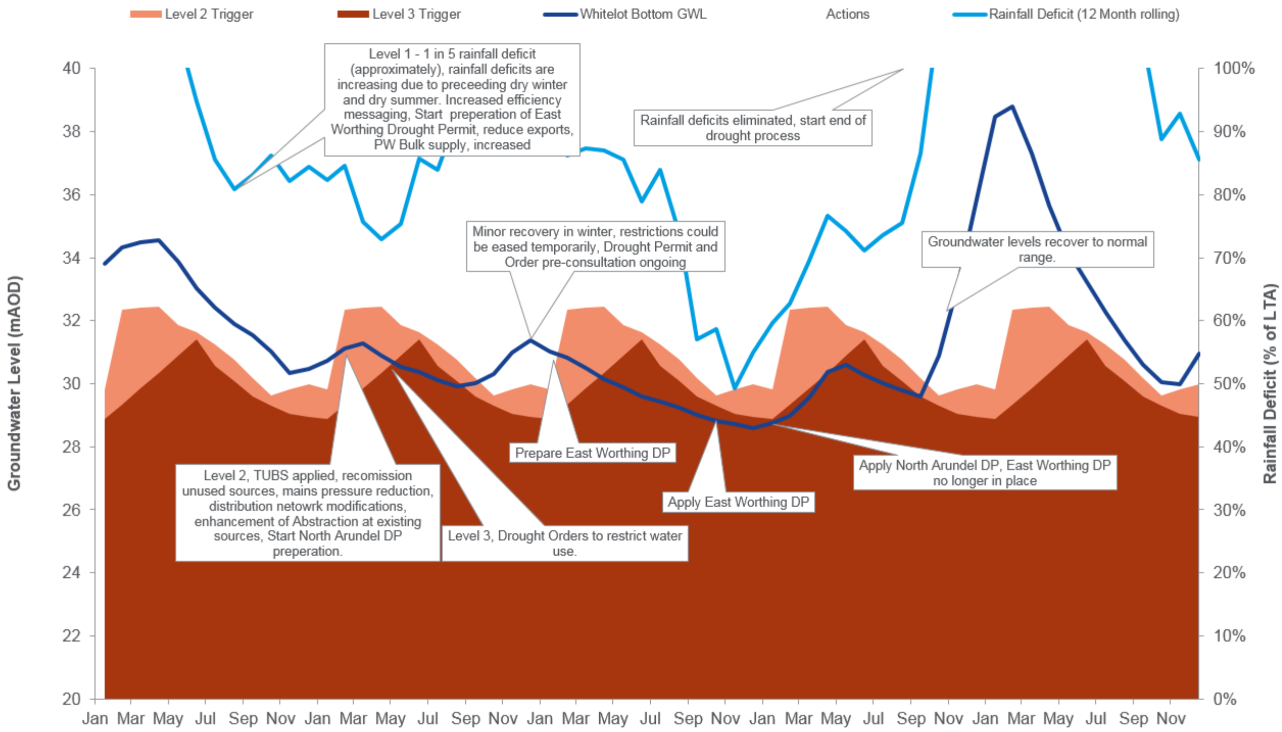


Figure 80: Drought control chart for 1-in-200 years groundwater drought for SBZ and SWZ WRZs.

The winter of Year 2 is initially slightly wetter than Year 1, leading to greater groundwater level recovery in the autumn back above the Level 2 trigger. However, by the start of Year 3 significant rainfall deficits again develop leading to the early onset of groundwater recession in January and which continues through to the following January.

The Level 2 trigger is again crossed in January leading to the imposition of TUBS again and the start of preparations of the East Worthing and North Arundel drought permits. The Level 3 trigger would be crossed in March with again imposition of drought orders to restrict water use (NEUBs) through the summer peak in demand. The East Worthing Drought Permit would be employed in the late Autumn to provide benefits to SWZ. Due to the extended groundwater recession, the North Arundel Permit is used briefly in December before groundwater levels and rainfall deficits start to recover in January of Year 4.

The supply-demand balance for this drought (Figure 81) shows that a surplus could be maintained through this drought without recourse to restrictions or drought permits/orders if water could be moved between the WRZs.

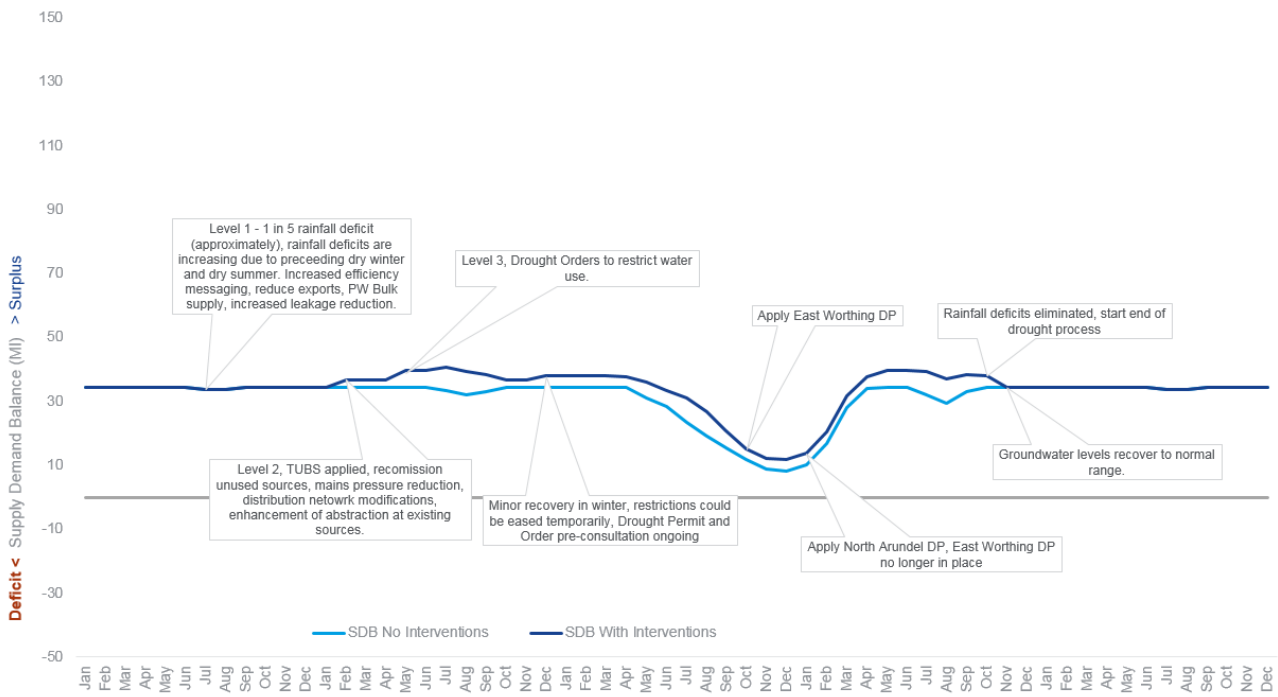


Figure 81: Combined supply-demand balance for 1-in-200 years groundwater drought in SBZ and SWZ WRZs.

5.2.6 Extreme 1-in-500 years groundwater drought – SBZ and SWZ

This drought (Drought Valerie) is a very extreme event for our Western area WRZs (worse than a 1-in-1000 years event) but is milder, although still extreme for our SBZ and SWZ WRZs.

The rainfall deficits (Figure 82) show an extremely severe single dry winter drought that develops from the early autumn and continues over the entire winter. Rainfall deficits do not start to recover until the following autumn.

The drought starts in the summer of a relatively normal year with the Level 1 rainfall deficit trigger likely to be reached in July. This would initiate our Level 1 actions, particularly increased water efficiency messaging to manage the summer peak in demand and to begin for the minimum groundwater level period in the autumn in case drought permits/orders are required.

The Level 2 trigger is reached in November and as the dry autumn progresses with almost no recovery in groundwater levels TUBs would be imposed. The Level 3 trigger is reached in January and drought orders to restrict water use (NEUBs) would be imposed. These would need to remain in place throughout the year until the autumn.

The North Arundel Drought Permit would be required in the spring and would remain in place through the summer peak in demand. The East Worthing Drought Permit would be implemented once available in October through to December.

Figure 82: Evolution of rainfall deficits for a 1-in-500 years groundwater drought in SBZ and SWZ WRZs.

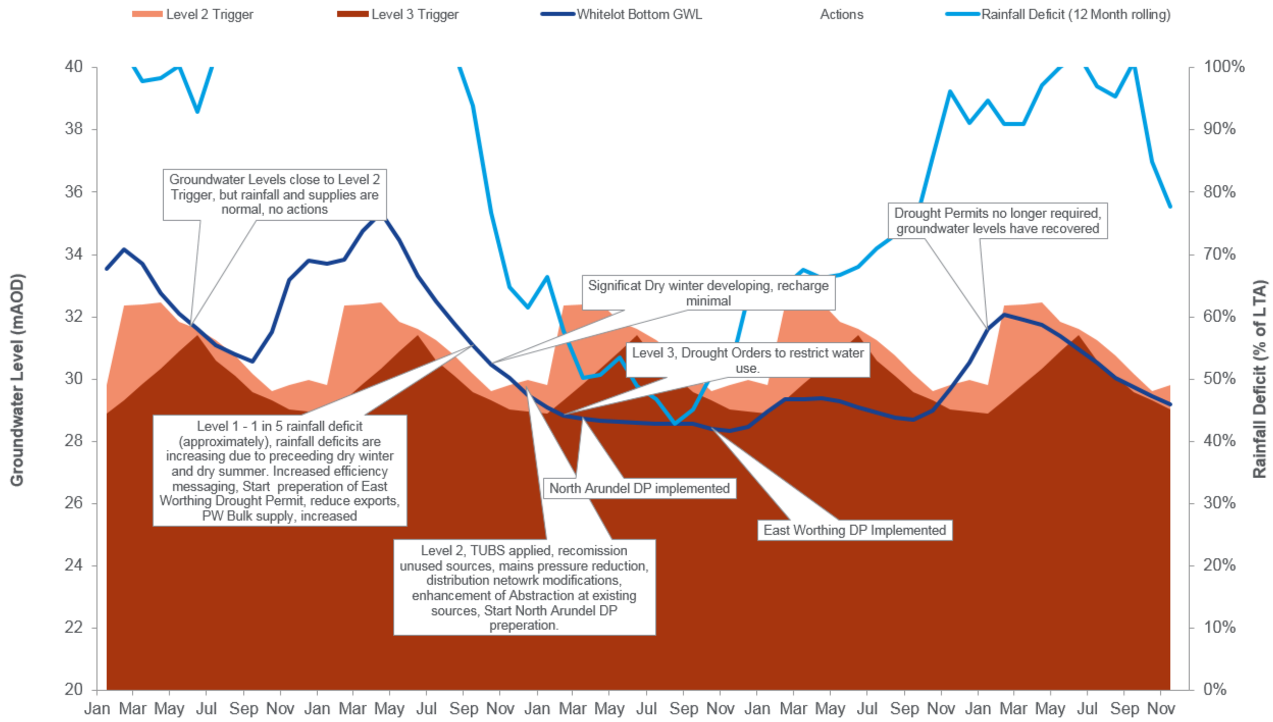


Figure 83: Drought control chart for 1-in-200 years groundwater drought for SBZ and SWZ WRZs.

Groundwater levels do not recover above the Level 2 trigger until the Autumn of Year 2 meaning that severe Level 3 restrictions and drought permits would be required for around 20 months before groundwater yields recover.

The supply-demand balance chart (figure 84) shows that the combination of restrictions and drought permits, as well as the good drought resilience of these groundwater blocks is sufficient to provide resilient supplies through this extreme drought event.

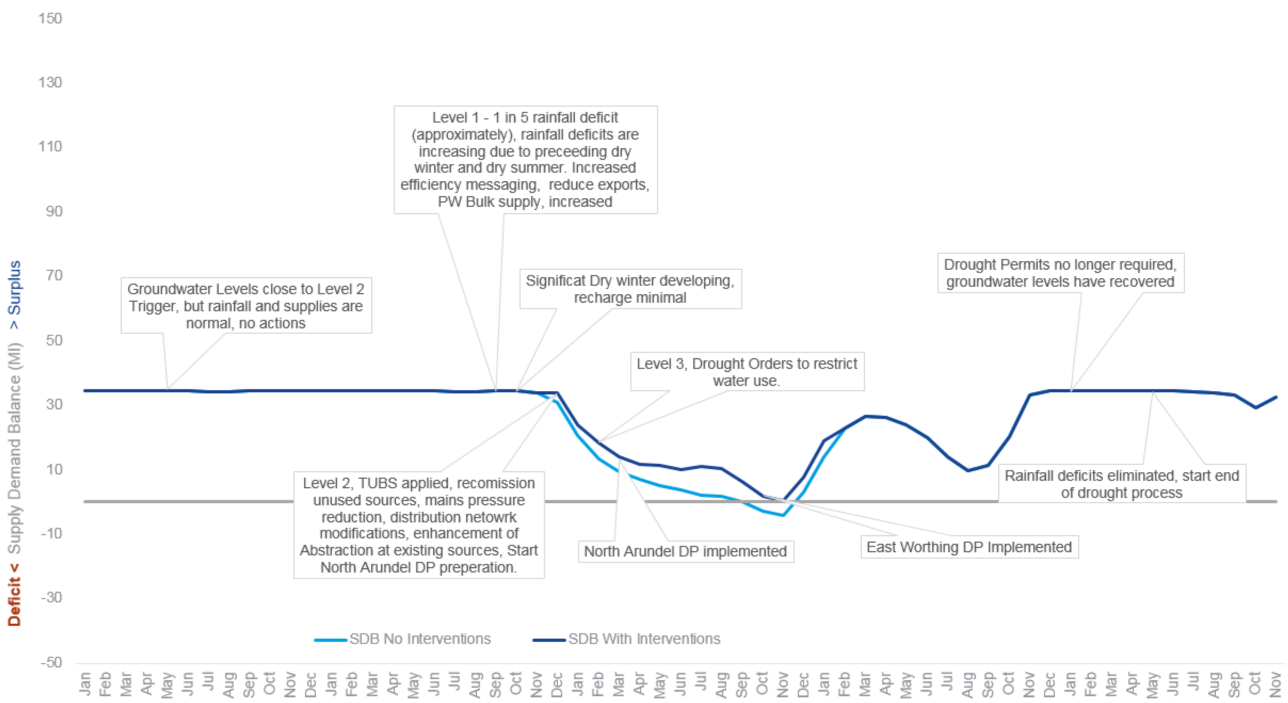


Figure 84: Combined supply demand balance for 1-in-500 years groundwater drought in SBZ and SWZ WRZs.

5.2.7 Severe 1-in-200 years drought – Eastern area reservoirs

We have used our Aquator model of the RMS to assess the impact of drought permits/orders for our Eastern area and to show the timing at which triggers will be reached for a severe 1-in-200 years drought.

The evolution of rainfall deficits Figure 83 for this drought shows a progressive increase in rainfall deficit over a long period of successive years with particular rainfall deficits developing over the winter months at the end of Year 3. This reflects that storage within the reservoir system provides an effective buffer against short duration rainfall deficits but is more vulnerable to sustained rainfall deficits and low flows over several years.

As with the other severe droughts, the Level 1 1-in-5 years rainfall trigger (approximately 85% of long-term average rainfall) would be met early in the drought and would remain in place for the duration of the event.

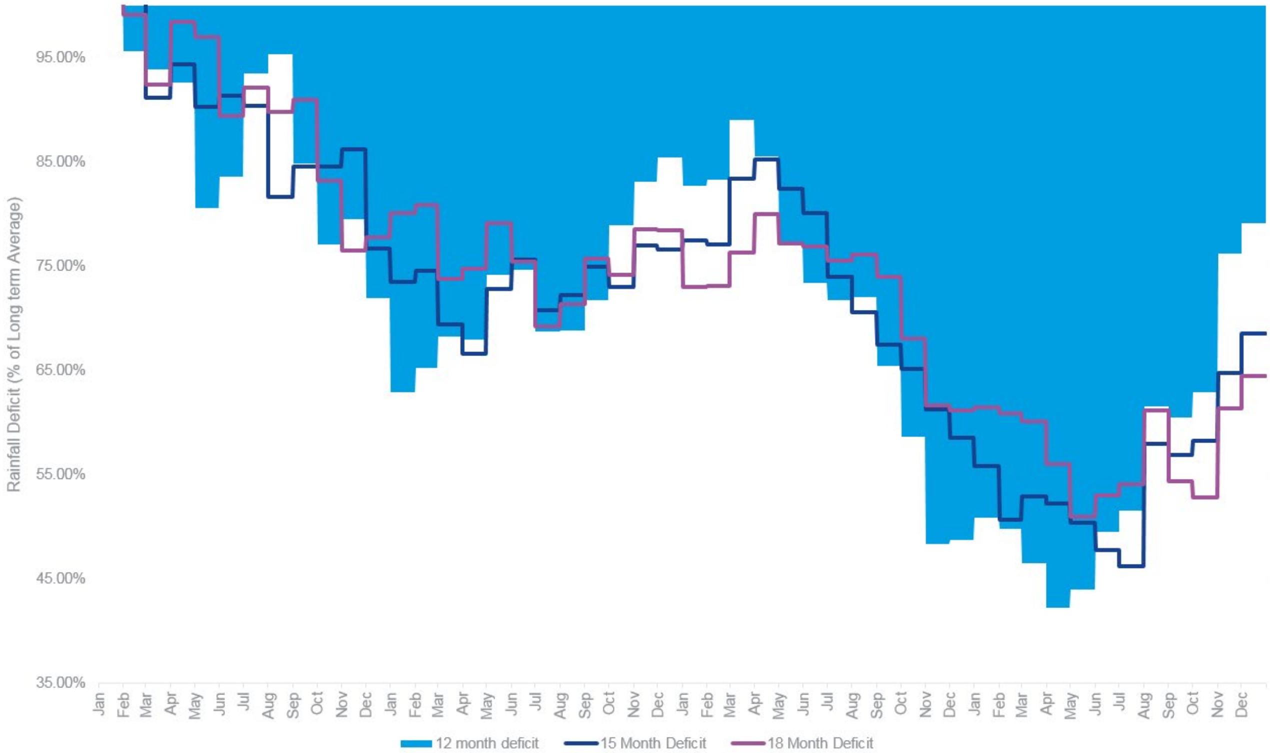


Figure 85: Evolution of rainfall deficits for 1-in-200 years drought for the Eastern area.

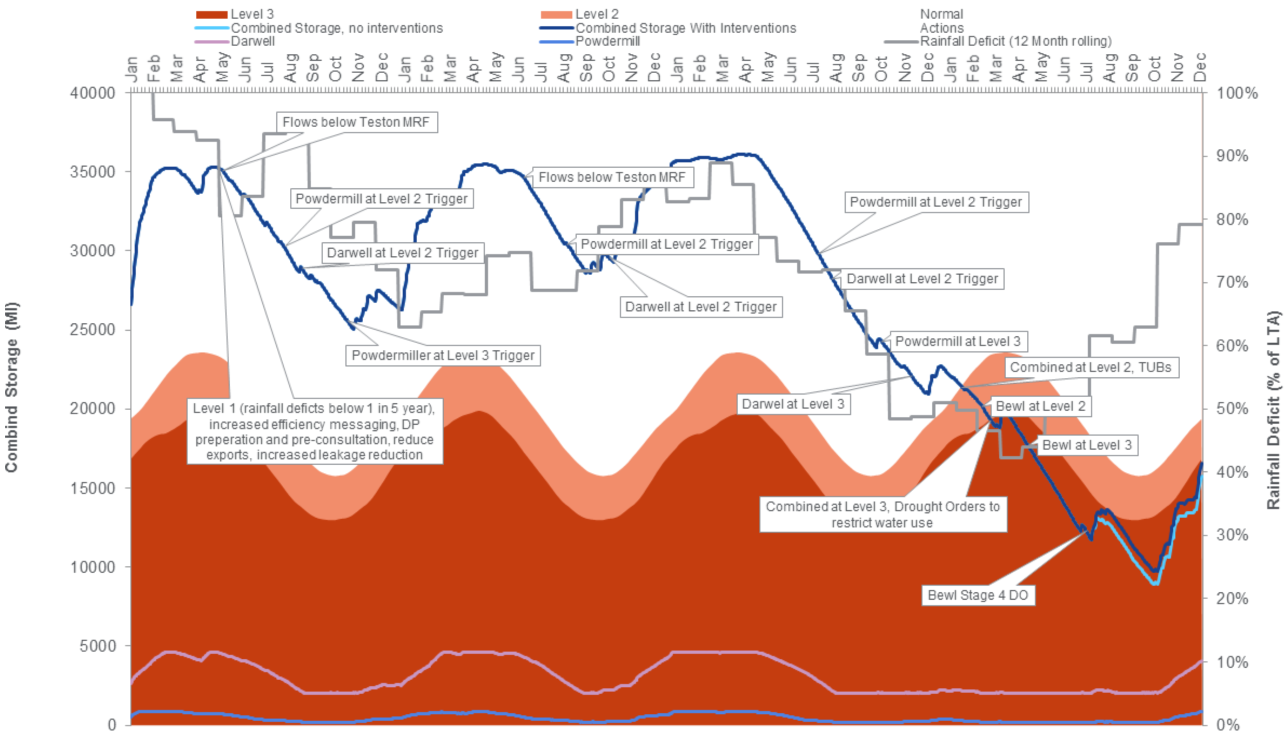


Figure 86: Drought control chart for 1-in-200 years drought for Eastern area.

The drought control chart shows that Level 1 actions well in advance of any significant storage deficit emerging in the combined reservoir system through the summer and autumn of Year 1, both Powdermill and Darwell would meet their individual Level 2 and Level 3 triggers.

Despite worsening rainfall deficits through the winter from Year 1 to Year 2, flows are sufficient to refill the reservoir system back to capacity and although there is some drawdown through the year, by year-end the system is again full at the start of Year 3 without any drought interventions. Due to the rainfall deficits, Level 1 interventions would likely remain in place.

It is through Year 3 that significant rainfall deficits start to emerge. Darwell and Powdermill reservoirs would both reach their Level 3 triggers by the autumn, though Bewl would remain above its Level 2 trigger.

The winter of Year 3 into Year 4 is exceptionally dry and there is very limited recovery in reservoir storage. The majority of flows being used to provide supply. The combined system eventually reaches the Level 2 trigger in February of Year 4 and TUBs would be applied throughout the spring. Level 3 trigger would be reached by April and drought orders to restrict water use (NEUBs) would be applied in May, ahead of the summer peak in demand.

Drawdown would continue throughout the year. Flows are well below the Teston MRF condition throughout the year and hence only the Stage 4 Bewl Drought Order would provide any supply-side benefit for this drought. This would be implemented in the summer of Year 4 and would remain in place until flows and reservoir storage recover in the autumn.

5.2.8 Extreme 1-in-500 years drought – Eastern area reservoirs

We have also considered an extreme drought scenario for the Eastern area reservoirs consistent with an approximately 1-in-500 years event. The evolution of rainfall deficits (Figure 85) shows this to be a very different style event to the 1-in-200 years scenario. For this drought, extreme rainfall deficits develop over a single winter resulting in negligible recovery of reservoir storage and sustained reservoir recession over the course of around a year.

This drought evolves from a relatively normal year, in the winter of Year 1 there is a surplus of rainfall and the reservoir storage is full (Figure 86). Rainfall deficits develop very rapidly over the summer months with the Level 1 rainfall trigger likely to be reached in August. At this time, the recession is relatively normal and summer rainfall deficits would not normally be a significant concern, though they may be linked with an increase in demand.

However, the rainfall deficit continues to deepen through the autumn and winter of Year 2 resulting in very little reservoir refill. The combined Level 2 reservoir trigger is met in January of Year 3 at which point TUBs would be imposed.

The Level 3 trigger is reached by March and drought orders to restrict water use (NEUBs) would be applied ahead of the summer peak in demand. Rainfall deficits slowly start to recover in the summer and some rainfall results in minor refill of the reservoir.

Due to the low flows, the Stage 1 and Stage 2 Bewl drought permits would not provide significant supply-side benefits. Instead, the Bewl Stage 3 Drought Permit would be applied in July and the Stage 4 Drought Order in September.

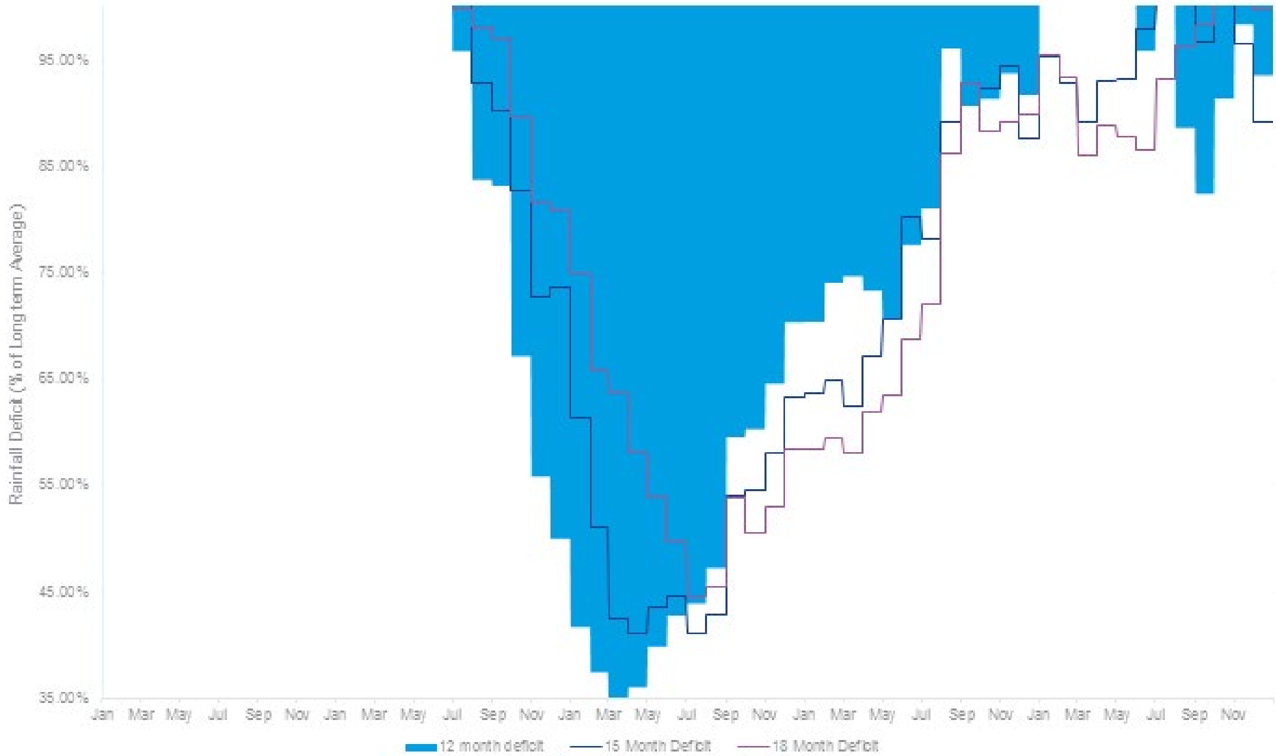


Figure 87: Evolution of rainfall deficits for 1-in-200 years drought for the Eastern area.

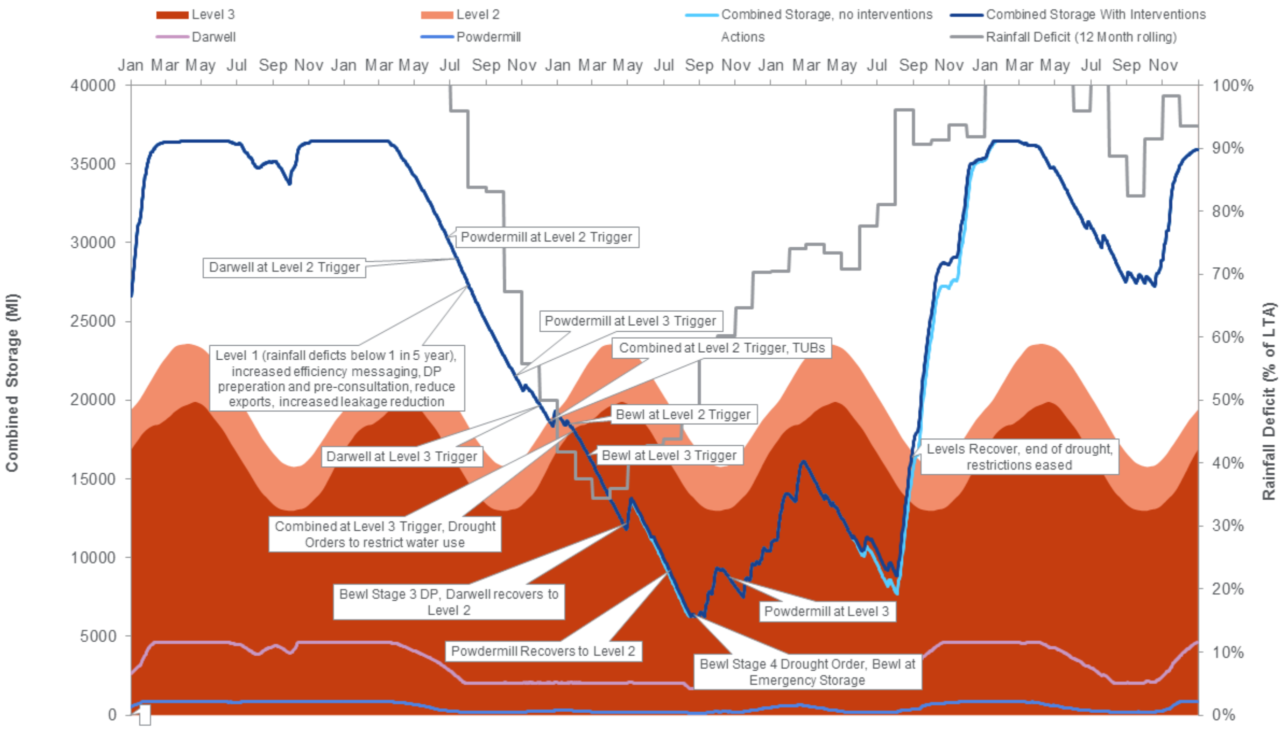
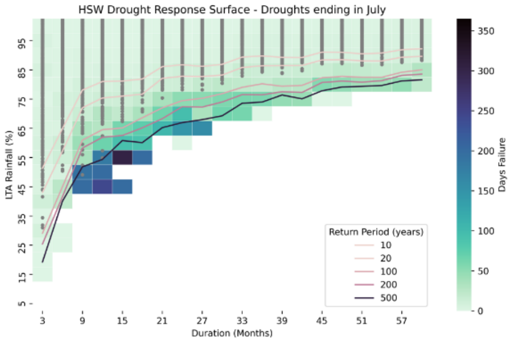


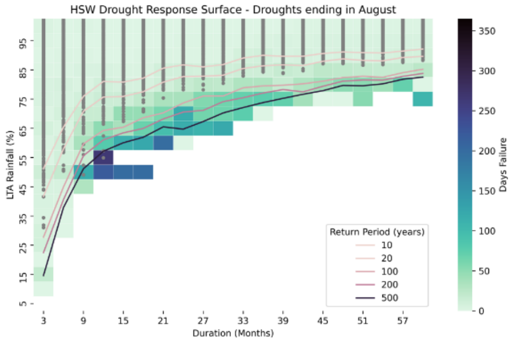
Figure 88: Drought control chart for 1-in-500 years drought for Eastern area.

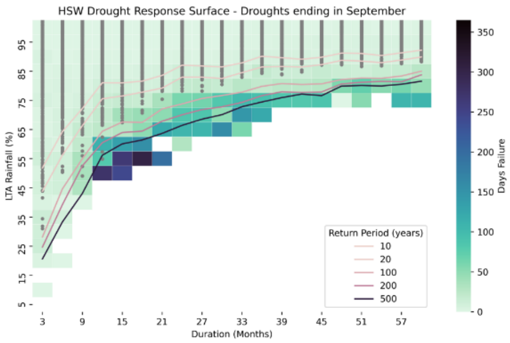
There is a moderate recovery in levels over the following autumn and winter but this is insufficient to restore reservoir levels above the Level 3 trigger. It is not until the autumn of Year 4 that levels recover fully. Restrictions and drought permits/orders would be required throughout that period.

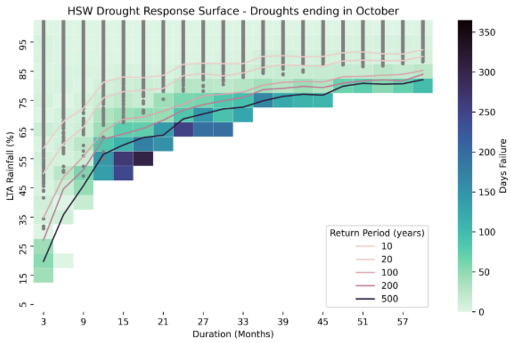
Appendix A: DRS plots by WRZ

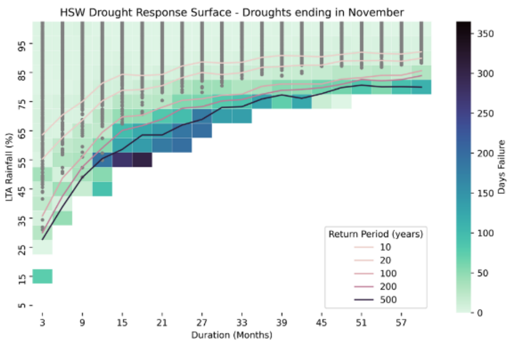
Hampshire Southampton West

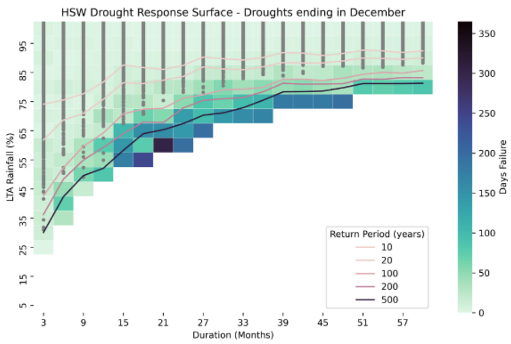




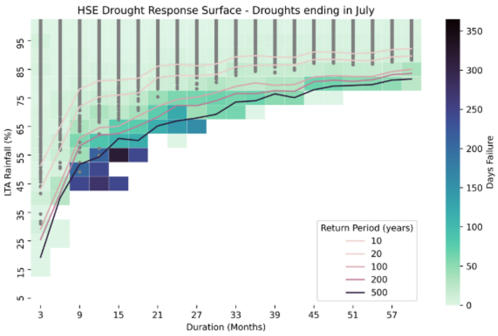


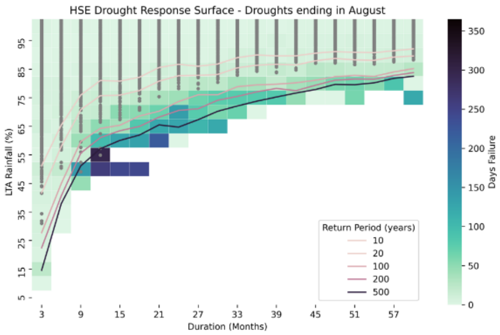


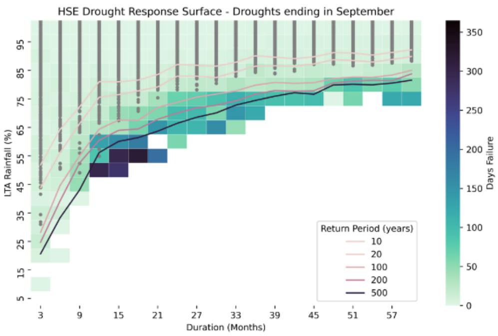


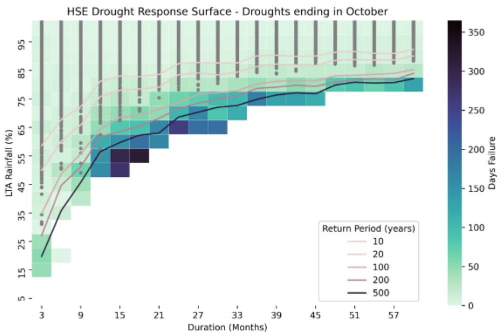


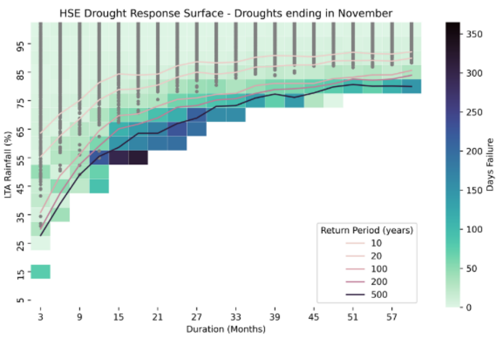
Hampshire Southampton East

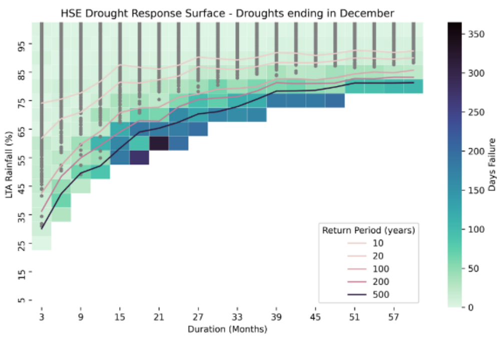




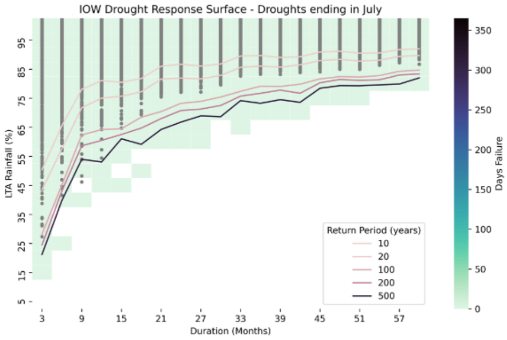


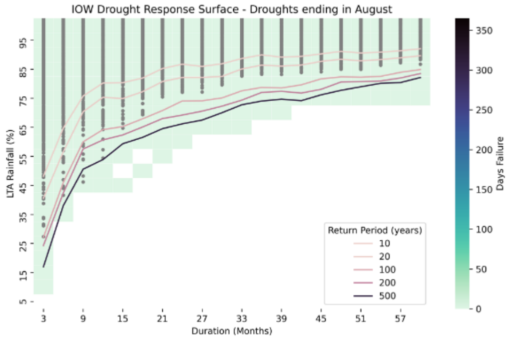


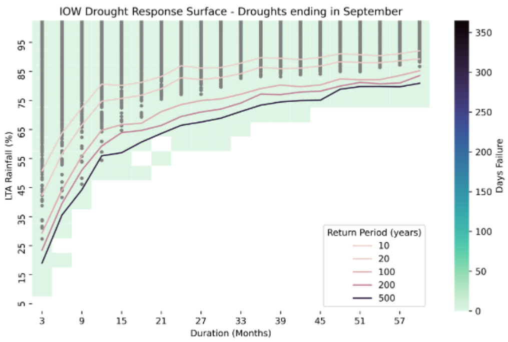


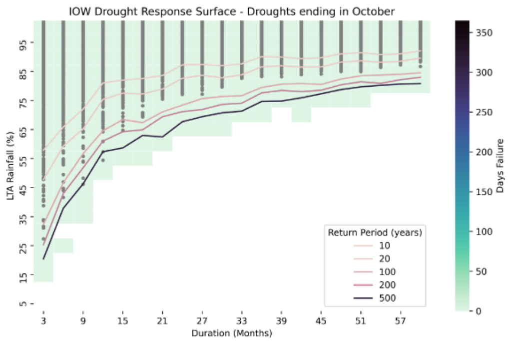


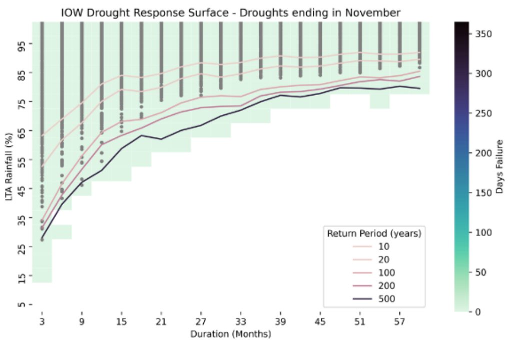
Isle of Wight

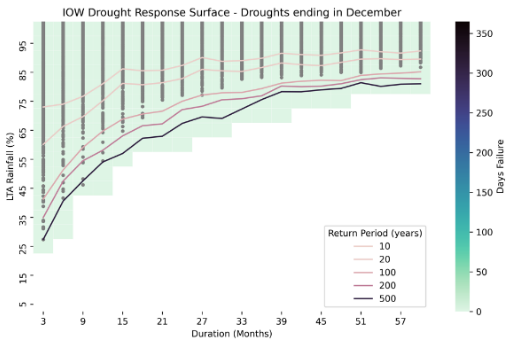




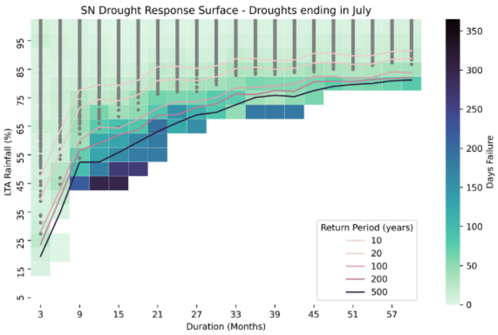


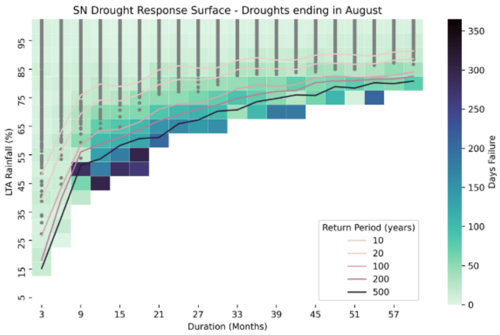


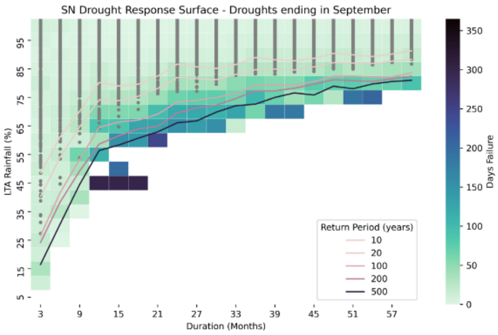


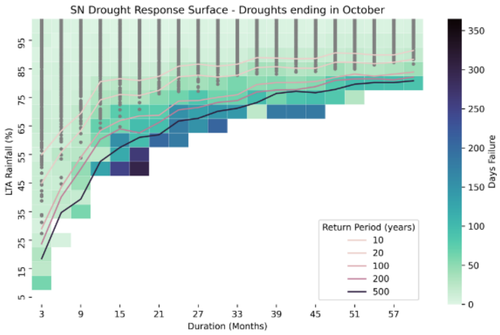


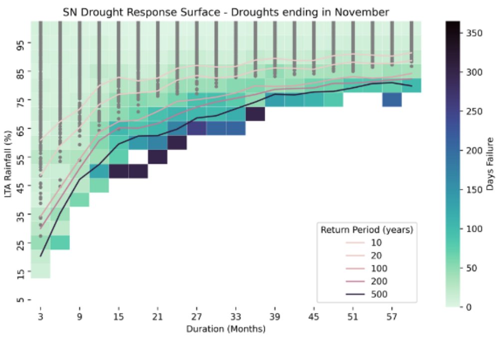
Sussex North

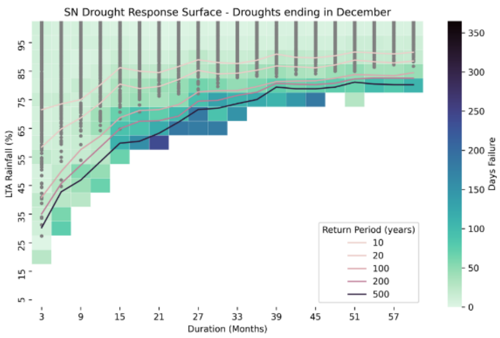












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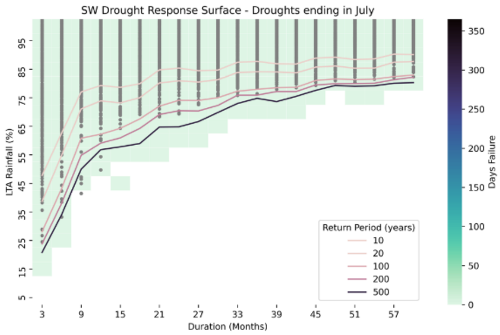

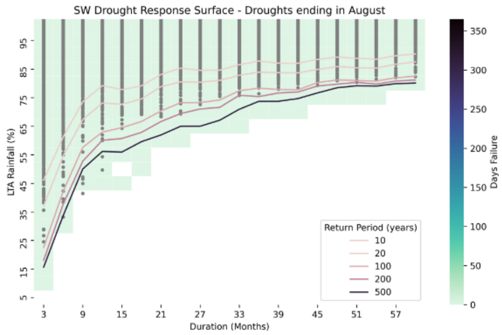

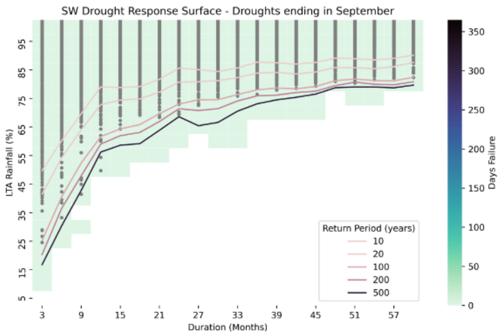

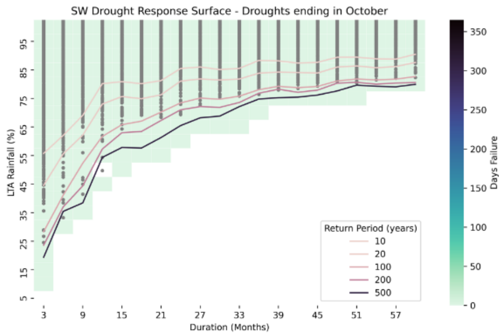

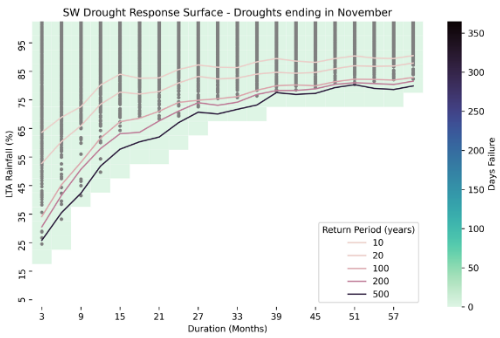

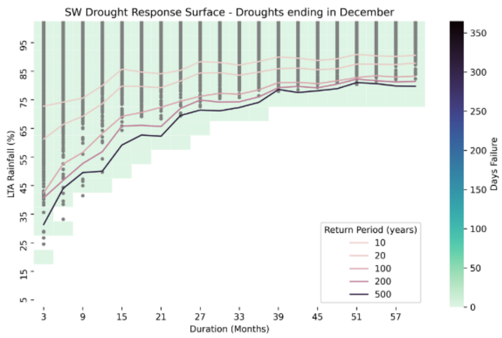

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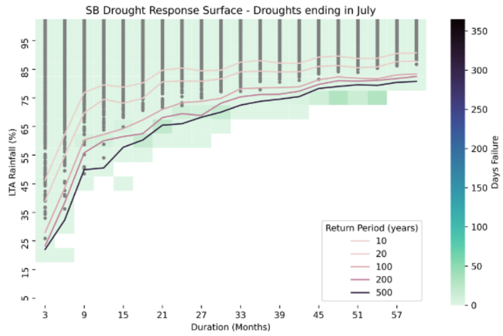
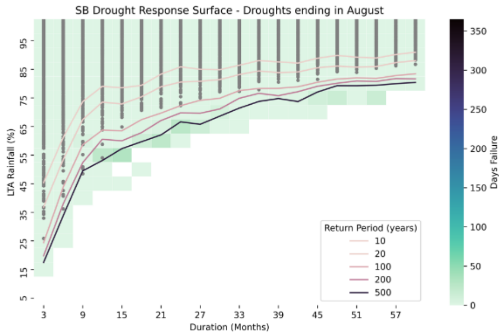
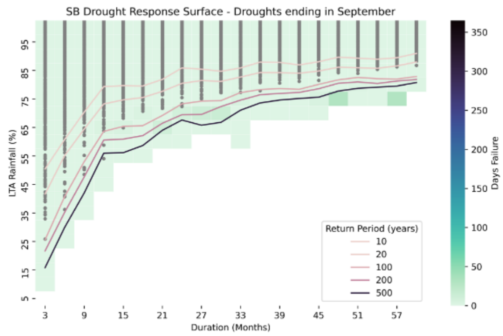
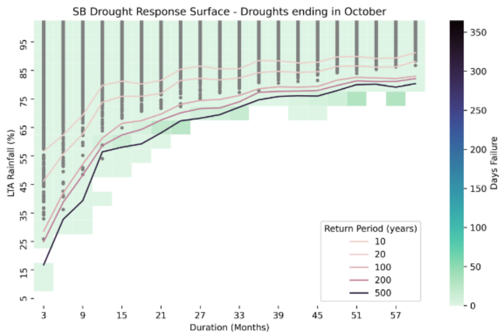
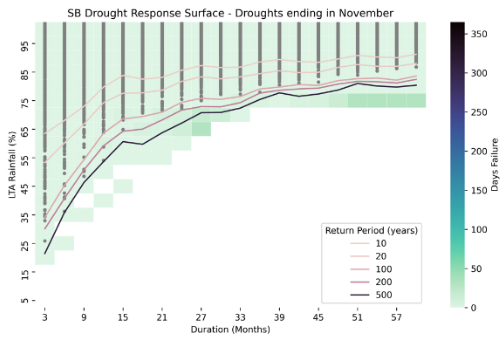
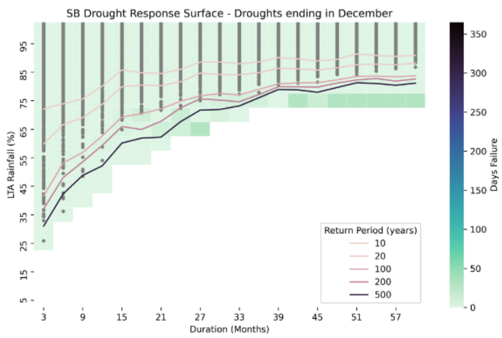




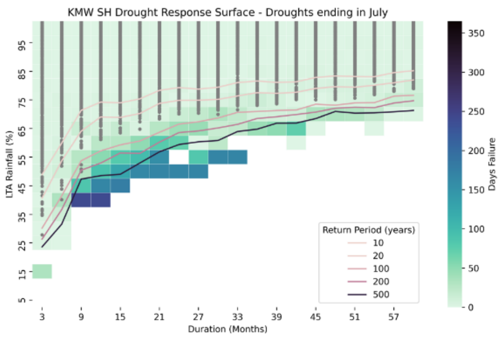


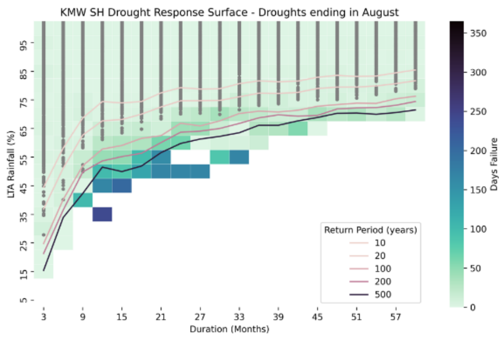


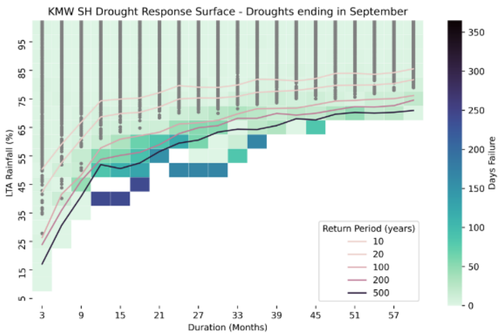


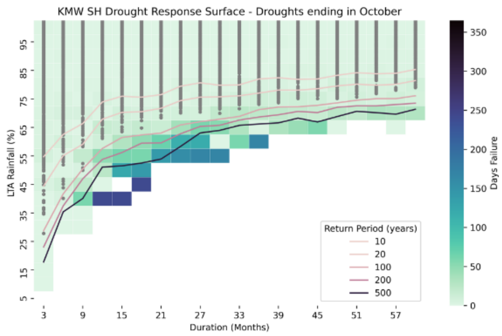


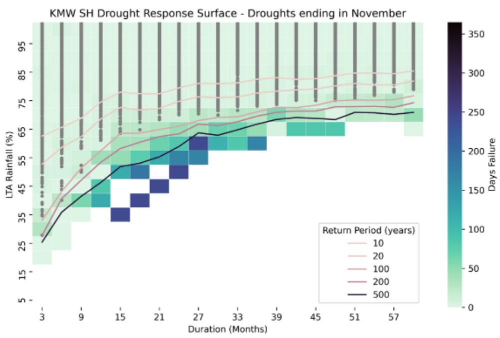
Kent Medway West and Sussex Hastings (River Medway Scheme)

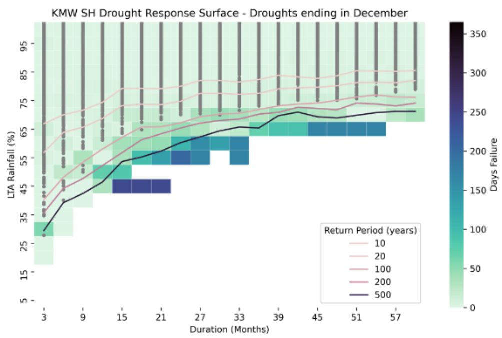




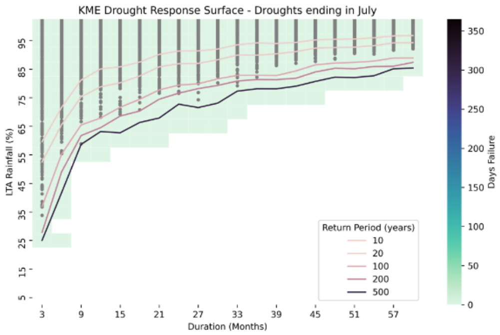


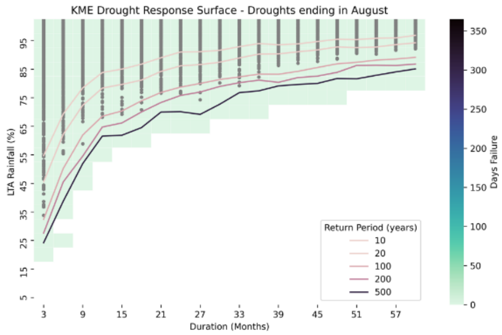


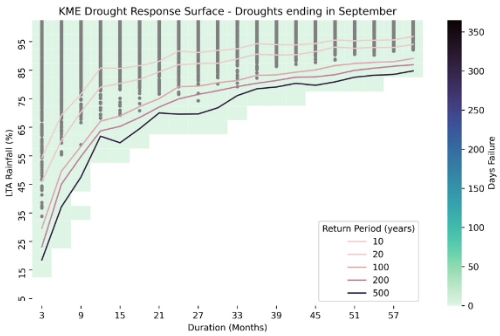


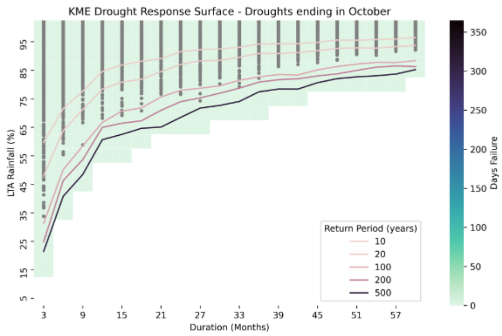


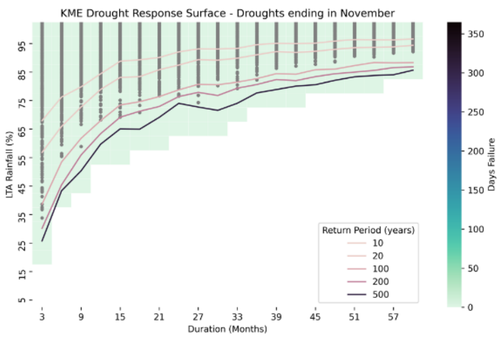
Kent Medway East

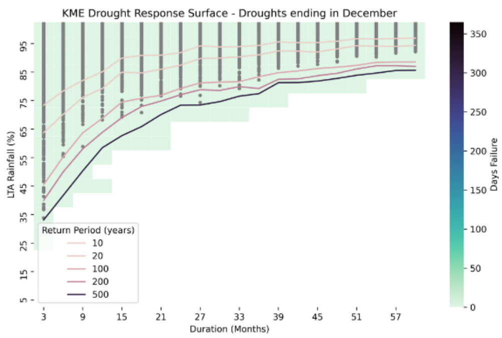




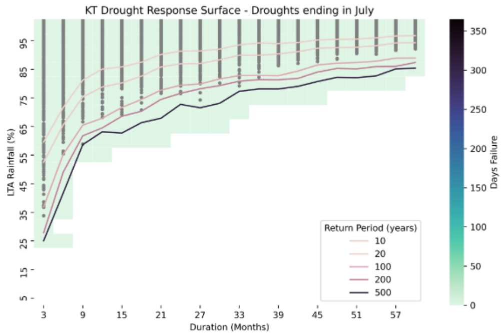


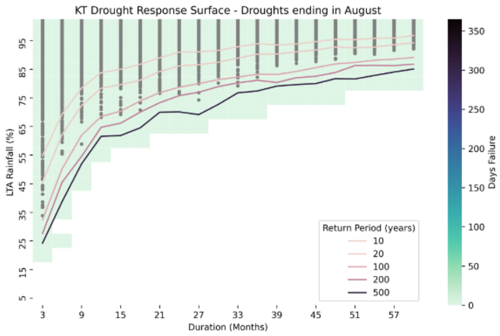


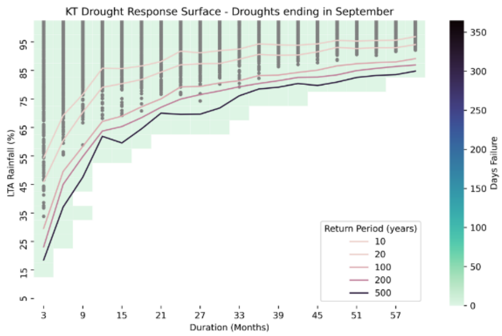


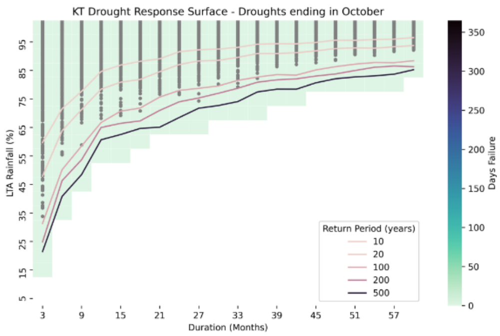


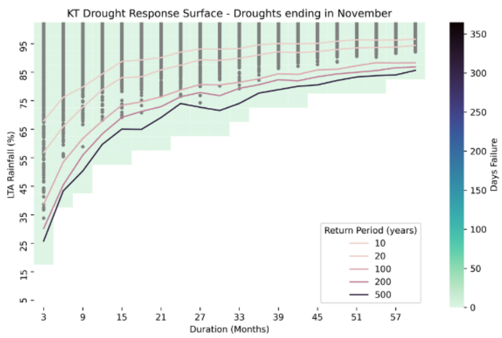
Kent Thanet

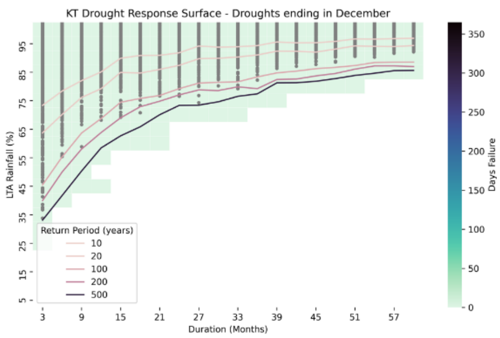

KT Drought Response Surface - Droughts ending in July
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500


KT Drought Response Surface - Droughts ending in August
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500


KT Drought Response Surface - Droughts ending in September
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500


KT Drought Response Surface - Droughts ending in October
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500


KT Drought Response Surface - Droughts ending in November
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500


KT Drought Response Surface - Droughts ending in December
LTA Rainfall (%)
Duration (Months)
Days Failure
Return Period (years)
10
20
100
200
500

Appendix B: Joint Modelling Study for River Test and River Itchen Drought Triggers

This document produced by consultants contains material contrary to the interests of national security so is not available online. Should you wish to view it please arrange an in-person appointment at our head office by emailing: wrmp@southernwater.co.uk

Appendix C: River Test, Candover and River Itchen Drought Triggers technical note

See separate document.