Water Resources Management Plan 2019
Annex 3: Supply Forecast

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Contents

Version Control

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Edits to Table 30 to clarify target levels of service to ensure alignment with the Technical Overview Report and Annex 1.

1. Executive summary

This annex sets out the components of our water supply forecast and describes how we have assessed the water resources available in the environment and constraints on our abstractions and water resources, including the effects of climate change. Any reductions in the water available to us, either through licence changes, source outage and treatment are also described.

Each of the components that makes up the water available for use are set out in Section 2.

1.1 The components of our supply forecast

The supply forecast refers to the estimation of the total water resources available to meet demands in each water resource zone (WRZ) for each planning scenario, and for each year throughout the fifty year planning period. This forecast is composed of several elements:

Deployable outputs
Bulk imports and exports
The impacts of climate change
Sustainability reductions
Process losses
Outage allowance

Deployable output (DO) forms the majority of the water resource supply available in any WRZ. DO is defined as the water available from a source after taking account of (UKWIR, 2014):

Source characteristics (e.g. hydrological or hydrogeological yield)
Physical and infrastructure constraints (e.g. aquifer properties, pump capacity, distribution networks)
Raw water quality and treatment constraints
Licence and other regulatory constraints on water abstraction
Demand constraints and levels of service

Our methodology for estimating DO is summarised in Section 3 and the results are presented in Section 4.

The bulk imports and exports component reflects transfers of water in and out of a WRZ. This can reflect both within company inter zonal transfers as well as exports and imports to other neighbouring water companies or other formal transfers. Our bulk imports and exports are summarised in Annex 5.

The Water Resource Planning Guideline (Environment Agency and Natural Resources Wates, 2016) requires that water companies make an assessment of the impact of climate change on water supplies. The impacts of climate change may materialise uncertainly between possible drier futures in which water resources will become scarcer, and wetter futures where increased winter rainfall translates to increased resource availability. Climate change can therefore act in both directions in terms of water resource yield assessments. Our assessment of impacts of climate change must account for this uncertainty. Our climate change modelling approach is set out Section 3 and the results are presented in Section 3.6.

In order to manage the requirements of recent European and national environmental legislation and regulations, the Environment Agency (EA) set up the over-arching Restoring Sustainable Abstraction (RSA) programme with funding for the investigations and (if shown to be required) implementation of mitigation options secured through the National Environment Programme (NEP). If water company abstraction licences are confirmed as constituting an unacceptable risk to the environment, the EA requires that companies find and implement solutions to the problem, which may include more abstraction licence conditions and/or constraints. The impacts that these changes might have on DO can be calculated or estimated. Our allowance for sustainability reductions is presented in Section 5.

“Process losses” also need to be considered - these relate to the treatment process water, i.e. the net loss of water, excluding water returned to the source during treatment before it is put into distribution. Our analysis of process losses is described in Section 7.

“Outage” refers to the planning allowance made for the temporary loss of DO from a source. An allowance for outage is made in the supply demand balance, calculated at the level of the WRZ. Outage reflects that sources are vulnerable to both unplanned events (e.g. mechanical faulure) or may need to be temporarily removed from supply in order to perform maintenance or upgrades (planned outage). Our assessment of our outage allowance is presented in Section 8.

1.2 Developing our supply forecast

Our plan has been developed in accordance with UKWIR Risk based planning methodologies (2016) and the water resource planning guidelines (Environment Agency, 2017). Under this approach we are developing a ‘fully risk based plan’ reflecting the complexity of the planning challenges we face in our area.

In the context of our supply forecast this approach requires us to derive a probabilistic estimate of DO under a range of drought severities and durations. To achieve this we have used an artificial weather generator in combination with water resource models to simulate water resources for droughts outside of the limited historical record.

1.2.1 Artificial drought generation

The weather generator we have used is an evolution of the original weather generator we employed for our previous plan and shares substantial commonality with those used to support recent Water Resource planning by others. This general approach has been widely adopted by the UK water industry.

The major enhancements are such that the model is now fully parametric and predicts rainfall for all seasons directly. This has removed issues relating to lack of persistence during long drought events. By simulating all seasons parametrically, spatial coherence is maintained across multiple rain gauges (beyond the three indicator gauges used in AMP5), removing the need for any disaggregation or random error modelling. The final enhanced model produces spatially and temporally coherent monthly rainfall time series at multiple sites and produces good calibration matches to these criteria:

Monthly mean / and seasonal rainfall distributions across all gauges
Spatially correlation of rainfall patterns across the whole domain at multiple time aggregations (1 month to 60 month)
Reproduction of extremes at multi-time aggregations (1 month to 60 month)

To generate input time series for our water resource models we used the weather generator to create an initial extremely long time series of data for each of the input rainfall sequences. This comprised ~1000 replicates of the input historic climate sequence. This created a single artificial time series for each rainfall site about 100,000 years in length. A series of post processing calculations were then performed on this time series to examine the nature of the artificial drought events generated in terms of rainfall deficit and the intensity (i.e. the magnitude of the deficit). The severity and frequency of droughts in the artificial sequence broadly match that of the historical record, including major historic droughts, but also includes more severe, low probability drought events. Again, this gives more confidence that the weather generator produces credible rainfall sequences suitable for water resource planning. The patterns are well replicated across all of the rainfall sites, but where observed rainfall sequences are shorter or have gaps, estimates of probability become less robust and tend to show greater deviation from the artificial dataset.

As it is not computationally practical to use the full data set with our water resource models, we have sub-sampled these data to a more manageable size (2000 years) for our subsequent modelling. Statistical analysis and sensitivity runs of our water resource model outputs were performed to make sure that the 2000-year sub-sample we selected gave a good representation of the overall synthetic data set and the historic climate.

We then disaggregated the 2000-year sequence to daily data using an analytical tool capable of rapidly and directly generating coherent daily rainfall and potential evapotranspiration (PET) data for multiple sites/models. These can be generated for very long synthetic rainfall time series in a single step.

1.2.2 Groundwater resource assessment

Groundwater makes up around 70% of Southern Water’s overall water supplied. Various methods for determining the DO of groundwater resources are set out in UKWIR (2014). Our approach builds on UKWIR (2014) guidance and enhances our approach developed for WRMP14.

A number of distributed groundwater resource models cover the major aquifer units that contain our groundwater sources. Most of these models were originally developed on behalf of the EA for the purpose of catchment scale water resource management. Some models have been specifically adapted for, or developed for the purpose of our water resource management and for calculation of DO.

Generally, these groundwater models have been accepted by the EA and other stakeholders as fit for purpose tools for assessing water resources and the environmental impacts of abstraction. They have been conditioned and calibrated to historical observations. The derivation and calibration of the river flow and groundwater models (which includes the Test and Itchen groundwater model, Brighton and Worthing groundwater model and East Kent groundwater model) were reviewed and ‘signed off’ during EA liaison meetings for all key resource models during AMP4 and AMP5.

The long-time time-series outputs from the synthetic weather generator (see above) are used as direct inputs (as rainfall and PET sequences) to our water resource (rainfall-runoff and groundwater models). We have used outputs from these resource models, comprising flows, recharge or groundwater levels to estimate DO using normal yield analysis methods.

Most commonly our groundwater DOs were estimated via established relationships between flows, recharge or groundwater levels and groundwater levels at indicator boreholes. Groundwater level fluctuations at indicator boreholes can then be translated via scaling and shifting to changes in rest water levels at our groundwater abstraction wells and used to estimate our DOs.

The Brighton and Worthing Chalk groundwater model covering our Sussex Brighton and Sussex Worthing WRZs was explicitly designed to be able to directly forecast source DO using recent developments to the MODFLOW code (Panday et al, 2013). Existing indicator borehole regression models also exist for both the Sussex Worthing and Sussex Brighton WRZ based on a single indicator borehole at Southwick in the Brighton Chalk Block. We employed a hybrid approach to look at DO using both methods and in many cases the two modelling methods agreed well and gave greater confidence in overall drought yields in for these sensitive Chalk Aquifer blocks.

1.2.3 Surface water resource assessment

For the critical surface water abstractions on the rivers Test and Itchen DOs were estimated using the same methodology as for our previous plans. These rely on groundwater model flow output from the EA Test and Itchen model. The 2000 year output flow sequences from the model were processed through a spreadsheet calculator tool that follows the methodology for surface water DO assessment set out originally in Environment Agency (1997) and used in WRMP09 and WRMP14 (Southern Water, 2009, 2014) and updated for UKWIR (2014).The sensitivity and impact of sustainability licence changes could also be examined through this tool.

As well as distributed groundwater models we also use Catchmod hydrological models to model river flows in relation to our surface water sources. Like the groundwater models these have been developed to produce flow sequences from the synthetic stochastic rainfall and PET sequences, as well as the historical records. For this plan, we undertook a project to update, recalibrate and enhance our hydrological models. The major enhancements include:

Extended calibration and validation period to include the period 2002 to 2014 with recalibration of the hydrological models to the ‘naturalised’ flow sequences generated for this period
Improved representation of reservoir inflows and outflows
Enhanced denaturalisation procedure which includes dynamic implementation of Minimum Residual Flow (MRF) conditions for each individual abstraction licence
Catchmod model and denaturalisation procedures written in Python for efficient processing of our large data sets
Seven catchments at river flow gauging stations were modelled, with four models for our reservoir catchments. These represent the key locations for the monitoring and assessment of our surface water abstractions and reservoir storage

Reservoir inflows were assessed using two methods, by back calculating inflows based on reservoir water balance, and by using nearby gauged catchments which were generally unaffected by artificial influences as a proxy. Inconsistencies and anomalies in the reservoir water balance datasets meant that proxy flow data from nearby catchments was preferred for estimating historical reservoir inflow sequences.

The Catchmod rainfall-runoff models simulate ‘natural’ catchment flows. To estimate the yield of surface water systems, we need to take account of the abstractions and discharges which would normally occur in the catchment. “Denaturalisation” is the procedure by which these artificial influences are added back to the simulated natural flows. The abstraction data were analysed and the year with the greatest aggregate abstraction was used to denaturalise the flows. Denaturalisation represents a sub-set of the abstractions and discharges in the catchment. The Southern Water surface water abstractions and reservoir releases are not represented in the denaturalisation process.

The synthetic stochastic daily rainfall and PET sequences developed for each surface water catchment, were used with our Catchmod models to generate 2000 year flow sequences. These output flow sequences were then used in combination with our conjunctive use Aquator models for the DO assessments of our surface water sources.

1.2.4 Conjunctive use modelling

Aquator water resource models were used to undertake analyses required for DO assessments of surface water resources and where the conjunctive yield of surface water and groundwater sources needed to be assessed in combination. The surface water and conjunctive use elements of the supply networks were modelled in Sussex Hastings, Kent Medway West, Sussex North and the Isle of Wight WRZs.

Our Aquator models were originally developed for our previous plan (WRMP14), and were updated for this plan. Models were reviewed and updated to reflect any changes in network connectivity, capacities and constraints. Licence conditions were updated to reflect any changes to licences, and groundwater source outputs were revised to reflect the updated groundwater DO assessments completed for this plan. Demand profiles were also updated to reflect recent actual dry year demand profiles for each of the demand centres in the models.

Control curves are used to represent and define mechanisms whereby operational activities vary according to storage, for example, the pumped refill of reservoirs is controlled by the storage volume in the reservoirs in relation to bespoke control curves. For Bewl Water, there are operational pump curves, which control the utilisation of the abstractions which refill the reservoir from pumping stations on the River Teise and the River Medway. There is also an ‘Operational Drought Bounding Curve’ (ODBC), which controls the target demand to be placed on reservoir resources by Southern Water, whereby when the reservoir falls below the ODBC, the Southern Water abstraction (which occurs indirectly via the releases and re-abstraction from the River Medway) needs to be restricted to DO. The DOs have been calculated on this basis. See Appendix D for more details.

Drought trigger curves are used in relation to reservoir storage to define transitions from ‘normal’ periods to ‘impending drought’ and on to ‘drought’ and then ‘severe drought’. Trigger curves may be used to implement drought measures such as demand restrictions related to Temporary Use Bans (TUBs) or Non Essential Use Drought Orders (NEUs), as well as other interventions such as changes to licences by Drought Permits and Orders. The benefits of drought restrictions have been reassessed to account for recent changes in demand in relation to the Universal Metering Programme.

DO assessments have been made using 2000 year hydrological sequences developed from stochastic modelling of climate. The DO assessments were made with the impacts of TUBs demand restrictions accounted for and implemented within the Aquator models. The in-built Scottish method analyser was used to assess the DOs of the full range of years in the hydrological time series, and the results were used to report the DOs for a range of return periods.

1.2.5 Modelling the impacts of climate change

To reflect the high vulnerability to climate change of some WRZs we have adopted one of the more advanced approaches set out in EA Guidance (Environment Agency, 2013a). The use of this methodology builds on the existing methods we developed for our previous plan.

We have derived “smart” samples from the national UK Climate Projections (UKCP09) probabilistic projections at a river basin scale. This sampling has been based on a rapid assessment of the impacts of climate change on drought indicators, specifically the impact on hydrologically effective rainfall of the perturbations of two major historic droughts events:

The 1918-22 drought, which forms the former historical design drought for the Western and Central areas
The 1900-1903 drought which was the former historical design drought for the Eastern area
The samples have been reviewed against the parent UKCP09 dataset to evaluate their overall credibility. We have then applied perturbations of the key climate variables (rainfall and PET) to input sequences to our water resource models to derive climate change perturbed estimates of flows and groundwater levels. This allows us to calculate DO under the influence of climate change using the same procedures as outlined above. Comparing these data to the baseline (no climate change) forecast allows us to derive the overall impacts of climate change under a range of possible scenarios.

In order to incorporate the transient effects of climate change and to avoid large step changes in DO a linear scaling factor is employed that translates the forecast DO for the 2080’s (2085), consistent with the UKCP09 projections, back to the base year of the WRMP (2016). The calculation therefore recognises that some climate change has already occurred and allows climate impacts to be smoothly applied over the planning period.

1.3 Deployable output

In keeping with our goal to develop a fully risk based plan we have developed a range of DO estimates covering different drought probabilities using the modelling approaches described above. We have also used the large synthetic drought and DO datasets we have generated to examine the drought vulnerability of each WRZ in order to better understand the drought behaviour of our sources. Where a WRZ shows a degree of hydrological or hydrogeological variation we have developed drought response surfaces. These are a series of figures that show how our DO varies with different rainfall deficits across a range of different drought probabilities.

The Water Resource Planning Guidelines (Environment Agency and Natural Resources Wales, 2016) allow water companies to take account for the benefit of demand restrictions in their DO forecasts. These benefits reflect that storage, either reservoir or groundwater, can be conserved by reducing demand in drought by implementing restrictions.

Where relevant we have included the positive DO benefits of demand restrictions in our DO forecasts. These benefits reflect that storage, either reservoir or groundwater, can be conserved by reducing demand in drought by implementing restrictions and increases overall DO. These benefits must be applied with caution and will not apply universally, for example where licence or infrastructure constraints limit the ability to draw water. The magnitude of these benefits was estimated from a review of the previous effectiveness of demand restrictions in each of our areas. It is notable that the universal metering programme (UMP) appears to have led to an overall reduction in the effectiveness of demand restrictions as demand has already been somewhat depressed.

A summary of our DOs and the relative changes compared to our previous plan are set out in Table 1.

Table 1 Our total baseline deployable output for 0.5% annual probability drought and the change from our previous WRMP14

		Change in deployable output (Ml/d)			
Deployable output		**Western area***	**Central area**	**Eastern area**	**Total**
MDO/ADO	This Plan	134	187	239	**560**
	WRMP14	308	194	237	**739**
	Change	-174	-7	+2	**-179**
PDO	This Plan	193	239	297	**729**
	WRMP14	357	251	319	**927**
	Change	-164	-12	-22	**-198**

*Note that for Western area the figures for WRMP14 included assumed impacts of possible sustainability reductions on the River Itchen but not the River Test, whereas the figures for This Plan include the impacts of the actual licences changes on both rivers as implemented in March 2019.

In most of our Western area WRZs the changes to DO for similar probability droughts as our previous plan are relatively minor. These generally reflect changes to infrastructure or raw water quality issues that have emerged. Some other minor changes reflect our updated synthetic drought and modelling methodology, but generally these are small compared to other constraints:

On the Isle of Wight WRZ we plan to decommission a number of low yielding spring sources with poor raw water quality

In Hampshire Andover WRZ we have assumed zero DO for a source that has suffered long term poor raw water quality

In Hampshire Winchester WRZ we have reduced peak deployable output (PDO) at our Winchester source reflecting a revised estimate of the source treatment capacity

The most significant changes in DO in this area occur in the Hampshire Southampton East and Hampshire Southampton West WRZs because of sustainability changes to our abstraction licences in these WRZs. These licence changes also make these WRZs the most drought vulnerable in our Western area. Two main styles of drought appear to constrain this area:

Shorter period rainfall accumulation (6-12 months) that represent a single severe dry winter and one or two dry summers. These are broadly similar to the historic 1976 event. These events can accumulate relatively large rainfall deficits over a single winter recharge period and primarily impact on peak / critical period flows in the next summer but, under sustainability reductions such events, will also constrain minimum flows.

We have also modelled several lower probability synthetic events that extend over multiple winter recharge seasons. As well as several synthetic droughts this style of events also includes the 1920-23 ‘worst historic’ drought. . Often the drought impacts will be mostly keenly felt in the second year after two severe winters. The probability of three sequential severely dry winters is very low and only relevant for the most extreme droughts.

In our Central area the baseline changes to our total DO is relatively minor at MDO and less than 10Ml/d at peak periods. In many cases these changes reflect improvements to our modelling approaches. There are also changes to the composition of our DO total:

In Sussex North WRZ, we are enhancing our Pulborough groundwater DO as an outcome of a water resource scheme from WMP14. This increase is somewhat offset by reductions in DO at two other groundwater sites, both of which suffer from poor raw water quality and require upgrades to their treatment capacity

We have also improved our modelling of surface water DO in Sussex North WRZ and this has led to a reduction in the yield from our Pulborough surface water source. This causes the largest change in DO for our Central area

Small increases in DOs for Sussex Brighton and Sussex Worthing WRZs reflect changes to modelling methods and the inclusion of TUBs benefits in our baseline DO

The effect of source write-downs (because of reduced treatment capacity outage) is largely offset by returning other sources to service in the Sussex Brighton and Sussex Worthing WRZs, leading to a small overall net change in available supplies

The drought vulnerability of our Central area varies between WRZs, reflecting the differing composition of source types in each WRZ. The Sussex North WRZ is most vulnerable to long duration drought events, typically of rainfall deficits accumulating over three to four years or more. This reflects the fact that the Lower Greensand aquifer which underlies most of the WRZ is somewhat drought resilient having relatively high storage and so is capable of sustaining baseflows in the River Rother over multiple seasons. The 1921 drought event appears to be particularly severe in Sussex North WRZ in terms of overall rainfall deficit and is broadly similar to some of the more severe synthetic droughts we have modelled.

Sussex Brighton and Sussex Worthing WRZs are dominated by groundwater resources from the Chalk aquifer. Many are drought sensitive being most vulnerable to multiple dry winter events, typically two to three years in length. Typical events include the historic drought of 1921 and several severe to extreme synthetic droughts.

In our Eastern area there has been an overall increase in DOs, this reflects:

Increased yield of the River Medway scheme from a licence variation and refinements to our surface water modelling approach for Kent Medway West and Sussex Hastings WRZs

Source improvement and changes to the ADO calculation method for some seasonal groundwater sources in Kent Medway East WRZ

Inclusion of TUBs benefits in baseline groundwater DOs.

Kent Thanet WRZ shows a decline in DO reflecting both the write down of the surface water source and changes to the modelling methodology. More write-downs in DO for Kent Thanet WRZ are forecast as consequence of deterioration in raw water quality, largely because of nitrates in the short to medium term.

Kent Medway East and Kent Medway West WRZs tend to be most vulnerable to long duration two to five year periods of rainfall deficit that comprise multiple consecutive dry seasons. There appears to be a substantial degree of overlap here, in terms of the more severe drought events, with the Central area in particular the extreme events in Sussex North WRZ, reflecting that certain drought events lead to substantial surface water impacts.

The droughts affecting Kent Thanet WRZ tend to be distinct from those affecting the Medway WRZs. Typically these are shorter, three to four year periods of rainfall deficit predominantly impacting winter rainfall. There is limited overlap of drought events with the groundwater droughts affecting the Western area and Sussex Brighton and Kent WRZs. Broadly they are similar in style to the early 1970s drought (1971-73) and mid 1990s drought. The difference in the drought events likely reflects the geographic separation from other WRZs and the greater dependence of our Kent Thanet WRZ on our drought vulnerable groundwater sources.

Estimating the true probability of the synthetic drought events which we have used to define our estimates of DO is difficult, owing to the relatively short historical record and the fact that it contains few severe drought events. We can only estimate relative probability based on the large dataset produced for the synthetic rainfall time series. This relies only on the assumption that the historically observed climate, the data for which underpins the synthetic weather generator, gives a reasonable representation of future climate variability. Given climate change and the short record, the extent to which this might be true is unknown.

Similar synthetic drought modelling work conducted elsewhere for others (e.g. Met Office, 2016, WRSE, 2016) suggests that this assumption may be reasonable and any uncertainty is at least comparable in magnitude, if not smaller, with the uncertainty introduced by hindcasting. Independent estimates of different rainfall accumulation periods for severe and extreme droughts prepared by the Met Office (2016) also match up relatively well with the estimated rainfall deficits for our synthetic design droughts.

The Met Office estimated that a reasonable range for stress testing water resource management plans should be somewhere between 0.5% and 0.2% annual probability (equivalent to the 1 in 200 to 1 in 500 return period drought events). Overall this assessment suggests that the range of synthetic droughts we have used in our DO assessments are credible and broadly consistent with independent empirical estimates.

1.4 Sustainability reductions

We believe it is in the best interest of our customers and the environment to address unsustainable abstraction as quickly as possible and to look beyond the five year Water Industry National Environment Programme (WINEP) / business planning cycle to make sure we address future risks. This will mean that optimal solutions can be implemented taking account of the long-term availability of supplies. We have been an active partner in supporting delivery of the EA's RSA programme, and more recently the Water Framework Directive (WFD) programme. In recent years we have revoked an abstraction licence in Hampshire, reduced licence volumes at a source in Sussex and carried out river restoration to a stream on the Isle of Wight WRZ in support of these programmes. We are already undertaking a number of WINEP schemes in AMP6, which are at different stages from investigation and options appraisal through to implementation. These include schemes at Bewl Water reservoir in Kent Medway West WRZ and the Little Stour in Kent Thanet WRZ.

We have worked with the EA to review the need for future sustainability investigations and reductions. Their 'sustainable catchments' programme was initiated at a national workshop in 2016 with an expectation that all water companies should undertake a comprehensive sustainability review of their licences. In early 2017 we proposed and agreed a detailed methodology with the EA to refine their initial assessment including a proposed risk categorisation of all of our sources. The outcome of this assessment was incorporated into the WINEP 1 programme issued to us in March 2017. This indicated a level of certainty and confidence of each assessment informing the extent of work required in AMP7 from 2020-2025 (
Table 2). There were no confirmed sustainability changes and no 'Indicative' (Amber) or 'Direction of travel' (Purple) sustainability reductions or investigations.

After the release of WINEP 2 and WINEP 3 we have reviewed the need for any changes to our estimates of sustainability reductions for this plan. In WINEP 3 more details were specified for investigations on the River Test and River Itchen. There were also changes in the level of certainty assigned to some investigations or completion dates. However, we concluded there was no need to change our sustainability reductions assumptions and hence the original assessment undertaken on the formal WINEP 1 release still stands.

Table 2 Summary of WINEP 1 categorisation based on number of abstraction points

Measure type	Green / Certain	Red / Unconfirmed	Total

Adaptive Management	22		22
Investigation and Options Appraisal	326	9	335
Restoration		10	10
Sustainability Change		4	4
Total	**348**	**23**	**371**

The vast majority of abstraction points are assigned to ‘investigation and options appraisal’ in the green / ‘certain’ category. This is in line with our aim to develop a sustainable abstraction base as quickly as is reasonably possible and we plan to undertake these investigations before 2025. Other ‘certain’ measures are for ‘adaptive management’, these relate to sources in the Sussex Brighton WRZ, previously subject to NEP investigations, where non-licence change solutions are proposed. The ‘unconfirmed’ or ‘red’ category related to sustainability changes and were listed against a source in the Hampshire Andover WRZ, two sources on the Isle of Wight WRZ and our surface water abstraction from the River Test. The first three sources relates to ongoing NEP investigations where a solution might be needed but the measures to be taken are not yet clear.

. To incorporate both confirmed and potential future sustainability reductions in this plan we have followed current guidance (Environment Agency and Natural Resources Wales, 2017) to define three potential scenarios that reflect the different levels of certainty:

a lower scenario that includes only green ‘confirmed’ sustainability changes
a middle scenario that includes green and amber ‘indicative’ sustainability changes and a pragmatic estimate of the red ‘unconfirmed’ sustainability changes
an upper scenario that includes green, amber and red sustainability changes and a pragmatic estimate of any more sustainability changes that may be required after investigations and options appraisals, or driven by future legislation or requirements

We have agreed the scope of each scenario as part of our pre-consultation with the EA and have carried out our assessment on the basis of the scenarios set out in Table 3.

Table 3 Sustainability reduction scenarios - Southern Water’s approach

Sustainability reduction scenario	Southern Water’s approach
Lower	Eastern and Central areas: None Western area: Test and Itchen licence changes as implemented in March 2019 (Section 20 Agreement)
Middle	As above, plus: 1) Sources at Andover and on the Isle of Wight at Newport and Lukely Brook: DO reduced to achieve the Environmental Flow Indicator (EFI). 2) Sources at Winchester and Alresford: DO limited to recent actual rates (because impacted water bodies are already compliant with the EFI). 3) A future unconfirmed sustainability reduction on the Itchen in 2024
Upper	As above, plus: 1) DO reduced to achieve the EFI for all licences impacting on surface water bodies assessed by the EA as being non-compliant with the EFI. 2) For sources not linked to non-complaint surface water bodies, but included in AMP6 investigations, a 10% reduction in DO has been assigned. This principally relates to a large number of sources being considered in the North Kent RSA investigation.

For **Western area** our preferred strategy in this final plan reflects the Section 20 Operating Agreement reached between Southern Water and the EA after the River Test, River Itchen and Candover abstraction licence Public Inquiry, as approved by the Secretary of State. The sustainability reductions include the Match 2019 licence changes to the River Itchen sustainability and Lower Test. The Lower Test changes result in sustainability reductions partially in 2018 and fully in 2027 (second phase of Lower Test licence change). This results in immediate sustainability reductions in the 1 in 200 year return period in PDO of 125Ml/d, rising to 152-227Ml/d across the EA's lower to upper sustainability cases after 2027. The immediate MDO impacts are 166Ml/d, rising to 166-228Ml/d across the three EA cases after 2027.

Alternative sustainability reduction scenarios B, C and D, which were examined in our draft WRMP before the outcome of the March 2018 Inquiry was known, are only included as alternatives to demonstrate the impact on option selection and costs of alternative licence change assumptions in Annex 9 in comparison to the preferred plan.

For **Central area** there are no sustainability reductions in the lower and middle scenarios. For the upper scenario, sustainability reductions are driven by reductions in DO rates to give a proportionate contribution to EFI compliance. The estimated sustainability reductions for the upper scenario, from 2029, are 74.9Ml/d for PDO and 53.1Ml/d for minimum deployable output (MDO)/average deployable output (ADO).

For our **Eastern area** there are also no sustainability reductions in the lower and middle scenarios. For the upper scenario, sustainability reductions are driven by: a) reductions in DO rates to give a proportionate contribution to EFI compliance, and b) an assumed 10% reduction in DO for sources which are being evaluated in the North Kent RSA investigation. The estimated sustainability reductions for the upper scenario, from 2029, are 28.6Ml/d for PDO and 23.0Ml/d for MDO/ADO.

1.5 Impacts of climate change

The impacts of climate change have been assessed at an individual source and WRZ level. We have modelled the impacts of climate change using the same approach as for our DO assessments but using input climate data factored to account for the potential influence of climate change. These factors were based on national climate change projections (UKCP09). As the outcomes of climate change are uncertain we have examined a range of projections between possible "dry" and "wet" futures and have allowed for this uncertainty in our integrated risk modelling. Our forecasts of climate change projects are produced for the period between the 2070s and 2090s, as required by Water Resources Planning Guideline (Environment Agency, 2017), and linearly scaled through the lifetime of our plan as required by current guidance. Table 4 summarises the forecast range of climate change impacts by area.

Table 4 Summary of forecast total climate change impacts on baseline deployable output by the 2080's by area (Ml/d) for a 0.5% annual probability drought (1 in 200 year event)

DO Scenario	Climate Scenario	Western area*	Central area	Eastern area
MDO / ADO change (Ml/d)	Dry	-21.5	-36.0	-7.9
	Wet	36.3	24.1	21.6
	Medium	4.4	7.1	6.2
PDO change (Ml/d)	Dry	-37.3	-41.7	-8.9
	Wet	74.1	-20.0	1.4
	Medium	28.1	-26.1	4.2

*These show the impact of climate change assuming implementation of proposed sustainability reductions in our Western area for the base year.

In our Western area the majority of sources and hence WRZs are licence or infrastructure constrained. This makes them relatively insensitive to the effects of drought and climate change and hence the majority of climate change impacts on DO WRZs are small (<1Ml/d) or negligible. Nearly all of the estimated climate change impacts and uncertainty in our Western area are forecast for Hampshire Southampton West and Hampshire Southampton East WRZs This reflects that in both WRZs DOs are constrained by the available flow in the rivers Test and Itchen respectively. In assessing these impacts we have assumed that the proposed sustainability reductions in Hampshire Southampton West and Hampshire Southampton East WRZs will be implemented in full.

In our Central area the Sussex North WRZ shows the greatest vulnerability to climate change in our Central area. This reflects the impacts on the large surface water resources in this WRZ and licence constraints that limit abstraction at low flows. Mid-range forecasts for both Sussex Worthing and Sussex Brighton WRZs show relatively minor changes in DO because of climate change. However, there is a relatively large range in the magnitude of impacts between the “wet” and “dry” scenarios, reflecting that the impacts of climate change are uncertain. This uncertainty has been included in our integrated risk modelling (Annex 5).

Climate change impacts in our Eastern area vary substantially between WRZs. In Kent Medway West WRZ there is a net DO benefit under all scenarios reflecting improved modelling of inflows to the reservoir system and the possible influence of wetter winters in the rainfall time series. There is also a large range of uncertainty in the magnitude of impacts between the “wet” and “dry” scenarios. Kent Medway East WRZ is relatively insensitive to climate change, reflecting that the majority of sources are licence or infrastructure constrained. In the groundwater dominated Kent Thanet WRZ, much like Sussex Brighton WRZ and Sussex Worthing WRZ, the mid-range impacts are small but there is a large degree of uncertainty between “wet” and “dry” scenarios that could respectively lead to a gain or loss in DO.

The magnitude of climate change impacts in this plan are generally larger than for our previous plan. This reflects the change in the forecasting period, projecting climate change to the 2080s where the effects are more keenly felt, compared to the previous cycle where we were only required to forecast to the 2040s. This shift has also increased the range of uncertainty. Enhancements to our surface and groundwater modelling approaches will also have played a role.

Overall, our most vulnerable WRZs are those where we have large surface water abstractions constrained by “handsoff flow” (HOF) licence conditions, specifically Hampshire Southampton East and Hampshire Southampton West and Sussex North WRZs. Our groundwater dominated WRZs tend to be less sensitive but our modelling has indicated a high uncertainty between potential outcomes for a predominately drier or wetter future climate. Where WRZs contain a high proportion of licence or infrastructure constrained abstractions the forecast influence of climate change is small or negligible.

1.6 Process losses

We have updated our analysis of process losses, this is volume of water we lose between abstraction from the environment and distribution because of water treatment processes. To update these data we have revisited the assumptions we have made around losses at specific sources and used the most recent data available.

We’ve looked at differences between figures recorded on our abstraction meters against those recorded on our distribution meters to get this data, and then worked with our Process Scientist teams to make sure these figures are appropriate for type of treatment technology used on each site.

Overall these updated data have led to an increase in the amount of process losses we are forecasting in many of our WRZs compared to our previous plan In our Western area process losses have increase by around 9.5Ml/d. In our Central area process losses are stable except for the Sussex North WRZ where they have increased by 1-2Ml/d. In the East they have increased by around 3-4.5Ml/d. Generally process losses are smaller at critical periods than during the rest of the year.

1.7 Outage

Outage is the planning allowance included in the supply-demand balance to account for the temporary loss of DO from a source. This allowance covers both unplanned outage (e.g. mechanical failure) and planned outage (e.g. to perform maintenance). Outage can be full outage or partial outage. Full outage is where a site is completely offline and partial outage is where a site is unable to reach its full capacity, for example one of five borehole pumps is out and therefore the site cannot reach its full DO. The full and partial outage then make up the total outage of the site. An allowance for outages is calculated for each of our 14 WRZs.

To develop our outage allowance we have taken account of our outage recovery plan. This takes account of planned schemes to reduce our outage as at May 2018 down to a DO level that can be maintained in each WRZ by 2024-25. The outage recovery plan takes account of full and partial outage.

Overall the total outage allowance in all WRZs in the severe and extreme drought planning scenarios is slightly higher than in WRMP14. The total company MDO outage allowance has increased from 27.15Ml/d to 29.45Ml/d.

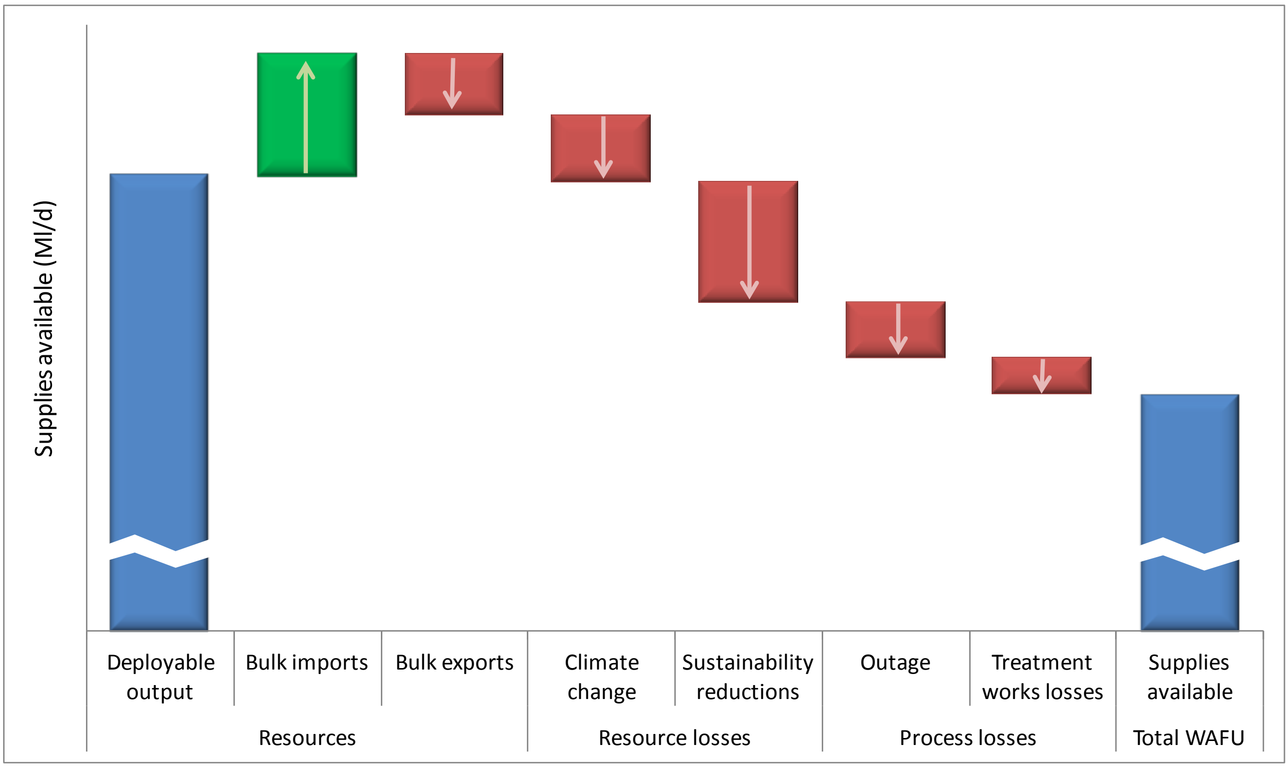
Changes to the arrangement of our WRZs, including the split of our former Hampshire South WRZ and Kent Medway WRZ, are also reflected in our assessment. Details of the outage allowance assessment are set out in Section 8 and in more detail in Appendix F of this annex.

2. Components of the supply forecast

In order to plan effectively to maintain security of supplies, it is important to know the water resources that will be available in the future. In this plan we have developed and refined our understanding of what supplies will be available under a range of drought events.

The total supplies available in a WRZ are composed of a number of elements, as shown in Figure 1. The supply forecast refers to the estimation of the total water resources available to meet demands in each WRZ for each planning scenario, and for each year throughout the fifty year planning period.

Figure 1 Components that make up our supply forecast in terms of the total supplies available for each water resource zone



A description of each supply component and its calculation is given in separate sub sections to this annex and are summarised below.

2.1 Deployable output

DOforms the majority of the water resource supply available in any WRZ. DO has a precise meaning in the context of water resource planning. DO is defined as the water available from a source after taking account of these constraints (after UKWIR, 2014):

Source characteristics (e.g. hydrological or hydrogeological yield)
Physical and infrastructure constraints (e.g. aquifer properties, pump capacity, distribution networks)
Raw water quality and treatment constraints
Licence and other regulatory constraints on water abstraction
Demand constraints and levels of service

We use three main metrics of DO in our assessments:
Minimum Deployable Output (MDO). This is the volume of water available from a source during the period of minimum resource availability. Most typically this is the hydrological yield of a source at the

time of lowest flow or groundwater level. It is most commonly calculated in the late autumn after the summer recession and before the onset of winter rainfall and recharge.
Peak Deployable Output (PDO). This is the volume of water available from a resource during the period of maximum demand. Typically demand peaks in early to mid-summer and so the PDO reflects the ability of a source to meet such demands.
Average Deployable Output (ADO) reflects the annual average DO from a source and is most useful for reflecting the yield drawdown from high storage systems such as reservoirs. The averaging process takes into account seasonal changes to DO including MDO and PDO periods. The ADO tends to be a less useful measure for groundwater sources as it does not capture the "within year yield" variability.

Our estimates of DO have been calculated through the development and application of a number of advanced mathematical models to estimate hydrological yield. We have used stochastically generated, but historically plausible, synthetic time series of weather to consider water resource availability under very severe droughts. Previously, water resource assessment had been based only on yields and droughts that had been in the historic record. The limitation of such an approach is that it is constrained by the drought events that have actually been observed. This method takes no account of different types of drought that could occur in future, or could have occurred in the past but for which no observation data exist.

Our methodology for calculating source deployable output is set out in Section 3 and the resulting DO totals are summarised in Section 4.

Once DO has been calculated, planning allowances (e.g. outage, process losses etc.) and net exports are subtracted, and net imports are added, to calculate the Water Available for Use (WAFU).

2.2 Bulk imports and exports

The Bulk imports and exports components reflect transfers of water in and out of a WRZ. This can reflect both within company inter zonal transfers as well as exports and imports to other neighbouring water companies or other formal transfers.

Bulk imports and exports can have a DO value assigned to them in order to reflect their performance under the same constraints and droughts as other water resources.

Our assessment of bulk transfers is discussed in Annex 5.

2.3 Climate change

The Water Resource Planning guidelines (Environment Agency, 2016) require that water companies must make an assessment of the impact of climate change on water supplies.

Current projections of climate change impacts on the UK forecast a general rise in temperature and sea level and changes to the pattern of precipitation. In South East England this is most likely to result in warmer and wetter winters, and hotter drier summers. The probabilistic nature of climate change forecasting, being based on model ensembles, also means that there is a relatively wide range of uncertainty in the outcomes. In the context of water resources, the impacts of climate change may materialise uncertainty between possible drier futures in which water resources will become more scarce, and wetter futures where increased winter rainfall translates to increased resource availability.

Climate change can therefore act in both directions in terms of water resource yield assessments and our assessment of impacts of climate change must account for this uncertainty. A description of the modelling approaches we have used to forecast the effects of climate change on supplies is given in Section 3.6. The resulting impacts of climate change are discussed in Section 6.

2.4 Sustainability reductions

All abstractions are subject to the terms of the existing abstraction licences. Many of these licences were issued in 1965, when the provisions of the Water Resources Act (1963) came into force. The EA considers that the terms of some of these licences are such that the abstraction could cause environmental damage, or which could affect sites with environmental designations.

In order to manage the requirements of recent European and national environmental legislation and regulations, the EA set up the over-arching Restoring Sustainable Abstraction (RSA) Programme with funding for the investigations and (if shown to be required) implementation of mitigation options secured through the National Environment Programme (NEP).

If water company abstraction licences are confirmed as constituting an unacceptable risk to the environment, the EA requires that companies find and implement solutions to the problem, which may include extra abstraction licence conditions and/or constraints. The impacts that these changes might have on DO can be calculated or estimated.

A summary of potential future licence changes and their resulting impact on DOs is presented in Section 2.4.

2.5 Process losses

The treatment of water from most sources will result in process and operational losses, except when treatment is in the form of simple chlorination. Process losses therefore relate to the treatment process water, i.e. the net loss of water, excluding water returned to the source. Our analysis of processes losses across each WRZ is presented in the Section 7.

2.6 Outage

Outage refers to the planning allowance made for the temporary loss of DO from a source. An allowance for outage is made in the supply demand balance, calculated at the level of the WRZ. Outage reflects that sources are vulnerable to both mechanical failures as well as external influences such as pollution events (unplanned outage) or may need to be temporarily removed from supply in order to perform maintenance or upgrades (planned outage).

Our assessment of current source outage and the definition of an allowance for future outage is discussed further in Section 8 and in more detail in Appendix F to Annex 3.

2.7 Other reductions in resource availability

To assess the impact of deterioration in raw water quality we have undertaken a detailed review and modelling programme of water quality trends. This assessment was carried out as part of NEP investigations to derive drinking water protected areas around our sources and have been integrated into our drinking water safety plans.

We have used distributed groundwater models to estimate groundwater catchments for over 40 of our groundwater sources. Bacteria, pesticides and other pollutants were also considered where they were considered potential risks to water quality at some sources.

Having delineated groundwater catchments, nitrate source apportionment within each catchment could then be quantified and used to parameterise predictive models of nitrate concentration trends at each source. The result of this modelling have been used to predict when drinking water standards for nitrates in raw water might be breached and hence cause DO of the source to be written down because of water quality constraints. We have used this modelling to focus where future catchment management should be targeted to mitigate increasing nitrate trends or where a treatment solution may be required.

3. Methodology for developing the supply forecast

3.1 Introduction

This section sets our methodology for estimating the available water supplies for the next 50 years of our plan. It contains a description of our assessment of available water resources or more specifically the DO of each individual source (See Section 3 and Section 4 sections or the Glossary).

3.1.1 Our risk principle

In developing our Water Resource Management Plan we have followed steps set out in the “WRMP 2019 Decision Making Methods” (UKWIR, 2016a) and “Risk Based Planning” (UKWIR, 2016b) guidance. Our assessment of the strategic risks and the complexity of the planning challenges we face (our ‘problem characterisation’) is set out in Annex 1.

We have found that we have medium “strategic needs” but that these create challenges that are highly complex to solve. Consequently, our planning approach would benefit from adopting some of the more advanced extended decision making tools and risk based methods (UKWIR, 2016a). To address these concerns, for our draft plan we have adopted a “Fully Risk Based” planning principle (after UKWIR 2016a, 2016b). This will allow us to better understand the risk, reliability and resilience of our supplies to drought and continue to develop the advanced approaches we have used to date.

In the context of our supply forecast, a fully risk based approach requires us to derive a probabilistic estimate of DO under a range of drought severities and durations.

This can most readily be achieved through the use of artificial weather generator in combination with water resource models. An artificial weather generator produces large synthetic time series of rainfall and potential evapotranspiration (PET). These time series are then supplied to our water resource models. These comprise recharge, runoff and groundwater flow models to forecast hydrological response of river flows or groundwater levels. Outputs from these models are then used to directly estimate source yield and DO such that an equivalent time series of DO is generated.

Where necessary, we have used conjunctive use “behavioural models” to directly calculate DO. Frequency analysis of these DO time series is used to derive a probabilistic estimate of DO in terms of a cumulative density function. These outputs can then be used directly with other fully risk based methods (See Annex 5) to derive a fully risk based assessment of supply and demand (see UKWIR, 2016b).

3.1.2 Supply (water resource) forecast

In all of our three supply areas we have expressed significant concerns over the reliability of supplies in a severe drought. This conclusion is based on several factors from the “problem characterisation”:

Forecast sustainability reductions in our Western area are likely to greatly reduce available resources during a drought
The reliability of Drought Permits and Orders was untested in the Western area as they have generally not been required during historic droughts but may be needed more in the future
In the Central area recent advances in resource modelling have indicated that our groundwater sources are especially vulnerable to severe drought
In the Eastern area frequent previous use of Drought Permits has indicated vulnerability, especially of our reservoir and surface water resources to drought

These concerns have been reinforced by our WRMP14 approach. Here, we used extended time series of synthetic climate data to explore our water resources under more severe droughts than have occurred in the historic record. This modelling highlighted the vulnerability of some sources to low probability but high impact severe or extreme droughts across all of our areas.

The Water Resource Planning Guidelines (Environment Agency, 2016) state that water resource supply forecasts should be based on a design drought, which as a minimum should include the worst drought in the historical record. The water resource planning guideline also makes allowance for water companies to consider a risk based planning approach considering drought events outside the historical record.

For our supply forecast, developing a “fully risk based” plan (Risk Composition 3) requires us to explore the water resource yield (i.e. DO) response to droughts of varying severity. This will allow probabilistic forecasts of system yield to be generated as used as input to our decision making tools. These data could either be generated through extreme value analysis or via artificial weather and flow generation (UKWIR, 2016b). Climate metrics derived from artificial weather generators do not necessarily correlate directly to water resource availability especially where large volumes or storage exist within either the environment (e.g. in groundwater) or artificially (e.g. reservoirs).

Recent evidence from the “National Water Resource Long Term Planning project” (Water UK, 2016 has highlighted that the spatial coherency, intensity and duration of drought needs to be carefully considered and is related to the natural variability in weather systems. Statistically, the longer a drought persists across a given area, the greater the possibility that storm systems occur which may partially alleviate a drought in some areas. This has the greatest impact in the west and north of the United Kingdom (Doug Hunt, pers. comm. 2016) but may also be important when considering how drought impacts could vary across Southern Water’s supply area.

To meet our desired risk composition under the “Risk Based Planning” framework UKWIR (2016b) we need to:

Produce a “*system stress based metric*” and associated return periods (probability of occurrence) for that metric for all the droughts we are using. To do this we must produce a continuous yield/probability curve or coherent time series of DO.

The UKWIR (2016b) guidance recommends examining system stress metrics, such as DO which integrates both the climate and hydrological variables of a system into a single metric. This approach is subject to a number of assumptions about operational rules (e.g. around antecedent operation) and is difficult to update to reflect system changes without a completely new assessment. (UKWIR, 2016b).

Generally, DO is a better metric of water supply “system stress” than climate (rainfall, PET) or hydrological indicators (flow, groundwater levels) alone as it also integrates an assessment of relevant supply system constraints. The primary purpose of these methods is therefore to explore the variability in the yield (DO) for those sources which are hydrologically or hydrogeologically constrained and which are most sensitive to drought.

As outlined in the Section 3, DO reflects both the yield of sources under different drought conditions but also any other relevant operational or infrastructure constraints on operation. Many of our sources are infrastructure (e.g. treatment capacity) or licence constrained and hence do not exhibit much variation in DO. In these cases, determining a probability density function of DO is not especially meaningful as uniform output can theoretically be achieved under all circumstances. However, this is not universally the case and to establish the system stress metric for hydrologically variable sources appropriately under this risk principle requires us to complete two steps:

Use an artificial weather generator to produce large time series of rainfall and potential evapotranspiration (PET) that are consistent with historic climate metrics and also contain severe or extreme droughts

Apply those time series to water resource models to create equivalent time series of DO and associated probabilities/return periods.

We must also demonstrate that the artificial weather generator we have used produces outputs that are comparable with the historical record. Generally, this can be shown by comparing the frequency and magnitude of drought events simulated to records measured over consistent time periods. More explicitly, an example could show that an estimated 1 in 100 year drought (1% annual probability) from the synthetic sequence is comparable to the worst drought on record, assuming a ~100 year record.

The generation of long time series of rainfall and PET and how they have been applied to our water resource models is described in the rest of this section. Section 4 summarises the outturn DO metrics for each WRZ and area.

3.2 Artificial weather generation

3.2.1 Background to our approach

For our 2014 Water Resource Management Plan (WRMP14) we adopted a “stochastic” artificial weather generator which generated extended synthetic sequences of weather with which the hydrological constraints of our supply system could be tested with extreme droughts not experienced within the historical record. This approach was developed to address key issues within the planning framework at the time, such as the discontinuity between the 'design droughts' that are used for the WRMP and the actual drought management that occurs because of the Drought Plan intervention and triggers. The aims of our 2014 approach were to:

Understand the relationship between DO and drought probability, particularly for events more severe than those on record
Understand how more severe droughts develop and the implications for levels of service in terms of frequency of use of drought interventions such as restrictions or Drought Permits and Orders
To allow climate change impacts on drought events to be better understood.

This approach reflected concerns that the traditional approach to DO assessment, based solely on the worst historical droughts was not a robust test of the supply system to meet our promised levels of service. Owing to poor historical records, particularly for groundwater droughts, historic events could not be hind-cast robustly enough to be useful. This was most relevant for low annual probability, drought events. Curve fitting through historic data or similar extrapolation approaches based on parametric models can fail because the shape of the curve or the underlying statistical models are poorly constrained by historic data. Consequently, extrapolation of historic system performance for low probability events introduces errors and uncertainties that can compromise system reliability estimates. Supply system performance during drought can be influenced by a number of factors including:

The overall intensity, timing and spatial extent of the drought (i.e. the climate variability).
Relative timing of drought events - two dry summers would have less impact on groundwater resources than two dry winters owing the general absence of summer recharge, irrespective of actual rainfall.
The relationship between drought climate variables (e.g. rainfall and PET) and response of water resources (groundwater levels, flows) reflecting the environmental and geological variation between individual catchments.

Antecedent conjunctive use of water resources and availability of storage (e.g. reservoir reserves or groundwater storage) within WRZs and the transfers between them.

Instead of extrapolating drought events from historic observations, a synthetic weather generator approach creates artificial climate time series but which also reflect the underlying statistics of the observed climate. The advantage of such an approach is that it is not limited by the often short historical record and very large 'stochastic' climate datasets can be produced. Use of these data sets to explore water resource availability and source yields therefore allows a wide range of drought responses to be assessed. The variance of these data can be quantified and probabilities derived in order to obtain a suitable data set for a risk based (probabilistic) planning.

3.2.2 Our weather generator

The weather generator we have used is effectively a bespoke version of those used to support recent Water Resource South East (WRSE) planning (Atkins, 2017a), the recent Water UK National Water Resource Long Term Planning framework (Atkins, 2016) and Water Resource Management Plans for Thames and Anglian Water. In turn, this weather generator was an evolution of that developed for our previous plan (Southern Water, 2014). All of these weather generators share substantial commonality and this general approach has now been widely adopted by the UK water industry.

After publication of the 2014 WRMP (Southern Water 2014), a strategy to refine and enhance both the weather generator and water resource assessment methods was agreed (the "Stochastic refinement plan", (Southern Water, 2014 Appendix C03) with the EA. Many tasks of this plan related to improvements in data handling rather than the weather generator specifically. The key themes of this plan were to:

Review and improve conceptual shortcomings of the weather generator in underestimating Spring-Autumn rainfall during long period severe droughts and if necessary enhance the statistical model.
Consider approaches for automatically integrating climate change effects with the weather generator rather than as a post processing perturbation.
Consider possible temperature and PET led approaches to overcome some of the shortcomings with the current PET sampling methodology and inconsistency in the historic PET data sets available.
Provide clearer documentation of the performance of the stochastic model against historic data sets, the number of replicate samples/runs likely to be required and the procedures involved in running the model and translating output time series into DOs.
Enhance and automate, where possible, some of the post-processing steps involved in translating key rain gauge sequences to other gauges and the downscaling of rainfall to daily rainfall and PET sequences for use with resources models to generate DO.
Engage more with the EA to discuss the level of service implications from historic drought performance and the stochastic sequences and how intervention thresholds and timings are derived.

We commissioned Francesco Serinaldi and Chris Kilsby from the School of Engineering at Newcastle University, authors of the original weather generator, to develop some more enhancements to address some of the issues found above.

In order to appropriately reflect UK climate patterns, our weather generator relates two regional scale climate indicators known to influence UK climate, specifically the North Atlantic Oscillation (NAO) and Atlantic Sea Surface Temperature (SST). Variations in both of these phenomena can be related to UK rainfall patterns (Serinaldi and Kilsby, 2012).

The North Atlantic Oscillation (NAO) reflects relative air pressure differences over the North Atlantic Ocean and influences the position and direction the North Atlantic Jet Stream and anticyclonic storm systems and resulting rainfall over the UK. The greatest influence of the NAO on rainfall occurs in the winter (Jones et al, 2003). Winter rainfall is most critical from a water resource perspective as it reflects the period of lowest soil moisture deficits and greatest groundwater recharge and is therefore a critical variable for drought.

A positive NAO phase is typically associated with mild and wet winter conditions in Northern Europe (Jones et al, 2003, Lopez-Moreno and Vicente-Serrano, 2008). A negative NAO phase is typically associated with cooler, less stormy and drier winter conditions in the UK. The spatial influence of the NAO varies across the UK, having the greatest influence along the Atlantic coast in the north and west and least influence in the South East (Serinaldi and Kilsby, 2012). This reflects both proximity to the ocean and orographic effects.

Sea Surface Temperature (SST) has less overall impact on rainfall occurrence and distribution but is linked to rainfall intensity (Atkins, 2017a) and hence is still a useful covariate for considering UK rainfall patterns (Serinaldi and Kilsby, 2012).

The weather generator functions by examining statistical relationships between these large-scale climate indicators and local rainfall data at a monthly scale. The enhanced weather generator for WRMP19 builds on other recent rainfall models (Serinaldi and Kilsby, 2012, 2014, Villarini et al, 2013). The weather generator uses parametric Generalised Additive Models for Location, Scale and Shape (GAMLSS). These models allow the incorporation of the large-scale climate indices (NAO, SST) and estimate their relation to single rain gauge sites or gridded rainfall data. A key enhancement for the WRMP19 generator was the inclusion of "at-site" modelling, again using GAMLSS. This allows the introduction of physical co-variates that help to adapt the shape of the "at site" (i.e. the rain gauge or gridded data time series in question) distribution to external climate and geographical drivers. Spatial variation between forecast sites and seasonal factors can also be captured. More detail on the model is given in Appendix A. A key outcome of these enhancements are such that the model is now fully parametric and predicts rainfall for all seasons directly. This has removed issues relating to lack of persistence which were associated with bootstrap sampling of spring-autumn rainfall in the original (Serinaldi and Kilsby, 2012) model.

By simulating all seasons parametrically, spatial coherence can be maintained across multiple rain gauges (beyond the three indicator gauges used in AMP5), removing the need for any extra disaggregation or random error modelling. The weather generator produces spatially coherent outputs for each of Southern Water's rainfall locations used in water resource models simultaneously (i.e. in a single modelling run and step).

The final enhanced model produces spatially and temporally coherent monthly rainfall time series at multiple sites and produces good calibration matches to these criteria.

Monthly mean / and seasonal rainfall distributions across all gauges
Spatially correlation of rainfall patterns across the whole domain at multiple time aggregations (1 month to 60 month)
Reproduction of extremes at multi-time aggregations (1 month to 60 month)
The reproduction of rainfall extremes is unique to this model and has not been tried or demonstrated elsewhere in the literature (Kilsby, pers. comm., 2016)

3.2.3 Weather generator overview

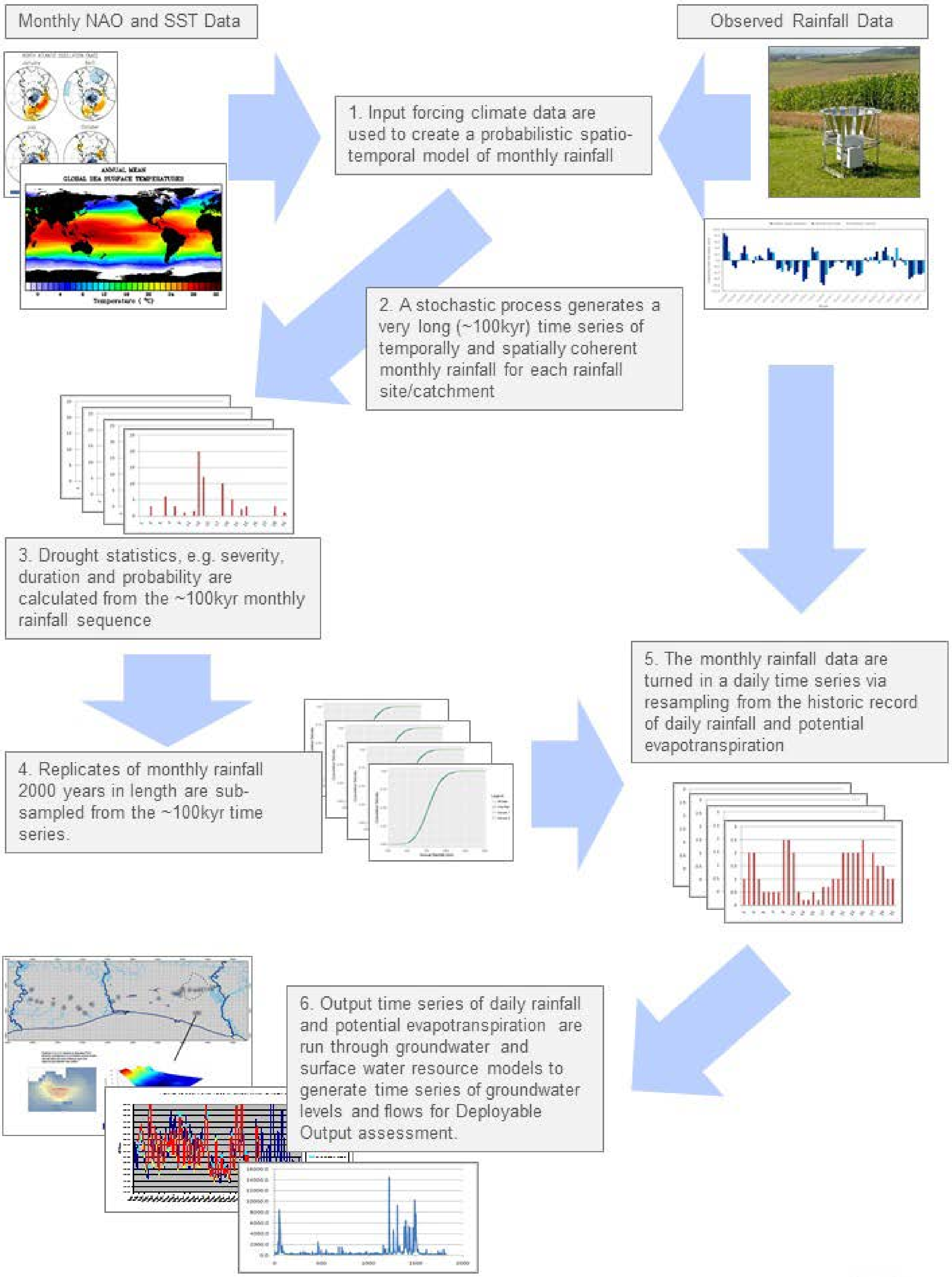
A high level schematic illustrating the key steps of the weather generator process is presented in Figure 2. The process involves 6 key steps, each of which is summarised below and more detail is presented in the following sections.

Input data comprising monthly North Atlantic Oscillation (NAO), Sea Surface Temperature (SST) and observed time series of the rainfall sequences for which an output stochastic series is required are supplied to the weather generator (see Section 3.2.4).

The weather generator fits a spatio-temporal probabilistic model to the input data and via a stochastic process creates a very long (~100,000 year) output time series of monthly rainfall for each required site. These time series are spatially and temporally coherent across our region.
The output time series are post-processed to examine drought characteristics. These include drought duration, intensity and severity. Return periods are estimated via frequency analysis of the very long time series (see Sections 3.2.5, 3.2.6 and 4.5).
The very long time series is sub-sampled to create shorter 2000 year time series suitable for processing in water resource models (see Section 3.2.7).
The shorter 2000 year time series of monthly rainfall data are disaggregated to daily data by sampling from the observed daily record. Associated time series of PET
data are generated simultaneously via the same process (see Section 3.2.8).
The daily time series of rainfall and potential evapotranspiration data are supplied to our water resource models, comprising various runoff-recharge, groundwater and surface water models (see Sections 3.3, 3.4 and 3.5).

Output time series of groundwater levels and flows from the water resource models are used with conventional DO methodologies to create a time series of DO from which return periods can be estimated.

Figure 2 Schematic overview of the key weather generator processes



Monthly NAO and SST Data

Observed Rainfall Data

1. Input forcing climate data are used to create a probabilistic spatio-temporal model of monthly rainfall

2. A stochastic process generates a very long (~100kyr) time series of temporally and spatially coherent monthly rainfall for each rainfall site/catchment

3. Drought statistics, e.g. severity, duration and probability are calculated from the ~100kyr monthly rainfall sequence

4. Replicates of monthly rainfall 2000 years in length are sub-sampled from the ~100kyr time series.

5. The monthly rainfall data are turned in a daily time series via resampling from the historic record of daily rainfall and potential evapotranspiration

6. Output time series of daily rainfall and potential evapotranspiration are run through groundwater and surface water resource models to generate time series of groundwater levels and flows for Deployable Output assessment.

3.2.4 Weather generator input data

The model is primarily driven by three different types of data:

North Atlantic Oscillation Monthly Time series for the period 1908 - 1998, the input data for this were sourced from University of East Anglia Climate Research Unit https://crudata.uea.ac.uk/cru/data/nao (CRU, 2017)https://crudata.uea.ac.uk/cru/data/nao (CRU, 2017).
SST Monthly Time Series for the period 1908 - 1998, source from the Hadley Centre HadSST2 Anomaly data set (Kennedy et al, 2011a, 2011b) spatially averaged for three grid squares between 50-55° N and 10°W to 5°E (after Serinaldi and Kilsby, 2012).
Rainfall data sets, these are based on either observed rain gauge data or gridded CEH GEAR data sets and cover a variety of input time periods depending on the site. Each of the input historic rainfall time series is an existing dataset used within our water resources models. The weather generator is compatible with both rain gauge time series and gridded data sets.

In general, use of rain gauge data were preferred as these data are more transparent and not subject to third party aggregation and processing but observed rain gauge data often have many gaps and data quality can vary substantially with time and are often sparser in the past.

Each of these historical time series were deliberately truncated at 1998 in order to remove apparent non-stationarity in the rainfall and climate indicator (e.g. sea surface temperature) datasets thought to arise from the impacts of anthropogenic climate change (Southern Water 2014a). As the impacts of climate change are calculated as a separate component to our supply forecast (See Section 6) it was desirable to remove any apparent effects from the historic records used for the weather generator. We have therefore adopted the same approach as for our previous analysis (Southern Water 2014a) and used rainfall data up to 1998.

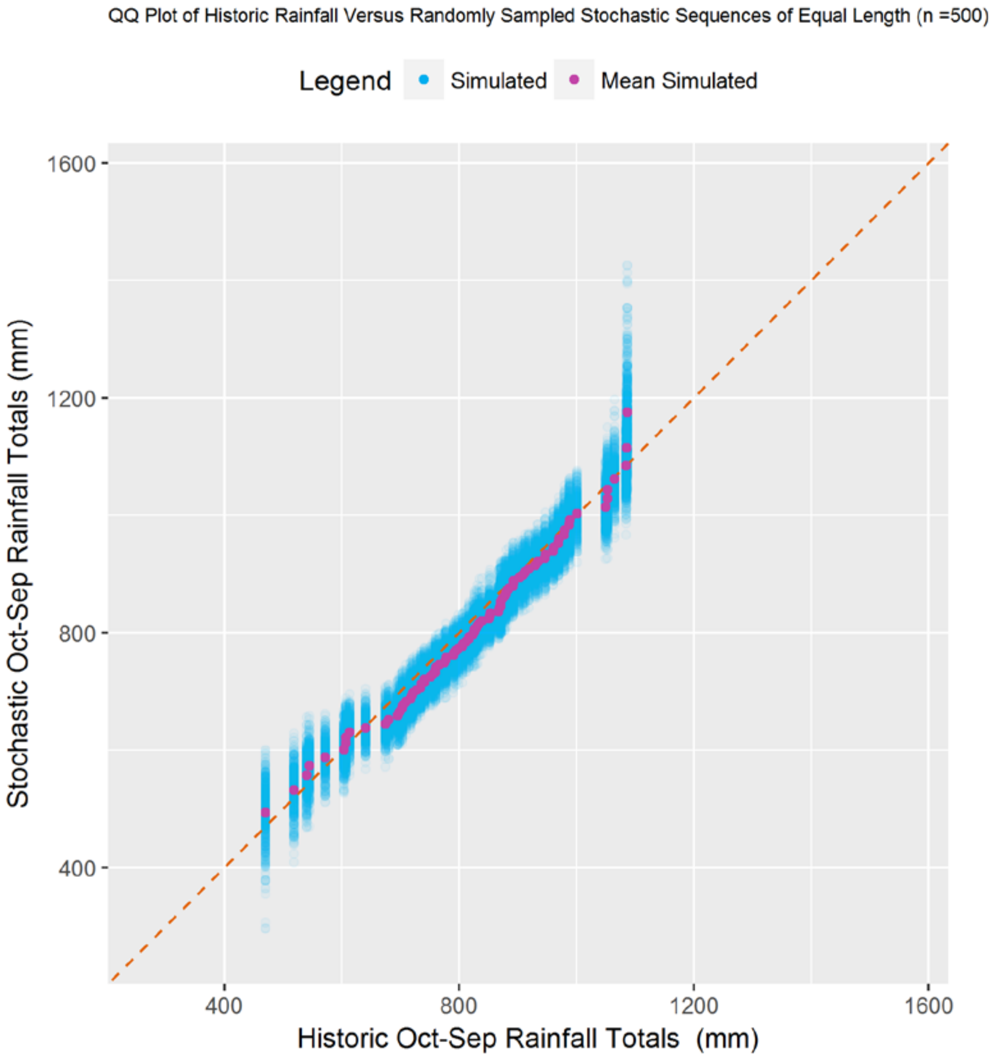
3.2.5 Weather generator calibration

A weather generator is only useful it if replicates the underlying properties of the observed climate well (i.e. the distribution of rainfall patterns, including droughts, produced by the weather generator should match well the observed historic pattern for which reasonable data are available).

To demonstrate the “calibration” of the weather generator outputs against the historical climate a series of Quantile-Quantile (Q-Q) plots have been produced (Appendix B). A quantile-quantile plot compares ranked outputs from the model against the equivalent rank of the observed data sets. For example, the rainfall total for fifth driest simulated year would be plotted against the fifth driest observed year. An example calibration plot is shown in Figure 3.

The blue points show the range and variability of the synthetic weather simulations for 500 different realisations of equal length to the historic record. The solid purple dots indicate the mean of that range. If the weather generator simulated the historical climate distribution exactly, then all of the data would plot on the dashed 1:1 line. The point of this modelling is not to exactly reproduce the historic climate, but to stochastically simulate alternative, but plausible climate sequences. For a reasonable calibration the pattern of the scatter include the 1:1 line but with a reasonable degree of variability about this line. Generally a roughly even scatter about the 1:1 line across the whole data range would be desirable as this would demonstrate the model is not systematically drier or wetter than observations, especially at either “tail” of the dataset.

Figure 3 Example quantile - quantile calibration plot



To examine the model calibration, rainfall totals are compared over a number of different accumulation periods - 6, 12, 18, 24, 30, 48 and 60 Month rainfall accumulations for months ending in October, November and December and presented in Appendix B. These plots are produced as a single set for each aggregation period across the whole of the rainfall dataset.

Overall the calibration to historic rainfall is well maintained by the weather generator across a wide range of accumulation periods. The spatial coherence is also maintained between individual rainfalls sites. This demonstrates that model is able to match historic rainfall patterns is similarly across each rainfall site and across multiple aggregation periods.

The GAMLSS model fitting is performed essentially at a monthly level there and there is no control on fitting of rainfall to longer accumulation periods. The variability of the historic climate appears to be well replicated even up to extremely long rainfall accumulation periods. The weather generator and so appears to be a credible tool for simulating rainfall for water resource modelling but there are a number of limitations that must be considered:

The observed input rain gauge data have many gaps and are of varying quality with time. Rainfall records are also sparser farther back in time. These data gaps introduce uncertainties in forecasting and model fit. The uncertainties in the input data are, overall, likely to be larger than “errors” in the model fit (Kilsby, pers. comm.)

Validation of model outputs (i.e. the Q-Q plots) can be produced both for individual sites and aggregated regions (e.g. for use with gridded rainfall data). Gauge by gauge validations tend to be poorer than aggregated outputs (e.g. gridded datasets) as individual gauge data quality is poorer, less complete and exhibit greater variability than an aggregated dataset. Errors, in single gauge records will have more prominent effects on calibration

There are few input rainfall records that are very long (approaching 100 years) and hence there is substantially uncertainty in accurately estimating rainfall events of low annual probability

The majority of these limitations are consequences of the quality of historic input data available, i.e., the historic record is incomplete, short (in the context of the number of severe drought events available) and contains errors. These problems are common to most water resource modelling, even conventional planning to the “worst historic drought”. Hindcasting or extrapolation approaches to infill missing data will not necessarily lead to any improvement in model accuracy as they too are conditioned only on the observed data available. It is also not practicable or accurate to run physically based rainfall models at the spatial and temporal resolution required for water resource planning and, indeed, they too are conditioned on observed data.

The key advantage of the stochastic weather generator approach is that while these inaccuracies are recognised, the inherent randomness of the output allows a wide range of plausible climate data (much greater than the historic record) to be generated. Use of this data in water resource models therefore allows a more robust estimate of source yield responses to be calculated. Accepting model credibility, a key limitation is that because the historic data are poor, estimating the true probability or “return period” of any given event, especially for more severe droughts is highly uncertain.

A “Fully risk based plan” requires a probabilistic estimate of DO to be derived. In recognition, of the uncertainty in assigning the true probabilities to any given event we have generated extremely long (~100,000 year) time series using the weather generator. On this basis, we can make an empirical estimate of rainfall event probability relative to the overall sequence. The resulting estimates of probabilities associated with DOs will be similarly derived on the basis of frequency analysis of the output time series.

3.2.6 Weather generator modelling process

The overall process to collate the input data, run the weather generator and produce output suitable for input into water resource models is summarised below.

To generate input time series for our water resource models we used the weather generator to create an initial extremely long time series of data for each of the input rainfall sequences. The weather generator employs an internal Monte-Carlo process within the fitted probabilistic model of rainfall and external climate covariates (NAO and SST). The resulting output data from the weather generator are in the form of single time series for each rainfall site around 100,000 years in length. This time series is spatially and temporally coherent across each rainfall site.

A series of post processing calculations were then performed on this time series, this classified each rainfall time series in terms of rainfall deficits (compared to long term average), and estimated drought indicators including calculation of Standard Precipitation Indices (McKee et al, 1995). Once found each period of rainfall deficit (or drought) in the very long time series was analysed in terms of overall duration of deficit, the intensity (i.e. the magnitude of the deficit) and its estimated probability. These drought metrics are not used to choose which droughts events are used to calculate DOs but to instead obtain information on the population of drought events and hence context to understanding drought severity and probability.

The estimates of DO return periods are based solely on frequency analysis of a time series of DOs, and are not directly related to the SPI. Our approach is consistent with the methodology set out in the 2016 UKWIR risk based planning guidance under Risk Composition 3 (Fully Risk based plan) (see Annex 1). Under this risk composition we need to undertake probabilistic drought analysis of system stress (effectively DO) in order to appropriately define our level of service and drought resilience statements.

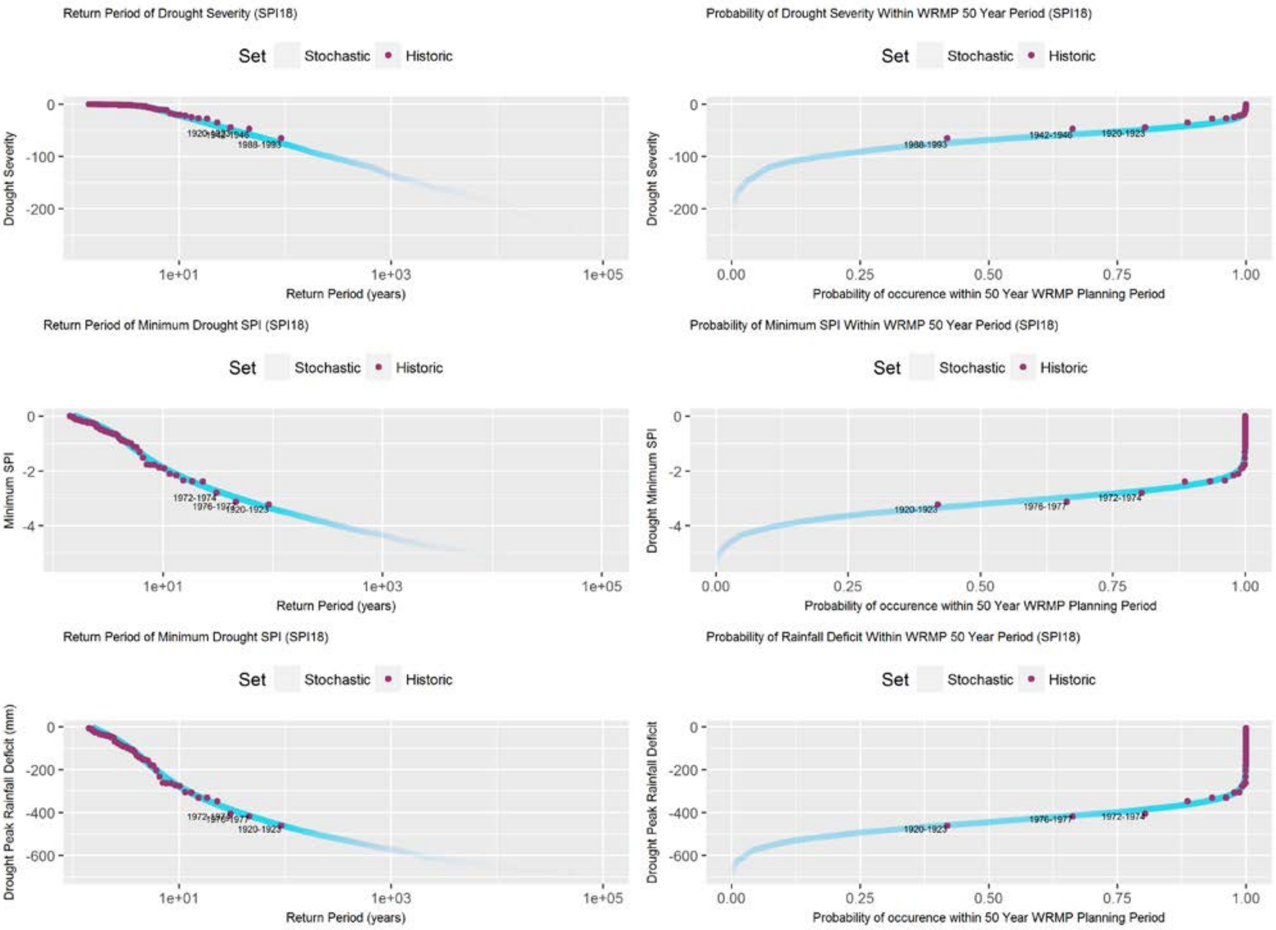
The SPI is calculated for each drought event within that continuous time series as a means of comparing the relative severity of rainfall deficits but it is not used to select or sample droughts (as might be the case in a drought library type approach under other Risk Compositions).

The drought characterisation allows a more direct comparison of the synthetic drought events (in terms of rainfall patterns) with historic events as an extra validation of the model. These assessments were performed for each gauge and over several different rainfall accumulation periods (from 6 months to 60 months). An example, comparing drought metrics for a rainfall site in our western supply area, is shown in Figure 4.

This shows 18 month rainfall deficits and standard precipitation indices (SPIs) for both the full synthetic sequence and calculated from the input historic rainfall sequence. The limitations on estimating these probabilities with accuracy have already been discussed and they should be treated with caution.

The data indicate that drought severity and frequency in the simulated sequence broadly matches that of the historic record, including major historic droughts but extends that data into more severe, low probability events. Again, this gives more confidence that the weather generator produces credible rainfall sequences suitable for water resource planning. Our modelling replicates these patterns well across all of the rainfall sites but where input rainfall sequences are shorter or have gaps, estimates of probability become even less confident and tend to show greater deviation from the synthetic dataset.

Figure 4 Example probability plots of rainfall deficits comparing the historic record and the stochastic sequence



3.2.7 Sub-sampling for water resource model input

Unfortunately, it is not practical to run the full (~100,000 year) synthetic rainfall sequence through our water resource models to quantify source yield response to the full range of data. This results from both long model run times and computational limitations, especially for cases where distributed groundwater models or Aquator behavioural models are required. For example, the Test and Itchen groundwater model covering much of our Western area takes around 3 days to complete a single run of the recharge-runoff and groundwater model of 2000 years in length. Scaling that up, a sequence of 100,000 years would take a run time of around 150 days to complete.

It was therefore necessary to produce a smaller subset of the synthetic data. This could be accomplished by one of two methods:

Specific drought events could be subsampled and collated into a single shorter input sequence (this would be equivalent to a drought library approach under the UKWIR (2016b) Risk Based Planning Methodology)
A continuous time series could be directly subsampled, either randomly or by deliberate selection.

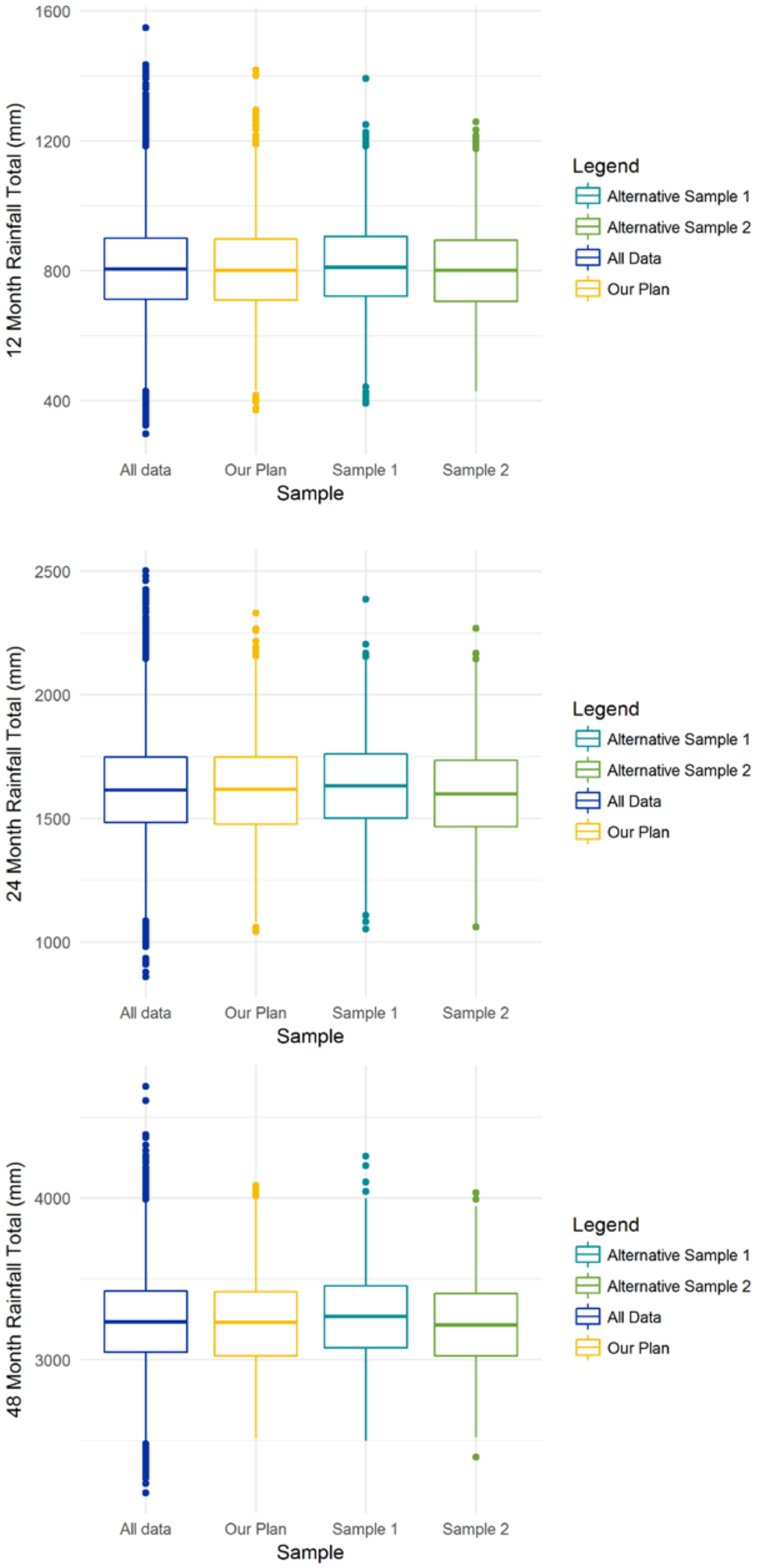
In keeping with our risk principle, and recognising that the probabilities of individual drought events cannot be estimated robustly when separated from their base sequence, we elected to use the second approach and subsample a sequence from the parent model. After WRMP14 our existing water resource, behaviour models and associated analysis tools are already set up to handle time series of 2000 years in length and given the anticipated computational limitations and time available this was considered to be an appropriate sub-sample length for our yield assessments. Given that a 2000 year sequence contains about 20 length equivalent replicates of the historical climate record this should give a reasonable estimate of drought variability.

To select an appropriate sub-sample we elected to select a sequence that closely replicated the broad underlying average statistics of the parent data set in terms of rainfall metrics, i.e. we deliberately chose a sequence that was not significantly wetter or drier than the global data set. This also means that the derived yield probabilities from the water resources models would be consistent with that which we might have derived had the full sequence been processed.

To select an appropriate 2000 years sample for use with the water resource model the full ~100,000 year data set was subject to bootstrap sampling with replacement of 200 separate 2000 years long sequences. The cumulative distribution of 12 month hydrological year rainfall totals was then compared to the equivalent cumulative distribution of the parent data set. A Komolgorov Smirnov test (Komolgorov, 1933, Smirnov, 1948) was performed to establish the similarity between the subsample and the parent data. The sample which had the closest overall match (in terms of the average distance parameter across each rainfall site) was then selected as the “design” time series for use with our water resource models. The actual range of variation between individual 2000 year sub-samples and the parent data set was relatively small and the majority of the 200 sub-samples show a statistically significant match across several rainfall metrics when compared to the parent data set (Figure 5). This suggests that 2000 year sample replicates the overall characteristics of the arent synthetic data set.

The box and whisker plots (Figure 5) show the distribution of rainfall totals across 12, 24 and 48 month periods for both the full 100kyr data set, the 2000 year sample used in our plan and two alternative samples. The boxes show the interquartile range (25% to 75% of the data), the line across the box show the median (50th percentile) of the distribution. The whiskers show 1.5 times the interquartile range and other data points show more extreme outliers. The three 2000 year sub-samples show a very close match across the range of the whiskers and interquartile range, but obviously as it is a smaller sample there are fewer extreme outliers compared to the parent 100kyr dataset. .

Figure 5 Box and whisker plots showing a comparison of cumulative annual rainfall distributions (12, 24 and 48 month) from 2000 year sub-sampling of the 100,000 year sequence to derive input to water resource models



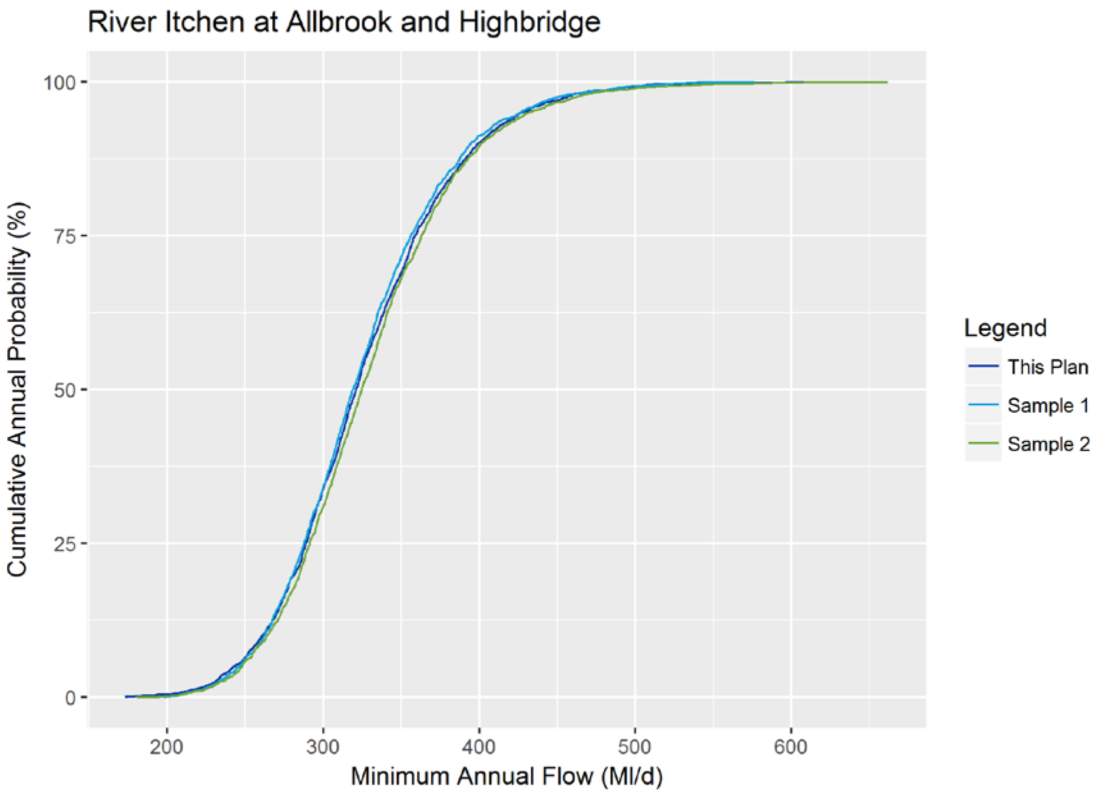
To assess the sensitivity of this sub-sampling process, two alternative 2000 year samples were also selected. One reflects slightly wetter conditions (Sample 1), the other slightly drier (Sample 2). To compare their effects on yields all three rainfall samples were used with the Test and Itchen groundwater resource model which covers our Western area. In this area, flows in the rivers Itchen and Test are closely related to the DO of those sources and hence are a suitable proxy of source yields before formal DO calculation. One reflects slightly wetter conditions, the other slightly drier.

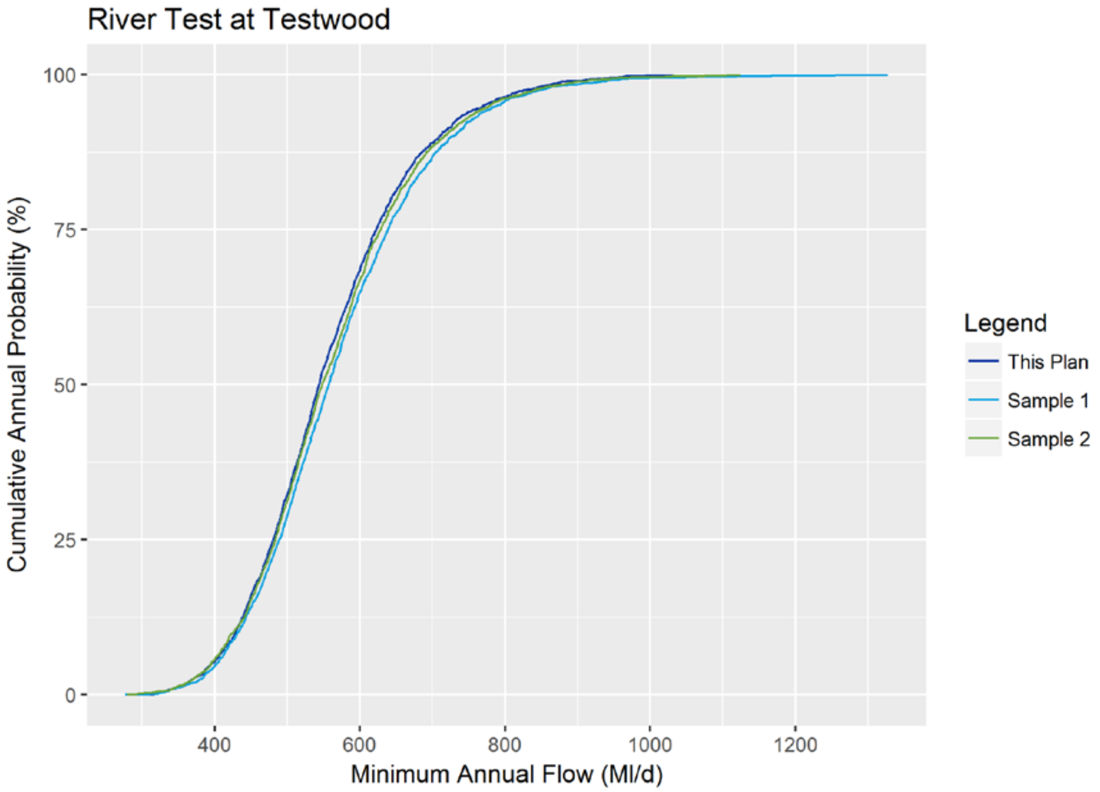
Flow Duration Curves for the rivers Itchen and Test under each of the three samples (“design”, “wet” and “dry”) are presented in Figure 6. These data show that the overall, flow patterns are extremely similar for all three replicates, especially for low flows which are of most interest. Consequently the outturn DO calculations are likely to be relatively insensitive to the specific 2000-year sub-sample weather generator period selected. Ideally, to produce a more robust dataset for the Risk Based Planning, DOs would be calculated over as large a climate dataset as possible but unfortunately more assessments beyond these three 2000-year runs was not possible with the time and computational resources available.

Our analysis has indicated that our sub-sampled 2000-year sequence contains a statistically significant similar distribution of annual rainfall to the parent 100 000 year data set. Analysis of modelled flow data using multiple samples of the 200-year rainfall sequence has shown that the resulting difference in flows between replicates, especially at low flows relevant to drought is small. We therefore consider it to be unlikely that our sub-sampling is generating either more or fewer drought events than exist within the full 100 000 year sequence and hence is unlikely to influence our assessment of drought DO and probability. Given expected advances in processing power and planned enhancement of our Water Resource models we will consider the viability of processing longer climate sequences to improve our supply forecasting for WRMP24.

The return periods for which our DOs are calculated are developed from probabilistic analysis of DOs as a measure of system stress. This is consistent with our Risk Composition (Annex 1) and the UKWIR Risk Based Planning Guidance (UKWIR, 2016b). DO return periods are estimated by ranking all the droughts that are generated from our sub-sampled 2000-year coherent time series. Consequently these system stress return periods will differ from those for the rainfall data which are based on analysis of the ~100kyr sequence. The rainfall return period and DO return period would be expected to differ anyway, since DO as a system stress metric integrates other factors, such as timing of rainfall deficit, potential evapotranspiration and antecedent storage. These issues are also discussed in Section 4.5.

Figure 6 Comparison of naturalised flow duration curves based on simulations of the Test and Itchen groundwater model for the rivers Test and Itchen for three 2000 year sub-samples of weather generator output





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3.2.8 Disaggregation of daily rainfall and generation of PET data

The synthetic weather generator and subsampling produces a spatially and temporally coherent 2000-year monthly time series of rainfall. These time series are produced for each input location required for our water resource models. However, most of our water resource models require daily climate data comprising both rainfall and potential evapo-transpiration (PET). Most recharge, runoff and surface water routing models calculate water balances on a daily time step. In groundwater models, these daily steps are then aggregated up into model “stress periods”. Typically, there will be between two and four stress periods each month, each several days in length. In order to produce suitable input data for our water resource models the monthly synthetic rainfall data must be disaggregated into a daily rainfall sequence together with a coherent PET time series.

A processing script, written in the Python programming language, performs this disaggregation. The purpose of the script is to both downscale the monthly stochastic data produced by the weather generator to daily data and to also create a coherent daily PET time series. The Python script was originally written by Atkins, for use with the stochastic modelling undertaken for Water Resources South East (WRSE) (Atkins, 2016). Southern Water obtained the script from Atkins as part of the package our associated work for this WRMP and aside from some minor modifications to the formatting of the output data to improve handling with our resource models, the calculation procedure is unchanged from Atkins (2016).

The disaggregation process occurs in several steps:

First, the input data are imported and saved into a database format. These data include:

- Daily historical rainfall and PET time series, for this modelling this covers the period 1970-1997
- A list of “catchment” areas that relate to the different rainfall and PET sequences - it produces one output time series for each catchment. For this modelling each rain gauge and associated PET sequence is treated as a single catchment.
- The synthetic monthly rainfall sequence for which daily rainfall and PET output is required. This could be either a stochastic or a hindcast rainfall sequence. For this modelling these data comprise a cycled warm up period (repeated 1995 monthly rainfall) from 1913-1917. Monthly rainfall from 1918-1997 based on observed rain gauge data for three rain gauges in Hampshire - Otterbourne, Salisbury and Greywells. Two years of cycled 1995 rainfall and then the projected 2000 year stochastic sequence from the weather generator model for the same rain gauges.

The script totals the historical daily rainfall and PE data to monthly equivalents. The procedure then matches these totals to the input “stochastic” month (or hindcast month). The matching procedure calculates the smallest difference in monthly total rainfall as summed across all of the input rain gauges. A single historical month is chosen for all of the input rain gauges to maintain spatial and temporal coherence of the daily rainfall sequence. The matching is performed calendar month to calendar month, such that it cannot match a historical January to a stochastic June, only January to January etc.

A scaling coefficient is then calculated for matched historical monthly rainfall totals such that the monthly totals can be scaled to be equal to the stochastic total.

To account for apparent persistence effects observed in historical data (i.e. in long dry spells PE stays high), in “summer” months (April to August) the matching procedure is carried out on aggregated 6 month rainfall totals.

This creates a matched sequence of historical months of the same length of the “stochastic” input sequence and an equivalent scaling coefficient that can be applied to factor that historical month to match the hindcast/stochastic monthly rainfall.

Daily data are output based on the daily record for the matched historic months. Both rainfall and PET are factored by the scaling coefficient to match monthly stochastic total rainfall.

This procedure creates a spatially and temporally coherent daily rainfall and PET sequence that matches the stochastic/hindcast monthly input data but reflects observed daily variability within months.

The extra processing carried out for summer months is to address issues found during WRMP14. Previously it was found that PET in being based on 6 monthly rainfall totals is to better account for some of the persistence issues with PET data found during the synthetic weather generation for WRMP14.

Leap years (i.e. years including the 29th of February) are automatically incorporated in the output daily data and follow the normal rules associated with their occurrence (e.g. not in years that are multiples of 100, but in years that are multiples of 400). This functionality could be switched off if desired.

Our adoption of this scripted algorithm addresses some tasks set out in our “Stochastic Refinement Plan” (Southern Water, 2014 – Appendix C03) agreed with the EA after WRMP14, specifically:

“Automating the PET and daily rainfall re-sampling process to allow rapid outputs to database files”
“derive approaches to automatically link output daily rainfall and PET records to the surface water flow models that already exist”

The daily disaggregation tool is capable of rapidly and directly generating coherent daily rainfall and PET data for multiple sites/models. These can be generated for very long synthetic rainfall time series in a single step. The Python scrip can also be readily batched for use directly with other pre- and post- processing tools to improve model workflows.

The output data can either be used directly as model input in some cases or automated pre-processing scripts using R (R Core Team, 2016) can be employed to rapidly reformat the data correctly for model input to both our Catchmod and 4R/MODFLOW groundwater models.

The disaggregation procedure is insensitive to the origin of the PE data used. The key requirement is that the daily rainfall and PE sequence being matched are coherent (i.e. cover the same space and time) and are the same location as the stochastic/hindcast monthly rainfall record for which daily data are required. The procedure can match gridded rainfall to gridded rainfall, rain gauge to rain gauge, and produce stochastic “Meteorological Office Surface Exchange Scheme” (MOSES), “Meteorological Office Rainfall and Evaporation Calculation System” (MORECS) or “Penman Evaporation for South East England” (PENSE) potential evaporation (PE) data depending on the requirements of the water resource model.

We needed to make sure that the synthetic rainfall and PE data were coherent and so the historical daily data input time series to the generator need to be of the same length. For example, it is not possible to match the full historical daily rainfall record (e.g. 1918-1997) with the MOSES PE data, which is only available from the 1960s. We therefore limited the historical daily inputs to the disaggregation process to the period 1970-1997. Limiting the input data to this period also produces outputs that are more consistent with the current climate given apparent warming trends we have

observed in PENSE PE over the 20th century (Soley, 2018). The input PET series for each of our water resource models are described in Sections 3.3 and 3.4 and summarised in Table 5.
Our water resource models use stochastic datasets that are consistent with the input data series. In these cases the output stochastic PET sequences will be generated from the same input historical time series used with the original historical water resource model run. The PET data are therefore unlikely to lead to more uncertainty in DO estimates than already exists within the calibrated water resource model.

The two exceptions are for the Test and Itchen groundwater model and Isle of Wight runoff recharge model. In these cases, two PE data sets; MOSES and PENSE datasets were used. Having been an issue of consideration in the Western area Public inquiry, more discussion on the implications of different PET (MOSES and PENSE) sequences within the Test and Itchen groundwater model is given in Section 3.3.7.

For the Isle of Wight WRZ model the only sensitive DO is likely to be at Newport for the incoming gravity flow. This has a forecast yield between 1-4Ml/d depending on drought severity (see Section 4.2.1). At the time of minimum groundwater levels when yield is most critical gravity flow yield is between 2.2 and 1.86Ml/d depending on return period.

Although it has not been explicitly calculated, PENSE and MORECS are typically much more consistent than PENSE and MOSES (see Section 3.3.7) as there are considerable similarities in the calculation methodology. The PENSE dataset was originally developed by the EA to emulate the MORECS approach. Hence the consequence of using a PENSE time series, as opposed to MORECS are likely to be smaller for the Isle of Wight than for the Test and Itchen model. The allowed uncertainty in the supply forecast for the Isle of Wight WRZ (Annex 5) of 5% is greater than the range of forecasts yield of the gravity flow and hence is likely to capture any variation in DO from the PET data.

Table 5 Summary of PET datasets used in our water resource models

Water Resource Model	Original Model PET data	Stochastic Input data (sampled 1970-1997)	Output data used with model
Test and Itchen Groundwater Model	Daily MOSES (1970-2012)	Daily PENSE (1970-1997) Daily MOSES (1970-1997)	Stochastic PENSE Stochastic MOSES
Isle of Wight Recharge Model	Daily MOSES	Daily PENSE	Stochastic PENSE
Brighton and Worthing Groundwater Model	Monthly MORECS	Daily (monthly equivalent) MORECS	Stochastic MORECS
Medway Recharge Model	Daily PENSE (1918-2012)	Daily PENSE	Stochastic PENSE
East Kent Groundwater Model	Monthly MORECS	Daily (monthly equivalent) MORECS	Stochastic MORECS
Wester Rother CATCHMOD models	Daily MORECS	Daily MORECS	Stochastic MORECS
Medway CATCHMOD models	Daily MORECS	Daily MORECS	Stochastic MORECS
Eastern Rother CATCHMOD	Daily MORECS	Daily MORECS	Stochastic MORECS

Isle of Wight (Eastern Yar) CATCHMOD	Originally PENSE but converted to Daily MORECS in AMP5	Daily MORECS	Stochastic MORECS

3.2.9 Peer review of our approach

The weather generator we have used is based on the publication by Serinaldi and Kilsby (2012) and incorporates extra enhancements by Serinaldi and Kilsby (2014b) and Villarini et al (2014). All of this work has been externally peer reviewed and accepted by the wider academic community as suitable for spatio-temporal rainfall modelling.

An external peer review of our use of the stochastic weather generator to develop our supply forecast has been undertaken by Dr Doug Hunt of SNC-Lavalin's Atkins. Dr Hunt previously helped to develop the synthetic weather generator and the stochastic DO assessment process on behalf of Southern Water for our 2014 WRMP (Southern Water, 2014). In the current round of Water Resource Management Planning Dr Hunt has also worked with other water companies and Water Resources South East to develop the stochastic modelling approach. Dr Hunt has also given training on the methodology to the EA.

Although Dr Hunt has been involved in some aspects of developing our current plan, for example the integrated risk modelling (Annex 5), he has not been directly involved in development of our supply forecast and is therefore able to give a quasi-independent review of our approach.

The review was undertaken in November 2017, and the main focus was:

The stochastic generation of rainfall and PET data, and in particular the representativeness of the very low probability events.
The generation of flows and groundwater levels, in comparison to WRMP14.
A review of the generation of DO from the flows and groundwater levels

The review confirmed that the weather generator approach we have used is consistent with used for Water Resource South East, Thames Water, Severn Trent Water, Anglian Water and Welsh Water.

The principal difference is that no extra bias correction has been applied to our stochastic rainfall data. Dr Hunt considered this potentially an important step to account for between-month persistence effects caused by regional climatic effects other than the principal forcing climate variables of NAO and SST.

These apparent 'persistence' effects tend to extend the extremes of the totals, so omitting any explanatory factor will tend to mean the tails of the distribution are less extended than the available data suggest. In general it has been found that observable deviation is visible in the driest 10% of years, but this will vary by basin and site. The size of the deviation also varies strongly according to area and the period of time over which the cumulative rainfall is measured. The level of deviation appears to be the inverse to the amount of 'explanatory power' that NAO and SST has – i.e. it will tend to be greatest where there are 'rain shadow' effects and/or lower lying areas away from the coast. This is probably because rainfall is naturally higher in those areas where NAO and SST have the most explanatory power, so any other effects are not noticeable.

It is possible that the absence of bias correction may have impacted the estimated drought risks in our Eastern area and Sussex North WRZs. The impact on drought and DO estimates for our Western area and Sussex Brighton and Sussex Worthing WRZs appear to be small.

We considered the need to introduce more bias correction in discussion with Newcastle University during development of the weather generator. Their review of calibration of the model was such that more bias correction was unnecessary and not justified by the quality of the available data. The observed rain gauge data have many gaps, display various inconsistencies with quality, and (of course) become sparser as we go back in time. These uncertainties were considered likely to be larger than “errors” in the model fitting.

Comparisons of model output with GEAR, data do exhibit some bias but have overall similar variability (range of values). Newcastle University consider that the process of generating the aggregated GEAR data likely involves some correction for point-to-area bias, essentially the smoothing effect of considering the point rainfall (from the underlying gauged data) constant over an area (Serinaldi, pers comm, 2016).

Comparison of the weather generator model against rain gauge records, which are of variable quality and length, will tend show poorer performance than for aggregated data some of which may exhibit apparent bias effects. This is because of errors and missing data in single gauge records which will have more prominent effects than aggregated data. The longest rainfall records used are also only of the order of 100 years, so the uncertainty in estimating the 100-year event (or beyond) is large and cannot be improved by more manipulation of the data.

On the basis of conflicting expert opinions, we have not included more bias corrections to our rainfall data at this stage. As recommended by Dr Hunt, we will undertake a review of apparent persistence effects in the rainfall data and weather generator. At present the physical basis for these apparent bias effects is poorly understood and any such corrections are made on an empirical basis to match mean modelled and observed data. For WRMP24 we consider this issue again and the results of recent climate and drought modelling undertaken as part of the recent “About Drought” research project.

The review found that the rest of our rainfall analyses (re-sampling to create daily rainfall and correlated seasonal re-sampling to generate PET) appear to be reasonable. Our methodology was found to effectively follow the same approach as used for WRSE.

It was noted that our groundwater modelling approach to DO assessment is improved since WRMP14, and the review did not identify any areas where the current analysis does not conform with current good practice.

For our surface water modelling, the review noted an improvement in model performance for our eastern area because of refinement and revision of our CATCHMOD models (Section 3.4). However, some concerns over the mass balance of flows at Weir Wood and the Rother at Pulborough for the revised CATCHMOD models were found. We have reviewed our approaches for these CATCHMOD models and this is discussed in Section 3.4.

The only other significant comment about our resource modelling is that we have not undertaken a comprehensive comparison of historic and stochastically generated DOs. Otherwise the methods are similar, but incrementally improved, from the WRMP14. Since WRMP14 a number of elements of our supply system have fundamentally (for example sustainability reductions in our western area), which makes an exact like for like comparison of DO’s more difficult. Generally, we have not re-run our water resource models with historic climate data as in many cases the resulting flows and groundwater levels will not have changed, only the constraints on DO.

Overall, the review found that the general approach and methods we have adopted are appropriate and support a ‘Risk Composition 3’ approach, as defined in the UKWIR Risk Based Methods document (UKWIR, 2016a).

The peer review made these specific recommendations to our approach

The evidence and amount of impact of climatic anomaly behaviour on rainfall is reviewed, and a bias correction is considered if appropriate
The hydrological model for the Western Rother is reviewed and either re-calibrated towards low flows, or the WRMP14 model is used with the updated flow denaturalisation
Comparisons between historic and stochastic flows are made, concentrating on the Q90 to Q100 range
Comparisons between historic and stochastic drought events are documented and conclusions drawn

3.2.10 Evaluation of an alternative, potential evapotranspiration led, approach

A future “stochastic refinement” task was to consider the pros and cons of developing a future temperature / potential evapotranspiration led approach. Under such a model the key climate data to be estimated would be PET, rather than a rainfall led approach that samples PET from the historic record. Several shortcomings are apparent with the current method for generating stochastic PET sequences which relies on nearest neighbour sampling from the historic record:

1. Long period consistent records of PET (i.e. on similar timescales to rainfall records) are not available. The current historical PET sequences are from combinations of Met Office MOSES/MORECS, EA PENSE and temperature record based estimates. Inconsistencies between these datasets are especially apparent in hindcast records for the Eastern area (Kent).
2. When sampling sequences for PET no extra scaling is applied to account for differences in simulated rainfall totals compared to those observed in the selected daily sequence. This introduces some inconsistency but was not considered to be a large source of error (Southern Water, 2014a) as the rainfall differences are small and the errors are random and tend to cancel out over long periods of time.
3. Existing water resources models for surface and ground water are themselves based on a variety of historic PET data including both MOSES and MORECs datasets, which are themselves inconsistent. Any changes to the source of input PET sequences may require refinement of the underlying water resource models to make sure a match to historic data is maintained.

Implementation of a physically based combined temperature / PET and rainfall model (e.g. the standard FAO paper 56 method) is not likely to be possible within this planning period owing to the high degree of local variability and parameter requirements. Simpler approximations for estimating PET (e.g. Hargreaves method) could be employed which require only temperature data input but linking these data at a catchment scale to global scale climate indices (e.g. SST/NAO) may not be possible.

As part of the extra work Newcastle University could undertake a trial approach to generate daily MORECS equivalent PET and temperature data coherent with the stochastic rainfall sequences generated for Southern Water. This task will involve:

Developing a written methodology with examples and agree the best method for implementation (e.g. at Newcastle University, or Southern Water to operate by remote access to Newcastle server).
Application of the UKCP09 spatial weather generator software at Newcastle University using Southern Water daily rainfall data as inputs to generate coherent series of daily PET and temperature (T_{max} and T_{min}) data.

As the outcome of this approach is uncertain and may require future updates of water resource models this approach could be trialled towards the end of the current AMP periods but does not form part of the current supply forecast.

3.2.11 Climate modelling for WRMP24.

On 19 March 2019 we received a letter from Defra asking for further information in support of our statement of response to our revised draft WRMP. In an annex to this letter, the EA asked that we provide some more information about the generation of climate sequences. The purpose is to demonstrate that our approach to generating drought sequences is appropriate. This issue was raised by the EA in improvement 1.6.

The request is set out in full below:

"For its final plan, the company should describe how it will for WRMP24;
Undertake a further review of apparent persistence effects in the rainfall data and weather generator; as identified in the peer review.
Applies bias correction to the stochastic rainfall data.
Applies multiple correction factors when generating the ~100,000 year stochastic time series from the weather generator. These factors would become obsolete, should the company revert to using ~1000 replicates, instead of a single time series.

We have considered these points in discussion below:

Our climate modelling for WRMP24 will be aligned with that undertaken for the regional resilience plan developed by Water Resources South East (WRSE). WRSE have recently prepared a draft invitation to tender (ITT) to develop a regional framework for climate datasets that will lead to a spatially coherent sequence of rainfall and potential evapotranspiration for use in water resource modelling for all Water Companies in South East England.

Definition of the precise framework is subject to the ITT and completion of the work but it sets out some requirements for bias correction and persistence effects:

An analysis of existing datasets to establish if some form of bias correction would be required to better align observed and stochastic droughts, including correcting for persistence effects in observed droughts. It is likely that some form of bias correction will be required.
It is recognised that bias correction is likely to be required for the UKCP18 datasets and the framework will design a methodology for bias correction of UKCP18 datasets for use with hydrological models of surface and groundwater.
A recommendation of a bias correction methodology and assessment of remaining bias that cannot be corrected will be a key deliverable.

In developing our WRMP24 supply forecast Southern Water will adopt the recommended approach at completion of this project. WRSE have specified that the framework must be produced for water companies by the spring of 2020.

In parallel to the WRSE review, we will undertake a review of our WRMP19 rainfall data to quantify the extent of apparent bias in the rainfall data. This work can be completed earlier and could be used under the WRSE methodology. We will follow the proposed methodology for characterising persistence effects (e.g. points over threshold) for the lower 10% and 20% of the rainfall data as set out the UKWIR Drought Vulnerability Framework.

The proposed framework will also address the most appropriate use of synthetic weather generators including the length of record to be simulated, number of replicates and any sub-sampling or boot strapping of those data. Our peer review found that there was unlikely to be any detrimental effects from using a limited (2000-year subsample) of a longer stochastic record (rather than say 20 x 100 year replicates based on different random number seeds).

3.3 Groundwater resource assessment

3.3.1 Introduction

Groundwater makes up around 70% of Southern Water's overall water supplied. Various methods for determining the DO of groundwater resources are set out in UKWIR (2014). Our approach builds on UKWIR (2014) guidance and enhances our approach developed for WRMP14.

In summary, the long-time time-series output from the synthetic weather generator (see above) are used as direct inputs (as rainfall and PET sequences) to our water resource (rainfall-runoff and groundwater models). Outputs from these resource models, comprising flows, recharge or groundwater levels are then used to estimate DO. Most commonly this is through established (WRMP14) relationships between these variables and groundwater levels at indicator boreholes. Groundwater level fluctuations at indicator boreholes can then translated via scaling and shifting to changes in water levels at abstraction wells. We have developed very long (2000 year) time series of DO suitable for determining a probabilistic density function of DO for use in our integrated risk modelling. This approach is consistent with our adopted Risk Composition (See Annex 1).

3.3.2 Our groundwater resource models

Several groundwater resource models (Table 6) cover the major aquifer units that contain most of our groundwater sources. Most of these models were originally developed on behalf of the EA for the purpose of catchment scale water resource management. Some models have been specifically adapted or developed for the purpose of Southern Water's resource management and to calculate DO.

Generally, these groundwater models have been accepted by the EA and other stakeholders as fit for purpose tools for assessing water resources and the environmental impacts of abstraction and they have been conditioned and calibrated to historic observations. The derivation and calibration of the river flow and groundwater models (which includes the Test and Itchen groundwater model, Brighton and Worthing groundwater model and East Kent groundwater model) were reviewed and 'signed off' during EA liaison meetings for all key resource models during AMP4 and AMP5, and is not detailed here.

These groundwater resource models are typically developed in various versions of the US Geological Survey (USGS) groundwater modelling code MODFLOW (McDonald and Harbaugh, 1988, Harbaugh and McDonald, 2006, WMC, 2002, Panday et al, 2015). The Isle of Wight recharge model does not include a groundwater flow element and is developed in the "Routing of Rainfall to Runoff and Recharge" ("4R") code (Heathcote et al, 2004). 4R is often used in combination with MODFLOW models to calculate aquifer recharge and run-off components and can be used to directly write input files for the MODFLOW recharge and stream flow (Prudic, 1989) packages.

Post processed outputs from these resource models were then applied to a series of regression or flow analysis models in order to calculate the response of indicator variables such as groundwater levels. The variation in these groundwater levels is directly related to DO and hence a time series of DO developed for each 2000 year input sequence.

Our groundwater DO assessment is therefore based on water resource predictions using existing, accepted models and approaches that were originally developed for WRMP09 and has been enhanced for WRMP14 and the current plan.

Table 6 Existing groundwater resource models covering Southern Water's abstractions

Resource Zone	Major Aquifer	Model	AMP5 Method for Deployable output	Model Owner and Permissions to Use
Hampshire (All Zones)	Chalk Group Upper Greensand Formation	Test and Itchen	Licence Constraint + Flows for Rivers Test and Itchen supplied to Aquator Groundwater Levels for Indicator Boreholes	EA Model, Southern Water have permission to use
Isle of Wight	Chalk Group, Upper Greensand Formation Lower Greensand Group	No groundwater model (recharge model only)	Indicator Borehole Regression model based on recharge model	Recharge Model EA Southern Water have permission to use
Sussex North	Lower Greensand Group	Pulborough Basin (only part of aquifer)	Indicator Borehole Regression model based on recharge model	Southern Water, no permission required (may be subject to data licencing)
Sussex Worthing	Chalk Group	Brighton and Worthing	Indicator Borehole Regression model based on recharge model	
Sussex Brighton				
Sussex Hastings	Ashdown Formation	n/a	Licence Constraint – no model	n/a
Kent Medway	Chalk Group	North Kent Chalk	Indicator Borehole Regression model based on recharge model	EA Model, Southern Water have permission to use
Kent Thanet	Chalk Group	East Kent Chalk	Indicator Borehole Regression model based on recharge model	EA Model, Southern Water have permission to use

3.3.3 Input time series

Four key input time series were used for our groundwater DO analysis. These were daily rainfall and PET data derived from our synthetic weather generator output discussed in Section 3.2 and climate change sequences discussed in Section 3.6. In summary they are made up of four daily sequences of rainfall and PET:

Synthetic Climate Sequence 5 – "Baseline"
Synthetic Climate Sequence 8 – "Climate Change - Dry"
Synthetic Climate Sequence 9 – "Climate Change - Mid"
Synthetic Climate Sequence 10 – "Climate Change - Wet"

3.3.4 Indicator borehole regression models

For most of our groundwater dominated zones estimates of MDO and PDO were made for a number of drought vulnerable indicator boreholes within the WRZ, for each year of the stochastic sequence. Changes in water level at each of the indicator boreholes were then translated using existing relationships to changes in rest water level at each source. These curve shifts were then used to estimate DO using the UKWIR unified methodology (2000, 2014).

The generated rainfall and PET sequences were combined with the same monthly recharge models and the same recharge/water level regression models that were developed for key indicator boreholes for WRMP09 and WRMP14 (Southern Water, 2009, 2014) . The ‘key indicator’ boreholes that were analysed in this way are:

Newport, for the Isle of Wight WRZ,
Southwick, for Sussex Worthing and Sussex Brighton WRZs
Rodmersham, for Kent Medway WRZ

The resulting groundwater levels for the indicator boreholes were then converted into changes in DO in accordance with the curve shifting approach described in the UKWIR Unified Methodology (2014).

Full details of the regression models and curve shifting approach can be found in document 5050675/70/DG/092 ‘Assessment of the impact of severe drought and climate change on groundwater DO’ (Atkins 2009), which was produced to support WRMP09 (Southern Water, 2009). These models have been used essentially unchanged from WRMP09 and WRMP14. The ‘scaling factors’ that were used in WRMP09 to translate RWL variability at the key indicator boreholes into RWL variation at each source were maintained. The approach and assumptions used were entirely consistent with WRMP09 and WRMP14. This allowed the DO to be estimated for each year of the synthetic weather generator sequence, and required two key components:

A range of drought bounding curves which were derived for each drought vulnerable source or borehole. These were, set at RWLs that equated to ‘normal year’, ‘dry year’ (equal to the drought bounding curve in the 2006 assessment), ‘drought year’ (1 in 20), ‘severe drought’ (approx. 1 in 100) and ‘extreme drought’ (1 in 200+) conditions. Representative DOs for each of those conditions were calculated for each source based on the relative amount of curve shifting for each condition (e.g. the ‘extreme drought’ DO was calculated based on a -2m curve shift from the ‘dry year’ RWL)
These five values of DO and RWL variability were used within a spreadsheet model that calculates the DO for each year in the stochastic sequence by interpolating the relative change in RWL for that year between these 5 values

For this plan these data were essentially unchanged unless other changes to constraints on DO were found (for example changes to pump cut out or deepest advised pump water level).

This modelling was not undertaken for sources that are primarily infrastructure or licence constrained as they do exhibit inter-annual variability because of changing water levels. In this sense they are insensitive to drought conditions as operational pumping constraints tend to be well below modelled minimum drought water levels

3.3.5 Other constraints to deployable outputs

The modelling approach we have employed focuses primarily on estimating variations in the hydrogeological yield under a range of plausible water levels and drought conditions. However, in many cases other constraints, such as abstraction licence or pump capacity can limit source yield.

Each five year water resource planning cycle Southern Water implement a Source Investigation and Optimisation Strategy (SIOS). The aims of this work include:

Gathering and updating source information to improve the DO assessments
Identifying potential changes in the operation of the sources to improve yield
To identify any infrastructure improvements that could also improve source yield.

Effectively the work includes an in-depth study of constraints and source characteristics and analysis of these issues. The SIOS programme is inherently linked to the wider water resources and supply strategy and in particular to assessment of groundwater DOs.

An extra 21 groundwater sources are being investigated during AMP6. The results of the work have been incorporated into our DO and constraint assessments. Where a SIOS investigation is not underway, source infrastructure constraints were reviewed in a series of internal workshops including water resource specialists, engineers and operational staff. Each source has been discussed including a review of all infrastructure constraints. The outcome from these workshops has been included into our DO assessments. The review was particularly useful to understand sources where there has been a write down in DO owing to infrastructure changes or long term outage. Future work and changes to source infrastructure has also been considered.

Changes to abstraction licences have also been reviewed. This reflects increased licence volumes from some sources after implementation of water resource schemes from WRMP14 and reductions in DO from sustainability reductions or licence revocation.

The forecast impacts of sustainability reductions to licences and current DO are discussed in Section 5.

3.3.6 Changes to catchment scale groundwater models

Our Methodology generally does not make any fundamental changes to the groundwater and recharge model structures or data. The two major changes we have made are:

Updating model files where necessary to aid handling of very long time series, i.e. extending model stress periods and any time series inputs to 2000 years in length.
Supplying new synthetic rainfall and PET sequences (output from our weather generator) as input time series to the groundwater models.

The methodology presented therefore is to only modify the groundwater models so that 2000 year daily rainfall and PET sequences can be run. This is the same process that was undertaken for the back-casting assessment of droughts to 1888 that was carried out during WRMP09 and the previous synthetic weather generator sequences for WRMP14. Generation of the synthetic daily input sequences is discussed in Section 3.2.

Amec Foster Wheeler (now Wood) undertook the majority of the distributed groundwater modelling on behalf of Southern Water. The application of these methods to each specific groundwater model is discussed below.

3.3.7 Test and Itchen groundwater model (Hampshire WRZs)

Model background and version

The Test and Itchen groundwater model and associated recharge-runoff model have been developed since 2004 by Amec Foster Wheeler in association with the EA and Southern Water.

The recharge-runoff model uses the ‘4R’ code (specifically version 041t) (Heathcote et al, 2004). The groundwater model uses the MODFLOW-VKD code (WMC, 2003) which has been enhanced by Amec Foster Wheeler and compiled as version ‘mfintel035i’.

Both models were parameterised in a similar fashion to those used in WRMP14 to produce outputs (river flows and groundwater levels) comparable with those needed for the indicator borehole regression modelling and flow modelling that is undertaken to generate DO values.

Table 7 outlines the key modelling files/parameters used for the Test and Itchen recharge-runoff model and Table 8 gives similar detail for the groundwater model.

Table 7 Key Components of the Test and Itchen (4R) recharge-runoff model

Input Type	Input Description
Rainfall data	The model uses rainfall from 3 rain gauges locations (Greywell, Salisbury and Otterbourne). Rainfall is assigned to each 250m model cell on a 'nearest neighbour' approach and factored for topographic change through comparison with the Met Office 1961-1990 long term average spatial distribution.
Potential Evapotranspiration (PET) data	The model uses one MOSES PET sequence and this is factored for topography for each 250m model cell by comparison with the CEH 1961-1990 long term average spatial distribution
Mains leakage	The model runs undertaken were 'Natural' and so do not include anthropogenic influences
Surface water abstractions	The model runs undertaken were 'Natural' and so do not include anthropogenic influences. A natural flow diversion of the River Test through the Broadlands Water Meadows of 40Ml/d is included as an abstraction and simultaneous discharge
Surface water discharges	The model runs undertaken were 'Natural' and so do not include anthropogenic influences. A natural flow diversion of the River Test through the Broadlands Water Meadows of 40Ml/d is included as an abstraction and simultaneous discharge
Stream Cell parameters	The stream cell distribution and parameterisation includes the refinements undertaken for the EA in 2014 and the dry valley extensions added for Southern Water Candover modelling in 2016
Other parameters	All other parameters in the model are identical to those developed during the original model construction

Table 8 – Key Components of the Test and Itchen (MODFLOW) groundwater model

Input Type	Input Description
Model Extent	This is controlled by the MODFLOW Basic (BAS) file. For these runs, the model extent developed during the original model construction is used. For consistency with WRMP14, it does not include the spatial extension to the north and east that was undertaken during the 2014 EA refinements
Aquifer parameterisations	This is controlled by the MODFLOW Block Centred Flow (BCF) file. For these runs, the model extent and aquifer parameters developed during the original model construction are used. For consistency with WRMP14, it does not include the spatial extension to the north and east that was undertaken during the 2014 EA refinements nor any of the aquifer parameter changes that were undertaken as part of the same refinements.
Groundwater abstractions and discharges	The model runs undertaken were 'Natural' and so do not include anthropogenic influences.

Processing of Input data

Only minor modifications of the input climate data were required:

1. The time period modelled in the groundwater model used years 4000-5999 to avoid any potential confusion with real dates. It was later found that the Aquator model cannot run dates earlier than

the year 5000, and so the dates were translated to the period 2800-3799. Note that the datasets used for the different model are spatially and temporally coherent.

2. The 4R model has been adapted to correctly handle leap years whereby years which are a multiple of 100 are not leap years, although years which are a multiple of 400 are leap years. Any erroneous leap year days in the sequence were deleted.

Model modifications undertaken

No model modifications were undertaken other than those required to extend the timeframe of the models and to assign the correct numbers of days to each model stress period. The groundwater model operates on two stress periods per calendar month. The first stress period is always 15 days long and the second stress period completes the rest of the month (i.e. 13, 14, 15 or 16 days depending on the month).

Model runs

Four model runs were undertaken - a baseline (current climate) and three climate change scenarios representing dry, medium impact and wet future scenario.

Model output

For each of the model runs undertaken, stress period output was produced for the groundwater level locations and river flow locations that were required for subsequent DO calculations.

Calculation of groundwater deployable output

For the Hampshire WRZ we estimated borehole rest water levels using two indicator boreholes, Woodside OBH and Chalk Dale (Table 9).

After applying the curve shifting many groundwater sources in Hampshire are still infrastructure or licence constrained and do not exhibit any variability in DOs. This is predominantly the case for Hampshire Kingsclere, Hampshire Andover, Hampshire Rural and Hampshire Winchester WRZs.

A summary of the DOs calculated is presented in Section 4.

River Test and Itchen deployable output

As well as the many groundwater sources, two key surface water abstractions are present in Hampshire. The River Test is the sole supply to Hampshire Southampton West WRZ, the River Itchen and associated groundwater sources supply Hampshire Southampton East WRZ. Both river systems are extremely baseflow dominated, i.e. the majority of flow being supplied by discharging groundwater.

Flows in both river systems are either now, or proposed to be, subject to Hands-off-Flow (HoF) conditions that stipulate the minimum flow that must be left in the river downstream of our abstraction to support environmental needs. We have assessed several scenarios to look at the effect of these licence changes on our DO and these are discussed more in Section 5.

Determining DO for these surface water sources followed a different approach to the groundwater sites and was based on methodology employed for WRMP09 and WRMP14 (Atkins, 2008, 2013). The 2000 year flow sequences derived from the naturalised runs of the Test and Itchen model are processed through a spreadsheet calculator tool that follows the methodology for surface water DO assessment set out originally in Environment Agency (1997) and used in WRMP09 and WRMP14 (Southern Water, 2009, 2014) and updated for UKWIR (2014).

The River Test and River Itchen sources are both run-of-river surface water sources. For the nearby groundwater sources at Lower Itchen groundwater and Twyford abstraction is assumed to have a direct and immediate impact on river flows and therefore the yields of these sources can also be assessed using the spreadsheet model.

The calculation of DO is based only on the difference between the minimum flow in the water course and the licensed quantities. Low-flow analysis based on low-flow frequency curves set out in the Institute of Hydrology Report, “Low Flow Estimation in the UK, IH Report 108, December 1992, is therefore appropriate.

For each timestep the spreadsheet model calculates the reductions in flow caused by abstraction from the two upstream sources groundwater sources and hence the residual flow available for abstraction. The residual flow available for abstraction is then compared against the licence conditions and the minimum volume available in each month. Abstraction from the upstream groundwater sources is assumed to have a direct influence on river flow, using the concept of ‘lumpy groundwater factors’ (UKWIR, 2013) and as used by EA for its CAMS and other water resource assessments. Licence constraints can be applied using simple limits in order to appropriately constrain abstractions where applicable.

The DO is constrained by the available flow above the HoF constraint and is calculated as a continuous time series for each model stress period output of the 2000 year sequence. The MDO is calculated as the minimum flow available in a given calendar year. The PDO is calculated as the minimum flow available during the critical period months of June-July. Return periods for DOs are estimated from frequency analysis of the 2000 year sequence (Figure 7).

Figure 7 Example of Return Period Calculation of available flow above the Hands-off-Flow for the Lower Itchen Sources (Southampton East) for the 2000 year sequence

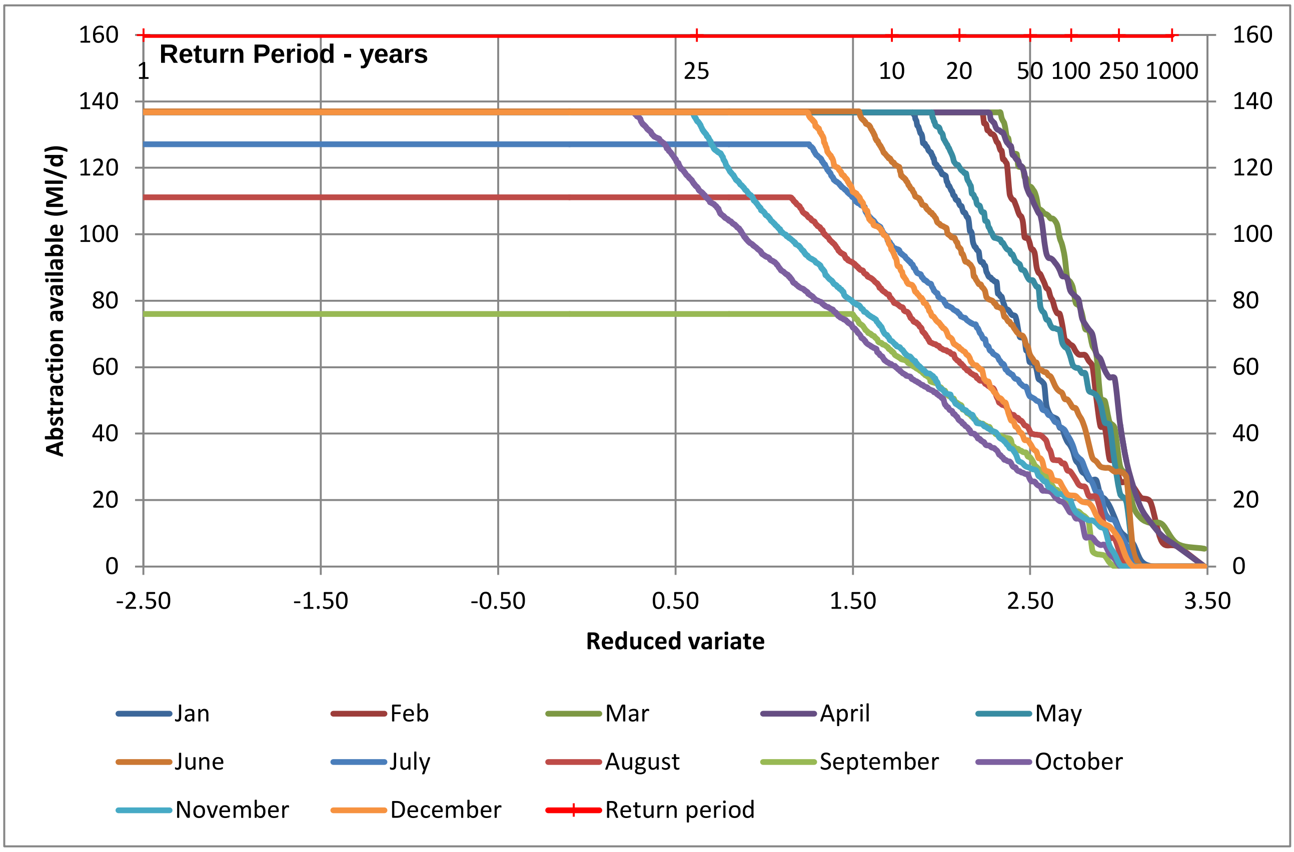


Table 9 Summary of indicator borehole egression modelling used for the Hampshire WRZs

			Deployable Output constraints		
Indicator Borehole	**Water Resource Zone**	**Source**	**MDO**	**PDO**	**Comments**
Woodside	Hampshire Kingsclere	Newbury	Pump Capacity except for 1:500 drought where yield constrains DO	Pump Capacity	Curve shift applied
		Near Basingstoke	Annual Licence	Daily Licence	Insensitive to curve shift
	Hampshire Andover	Andover	Annual Licence	Daily Licence	Insensitive to curve shift
		Chilbolton	DO written down, poor water quality	DO written down, poor water quality	No curve shift applied
		Near Whitchurch	Yield	Demand Constraint	Insensitive to curve shift
		Overton	Operational Pump Capacity	Operational Pump Capacity	Insensitive to curve shift
		Whitchurch	Annual Licence	Daily Licence	Insensitive to curve shift
Chalk Dale	Hampshire Winchester	Barton Stacey	Annual Licence	Daily Licence	Insensitive to curve shift
		Winchester	Annual Licence	Treatment Capacity	Insensitive to curve shift
		Alresford	Annual Licence	Daily Licence	Insensitive to curve shift
	Hampshire Rural	Kings Sombourne	Network/Infrastructure Capacity	Network Infrastructure Capacity	Insensitive to curve shift
		Romsey	Treatment Capacity	Treatment Capacity	Insensitive to curve shift
	Hampshire Southampton East	Twyford	Pump Capacity and Prescribed River Flow and Daily Licence	Pump Capacity and Prescribed River Flow and Daily Licence	See “Calculation of Surface Water Deployable Output”
		River Itchen Groundwater	Prescribed River Flow and Daily Licence	Prescribed River Flow and Daily Licence	See “Calculation of Surface Water Deployable Output”

Two groundwater sources are present in the Hampshire Southampton East WRZ, Lower Itchen groundwater and Twyford. For these sources DO was first estimated using the same curve shifting approach employed above. A summary of the resulting DOs for Hampshire Southampton West and Hampshire Southampton East WRZs is given in Section 4.2. The implications of the Sustainability reductions and scenarios are discussed in Section 5.

Our analysis assumes that these two groundwater sources have an immediate and direct impact on river flows. The possible depletion in flow was also assessed against the minimum residual flow licence constraints on the River Itchen. Consequently, the DO was therefore defined as either the minimum available flow in the river, or the groundwater yield/infrastructure constrained volume, whichever is smaller. As our Twyford source is located furthest from the River Itchen it was used in preference to the Lower Itchen groundwater and surface water. Pump capacity constraints and drought modes of operation were also considered. We have reflected this in our DO assessments for these groundwater sources in Section 4.

A summary of the key assumptions we have used in the Hampshire Southampton East and West surface water DO assessments is presented in Table 10.

Table 10 Summary of modelling assumptions for surface water deployable output assessments in Hampshire Southampton East and Hampshire Southampton West WRZs

Assumption	Hampshire Southampton West (River Test(	Hampshire Southampton East (River Itchen)
Flow Data	Naturalised Test and Itchen GW Model Flows	Naturalised Test and Itchen GW Model Flows
Hands-off Flow	91Ml/d (Baseline) 2017 s.52 Notice (Scenarios for both 2017 (355Ml/d) and 2027 seasonal HoF)	198Ml/d (Baseline)
Abstraction Licence	Baseline 136.5Ml/d 2017 s.52 Notice limit at 80Ml/d	with the proposed Sustainability Reductions expressed as monthly limits for June through September for the Lower Itchen sources (including Twyford Moors, Twyford GW)
'Lumpy Groundwater' Impacts	Applied for upstream Hampshire Rural abstractions	Applied for upstream Hampshire Winchester abstractions
Peak (Critical Period)	June – August	June - August
Other Assumptions	Assumed Coleridge Award Split of 56%:44% between Great Test and Little Test (After Atkins, 2013a)	

Versions of the Test and Itchen model

During development of our plan several versions of the Test and Itchen groundwater model have been to derive DOs at different stages. This reflected evolution of the modelling procedure from that developed during AMP5. We also wanted to make sure that our initial Water Resource modelling, which was carried out at a relatively early stage, was consistent with later work for the Western area Public Inquiry and Drought Plan. We have summarised the key versions of the Test and Itchen model used in development of our plan, and their differences, in Table 11.

For our revised draft Water Resources Management Plan all our DOs in Hampshire have all been calculated based on outputs from Run 178 of the Test and Itchen model. This produces the closest compatibility and calibration to the standard EA of the model. Multiple iterations of the flow, groundwater and DO calculations allow comparative analysis of the range of uncertainty in DO forecasts because of different model and climate parameters.

Table 11 Key versions of the Test and Itchen groundwater model used in development of our plan

Model Version	Description	Use
EA (Run 125)	40+ Rain gauge and historic rainfall and MOSES PET (1970-2012)	EA Water Resource Planning
AMP5 (Run 157)	3 Rain gauge version with 2000 year stochastic rainfall and PENSE PET data. Based on Pre 2012 refinement version of Test and Itchen model	WRMP14 DO assessment (groundwater and surface Water) Draft WRMP19 groundwater DO, initial estimates of River Test and Itchen DO
AMP6 Initial (Run 163)	3 Rain gauge version with 2000 year stochastic rainfall PENSE PET data. Based on Run 163 (post 2012 refined version of the model)	Draft WRMP19 Surface Water DO for River Test and Itchen only
AMP6 Final (Run 178)	3 Rain gauge version with 2000 year stochastic rainfall MOSES PET data. Based on Run 163 (post 2012 refined version of the model)	Final WRMP19 groundwater and Surface Water DO assessment

Effect of model parameterisation on deployable output

In the period since WRMP14, the Test and Itchen groundwater model has been subject to an update and refinement in 2013 commissioned by the EA (Amec, 2013). This update extended the model time series and spatial extent of the model. The new model areas were predominantly to the north and to the east. Areas of the model were also subject to parameter refinement.

For the initial development of our draft plan, groundwater DO in Hampshire was calculated based on the indicator borehole regression models for Woodside and Chalk Dale observation boreholes and output forecast groundwater levels from the Test and Itchen groundwater model. Both sets of analyses followed the same procedure as employed for WRMP14 and

The previous EA version of the model at the time (Run 90), which is equivalent in terms of model parameter distribution to that used for Run 153 was still considered to be signed off by the Agency as “calibrated” and was used by both ourselves (for WRMP14) and the EA before 2012.

The recalibration of the model in 2013 (Amec, 2013) resulted in changes to flows and groundwater levels across the model area. Of particular relevance were improvements to modelled flows (compared to observed) in the River Itchen. Other changes were generally considered to be small but actual changes at low flows (<Q90) are not documented in detail.

Comparison of DOs for the River Test and River Itchen are shown in Table 12. For the River Test, the updated model generally leads to a reduction in flow and consequently a reduction in DO. Conversely, for the River Itchen, at low and average flows there is a gain. Where impacts are zero, this is either because the full licence volume is available under both model scenarios (at high frequency return periods) or that there is no flow available above HOF conditions (at low frequency return periods).

Table 12 Summary of changes to deployable output using the updated Test and Itchen groundwater model comparing Run 163 with Run 157

Deployable Output	Return Period	River Test DO* (M/ld)	River Itchen DO**	River Test Change (Ml/d)	River Itchen Change (Ml/d)
MDO	1 in 2	79.8	76	0	0
	1 in 20	44.0	60.5	-16.6	+16.5
	1 in 100	0	34.8	-8.4	+18.5
	1in 200	0	20.9	0	+17.7
	1 in 500	0	0	0	0
PDO	1 in 2	79.8	127.1	0	0
	1 in 20	79.8	91.9	0	+15.7
	1 in 100	15.6	54.4	-17	+16.1
	1in 200	0	37.0	-6	+19.7
	1 in 500	0	9.9	0	+9.9

*River Test scenario shows DO for s. 52 Notice implementation in 2017 (See Section 5)
**Total DO for Lower Itchen Sources (Itchen Surface, Groundwater and Twyford)

Assessment of deployable output sensitivity to potential evapotranspiration

For WRMP09 and WRMP14 modelling of flows and groundwater levels was undertaken using historical rainfall data back to 1918 in combination with stochastic rainfall to allow historic and stochastic droughts to be directly compared and allows a validation of the stochastic modelling approach. In order to hindcast flows and groundwater levels for historical droughts (e.g. the 1921-22 drought, which is generally considered to be the worst historical drought event on recorded) only a single Potential Evapotranspiration (PE) data set (the EA PENSE data) is available. To allow us to more directly compare DOs, validate the enhancements to the stochastic weather generator and to give a consistent approach with previous plans the same PE dataset has been used for this plan.

The Test and Itchen groundwater model was originally calibrated using the Met Office MOSES PE dataset. This is based on many of the same input data as the PENSE data, but differs in its calculation method and hence in the total evaporation.

The effects of different potential evapotranspiration datasets on water resources in Hampshire are discussed in detail in supporting documentation prepared for the Western Area Public inquiry (Soley, 2018). This analysis was developed subsequent to the submission of our draft Water Resource Management Plan. A summary of that analysis with relevance to our revised draft plan is presented here

Two key versions of the model have been compared for this analysis - Run 163 and Run 178. Both models follow the same parameter set (i.e. the refined version of the Test and Itchen model) but differ in their potential evapotranspiration datasets. Run 163 employs a stochastic PENSE PET time series, Run 178 uses a stochastic MOSES dataset.

Comparison of PET daily data (for the period 1990-1997) between the Run 178 MOSES (average of MORECS squares 169, 170 and 171) and Run 157/163 PENSE (West Stoke Farm) time series indicate the annual averages of these data are similar (526 mm/a and 549 mm/a). However, the spread of data is greater in the MOSES series and is consistently lower in the winter recharge seasons. Overall, the MOSES PET is lower than PENSE PET data for the majority of the time series.

The day to day variation is also greater in the MOSES series (and likely to be better linked to the corresponding rainfall on a given day). The MOSES series also contains negative values to account for condensation and this condensation input is capable of reducing soil moisture deficits and increasing recharge generation within the recharge model calculation.

Figure 8 gives the clearest indication of the impact of the different PE datasets on the recharge model calculation during the historic period. It is also important to note that important to note that:

The results shown are for the Itchen groundwater catchment and so include the topographic factoring of the PE input series

The red lines are related to the EA model using MOSES PE and distributed rainfall (MODFLOW Run 125) and the green lines relate to the model using PENSE and 3 rain gauges (MODFLOW Run 163)

While the 4R Recharge model operates on a daily time-step, the output presented is for stress period aggregates (2 per month)

The recharge shown is as generated at the ‘bottom of the soil zone’ and not as it is delivered to the water table (i.e. before the decay and lag that is applied to represent the unsaturated zone)

The model contains ‘bypass recharge’ (namely recharge that bypasses any soil moisture deficit) and hence recharge can be generated even at times of increased soil moisture deficit.

The soil moisture deficits modelled and the recharge generated are broadly similar across the period. The main differences are apparent during certain recharge periods (most striking in the 1991 - 1992) where the soil moisture deficit does not reduce as much using PENSE data as it does with MOSES data. Consequently, the MOSES PE run generates more winter recharge (albeit less than average years).

Table 13 quantifies the rainfall and PE inputs to the model for the different runs and over different time slices. It also includes results from Run 178 where the 3 rain gauge model uses MOSES rather than PENSE input. Run 178 brings results closer to those for Run 125 but these are not identical because of the different rainfall inputs. Of particular importance, (by way of an example) is the differential between the recharge generated in 1991-1992 for the two PE input series when compared to the differential over longer periods. For the period 1970-1997 the MOSES PE (Run 125) generates 3% more recharge than the PENSE PE (Run 168), whereas in 1991-1992, MOSES PE generates 18% more recharge than PENSE.

Comparison of simulated historical flows at the lowest flow range relevant to drought and dry period simulation (i.e. Q_{90} down), the MOSES PE-based 3 rain gauge model (Run 178) is closer to the EA’s MOSES and 40+ rain gauge model (Run 125) than the PENSE-based 3 rain gauge model (Run 163). This is true across the model area, for Broadlands gauge on the River Test, at Allbrook and Highbridge gauge on the River Itchen and at Borough Bridge on the Candover stream.

Figure 8 Modelled soil moisture deficit and generated recharge for the Itchen groundwater catchment

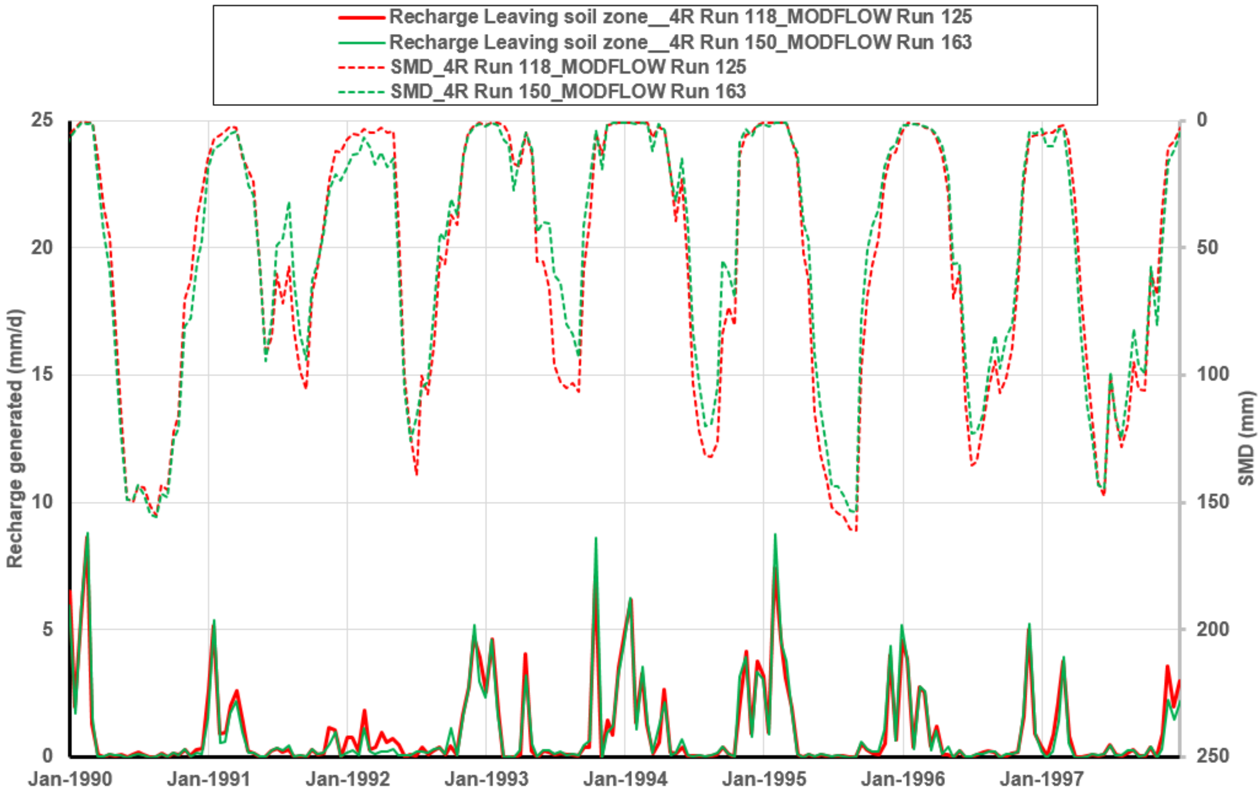


Table 13 Comparison of recharge model inputs and outputs for the Itchen groundwater catchments

Period	1991-1992			1970-1997			Stochastic 2000 Years		
Run	Rainfall mm/d	PE mm/d	Recharge mm/d	Rainfall mm/d	PE mm/d	Recharge mm/d	Rainfall mm/d	PE mm/d	Recharge mm/d
125_40 + rain gauges & MOSES	2.189	1.437	0.876	2.249	1.415	1.053	n/a	n/a	n/a
163 _3 rain gauges & PENSE	2.179	1.504	0.741	2.320	1.465	1.018	2.316	1.456	1.006
178 _3 rain gauges & MOSES	2.179	1.431	0.868	2.320	1.411	1.118	2.316	1.441	1.094

MOSES data are only available for the period 1961-present and hence do not cover the full range of historical droughts (e.g. the 1921-22 event). To assess the sensitivity of model results, DOs and investment strategy to the PE dataset, an alternative hindcast and stochastic PE MOSES data set has been generated using the same disaggregation procedure as employed for other stochastic droughts (Section 3.2.8). The greatest impacts on DO are to the sources from the River Test and River Itchen in the HSW and HSE WRZs, which are presented in Table 14 and 10b below.

The MOSES PE time series the Test and Itchen model together with the rainfall data and projections for the three rain gauge sites. This 2080 year natural simulation was Test and Itchen model run number 178 (Table 11). Both run 178 and the PENSE-based 3 rain gauge model run number 163 include the 1970 to 1997 historical period which is also covered by the EA's natural model run number 125 (based on 40+ rain gauges and MOSES PE).

This comparison shows that there is gain in DO in both the HSW and HSE zones as might be expected for a scenario with less evaporation and hence higher flows. The magnitude of the impacts are generally between 12-25Ml/d across the different return periods with the greatest impacts occurring under the PDO scenario on the River Test. There is no difference in minimum DO for the River Test under severe and extreme drought scenarios. All of the modelled scenarios above assumed full implementation of the Western area sustainability reductions (Strategy A) that occurred in March 2019.

Table 14 Estimated changes to deployable output for the River Test using the MOSES version of the Test and Itchen groundwater model

Return Period	Deployable Output (Ml/d)					
	3 Gauge + MOSES (Run 178)		3 Gauge + PENSE (Run 163)		Difference (Run 178-163)	
	MDO	PDO	MDO	PDO	MDO	PDO
2 years	79.78	79.78	79.8	79.78	0.00	0.00
10 years	79.78	79.78	79.5	79.78	0.25	0.00
20 years	66.66	79.78	44.0	79.78	22.67	0.00
50 years	35.84	79.78	9.7	43.95	26.16	35.83
100 years	19.60	61.90	0.0	15.60	19.60	46.30
200 years	0.00	26.74	0.0	0	0.00	26.74
500 years	0.00	2.89	0.0	0	0.00	2.89

Table 15 Estimated total deployable output for the River Itchen sources using the MOSES version of the Test and Itchen groundwater model

Return Period	Deployable Output (Ml/d)					
	3 Gauge + MOSES (Run 178)		3 Gauge + PENSE (Run 163)		Difference (Run 178-163)	
	MDO	PDO	MDO	PDO	MDO	PDO
2 years	76.00	127.10	76.00	127.10	0.00	0.00
10 years	76.00	127.10	76.00	111.68	0.00	15.41
20 years	73.21	113.21	60.50	91.90	12.71	21.31
50 years	59.46	90.57	43.23	68.22	16.24	22.34
100 years	51.34	79.49	34.84	54.37	16.50	25.12
200 years	40.64	57.58	20.92	37.02	19.72	20.56
500 years	12.05	37.23	0.00	9.90	12.05	27.33

Effects of model version on groundwater deployable output

For our draft plan, estimates of groundwater DO in Hampshire were based on existing indicator borehole regression relationships developed with pre-refinement version of the model (Run 157). The updated refined version of the model with PENSE PET data (Run 163) was not been used to update the curve shifts for drought indicator boreholes in Hampshire as there was insufficient time to derive new regression relationships. Only surface water DOs were re-evaluated.

For our revised draft plan, we updated the indicator borehole regression relationships for our Hampshire groundwater sources. Our baseline DOs are now based on outputs from model Run 178, the refined version of the Test and Itchen model with stochastic MOSES PET data. Our review of potential evapotranspiration datasets has demonstrated that this version of the model gives a closer match to observed flows and to core the EA version of the model.

Groundwater DOs in Hampshire are variable in their drought sensitivity across different WRZs. Two WRZs (Hampshire Rural and Hampshire Winchester WRZs) are insensitive to drought as DO from groundwater sources is infrastructure or Licence constrained (see Section 4). Other WRZs (Hampshire Andover and Hampshire Kingsclere WRZs) show only minor sensitivity at some sites and return periods. The greatest impact on groundwater DO occurs in Hampshire Southampton East WRZ for the Itchen groundwater and Twyford sources, largely because these sources are sensitive to the proposed (HoF) conditions on the River Itchen.

Comparison of DO for groundwater sites shows that the change in model parameterisation between Run 157 and Run 163 resulted in an increase in DO of around 17.7Ml/d in Hampshire Southampton East largely because of increased modelled flows above the proposed HoF in the River Itchen.

An increase in groundwater DO of this WRZ occurred because of swapping from PENSE to MOSES PET data (Run 163 to Run 178). There was a slight decrease because of both model refinement and differing PET data in Hampshire Andover WRZ. An estimate of the magnitude of the uncertainty has been calculated based on half the range of the estimates across model versions.

Table 16 Variation in minimum groundwater deployable output (for a 0.5% annual probability drought) by WRZ and groundwater model version

	Deployable output estimate for 0.5% annual probability drought (Ml/d)			
WRZ / Model Run	**MODFLOW Run 157**	**MODFLOW Run 163 (draft WRMP)**	**MODFLOW Run 178) (final WRMP)**	**Estimated Uncertainty Error**
Hampshire Kingsclere	8.68	(Not recalculated)	8.68	-
Hampshire Andover	21.47	(Not recalculated)	21.43	±0.02Ml/d
Hampshire Rural	12.3	(Not recalculated)	12.3	-
Hampshire Winchester	23.83	(Not recalculated)	23.83	-
Hampshire Southampton East	3.17	20.92	40.64	±18 .74Ml/d

Climate Change and the revised Test and Itchen groundwater model

For our draft plan, insufficient time was available to run perturbed climate change sequences (Section 3.6 and Section 6.1) through the refined three rain gauge and MOSES version of the Test and Itchen groundwater model.

Instead, to estimate the impacts of climate change for the revised model a linear regression scaling was employed. This derived linear relationships between flows in Run 157 (the old model) and Run 163 (the new model). Outputs from the original climate change model runs (Runs, 160-162) were then scaled using the regression relationships to estimate climate change impacts for the revised model.

For this plan we have now carried out these extra model runs using perturbed rainfall and PET (MOSES) time series data for each climate change scenario with the Test and Itchen groundwater model. The previous scaling relationships have been abandoned. The results of these analysis are discussed in Section 6.1.

Future of the Test and Itchen groundwater model

We understand from our recent discussions with the EA that the Test and Itchen model will be substantially revised upgraded and recalibrated in the near future. As a key stakeholder of the groundwater model we welcome these improvements and the opportunity to for future alignment of modelling approach with the EA.

In our discussions we have discussed our requirements and recommendations for enhancement and use future of the groundwater model with the EA (Southern Water, 2016). In particular, we foresee that we will continue to use the groundwater model for environmental (e.g. WINEP) investigations and water resource planning.

Enhancements and updates of the model will include a full review of the input climate data sets (including rainfall and potential evapotranspiration). This reflects our understanding, shared by the EA that the MOSES potential evapotranspiration data set may not be supported in the future. We will need to consider how to account for any changes to input rainfall and PET datasets within our stochastic modelling methodology for our next Water Resource Management Plan.

A detailed strategy for how the model improvement work will be undertaken will be developed in collaboration with the EA, Portsmouth Water and South East Water.

3.3.8 Isle of Wight WRZ

Although indicator borehole models are available, the majority of groundwater sources on the Isle of Wight WRZ are constrained by infrastructure or licence constraints. These limit the yields of the sources before the impacts of reduced groundwater levels are felt.

We have estimated the hydrological yield of the Isle of Wight groundwater sources for each of the 2000 year input sequences based on two drought vulnerable observation boreholes:

Downend Tank OBH
Lowtherville School OBH

Indicator borehole regression models are available for both sites, these relate modelled recharge for the Central Chalk Downs catchment, as estimated by a 4R runoff-recharge model to groundwater levels. For this plan only the Downend Tank OBH relationship has been used as the sources for which Lowtherville School OBH is used as an input, in the Southern Downs of the Island, are planned to be decommissioned.

Recharge model background and version

The Isle of Wight Rainfall to recharge-runoff (4R) model was developed by the EA between 2006-2008 as part of some exploratory recharge and groundwater modelling of the Isle of Wight WRZ.

The configuration of the Isle of Wight 4R model was based on the parametrisation of the adjacent Test and Itchen 4R model. The EA shared this exploratory model with us in support of our WRMP14 DO calculations. The version of the model used in WRMP19 is identical to that used in WRMP14

The recharge-runoff model uses the 4R code (specifically version 041t). . Table 17 outlines the key modelling files/parameters used for recharge and runoff model.

We are developing a new groundwater model for the Isle of Wight WRZ and the existing 4R model will be replaced by the end of AMP6. We will use the new groundwater model in our supply assessments for next Water Resource Management Plan.

Processing of Input data

Only minor modifications of the input climate data were required:

1. The time period modelled was moved to the years 4000-5999 to avoid any potential confusion with real dates.
2. The 4R model has been adapted to correctly handle leap years (e.g. 4100, 4200 and 4300 are not leap years, but 4000 and 4400 are leap years). Any erroneous leap year days in the sequence were deleted.

Model modifications undertaken

No other changes to the WRMP14 model have been undertaken in WRMP19. Compared to the original model constructed by the EA, two key changes were made (in WRMP14):

1. The original model used rainfall from 8 rain gauges and this was distributed topographically using the Met Office 1961-1990 long term average rainfall grid (on a 1km scale). In WRMP14, this factoring was recalculated on the basis that only one rain gauge (Newport) is used in the 2000 year runs.
2. The PET sequence in the original model used the MOSES dataset for MORECS Square 182. These data were uniformly distributed to each model cell with no correction for topography. For WRMP14 and this plan, the data were still unfactored but were replaced with a PET sequence for Newport.

Model runs

Four model runs were undertaken - a baseline (current climate) and three climate change scenarios representing dry, medium impact and wet future scenario.

Model Output

For each of the model runs undertaken, monthly recharge output was produced for each of the groundwater catchments.

Calculation of deployable outputs

Curve shifts were developed using the indicator borehole models but in the majority of cases licence or infrastructure constraints limit deployable output before any change from groundwater level arises (see Table 18). Consequently, only the Collecting Main near Newport shows variations in yield with changing water level relating to the Downend Tank indicator borehole. These have been included in the deployable output total

Table 17 Key Components of the (4R) recharge-runoffrunoff model

Input Type	Input Description
Rainfall data	One rainfall series for Newport with topographic factoring through comparison with the Met Office 1961-1990 long term average spatial distribution
PET data	One PET series for Newport with **no** topographic factoring
Mains leakage	The model runs undertaken were ‘Natural’ and so do not include anthropogenic influences
Surface water abstractions	The model runs undertaken were ‘Natural’ and so do not include anthropogenic influences.

Input Type	Input Description
Surface water discharges	The model runs undertaken were ‘Natural’ and so do not include anthropogenic influences.
Other parameters	All other parameters in the model are identical to those developed during the original model construction

.

Table 18 Summary of Indicator borehole regression modelling used for the Isle of Wight WRZ

		DO constraints		
Indicator Borehole	**Source**	**MDO**	**PDO**	**Comments**
Downend Tank OBH	Lukely Brook	Prescribed River Flow	Prescribed River Flow	Insensitive to Curve shift
	Caul Bourne	Prescribed River Flow	Prescribed River Flow	Insensitive to Curve shift
	Newport	Gravity flow & Pump Capacity	Gravity flow & Pump Capacity	Curve shift applied to gravity flow on main only
	Rookley	Prescribed River Flow	Prescribed River Flow	Insensitive to Curve shift
	Newchurch (Chalk)	Pump Cut-off	Pump Cut-off	Insensitive to Curve shift
	Newchurch (LGS)	Pump Capacity	Pump Capacity	Insensitive to Curve shift

3.3.9 Sussex North WRZ

The Sussex North WRZ contains a number of groundwater sources, some of which are covered by the existing Pulborough Basin groundwater model. The majority of groundwater sources in this WRZ are licence or infrastructure constrained, consequently their DO has not historically been estimated using modelling techniques. These constraints were reviewed as part of our DO assessment and for all but one source at Pulborough, constraints have not changed.

Two groundwater sources at Petersfield and West Chiltington have had their DO written down owing to long term outage because of water quality problems that require treatment solutions.

The Pulborough groundwater source is represented within the Pulborough basin groundwater model. We developed this model to both examine the environmental impacts of this source and its DO under drought conditions. As this source is sited within a confined aquifer, it is not directly sensitive to drought or climate change. Our modelling has established that the long-term sustainable yield of the Pulborough groundwater source is a function of long term average catchment recharge in combination with pump yield and borehole drawdown.

We have a scheme to upgrade the Pulborough groundwater source with reconfigurations of the well field expected to improve short term (90 day) MDO. This will be achieved by increasing spacing between newly drilled boreholes to reduce pumping interference and rehabilitation of older boreholes. Although the individual borehole yield will be reduced to improve resilience, increasing the number of operational boreholes will improve total yield. Our initial modelling and designs have indicated that under severe and extreme drought conditions borehole yields are achievable with acceptable drawdown to prevent well encrustation. However whilst the locations for the new boreholes have been identified they have not yet been constructed and there are ongoing discussions with Natural England about the relationship with nearby designated sites. Despite that we are still planning to deliver the scheme and for the DO assessment for this source we have assumed that minimum DO will be increased from 13Ml/d to 20Ml/d for a 90 day period.

Table 19 summarises the DO constraints for groundwater sources in the Sussex North WRZ. Our Steyning groundwater source is located within the area of the Brighton and Worthing Chalk groundwater model but as this source is demand and infrastructure constrained no direct modelling of its yield using this model has been undertaken.

Table 19 Summary of groundwater deployable output constraints for Sussex North WRZ

	DO Constraint		
Source	**MDO**	**PDO**	**Comment**
Pulborough Groundwater	Annual Recharge / Well Drawdown	Pump Capacity	MDO is based on a 90 MDO, assumed AMP6 upgrade complete
Petworth South	Annual Licence	Daily Licence	Insensitive to curve shift, none applied
Petersfield	Written down (needs treatment upgrade)	Written down (needs treatment upgrade)	No deployable output
Midhurst	Annual Licence	Daily Licence	Insensitive to curve shift, none applied
West Chiltington	Written down (needs treatment upgrade)	Written down (needs treatment upgrade)	No deployable output
Steyning	Demand constraint	Pump capacity	Insensitive to curve shift, none applied

3.3.10 Sussex Worthing and Sussex Brighton WRZs

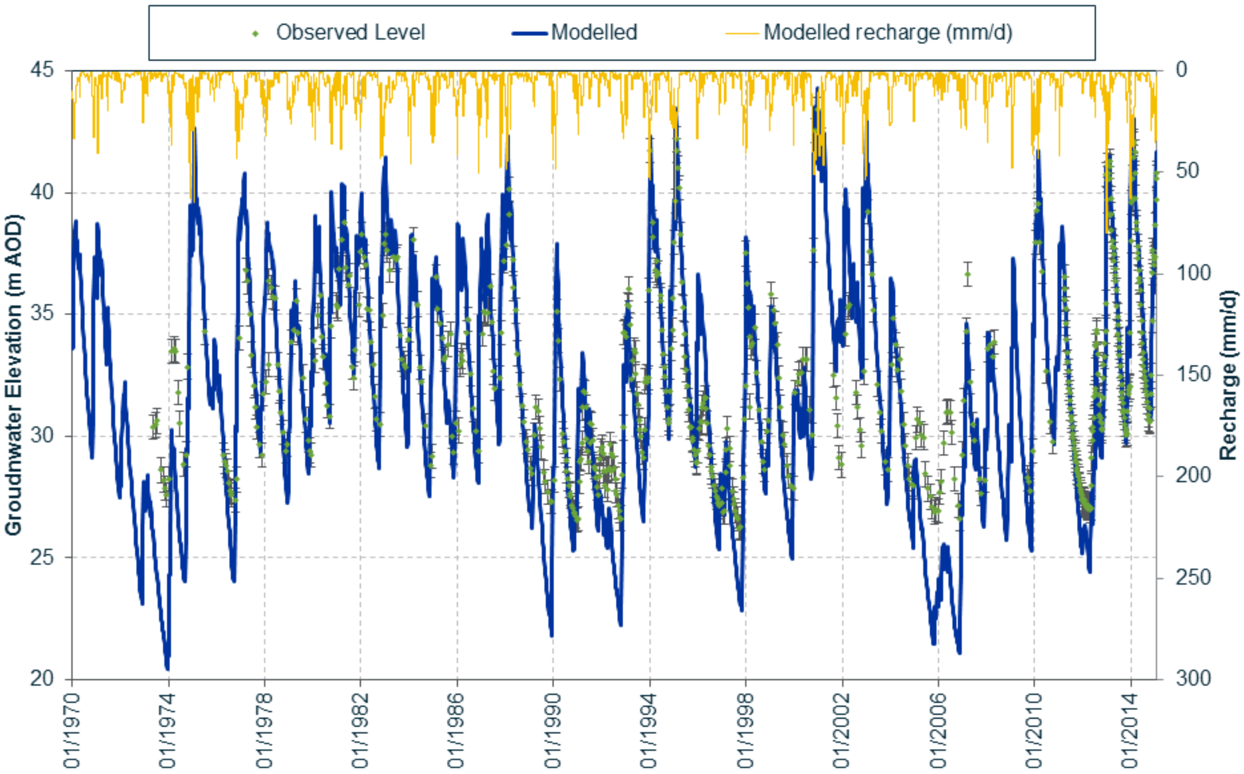
Both of these WRZs are entirely supplied by groundwater from the Chalk aquifer and are covered by the Brighton and Worthing Chalk groundwater model. We developed this model in AMP5 to aid NEP investigations into the environmental impact of abstractions. The model has also been explicitly designed to be able to directly forecast source DO using recent developments to the MODFLOW code (Panday et al, 2013).

Existing indicator borehole regression models exist for both the Sussex Worthing and Sussex Brighton WRZs based on a single indicator borehole at Southwick in the Brighton Chalk Block.

A number of possible options were therefore available for estimating groundwater DO in these WRZs:

Historic recharge regression relationships to the Southwick indicator borehole could be used
The Brighton and Worthing groundwater model could be used to simulate groundwater levels at Southwick borehole (Figure 9). These groundwater levels could be used with existing regression relationships to estimate variable DOs
Groundwater DOs could be simulated directly within the Brighton and Worthing groundwater model

Figure 9 Observed and predicted groundwater levels at Southwick using the Brighton and Worthing groundwater model



Both the existing recharge – regression model, and the more recent 4R model associated Brighton and Worthing groundwater model require the same input datasets:

Input rainfall for three rain gauges, Applesham Farm, Housedean and Peacehaven
MORECs PET data for two MORECs squares, 184 and 185

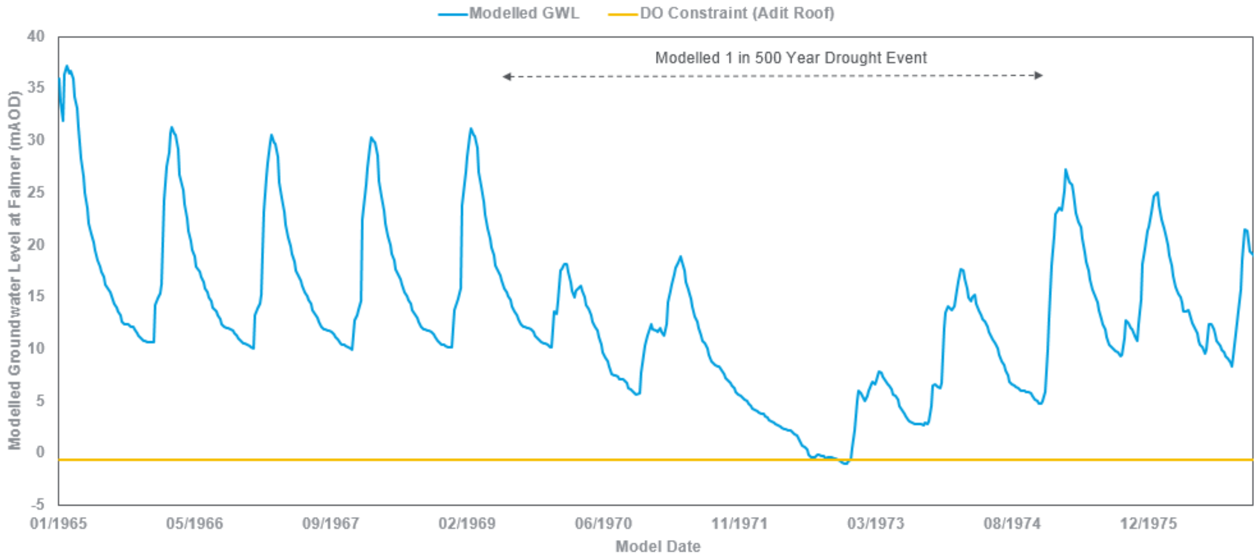
The synthetic weather generator and daily disaggregation process can directly simulate time series for both of these datasets. Owing to the model complexity, and computational requirements, it is not feasible or practical to execute long period (2000 year) runs of the Brighton and Worthing groundwater model now. Such a run would take a few weeks to complete based on current runtimes. In order to be able to sufficiently define a probability density function of DOs required by our adopted risk principle (Annex 1) a hybrid modelling approach was employed.

An initial estimate of DOs for both zones was made using the existing (WRMP09 and WRMP14) recharge – regression relationships to the Southwick Indicator Borehole
A Series of estimated 1 in 200 and 1 in 500 drought events from the original rainfall and PET sequence were then collated into a drought library around 50 years in length. Each drought event was separated by several years of average rainfall to allow groundwater recovery.
The drought library was then input as a scenario to the groundwater model along with the forecast DO as abstraction rates. The model was then used to calculate pumped water levels during these drought events.
The predicted DO from the regression modelling could then be validated against the regional distributed groundwater model.

Unlike the majority of our groundwater zones in the Western area, groundwater sources in the Sussex Worthing and Sussex WRZs are much more vulnerable to low groundwater levels and droughts. This is because of a large number of relatively shallow shaft and adit sources were preventing dewatering of the adit or fissure zones imposes constraints on pumping. Many more sources are therefore hydraulically constrained in these zones than elsewhere.

The hybrid approach was therefore especially useful for some of these large shaft and adit sources, such as Falmer and Brighton A (Figure 10). Here there were concerns about the drought resilience of sources that were found during development of the Brighton and Worthing groundwater model. In many cases the two modelling methods agreed well and gave greater confidence in overall drought yields in these sensitive Chalk Aquifer blocks.

Figure 10 Example of simulated pumped water levels using the Brighton and Worthing groundwater model used to verify hydraulically constrained severe and extreme drought deployable output derived from the indicator borehole regression modelling.



Where yields were not considered to be drought vulnerable the constraints on DO were reviewed as part of our DO assessment both through our SIOS investigations and internal consultation. Table 20 summarises the key DO constraints for both the Sussex Worthing and Sussex Brighton WRZs. The results of our DO modelling are given in Section 4.3.

Table 20 Summary of groundwater deployable output constraints for Sussex Worthing and Sussex Brighton WRZs

		DO Constraint		
WRZ	**Source**	**MDO**	**PDO**	**Comment**
Sussex Worthing	Littlehampton	Annual Licence	Pump Capacity	Insensitive to drought
	Arundel	Treatment Capacity	Treatment Capacity	Insensitive to drought
	Worthing	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shifting applied
	South Arundel	Turbidity / Water Quality	Turbidity / Water Quality	Updated curve shifting applied
	South Arundel A	DAPWL	Annual Licence	Updated curve shifting applied
	Long Furlong A	Infrastructure (Distribution) Constraint	Infrastructure (Distribution) Constraint	Insensitive to drought
	North Worthing	DAPWL	Predicted sustainable DO (BH1 + BH2)	Updated curve shifting applied
	North Arundel	Treatment Capacity	Treatment Capacity	Insensitive to drought
	East Worthing	Daily Licence	Daily Licence	Insensitive to drought
	Long Furlong B	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shifting applied
	Durrington	Daily Licence	Daily Licence	Insensitive to drought
Sussex Brighton	Rottingdean	Salinity	Salinity	Tidal factors included in curve shift
	Falmer	DAPWL (Adit Roof)	DAPWL (Adit Roof)	DO Verified with GW model
	Hove	Licence	Licence	
	North Falmer A	DAPWL	Pump Capacity	Updated curve shifting applied to MDO
	Lewes Road	DO written down (Long term outage)	DO written down (Long term outage)	Needs treatment upgrade
	Hove B	Treatment Capacity	Treatment Capacity	Insensitive to drought
	North Shoreham	DAPWL	DAPWL	Water Quality concerns
	North Falmer B	DAPWL	DAPWL	Updated curve shifting applied
	Brighton A	Treatment Capacity (with Brighton B)	Treatment Capacity (with Brighton B A)	DO Verified with GW model
	Brighton B	Treatment / Pump Capacity with Brighton A	Treatment / Pump Capacity with Brighton A	Insensitive to drought
	Shoreham	DAPWL	Daily Licence	Updated curve shifting applied
	Lewes	Pump Capacity	Pump Capacity	Insensitive to drought
	Sompting	Annual Licence	Annual Licence	Insensitive to drought

3.3.11 Kent Medway WRZs

The Kent Medway WRZs (west and east) are two of our largest WRZs. Kent Medway West WRZ includes both groundwater and conjunctive use surface water and reservoir sources. Kent Medway East WRZ is entirely groundwater dependant but can receive water via intra-zonal transfer from Kent Medway West WRZ.

The North Kent groundwater model covers most of the Chalk aquifer that supplies these two zones. Because of difficulties in constraining model outflow the model is not seen as “fit for purpose” for water resource modelling. Our initial intended approach for WRMP19 was to use the runoff recharge code developed for this model in combination with existing recharge – groundwater level regression relationships.

3.3.12 North Kent groundwater model

The North Kent groundwater model was developed by the EA (WMC as lead consultant) between 2002 and 2006. It uses an adapted version of version 3 of EA recharge code to produce recharge input for an underlying MODFLOW (WMC, 2003) based groundwater model.

We tried to resurrect the recharge model and adapt it for 2000-year model runs consistent with our synthetic input time series. Unfortunately, the changes made to version 3 of EA code were significant in terms of file format and FORTRAN code edits. While the documentation for subsequent versions of the EA code hints that the various North Kent model alterations have been included, the file formats were inconsistent with these changes.

It was therefore not possible to run the existing North Kent input files through newer code executables. The FORTRAN (text based) source code listing for the North Kent recharge model was also not available, only the compiled executable. Amec Foster Wheeler, Southern Water and the EA worked in collaboration to try to locate the missing files, but were unable to do so.

Consequently it was not feasible, in the time available, to use the North Kent model in support of WRMP19. We intend to develop a new groundwater and recharge model for the area in AMP6/AMP7. Like the Brighton and Worthing and Pulborough Basin models, this model will be explicitly designed to support calculation of time varying DOs.

Use of the Environment Agency recharge code

As we could not use the distributed recharge model, instead we used the same methodology as employed for WRMP14 to calculate variable DOs. This employed a 2000-year version of the EA recharge calculator (Hulme, et al, 2001). This calculator operates on a daily time step and used these input time series.

Synthetic 2000 year daily rainfall time series for the Canterbury Rain Gauge
Synthetic 2000 year daily PET data for Medway Catchment (based on EA Pense data)

Our synthetic weather generator and daily disaggregation process directly generate both of these time series.

The input time series were supplied to the recharge calculator, this produced an output time series of daily recharge that was then aggregated up to monthly output. This output was then used with our existing (WRMP14) drought indicator borehole regression model for Rodmersham OBH to forecast time series of rest water levels and DO for the Kent Medway WRZ sources.

As with other WRZss, constraints on DO for the Kent Medway WRZs were reviewed for some sources as part of our SIOS investigations, for the rest via internal consultation. A summary of the constraints on DO in Kent Medway East and Kent Medway West WRZs is presented in Table 21. Our DO forecasts are presented in Section 4.4.

Table 21 Summary of groundwater deployable output constraints for Kent Medway West and Kent Medway East WRZs

		DO Constraint		
WRZ	Source	MDO	PDO	Comment
Kent Medway West	Strood	Pump Capacity	Pump Capacity	Insensitive to drought
	Rochester	Annual Licence	Adit Roof	
	Gravesend	Written Down (poor water quality)	Written Down (poor water quality)	Needs treatment works upgrade
	Higham	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	
	Meopham	Pump Capacity	Pump Capacity	Insensitive to drought
	Longfield	Annual Licence	Pump Capacity	Insensitive to drought
	Cuxton	Yield at DAPWL (Adit Roof)	Pump Capacity	
	Gravesend South	Pump cut out, set at DAPWL	Pump Capacity	
	North Cuxton	Pump Capacity	Pump Capacity	Insensitive to drought
	Northfleet Chalk	Pump Capacity	Pump Capacity	Insensitive to drought
Kent Medway East	Hartlip Hill	Booster Pump Capacity	Booster Pump Capacity	Insensitive to drought
	Newington	Demand	Pump Capacity	Insensitive to drought
	Faversham3	Pump Capacity / Water Quality	Pump Capacity / Water Quality	Insensitive to drought
	Hartlip	Operational Pump Capacity	Operational Pump Capacity	Insensitive to drought
	Gillingham A	Booster Pump Capacity	Booster Pump Capacity	Insensitive to drought
	Gillingham B	Booster Pump Capacity	Booster Pump Capacity	Insensitive to drought
	Gillingham	Booster Pump Capacity	Booster Pump Capacity	Insensitive to drought
	Chatham West	Pump Capacity	Pump Capacity	Insensitive to drought
	Chatham	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	
	Sittingbourne1	Annual Licence	Annual Licence	Insensitive to drought
	Sittingbourne2	Yield at DAPWL	Yield at DAPWL	
	Millstead	ADO at Seasonal Licence	Daily Licence	Insensitive to drought
	Sheldwich	Booster Pump Capacity	Booster Pump Capacity	Insensitive to drought
	Faversham2	Demand	Pump Capacity	Insensitive to drought
	Faversham1	Pump Capacity / Water Quality	Pump Capacity / Water Quality	Insensitive to drought
	Faversham4	Operational Pump Capacity	Operational Pump Capacity	Insensitive to drought

3.3.13 East Kent groundwater model (Kent Thanet WRZ)

The Chalk Aquifer of the Kent Thanet WRZ is entirely contained within the East Kent groundwater model.

Model background and version

The East Kent groundwater model and associated recharge-runoff model were developed between 2003 and 2006 by the EA (Mott MacDonald as lead consultant). The original model period covered January 1970 and December 2002.The model was updated (for drought prediction purposes) in 2006 and this brought the model end date to August 2006.

In 2013, the EA commissioned more work to improve the stability and model run speed. The model files, as held by Southern Water and EA were supplied to Amec Foster Wheeler to produce model runs for DO assessment. The various recharge code and groundwater input files, procedures and executables were collated and adapted to form a set that could be used for 2000 year runs of the model(s).

For WRMP14, running the East Kent groundwater model for 2000 year sequences was not practical. Instead a drought library approach (see UKWIR, 2016a) was employed for the Kent Thanet WRZ. Advances in computing power and the 2013 refinements to the model which improve run times and file sizes have since made such a task much more practical.

While no underlying code or translation spreadsheets were altered in terms of their functionality, it was necessary to update and/or recompile certain elements of the process to handle the longer run period (2000 years being equal to 48000 stress periods).

The recharge-runoff model uses the EA recharge code (specifically version 4). The groundwater model uses the MODFLOW-VKD code (WMC, 2003) which has been enhanced by the EA (utilising various consultancies) and compiled as version ‘MF96VKD_NGMS_Portable’.

The running of the model follows a multi-step process:

Running the EA recharge code to form the ‘raw’ recharge and runoff files
Post-processing the runoff data (through a spreadsheet) to form input (A) for the MODFLOW stream file creation spreadsheet
Forming a surface water abstraction and discharge time series to form input (B) for the MODFLOW stream file creation spreadsheet
Running the MODFLOW stream file creation code with inputs (A) and (B)
Post processing of the raw recharge file (through two FORTRAN utilities and one spreadsheet) to distribute (‘smooth’) the raw recharge file over a number of stress periods to form the input MODFLOW recharge file. This smoothing is included as a representation of recharge lag through the unsaturated zone.
Run MODFLOW and then post-process to generate time series groundwater levels for a number of user defined abstraction boreholes and observation boreholes.

Table 22 outlines the key modelling files/parameters used for recharge-runoff model and Table 23 presents similar detail for the groundwater model. Although the East Kent Recharge model uses a large number of rain gauges, a regression approach relating these inputs to a single indicator rain gauge was developed for WRMP14. This approach factors and scales a single rain gauge input time series (Canterbury) to the other input time series (Mott MacDonald, 2013).

Table 22 Key Components of the East Kent recharge-runoff model

Input Type	Input Description
Rainfall data	Rainfall Data were available for 32 rain gauges as per the original model and distributed according to topography. These 32 rainfall records are synthetically generated by using fixed factors to relate them to one (stochastic) rain gauge series at Canterbury.
PET data	PET data are notionally input for 4 stations/locations and distributed according to topography. In the 2000-year stochastic runs, the PET data (based on Canterbury) is identical for the four stations.
Mains leakage	Mains leakage was included as for previous model runs of East Kent
Surface water abstractions	No surface water abstractions are modelled
Surface water discharges	As the groundwater model does not cover the full Stour surface water catchment, flows are added to the model at the point at which the Stour flows in the active model extent. In these runs, the 1996 naturalised series for the Wye gauging station is repeated for each year. This assumption is consistent with the WRMP14 modelling.
Other parameters	All other parameters in the model are identical to those developed during the original model construction

Table 23 – Key Components of the East Kent (MODFLOW) Groundwater Model

Input Type	Input Description
Model Extent	The model extent is unchanged (other than a small error correction from 2013) from the original model
Aquifer parameterisations	The model aquifer parameters are unchanged other than localised increase in hydraulic conductivity close to large abstractions (as applied during the 2013 refinements)
Drain distribution	The drain distribution and levels are unchanged from the original model
General head boundaries	The general head distribution and levels are unchanged from the original model
Stream distribution	The stream distribution are unchanged from the original model
Solver	The solver from the 2013 refinement has been used as this allows the model to run faster
Groundwater abstractions and discharges	No ground water abstractions or discharges are modelled.

Processing of Input data

Only minor modifications of the input climate data were required:

The time period modelled was moved to the years 4000-5999 to avoid any potential confusion with real dates.

The EA model has not been adapted to correctly handle leap years and so it was necessary to make sure that every fourth year was a leap year even when they strictly are not leap years (e.g. 4100, 4200, 4300, 4500 etc.). As required, data for the 28th February was copied and applied to the 29th February for the years in question.

For the DO analysis the model dates were then translated back to the period 2800-3799 to be consistent with other water resource modelling

Model modifications undertaken

No model modifications were undertaken other than those required to make the models long enough in time and to assign the correct numbers of days to each model stress period. The groundwater model operates on two stress periods per calendar month. The first stress period is always 15 days long and the second stress period completes the rest of the month (i.e. 13, 14, 15 or 16 days depending on the month).

Model runs

Four model runs were undertaken - a baseline (current climate) and three climate change scenarios representing dry, medium impact and wet future scenario.

Model output

For each of the model runs undertaken, stress period output was produced for the groundwater level locations that were required for subsequent DO calculations. Unlike most WRZs a drought indicator regression model is not directly employed for Kent Thanet WRZ, instead rest water levels at groundwater sources are estimated directly from predicted groundwater levels output from the modelling. Some scaling and shifting of groundwater level output, consistent with the UKWIR (2014) methodology are still required to translate the output data to be suitable for DO assessment.

Reviewing model groundwater level outputs suggested a number of differences to the WRMP14 outputs at some sources used to derive the baseline curve shifts. These differences have likely arisen from a number of subtle differences.

The model refinements undertaken in 2013, which were not incorporated into the previous (WRMP14) version of the model

Difficulties in fully tracing the model input files and provenance between EA, Southern Water and Amec Foster Wheeler. Despite close liaison with the EA we have limited confidence that all model input files, especially relating to the recharge model are fully consistent with the AMP4/5 version of the groundwater model.

There were inconsistencies highlighted in WRMP14 with the hindcast PET data for historic droughts the Eastern area. The current weather generator modelling only uses more robust recent PET input data.

Analysis of historical droughts using the East Kent groundwater model has indicated that worst historic drought (in terms of groundwater levels) varies depending on the source under consideration. Analysis of rainfall records (Met Office, 2016) has indicated that either the 1921/22 or 1976 events are the worst historic rainfall droughts. However, minimum modelled groundwater levels are actually forecast for either the 1902, 1973 event or 1997 which may represent differences in the timing of effective rainfall. However, for events farther in the past (pre 1996) no observed groundwater level data at our abstraction sources are available to aid development of drought bounding curve from which rest water levels can be perturbed for the purpose of DO assessment.

Consequently, the baseline rest water level and drought bounding curves for the Thanet groundwater sources are based on more recent droughts either 1996, 1997 or 2006. These are considered to be much less severe the 1902 event at around a 1 in 10 to 1 in 20 return period. The stochastic DO assessment assumes the same drought bounding curves but the previous AMP5 curve shifts were adjusted to improve consistency between the stochastic groundwater levels and historic levels. This was necessary because of model refinement undertaken by the EA which changed the pattern and magnitude of groundwater fluctuations in some areas of the model.

Generally model outputs are still consistent with the range of historic observations of groundwater levels but the model output is clearly different to that used in AMP4. In order to derive appropriate baseline levels for the curve shifting approach we followed a stepped procedure.

1. The 1 in 20 drought water level estimated from frequency analysis of the 2000 year data was compared to simulated water levels for the historic 2006 drought (from the WRMP14 modelling) which is consistent with the return period of this event.
2. The Historic baseline Rest Water level was then offset to be equivalent to the 1:20 year synthetic drought groundwater level.
3. Differences in modelled rest water level relative to the adjusted 1:20 event baseline were used, in combination with existing scaling factors to estimate variable rest water levels for each source.
4. As with other zones a range of drought bounding curves were derived for each drought vulnerable source, at RWLs that equated to ‘normal year’, ‘dry year’ (equal to the drought bounding curve in the 2006 assessment), ‘drought year’ (1 in 50), ‘severe drought’ (around 1 in 100) and ‘extreme drought’ (1 in 200+) conditions. Representative DOs for each of those conditions were calculated for each source based on the relative amount of curve shifting for each condition

Model output time series at the location of each source were then used to estimate both PDO and MDO. The DO for the 1:200 design events were compared and found to be generally consistent for WRMP19 and WRMP14. The largest difference occurred at Canterbury source. This source was subject to refinement and enhancement of transmissivity during the 2013 EA model refinement project. Enhancement of local transmissivity around the source has decreased drawdown and thereby slightly increased yield at MDO conditions at this source.

A summary of the DO constraints for groundwater sources in Kent Thanet WRZ is given in Table 24 and outputs from the modelling are presented in Section 4.5.

Table 24 Summary of groundwater deployable output constraints for Kent Thanet WRZ

	DO Constraint		
Source	**MDO**	**PDO**	**Comment**
Deal	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Water Quality constrains output
West Langdon	Annual Licence	Daily Licence	Insensitive to drought
Manston2	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shift applied
Ramsgate B	Yield at DAPWL (Fissure Zone)	Yield at DAPWL (Fissure Zone)	Updated curve shift applied
Kingsdown	Annual Licence	Pump Capacity	Insensitive to drought
North Deal	Pump Capacity	Pump Capacity	Insensitive to drought
Sandwich	Annual Licence	Annual Licence	Insensitive to drought
West Sandwich	BHA Yield / Pump Capacity	BHA Yield / Pump Capacity	Updated curve shift applied
North Dover	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shift applied
Near Canterbury	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shift applied
Birchington	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	Updated curve shift applied

3.4 Hydrological modelling

3.4.1 Summary

CATCHMOD hydrological models are used to model river flows in relation to our surface water sources. The models have been developed to produce flow sequences from the synthetic stochastic rainfall and PET sequences, as well as the historic records of rainfall and PET. These hydrological models have been updated and recalibrated for this plan on the basis of observed data up to 2014. CEH GEAR gridded catchment rainfall data (Tanguy et al, 2015) and MORECS PET data were used for the calibration process. Naturalised flows were generated for the calibration process by decomposition.

An improved denaturalisation module has been developed which dynamically accounts for abstractions in relation to HOF conditions. The module also automatically aggregates the relevant time series to derive flows in the Medway at Teston. The denaturalisation procedure excludes Southern Water abstractions and reservoir releases, these are modelled separately within the Aquator water resource models.

3.4.2 Background

Hydrological models may be used to assess the potential impacts of drought on river flows. We have used CATCHMOD (Greenfield, 1984) rainfall-runoff hydrological models to model river flows since 2005. The models are calibrated against observed data, and are used to simulate the likely river flows which would occur in a catchment given a particular sequence of weather. The models are used to estimate river flows on the basis of hindcast historical data – relevant weather records can be collated on the basis of observations back to the 1880s - and also on the basis of synthetic weather records, such as the stochastic synthetic records developed for this Plan.

The CATCHMOD hydrological model was originally developed in 1984 (Greenfield, 1984) and the model has been used by among others, Thames Water, the EA, Southern Water for modelling surface water systems.

A number of CATCHMOD models were originally developed and calibrated for Southern Water in 2005 to undertake yield assessments of surface water sources for WRMP09 (Southern Water, 2009) based on hindcast historical weather sequences. The same models were used for WRMP14 (Southern Water, 2014), with minor adjustments to allow the use of extended synthetic stochastically generated weather sequences.

3.4.3 Model update

For this plan, we undertook a project to update, recalibrate and enhance the CATCHMOD hydrological models and this is described in full in a separate report (Atkins 2017a).

The models included these enhancements:

Extended calibration and validation period to include the period 2002 to 2014 with recalibration of the hydrological models to the 'naturalised' flow sequences generated for this period
Improved representation of reservoir inflows and outflows
Enhanced denaturalisation procedure which includes dynamic implementation of HoF conditions for each individual abstraction licence
Catchmod model and denaturalisation procedures written in Python for efficient processing and to allow 2000 year datasets be generated.

Seven catchments at river flow gauging stations were modelled (see Table 25), with four models for reservoir catchments (see Table 26).

Table 25 Catchments at gauging stations modelled using CATCHMOD

Gauge Name	River	Associated Abstractions
Medway	River Medway	River Medway Scheme (proposed MRF location for Medway)
Medway	River Medway	River Medway Scheme (MRF location for Medway)
Teise	River Teise	River Medway Scheme (MRF location for Teise)
Brede	River Brede	Rye (MRF location for Rye)
Eastern Rother	River Rother	Robertsbridge (MRF location for Eastern Rother)
Western Rother	River Rother	Pulborough (MRF location for Western Rother)
Arun	River Arun	None, although relevant for Arun abstraction

Table 26 Reservoir catchments modelled using CATCHMOD

Reservoir	Catchment Area (km2)	Reservoir surface area (km2)	% of Catchment covered by	Catchment Area excluding	BFI from Low Flows 2000

			reservoir surface	Reservoir (km2)	
Bewl	21	3	15%	18	0.56*
Darwell	10	0.6	6%	9	0.46
Powdermill	5	0.2	5%	5	0.46
Weir Wood	27	1	4%	26	0.45
Bough Beech	6	1	17%	5	0.43

3.4.4 Flow naturalisation

Flow naturalisation is the term given to the process of determining the ‘natural’ flow within a river. Naturalised flows represent the flows that would have occurred in the river without the influences of artificial abstractions and discharges within the catchment. The naturalised flows are then used to calibrate the hydrological models, so that the models simulate flows without these influences.

Flow naturalisation by decomposition involves estimating flows as might have occurred without the artificial influences through the re-addition of abstracted water to the gauged flow and the removal of discharges. Flow naturalisation was undertaken in line with EA guidance (2001).

Equation 1 shows that naturalised flow in a catchment is calculated as the observed flow plus the sum of the abstractions minus the sum of the discharges.

Equation 1 Calculation of naturalised flow

$$Q_{Nat} = Q_{Obs} + \sum Abstractions - \sum Discharges$$

Q_{Nat}	naturalised flow
Q_{Obs}	observed flow
$\sum Abstractions$	sum of abstractions in catchment
$\sum Discharges$	sum of discharges in catchment

A dataset of abstractions in each catchment was collated from information shared by the EA and the largest 99% of abstractions based on licence volume were extracted for analysis and missing data were infilled. The impact of groundwater abstractions were represented using the ‘lumpy groundwater factor’ methodology described in Environment Agency (2001). Time series of discharges were developed using estimates of dry weather flows (DWFs), based on either measured discharge date, or consented-DWFs.

Using the procedures outlined above, which are described in more detail in Atkins (2017c), the catchment abstraction and discharge time series datasets were used to generate naturalised flow sequences from the observed gauged daily flows.

Reservoir inflows were assessed using two methods, by back calculating inflows based on reservoir water balance, and by using nearby gauged catchments which were generally unaffected by artificial influences as a proxy. Inconsistencies and anomalies in the reservoir water balance datasets meant that proxy flow data from nearby catchments was preferred for estimating historical reservoir inflow sequences.

3.4.5 Rainfall-runoff modelling

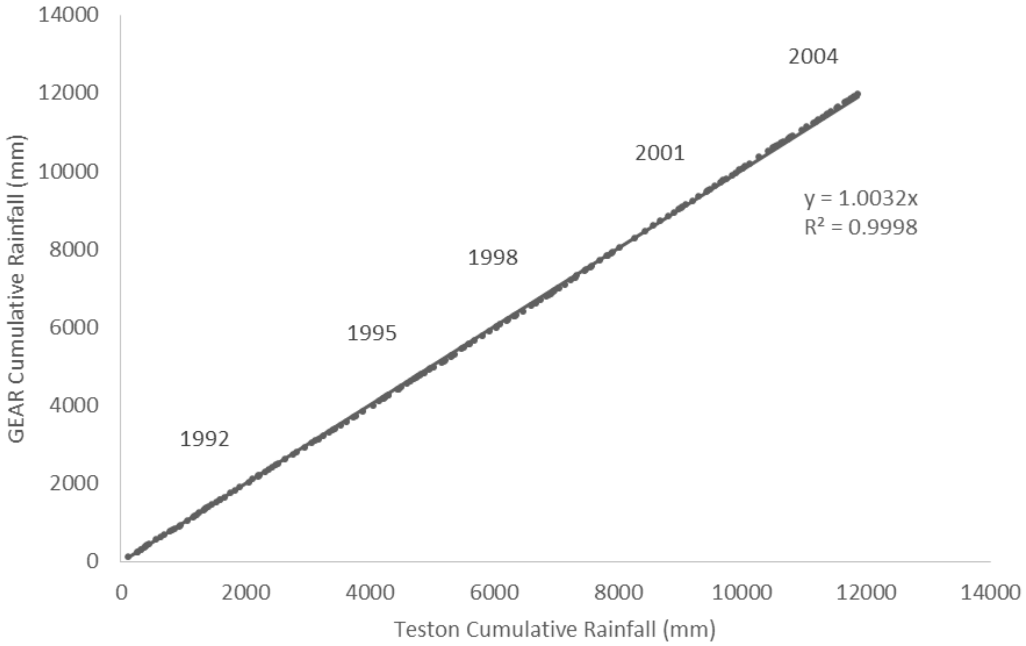
Rainfall and PET are the two time-varying inputs used in the CATCHMOD models to simulate weather conditions.

Rainfall data

Nationwide gridded rainfall datasets are available at 1km scale for the period 1890-2014 have been developed by CEH and are available for free download from the CEH website (Tanguy et al, 2015). These data were extracted for each of the modelled catchments. Checks were made to compare the CEH gridded datasets with the catchment rainfall sequences based standard Thiessen-polygon techniques using gauged data which were created when then hydrological models were originally developed in 2005. A good fit was found between CEH gridded catchment rainfall data and the catchment rainfall data derived from rain gauges – see Figure 11 as an example.

The CEH gridded catchment rainfall data was used for the calibration and historical rainfall datasets. These datasets have the advantage that they have been developed using nationally standardised techniques, and they are going to be regularly updated.

Figure 11 Teston catchment – comparison of cumulative rainfall between CEH GEAR gridded data and catchment rain-gauge data



Potential Evapotranspiration data

PET data was derived from the MORECS data (Thompson et al, 1981), which is updated monthly and is available from 1961 onwards. Monthly PET data for each MORECS 40km x 40km grid square were extracted and integrated for each catchment, apportioned by the area catchment falling in each grid square. MORECS data was used for the calibration and validation period of the models.

PET data was also required for the period before 1961 for analysis of historical droughts, for which period MORECS data is unavailable. Times series for these earlier periods were developed, based on either the EA's Potential Evapotranspiration in South East England (PENSE) model for the period 1918-1960, or based on a regression against temperature records from Southampton airport for the period 1890-2017 using the Blaney-Criddle PET equation (Hargreaves, 1982). The Blaney-Criddle equation is particularly useful when only air temperature is available, which is the case for the south east of England before 1918.

The pre-1961 PET datasets derived from PENSE and Blaney-Criddle methods were modified by factoring to the MORECS PET series using a linear relationship based on data from each method which overlapped with the MORECS data. This made sure the different methods generated data consistent with the MORECS calibration period. This was an enhancement in relation to the derivation of PET when the models were originally developed and as used for WRMP09 and WRMP14.

Calibration of flows

The extended and revised rainfall and PET time-series were used as input datasets to the CATCHMOD models. Simulated flows were compared with the observed naturalised flows and the models were re-calibrated and validated. Validation was not undertaken for the Allington, Brede and Pallingham models as only short periods of data were available and therefore solely used for calibration. Stonebridge has a shorter record than Teston for calibration after a decision to not use certain data because of a lack of confidence in its quality. Calibration plots showing simulated and observed flows are shown in Appendix C.

Table 27 compares the statistical fit (calibration) of the original models developed in AMP4 and the models developed for this plan (AMP6). This shows that statistically the calibration is improved in all cases, except for Pallingham which has shown a slightly poorer fit because of the inaccuracy of the recorded high flows, which biases the statistical fit. In reality, the fit at Pallingham has improved, except for the high flows.

3.4.6 Flow denaturalisation

The Catchmod rainfall-runoff models simulate ‘natural’ catchment flows. To estimate the yield of surface water systems, we need to take account of the abstractions and discharges which would normally occur in the catchment. “Denaturalisation” is the procedure by which these artificial influences are added back to the simulated natural flows.

Denaturalisation represents a sub-set of the abstractions and discharges in the catchment. The Southern Water surface water abstractions and reservoir releases are not represented in the denaturalisation process. These are modelled instead in the Aquator model for which the denaturalised flows are a key input. The abstractions and discharges which are modelled in Aquator are presented in Table 28.

Table 27 Calibration and validation of modelled flows against observed flows – comparison of AMP6 statistics (this plan) against AMP4 statistics (the original versions of the hydrological models)

Catchment	Cal/Val	AMP4 R^2	AMP4 Log R^2	AMP4 $\sum$Calc/ $\sum$Obs	AMP6 R^2	AMP6 Log R^2	AMP6 $\sum$Calc/ $\sum$Obs
Bewl	Cal	N/A	N/A	N/A	0.70	0.84	0.94

	Val	N/A	N/A	N/A	0.79	0.89	0.89
Darwell	Cal	N/A	N/A	N/A	0.73	0.88	1.01
	Val	N/A	N/A	N/A	0.66	0.88	0.94
Powdermill	Cal	N/A	N/A	N/A	0.69	0.84	1.01
	Val	N/A	N/A	N/A	0.64	0.88	0.96
Weir Wood	Cal	N/A	N/A	N/A	0.80	0.84	0.99
	Val	N/A	N/A	N/A	0.66	0.79	1.12
Pulborough	Cal	0.86	0.89	1.07	0.83	0.90	1.06
	Val	0.84	N/A	1.06	0.82	0.92	1.17
Udiam	Cal	0.63	0.86	1.70	0.80	0.88	1.08
	Val	0.75	0.89	1.09	0.84	0.90	1.04
Brede	Cal	0.73	N/A	0.92	0.84	0.89	1.06
	Val	N/A	N/A	N/A	N/A	N/A	N/A
Stonebridge	Cal	0.78	0.86	1.02	0.79	0.78	1.03
	Val	0.75	0.77	0.80	0.83	0.76	0.91
Pallingham	Cal	0.89	N/A	0.97	0.86	0.86	1.21*
	Val	0.88	N/A	0.98	N/A	N/A	N/A
Teston	Cal	0.82	0.90	1.10	0.83	0.85	1.04
	Val	0.88	N/A	0.93	0.86	0.86	0.98
Allington	Cal	N/A	N/A	N/A	0.91	0.87	1.06
	Val	N/A	N/A	N/A	N/A	N/A	N/A

Table 28 Artificial influences excluded from denaturalisation procedure and modelled in Aquator

Catchment	Abstractions excluded from denaturalisation	Discharges excluded from denaturalisation
Teston	02/114_Yal (WPS near Maidstone)	Bewl release
Teston	02/114_Sma (Smallbridge)	Weir Wood release
Teston	9/40/03/0386/S (Abstraction to Bough Beech)	Bough Beech release
Stonebridge	02/114_Sma (Smallbridge)	Bewl release
Udiam	9/40/06/0162/SR (Robertsbridge)	Darwell release
Brede	16/144 (Brede WTW)	Powdermill release
Weir Wood	9/30/93/0387/SR (Abstraction from Weir Wood)	Weir Wood release

The abstraction data were analysed and the ‘peaky worst year’ (PWY) selected to use for the denaturalisation, being the year with the greatest aggregate abstraction. Discharges used the 2015 values. We have developed extra profiles for the assessment of ‘Recent Actual’ (RA) and ‘Fully Licensed’ (FL) scenarios but we have not used these for assessment of DOs.

Denaturalisation was carried out using a bespoke script written in Python. This procedure accounted for the licenced HOF condition for each abstraction with a dynamic denaturalisation process which checked the amount of water available above the HOF for each licence, and only accounted for an abstraction if there was sufficient water available.

3.4.7 Aggregation of flows in the Medway

The water resources infrastructure of the River Medway is complex, as shown in a simplified schematic in Figure 12. The catchment includes Bewl Water and Weir Wood reservoirs of Southern Water as well as Bough Beech reservoir of SES Water. A more complex set of procedures was required to calculate the flows at Teston to be used in Aquator, as set out in Table 29.

The River Medway Scheme (RMS) (licence 2/114) controls the abstractions from the River Teise and from the River Medway upstream of Teston gauging station both of which refill Bewl Water. The RMS also includes the PWS abstraction from the River Medway at Springfield and controls the requirements for reservoir releases which are made from Bewl Water to support the abstraction at Springfield in the lower Medway when river flows are below the minimum residual flow requirement.

Weir Wood reservoir is an impounding reservoir in the upper part of the River Medway catchment, with compensation releases made to support downstream flows. Bough Beech reservoir is operated by SES Water and has a pumped abstraction from the River Eden which is a tributary of the River Medway.

All of these components are represented in the process to denaturalise the modelled flows.

Modelling of the catchment to represent denaturalised flows for the Aquator modelling was undertaken in a stepwise process as presented in Table 29. Naturalised and denaturalised flows were first generated for upstream catchments using Catchmod and the denaturalisation tool. Separate stand-alone Aquator models were used to generate the reservoir releases for Weir Wood and Bough Beech reservoirs. The simulated flows for the Medway at Teston are calibrated to naturalised flow data which exclude the catchments of the reservoirs. The denaturalisation tool then generates the flows for Teston. Denaturalised flows exclude Southern Water controlled abstractions and releases, as these are simulated by the Aquator model.

Note the hydrological model for Teston flow gauge is calibrated to natural flow sequences which exclude the reservoir catchments. Reservoir outflows as calculated in Aquator can be added to the Teston natural flows. Flows for the Teise at Stonebridge are represented separately in Aquator and are therefore subtracted from the Teston flows.

3.4.8 Generation of stochastic flow sequences

The synthetic stochastic daily rainfall and PET sequences developed for each surface water catchment, as described in the section above, were modelled using the procedures described above to generate 2000 year flow sequences. These generated flow sequences were then used in Aquator for the DO assessments of the surface water sources and conjunctive use modelling. Calibration and comparison of flow datasets with AMP4 hydrology and observed data are presented in Appendix C.

Figure 12 Simplified schematic of the Medway catchment and Darwell reservoir

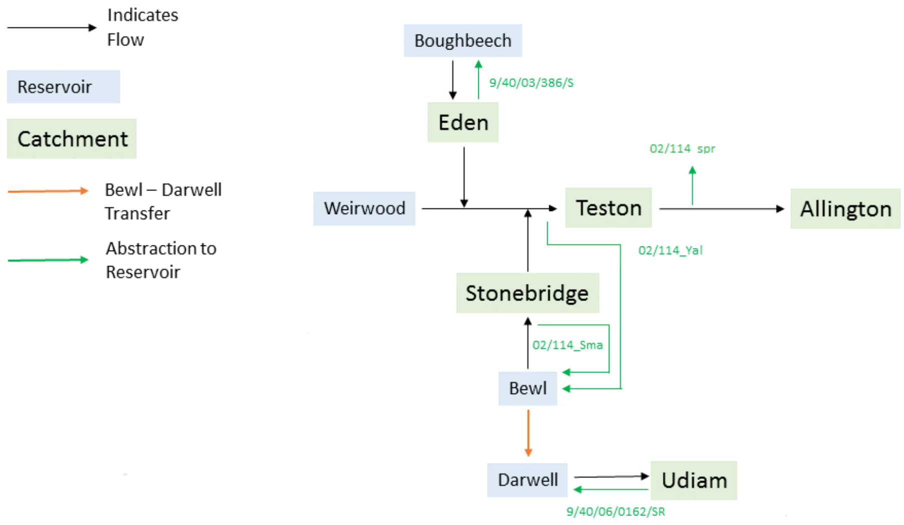


Table 29 The process of generating flows for Aquator

Stage	Catchments	Modelling tool	Inputs
1 Generate natural flows for reservoirs and catchments	Weir Wood Bough Beech Bewl Darwell Stonebridge Udiam Pulborough	Python Catchmod rainfall runoff model	Rainfall PET
2 Denaturalise flows (accounting for non-RMS abstractions and discharges)	Weir Wood Bough Beech Bewl Darwell Stonebridge Udiam Pulborough	Python Denaturalisation tool	Denaturalisation Artificial Influence profiles MRFs
3 Generate reservoir releases to denaturalise Teston	Weir Wood Bough Beech	Aquator stand-alone reservoir models for Bough Beech and Weir Wood	Denaturalised flows Reservoir control parameters
4 Denaturalise flows and combine upstream time series to generate Teston flows for Aquator	Teston	Python Denaturalisation tool	Teston naturalised flow + Weir Wood releases + Bough Beech releases – Stonebridge denaturalised flow
5 System simulation resource modelling	All catchments	Aquator Eastern area model. (simulates operation of RMS, Darwell and Powdermill surface water sources, and can be linked models of KME, KMW and KT WRZs)	Denaturalised catchment flows Abstraction and operational controls Demands and Demand Profiles

3.5 Surface water resource assessment and conjunctive use modelling

3.5.1 Summary

Aquator water resource models were used to undertake analyses required for DO (DO) assessments of surface water resources and where the conjunctive yield of surface water and groundwater sources need to be assessed in combination. The surface water and conjunctive use elements of the supply networks were modelled in Sussex Hastings, Kent Medway West, Sussex North and the Isle of Wight WRZs.

The Aquator models were originally developed for WRMP14, and were updated for this plan. Models were reviewed and updated to reflect any changes in network connectivity, capacities and constraints. Licence conditions were updated to reflect any changes to licences, and groundwater source outputs were revised to reflect the updated groundwater DO assessments completed for this plan. Demand profiles were also updated to reflect recent actual dry year demand profiles for each of the demand centres in the models.

Control curves are used to represent and define mechanisms whereby operational activities vary according to storage, for example, the pumped refill of reservoirs is controlled by the storage volume in the reservoirs in relation to bespoke control curves. For Bewl Water, the demand placed on the reservoir is allowed to vary in relation to storage in relation to an ‘Operational Drought Bounding Curve’, whereby below the curve demands are restricted to the DO.

Drought trigger curves are used in relation to reservoir storage to define transitions from ‘normal’ periods to ‘impending drought’ and on to ‘drought’ and then ‘severe drought’. Trigger curves may be used to implement drought measures such as demand restrictions related to TUBs or NEUs, as well as supply interventions such as changes to licences by Drought Permits. The benefits of drought restrictions have been reassessed to account for recent changes in demand in relation to the Universal Metering Programme.

DO assessments have been made using 2000 year hydrological sequences developed from stochastic modelling of climate. The DO assessments were made with the impacts of TUBs demand restrictions accounted for and implemented within the Aquator models. The in-built Scottish method analyser was used to assess the DOs of the full range of years in the hydrological time series, and the results were used to report the DOs for a range of return periods.

3.5.2 Background

We have used Behavioural models for the assessment of water resource yields since the 1990s. A simulation model of the River Medway Scheme was originally written in Fortran code. Water resource models were later developed for a number of WRZs using the MISER software platform and were used for the assessment of yields for WRMP09 (Southern Water, 2009). These models were later replaced by water resource models developed in Aquator for WRMP14 (Southern Water, 2014).

For this plan, the Aquator models have been revised and updated on the basis of the most up-to-date information, and have been used to derive the MDO/ADO and PDO for the these WRZs:

Kent Medway West WRZ, together with Sussex Hastings WRZ
Sussex North WRZ
Isle of Wight WRZ

The approaches used for the DO assessments have been broadly similar to those used for the previous WRMP, although with some key updates to reflect the enhanced analyses for stochastic rainfall / hydrology, updated demand profiles and demands, refinement and updates to the representations of the supply networks, and licence changes and groundwater yields.

3.5.3 Aquator models

Eastern area - Kent Medway and Sussex Hastings WRZs

For Kent Medway and Sussex Hastings WRZs, an Aquator model represents the River Medway and Bewl Water (the River Medway Scheme) in Kent Medway East WRZ, together with Darwell and Powdermill reservoirs in Sussex Hastings WRZ. This was used for the assessment of conjunctive-use DO for the combined surface water resource system as a whole, as well to calculate relative individual surface water DOs for the reservoirs.

Central area - Sussex North

The Aquator model of Sussex North WRZ was used to assess the conjunctive-use DO of the Sussex North WRZ, which includes the surface water sources at from the River Rother at Pulborough and Weir Wood reservoir, as well as the groundwater sources in the zone. The sum of the groundwater sources was subtracted from the conjunctive-use DO to derive the surface water DOs, which were then apportioned between Pulborough surface water and Weir Wood.

Western area - Isle of Wight

The Isle of Wight Aquator model was used for the assessment of DO at Sandown, where the Eastern Yar is augmented by a number of groundwater sources as well as a transfer from the River Medina Flow in the Medina can also augmented by groundwater sources. This complex resource system is represented in Aquator in VBA. Updated stochastic hydrological flow sequences were used to reassess the hydrological yield and DO for Sandown.

Western area - Hampshire

An Aquator model of Hampshire has been developed which represents the River Test and the River Itchen and the sources of the Hampshire Rural, Hampshire Winchester, Hampshire Southampton East and Hampshire Southampton West WRZs. The original purpose of the Western area Aquator was to support the AMP5 RSA investigations on the River Test and for the Candover Technical Working Group. The Western area Aquator model has never historically been used to estimate surface water DOs in Hampshire, either for WRMP14 or this plan.

In 2017 the existing Western area Aquator model was revised and updated with revised demands and flow input data sets to support our preparation for the Western area Public Inquiry but the Aquator model was not in a sufficiently ready state to be used for DO assessment.

The river flow input datasets for the Aquator model are derived from the Test and Itchen groundwater model (see Section 3.3.7.) For this plan the Test and Itchen groundwater model has been updated with the revised stochastic rainfall sequences and used to generate flows for the Rivers Test and Itchen. In Hampshire, resources are all driven by groundwater (either as groundwater sources, or from the baseflow dominated river flows of the Test and Itchen) and there is no effective storage within the system. Therefore an Aquator model is not required to assess DO. Instead, a spreadsheet-based approach was used to reassess the DOs of these sources by comparing licences and HoFs against the flows in the Rivers Tes and Itchen. This employed the same approach as used for WRMP14.

Rather than change our DO assessment methodology between the draft WRMP, Public Inquiry and the final plan, we have consistently applied the same spreadsheet model for the rivers Test and Itchen (as developed in AMP5) for this plan. As an updated Aquator model is now available we will consider its use and suitability for DO assessment in preparation for WRMP24 and more work may be required to enhance the model.

The updated model has been used to explore the various levels of service implications of the sustainability reductions and options. The outputs of this are discussed in Section 5 and Annex 9.

3.5.4 Aquator model updates

Each Aquator model was reviewed, with the following updates and revisions:

Revised synthetic stochastic time series – as described above, new 2000 year synthetic stochastic flow sequences were developed and imported into Aquator
Network connectivity and constraints – the representation of the supply network was reviewed and changed as necessary
Licence conditions – new, revised and varied licences were updated
Representation of groundwater – revised to reflect updated groundwater DOs and constraints
Demands – overall demands and demand profiles were updated as described in the section below.

3.5.5 Overview of Aquator models and surface water resources

The Aquator models are used to assess resource availability for the parts of the supply system which include surface water abstractions from rivers and storage reservoirs. For each source, or set of sources, there may be a complex suite of rules which are governed by licence conditions as well as in some instances operational control rules. Either these rules are represented in Aquator using the built-in suite of components and parameters, or using bespoke Visual Basic for Applications (VBA) code. Schematics of each Aquator model are shown in Appendix D.

The Aquator models include these general components and behavioural controls:

River catchments – including time-series of inflows, acting as the key hydrological variable
River abstractions – including daily annual and seasonal licence conditions. VBA implemented for complex licence conditions
Storage reservoirs – including operational control rules
Reservoir releases to rivers – including compensation releases, augmentation releases and spill releases
Groundwater sources – including licence constraints / operational constraints
Group licences – for licence conditions applied to multiple sources
Supply networks – including trunk mains and network constraints
Demand centres – including overall demands and demand profiles
Demand restrictions – modelling of anticipated impact of drought demand reduction measures by way of control curves on reservoirs and river flows

Complex river control and augmentation schemes, such as the River Medway Scheme in Kent, the Eastern Yar augmentation scheme on the Isle of Wight and the proposed Candover scheme in Hampshire, are modelled in Aquator using bespoke VBA code within the respective model.

Extra bespoke controls are applied in VBA to represent more complex elements of the resource systems, for example, the River Medway scheme in the Kent Medway East WRZ, Pulborough groundwater in Sussex North WRZ, and Sandown augmentation in the Isle of Wight WRZ.

3.5.6 Demand profile development

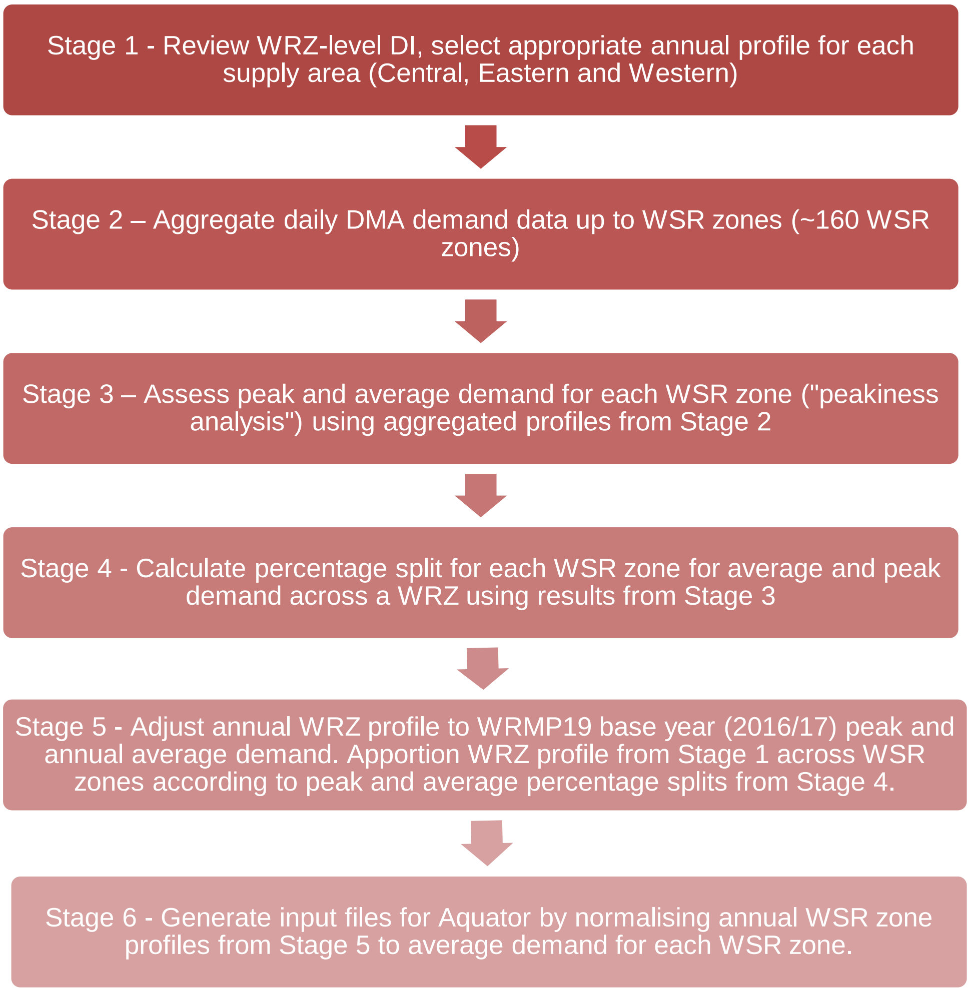
Demand profiles are used in Aquator to represent the variation in demand through the year, and they should be based on recent actual dry year demand periods which reflect how demands tend to be elevated during summer peak periods.

Demands and demand profiles were reviewed and updated for this plan so that changes in usage pattern and demand that have occurred since the introduction of universal metering are reflected in the modelling. The approach used to update the demand profiles are summarised in Figure 13 and the method is presented in full in Atkins (2017d).

Recent historical DI profiles since 2010 were inspected and analysed to assess variability in demand and whether a clear summer peak was evident in the data. On this basis, particular years were selected to represent the 'peakiness' and to generate the profiles. The demand profiles used for Western, Central and Eastern areas are shown in Figure 14, Figure 15 and Figure 16.

For the allocation of demand in the Aquator model, these demand profiles are then normalised to the overall demand of the base year, being 2016/17 and then apportioned to the relevant Demand Centres as represented in the Aquator model. Demand Centres are defined by one or more Water Service Reservoir (WSR) zones, these being defined units with known apportionment of District Meter Areas (DMAs).

Figure 13 Approach to review and revise demand profiles for behavioural modelling



Stage 1 - Review WRZ-level DI, select appropriate annual profile for each supply area (Central, Eastern and Western)

Stage 2 – Aggregate daily DMA demand data up to WSR zones (~160 WSR zones)

Stage 3 – Assess peak and average demand for each WSR zone ("peakiness analysis") using aggregated profiles from Stage 2

Stage 4 - Calculate percentage split for each WSR zone for average and peak demand across a WRZ using results from Stage 3

Stage 5 - Adjust annual WRZ profile to WRMP19 base year (2016/17) peak and annual average demand. Apportion WRZ profile from Stage 1 across WSR zones according to peak and average percentage splits from Stage 4.

Stage 6 - Generate input files for Aquator by normalising annual WSR zone profiles from Stage 5 to average demand for each WSR zone.

Figure 14 Demand profiles for Eastern area 2010-11

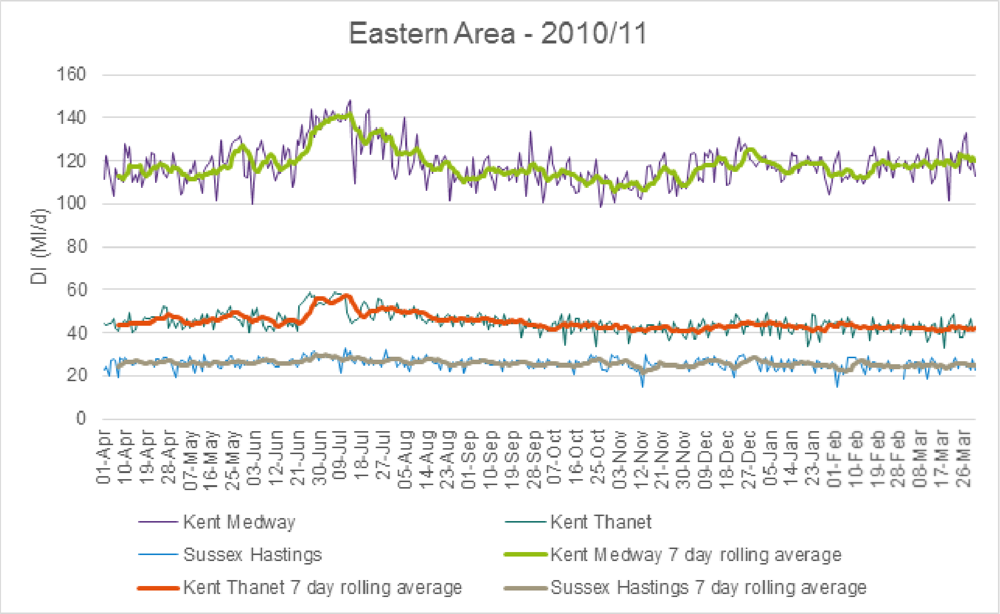


Figure 15 Demand profiles for Western area 2015-16

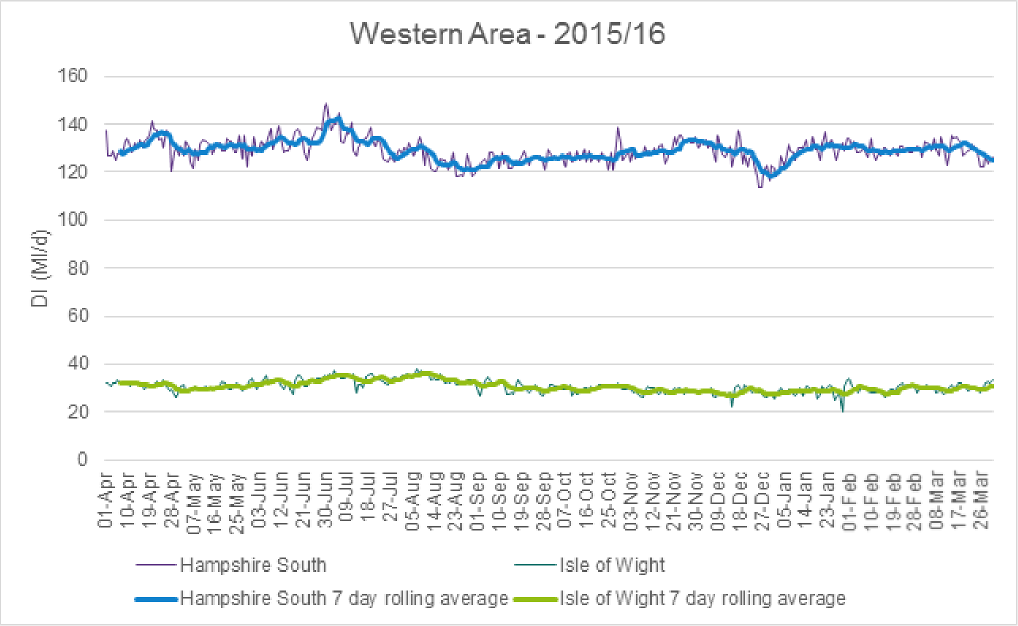
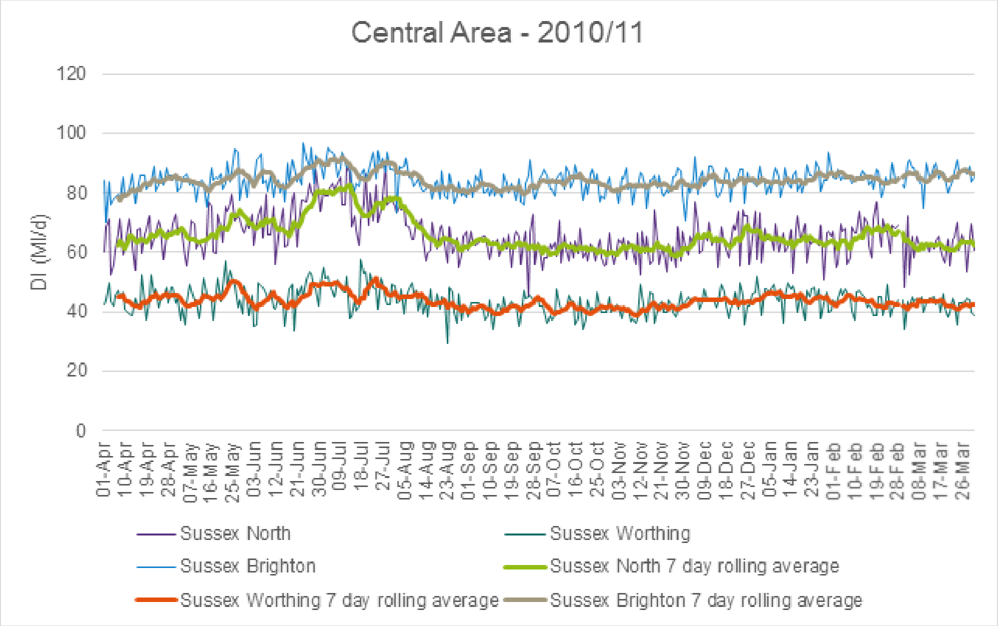


Figure 16 Demand profiles for Central area 2010-11



3.5.7 Operational control rules

The operation of reservoirs varies according to demand, the time of year, prevailing hydrological conditions and the amount of water in storage. Towards the end of a recharge season, if the reservoir is nearly full, then pumped recharge to the reservoir may be stopped on the basis that recharge from the natural catchment is likely to fill the reservoir to its maximum capacity. Conversely, if the supply area has been experiencing a lack of rainfall and reservoir stocks are lower than normal, then the utilisation of the reservoir may be restricted and alternative sources used as much as possible to conserve reservoir storage.

As discussed in the ‘Handbook of Source Yield Methodologies’ (UKWIR 2014, p. 160), these changes in operational activity may be defined and modelled by the use of operational control curves. These reflect a change in operational behaviour when reservoir storage is above or below a specific control curve. The rules are generally defined using annual profile so that behavioural changes follow the changes in risk occurring throughout the year with normal drawdown and refill rates. The operational control curves for the reservoirs are presented and described in more detail in Appendix D.

3.5.8 Drought triggers and drought interventions

Trigger curves are used in relation to reservoir storage and river flows to monitor and control the transition from periods of ‘normal operation’ to ‘impending drought’ then to ‘drought’ and ‘severe drought’. These trigger curves were developed as part of the Drought Plan process (Southern Water, 2018). We use triggers related to surface water resources in Aquator to simulate the timing and duration of drought interventions such as Temporary Use Bans (TUBs), Non Essential Use bans (NEUs) and Drought Permits.

In the Eastern area, the key triggers are applied in relation to the storage levels in Bewl Water. In the Central area, the triggers are implemented in relation to the flows in the River Rother at Pulborough. In the Western area, triggers have been developed for the River Itchen at Allbrook and Highbridge.

The trigger curves are used to apply the assumed demand reductions which may be expected to occur when drought demand management activities are implemented. These can include Level 1 TUBs and Level 2 NEUs. Other drought interventions can also be modelled in Aquator such as specific changes to licence conditions which may be implemented under Drought Permits, which are set out in our Drought Plan (Southern Water, 2018). The triggers used are presented in Appendix D.

The model runs for the baseline DO assessments have been carried out without demand restriction factors relating to TUBS or NEUs implemented. Separate model runs were conducted to assess the benefits of TUBS and NEUs and these have been represented in the investment model as separate options.

We discuss the benefits of demand restrictions as applied in surface water and groundwater dominated zones in Section 4.1.

3.5.9 Modelling of drought measures

The Water Resource Planning guidelines (Environment Agency, 2017) allow water companies to take account for the benefit of demand restrictions in their DO forecasts. These benefits reflect that storage, either reservoir or groundwater, can be conserved by reducing demand in drought by implementing restrictions.

Model runs were the baseline DO (without triggering drought demand restrictions). We undertook more runs to assess the DO benefits of TUBs, NEU bans and Drought Permits. The impacts of TUBs and NEUs are modelled as a reduction in demand within the model and are applied in relation to drought trigger curves based on reservoir storage or river flows.

The drought trigger control curves were those set out in our draft Drought Plan (Southern Water, 2018), which are shown in Appendix D. The demand reduction benefits of TUBs are therefore evaluated within Aquator and reflected as a higher DO than without TUBs. Drought Permits were modelled as the specific changes in licence conditions as set out in our draft Drought Plan.

3.5.10 Levels of service

For the final Plan, we assessed DOs without the benefits of restrictions. The benefits were then added where relevant using the analysis set out in Appendix E (Atkins, 2017b) (See Section 4). Our target levels of service have not change from our previous plan (Southern Water 2014), and are set out in Table 30 and described in Annex 1. Our levels of service for less severe demand restrictions (TUBs and NEU bans) are much lower than for loss of supplies because the conditions that indicate a severe (e.g. 1 in 200 or 1 in 500 year) drought event may occur happen much more frequently than the drought event itself. This issue is discussed in detail in relation to each of our supply areas in Appendix C02 of our 2014 WRMP (Southern Water 2014).

Table 30 Target levels of service

Type of restriction or measure	Annual probability	Frequency (return period)
Customer target level of service		
Advertising to influence water use	20%	1 in 5 year
Temporary Use Ban on different categories of water use (Section 76)[3]	10%	1 in 10 year[1]
Drought Order (Non Essential Use Ban on different categories of water use) to restrict water use (Section 74(2)(b))[4]	5%	1 in 20 year[1]

Emergency Drought Order to restrict water use (rota cuts and standpipes) (section 75)[4]	0.2%	Only in a civil emergency (1 in 500 years)
Environmental target levels of service		
Application for Drought Permit/Order to increase supplies through relaxation of licence conditions, increase in licensed quantities, or other measures[2]	5%	1 in 20 year
Implementation of Drought Permit/Order to increase supplies through relaxation of licence conditions, increase in licensed quantities, or other measures[2]	0.5%	1 in 200 year

[1] Frequency of first implementation but would be introduced via a phased approach

[2] For Hampshire Southampton East and Hampshire Southampton West WRZs we expect the short term level of service for these Drought Permits and Orders to be less than our target

[3] The Water Industry Act, 1991, HMSO

[4] The Water Resources Act, 1991, HMSO

3.5.11 Assessment of deployable outputs

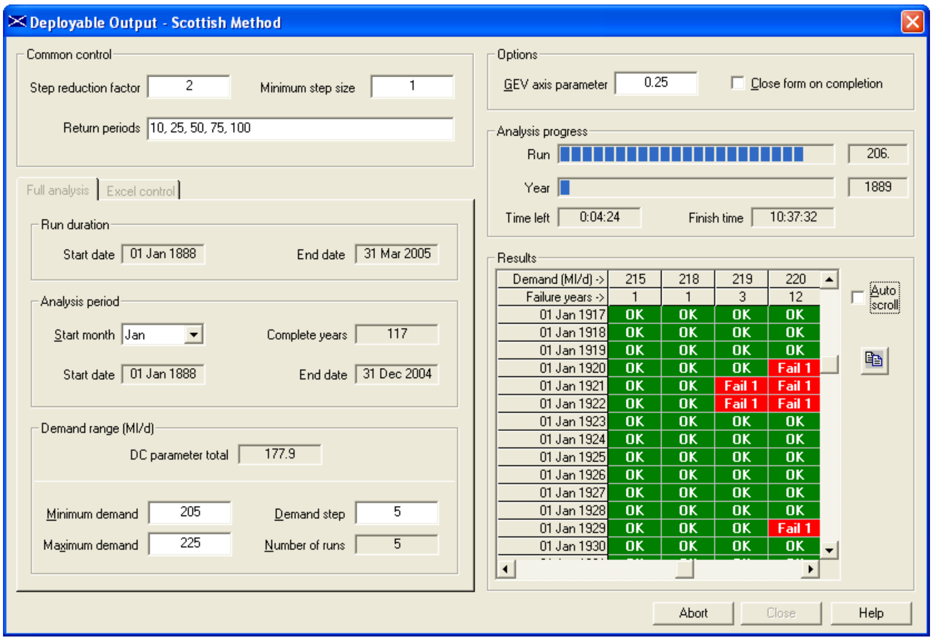
The assessment of conjunctive-use and surface water DOs used the in-built functionality of the 'Scottish Method DO' analyser, which is a standard analyser module in Aquator. By this approach the Aquator model repeatedly runs through the full hydrological sequence (2000 years for the stochastic hydrology records) for a range of different overall demand levels. As the overall demand levels are changed, the individual demands for selected demand centres are incrementally increased. The analyser counts and reports the number of days with failures (i.e. when there are insufficient resources to meet demand) in each year for each demand level.

Years with failures are defined as instances when demand is unable to be met at a demand centre in the model for one or more days of the year, with failures caused by a lack of resources, for example depletion of a reservoir, or insufficient river flows. Checks were made during the model development, and analysis of the outputs to check the failures reported by the DO analyser were the result of resource failures.

The output from the Scottish method analyser is a matrix of increasing demands and an indication of which years in the sequences have failed to meet the demand, as shown in . The available yield (DO) for each year is equal to the demand increment just below the lowest level of demand that it failed to meet. The matrix can be output and analysed to estimate the return period of DOs based on the ranking of the years in the 2000-year sequence. This method is described in the WRMP 2019 Methods - Risk Based Planning guidance (UKWIR 2016b, pp. 64-65).

This method was used to calculate DOs for these return periods:
1 in 2 years
1 in 20 years
1 in 50 years
1 in 100 years
1 in 200 years
1 in 500 years

Figure 17 Example of model set-up and output display for Scottish Method analyser in Aquator



Step reduction factor: 2
Minimum step size: 1
Return periods: 10, 25, 50, 75, 100

Run duration
Start date: 01 Jan 1888
End date: 31 Mar 2005

Analysis period
Start month: Jan
Complete years: 117
Start date: 01 Jan 1888
End date: 31 Dec 2004

Demand range (Ml/d)
DC parameter total: 177.9
Minimum demand: 205
Demand step: 5
Maximum demand: 225
Number of runs: 5

GEV axis parameter: 0.25
☐ Close form on completion

Run: 206.
Year: 1889
Time left: 0:04:24
Finish time: 10:37:32

Demand (Ml/d) ->	215	218	219	220
Failure years ->	1	1	3	12
01 Jan 1917	OK	OK	OK	OK
01 Jan 1918	OK	OK	OK	OK
01 Jan 1919	OK	OK	OK	OK
01 Jan 1920	OK	OK	OK	Fail 1
01 Jan 1921	OK	OK	Fail 1	Fail 1
01 Jan 1922	OK	OK	Fail 1	Fail 1
01 Jan 1923	OK	OK	OK	OK
01 Jan 1924	OK	OK	OK	OK
01 Jan 1925	OK	OK	OK	OK
01 Jan 1926	OK	OK	OK	OK
01 Jan 1927	OK	OK	OK	OK
01 Jan 1928	OK	OK	OK	OK
01 Jan 1929	OK	OK	OK	Fail 1
01 Jan 1930	OK	OK	OK	OK

The Scottish method counts failures on an annual basis, with the number of failures separately recorded for each year. A number of our supply systems are more vulnerable to longer-term multi-year drought events. The DO of a particular drought is generally represented as the minimum DO reported during any one year of that drought. We have examined the characteristics and durations of the key 'design' drought events for each of the areas, presented in Section 4.5.3. This section discusses the duration and severity of the 'design' droughts, and how the groundwater and surface water resource systems characteristically respond to various types of droughts.

For the Eastern area, more analysis was required to take account of operational management of the reservoirs - we have described this in the section below.

3.5.12 Modelling of the Eastern area

The Aquator modelling for the Eastern area concentrated on analysis of the connected surface water resources of Bewl Water and the River Medway Scheme, Darwell reservoir and Powdermill reservoir. These resources are split across two WRZs, with the River Medway Scheme (RMS) in Kent Medway West WRZ, and Darwell and Powdermill reservoirs in Sussex Hastings WRZ. There is a bulk transfer from Bewl to Darwell which can be used to supplement storage in Darwell if required.

Bulk transfers

There is a bulk supply agreement with South East Water for them to abstract a maximum of 8Ml/d from Darwell reservoir.

South East Water also have a 25% stake in the River Medway Scheme and are entitled to 25% of the DO. They take this water from their own abstraction point at Bewl Water as well as in the form of a treated water bulk supply from a WSW near Rochester. For the purpose of resource modelling, the apportionment of the three supplies from the RMS are split as follows:

SEW abstraction at Bewl Water	10.75%
SEW from treated bulk supply at a WSW near Rochester	14.25%
Southern Water at a WSW near Rochester	75%

Representation of operational reservoir management

The treatment works associated with the Bewl-Darwell system have significant excess capacity in relation to their ADO, and reflect the fact that the original system yield had been assumed to be higher than the more recent (AMP4 and AMP5) modelling has shown it to be. This is demonstrated by the large PDO: ADO ratios for those sources. This means that there is both significant spare capacity in the works, and the overall supply system is designed to push water from Bewl out towards the eastern and western parts of the Medway WRZ. This has significant practical implications, as under 'normal' year conditions. Both, Southern and South East Water use Bewl at higher outputs than could be achieved under drought conditions, partly because the WSW near Rochester works is less prone to outages than the groundwater sources in the area. The system can be managed down to its 'design DOs' during drought situations, but it is impractical to manage the system this way during the majority of more normal years. This means that demand on the reservoir tends to be higher than the theoretical 'design DO' during non-drought periods, and hence storage at Bewl as the system enters a drought situation tends to be lower than the theoretical levels suggested by conventional water resource modelling approaches.

An 'Operational Drought Bounding Curve' (ODBC) has therefore been defined and used represent the point at which the operation of the RMS is reduced from 'normal year' operations down to drought conditions. This feature was modelled using a three step approach to define the DO.

Calculation of conjunctive-use DO for Bewl, Darwell and Powdermill

There were a number of steps in calculating the DOs of the reservoirs and the River Medway Scheme of the Eastern area.

Calculation of conjunctive RMS, Darwell and Powdermill DOs

1) A DO analysis was run for the full 2000 year stochastic sequence (Scottish method), including the imposition of TUBs) to calculate the regulated DO for the full range of drought events and to rank each year by drought severity.
2) The system was modelled for the full stochastic time series at a level of output that was equal to the lowest level of demand that is normally placed on Bewl outside of drought periods. A control curve was developed from this - the 'Operational Drought Bounding Curve' (ODBC). This reflects reservoir levels at Bewl that are breached once every 5 years, and therefore represent the operational change from 'normal' to 'dry' conditions (as per the 'impending drought' trigger within the Drought Plan (Southern Water, 2018).
3) For each severe synthetic drought, the time at which this curve was breached on a sustained basis was noted, and reservoir levels at Bewl, Darwell and Powdermill were set as the starting point for an England and Wales method analysis of that drought.
4) The operationally realistic DO for the Bewl-Darwell-Powdermill system was taken as the England and Wales method DO run for each drought sequence based on these starting storage values.
5) The 2000 year DOs could then be adjusted to account for the operational impacts to develop the DOs for the combined Bewl-Darwell-Powdermill system for the full range of droughts throughout the sequence.

Calculation of source DOs

Steps 1) to 5) above allow the calculation of the conjunctive use DO of the combined surface waters of Bewl, Darwell and Powdermill.

6) 2000 year Scottish method assessments of the DOs of the RMS and Darwell reservoir systems were conducted for these systems in isolation. The ratios between the isolated DOs were then used to apportion the overall conjunctive-use DO between the three reservoirs so that the individual DOs for each source can be produced.

Adjustment of RMS DO to account for supplementary licence conditions

7) A revised licence for the RMS has been under discussion with the EA and was issued in November 2017. All modelling work was done based on the proposed new licence conditions. The yield benefit of the new licence had been calculated as 2.2Ml/d during modelling undertaken during 2016. This was therefore subtracted from the DOs calculated for droughts with 100-year return period or greater. A draft licence was issued by the EA after the yield assessments were complete. This revision includes conditions whereby if water quality metrics in relation to Dissolved Oxygen are breached then the licence must revert to the original conditions. There is a risk that these conditions would be breached during a severe drought, and therefore the yield benefits of the new licence cannot be relied on.

TUBs, NEUs and Drought Permit benefits

8) Extra runs were conducted to assess the benefit of applying TUBs and NEU restrictions as well as a Drought Permit to reduce the MRF at Teston. This was applied by assuming that such measures would be imposed 90 days after the TUBs ban.

More information about how the Eastern area surface water systems are modelled in Aquator is presented in Appendix D.

3.5.13 Modelling of Sussex North WRZ

Sussex North WRZ includes a number of groundwater sources as well as the surface water sources from River Rother, the River Arun abstraction, and Weir Wood reservoir. There is also a bulk supply from Portsmouth Water, as well as an export to South East Water, which is supplied from Weir Wood reservoir. There is an inter-zonal bulk transfer between Sussex North and Sussex Worthing WRZs, which can operate in either direction depending on relative resource requirements. The critical sources within the WRZ relate to the moderately ‘flashy’ nature of the River Rother source, the high yield of the Pulborough groundwater source in relation to accessible storage, and the flashy nature and limited refill potential of Weir Wood reservoir.

We have individually assessed the DOs of the groundwater sources in Sussex North WRZ as described in Section 4.3.1. In the main, the groundwater source yields are independent of hydrological conditions and the DOs do not vary for droughts of different severity.

The River Arun abstraction is in the tidal reach of the river but it is supported by wastewater treatment works (WTW) discharges from in the upper part of the catchment. The yield of this abstraction is therefore not constrained by drought, and the ADO/MDO are constrained at 10Ml/d by the licence, and the PDO is constrained at 15 Ml/ by the volume of bankside storage, whereby the stored water may be used to supplement the river abstraction to meet peak demands for a short period.

The groundwater source yields were configured in Aquator, and the WRZ was modelled using the 2000 year hydrological sequences to evaluate the overall conjunctive yield of the combined sources within the zone. The combined yield of Pulborough surface water abstraction and Weir Wood reservoir is established as the residual of the conjunctive DO for the WRZ minus the DOs of the individual groundwater abstractions and the River Arun abstraction.

A mechanism was required to apportion the calculated combined DO of Weir Wood and Pulborough surface water between the two sources. The South East Water bulk supply can only be sourced from Weir Wood Reservoir and for the purpose of the assessments, it was assumed that the bulk supply volume would be used as the basis of the minimum DO for Weir Wood, with the residual used to calculate the DO for Pulborough – a similar mechanism as was used to apportion the individual surface water source DOs in the Medway West and Hastings WRZs from the conjunctive DO figures.

For the most severe droughts (i.e. at greater than 1 in 500 year return period for baseline scenario), both the Pulborough surface water and Weir Wood sources would be likely to have failed, which drives the significant drop-off in DO for these events. Under these conditions it must be assumed that the bulk supply to SEW would be unavailable.

3.5.14 Modelling of the Isle of Wight at Sandown

The DO of the Sandown surface water abstraction on the Isle of Wight WRZ has been assessed in isolation (i.e. including the Eastern Yar augmentation scheme, but not including other sources in the WRZ).

The Sandown surface water abstraction and Eastern Yar augmentation scheme are modelled in Aquator using VBA. The configuration of the model has not been changed from when the model was developed for WRMP14, and is described in Atkins 2013d, and summarised in Appendix D.

The model was updated with revised demand profiles developed for the demand centres at Cooks Castle and Brading. Updated demand profiles and average demand values were generated for each demand centre, based on the aggregated DMAs and associated WSRs.

The model has also been updated with updated hydrological flow sequences from the revised stochastic sequences developed for AMP6. The updated daily stochastic rainfall and PET time series were input into existing Catchmod models for the three flow gauges in the system (Eastern Yar near Alverstone, Medina at Blackwater and Medina at Shide) to produce 2000 year naturalised flow time series. The flow time series were then denaturalised using monthly values of abstraction and discharge.

The DO was assessed using the Scottish method, as implemented in Aquator.

Temperature related constraints on the treatment capacity of the Sandown works have meant that the works has had a maximum capacity at the works as set out in Table 31. The DO analysis was run with the 8/10/12Ml/d constraint on the Sandown works applied during post-processing so that the hydrological constraints could be fully explored, up to the 18Ml/d daily licence.

The findings of the modelling were that the MDO at Sandown is constrained by the winter treatment constraints at 8Ml/d and the PDO is constrained at 12Ml/d.

Table 31 Annual works-constrained DO profile for Sandown

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Ml/d	8	8	10	10	10	12	12	12	10	10	8	8

3.6 Methodology for modelling the impacts of climate change on water resources

This section examines the potential impacts of climate change on our water resources supply over in the next 50 years. Our climate change vulnerability assessment (Annex 1.2) indicated that impacts of climate change are variable across our supply areas. Zones where infrastructure or licence constraints dominate tend to show little vulnerability, whereas zones where DO is predominantly constrained by hydrogeological and hydrological yield are much more vulnerable, especially where surface water is a large proportion of overall supply.

To reflect the high vulnerability of some zones we have adopted one of the more advanced approaches set out in EA Guidance (Environment Agency, 2013a). The use of this methodology, outlined in Annex 1.2 builds on the methods we developed for WRMP14.

In summary, we have derived "smart" samples from the UK Climate Projections (UKCP09) probabilistic projections at a river basin scale. This sampling has been based on a rapid assessment of the impacts of climate change on drought indicators, specifically hydrologically effective rainfall by perturbation of two major historic droughts events:

The 1918-22 drought, which forms the former historic design drought for the western and Central areas
The 1900-1903 drought which was the former historic design drought for the Eastern area

This section describes how we have sampled the UKCP09 probabilistic data to evaluate drought indicators and generate "smart" samples. The samples have been reviewed against the parent UKCP09 dataset to evaluate their overall credibility. We have then applied perturbations of key climate variables (rainfall and PET) to input sequences to our water resource models to derive climate change perturbed estimates of flows and groundwater levels. This allows us to calculate DO under the influence of climate change in line with the same procedures as outlined in Section 3.3 and 3.4. Comparing these data to the baseline (no climate change) forecast allows us to derive the overall impacts of climate change under a range of possible scenarios.

3.6.1 UKCP09 datasets used

The initial step in our analysis was to download the UKCP09 datasets. These data are available at the UKCP09 User Interface (http://ukclimateprojections-ui.metoffice.gov.uk/ui/). The UKCP09 data we have used in our analysis are subject to copyright and must be acknowledged as follows:

> © Crown Copyright 2009. The UK Climate Projections (UKCP09) have been made available by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC) under licence from the Met Office, UKCIP, British Atmospheric Data Centre, Newcastle University, University of East Anglia, EA, Tyndall Centre and Proudman Oceanographic Laboratory. These organisations give no warranties, express or implied, as to the accuracy of the UKCP09 and do not accept any liability for loss or damage, which may arise from reliance upon the UKCP09 and any use of the UKCP09 is undertaken entirely at the users risk.

After UKCP09 Data Licence (2014).

Data for 6 scenarios of the UKCP09 probabilistic projections were used in our assessment, associated metadata are summarised in Table 32. The final data used in our assessment were accessed and downloaded from the UKCP09 user interface in March 2017.

A number of variables were common to all scenarios in terms of the data type, climate variables used, and time period. All three emissions scenarios, which related to the rate of CO_2 emissions from the UKCP09 data (high, medium and low) have been evaluated. The principal differences between the datasets are the spatial extent, covering the "South East" and "Thames" River Basins. The South East River Basin data covers the majority of our water resource supply areas, including the entire Western and Central area, the River Medway Catchment and Kent Thanet WRZ. The Thames River Basin covers the Chalk Aquifer outcrop that supplies groundwater sources in Kent Medway East and Kent Medway West WRZs.

Four key climate variables have been used that reflect the key climate indicators found in our climate change vulnerability assessment:

Change in mean daily temperature by month (expressed as the anomaly from baseline in ^oC)
Change in minimum daily temperature by month (expressed as the anomaly from baseline in ^oC)
Change in maximum daily temperature by month (expressed in oC)
Change in Monthly Precipitation (expressed as % of Baseline rainfall)

Table 32 Summary Metadata of the UKCP09 datasets used in our climate change impact assessment

Dataset	SEE High	SEE Med	SEE Low	THA High	THA Med	THA Low
UKCP09 Dataset	Probabilistic Projections over land					
Climate Variables	Anomaly in Mean Daily Temperature Anomaly in Min Daily Temperature Anomaly Max Daily Temperature % Change to Monthly Rainfall					
Emissions Scenario	a1fi (High)	a1b (Medium)	b1 (Low)	a1fi (High)	a1b (Medium)	b1 (Low)
Time Period	2070-2099					
Spatial Averaging	River Basin					
Time Averaging	Monthly Data					
Location	South East	South East	South East	Thames	Thames	Thames
Sampling	All Data					

These datasets were collated into two spatial datasets, the first covering the South East and the second the Thames River Basin Regions, each comprising 10,000 replicates for each emissions scenario and 3 emissions scenarios for a total of 30,000 replicates for each region. As discussed in Annex 1.2, the emissions scenarios are considered equally probable under the UKCP09 framework, though the climate change guidance only specifies use of the medium emissions scenario data. Some samples from the high and low emissions scenario show "drier" rainfall impacts than the medium scenario and hence in our screening evaluation we have considered all three emissions scenarios.

3.6.2 Evaluation of drought indicators

The ensemble climate change data comprise some 30,000 potential scenarios for each River Basin region. Given the computational resources and run time required to process any given climate sequence through our water resource models it is simply impractical to fully evaluate the full range of UKCP09 climate projections. Instead we have employed a relatively simple and rapid screening procedure.

We have followed approach 2.2 of the Environment Agency (2013) climate change guidance reflecting our medium to high vulnerability. This requires us to evaluate the response of drought indicators to climate change perturbations and thereby sub-sample these data to a more manageable number of replicates that still represent the underlying variability of the full data set.
For the south east England data set covering the Western, Central and some of the Eastern areas, where supplies are predominantly groundwater the drought indicator we have used is the 24 month hydrologically effective rainfall (HER) which we have taken to be a proxy of groundwater recharge. Our vulnerability assessment and past experience has established that our Chalk groundwater dominated zones tend to be relatively resilient to short (<18 month) duration droughts but are more vulnerable to multiple dry winters (24-36 month events). For each climate change replicate the 24 Month HER was evaluated as it would have been in October 1921 which was the peak of the 1918-1922 drought. This drought event was the previous “worst historic” design drought for the Western and Central areas and is recognised as a severe drought event in the Eastern area (see Annex 1.2).

Two baseline climate time series were obtained, these were then subsampled to cover the 1918-1922 drought period:

Daily rainfall was obtained from the Met Office Hadley Centre South East England Precipitation (SEEP) dataset. This is an aggregated rainfall data set of around the same spatial extent as the South East England River Basin dataset in UKCP09.
Historic temperature data were taken from the Met Office Central England Temperature Series (REF). Again this is a spatially aggregated data set that gives a reasonable approximation of historic temperature.

To evaluate the HER drought indicator response this procedure was employed.

1. The SEEP rainfall time series data were perturbed by the monthly rainfall change factors in a single UKCP09 replicate.
2. The baseline temperature data were also perturbed by applying the temperate anomalies in the same UKCP09 replicate used to perturb rainfall.
3. A Penman-Monteith calculation of PET (PET), in line with the procedure outlined in FAO Irrigation and Drainage Paper 56 (FAO, 1998)
   a. This procedure assumed equivalent PET of grass at a latitude of 51oN, consistent with our supply area.
   b. Perturbed Minimum, mean and maximum daily temperature were used in the calculations.
4. Monthly HER was calculated as the difference between the perturbed rainfall and estimated PET sequence and aggregated up to 12 month, 24 month and 36 month totals
5. The results were saved and the procedure repeated for each of the 30,000 replicates in the entire dataset.

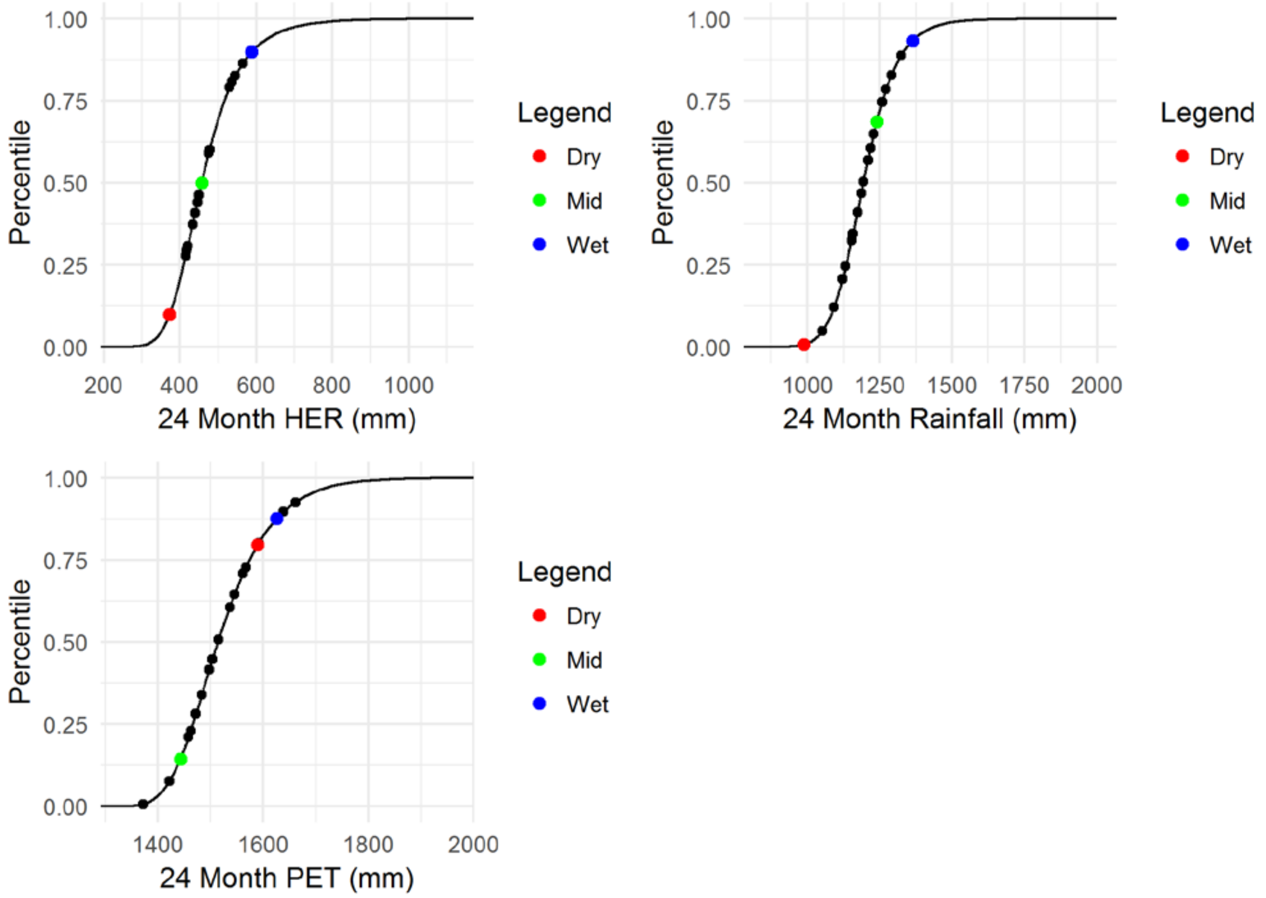
This procedure was automated using the programming code R which allowed relatively rapid evaluation of HER response for the entire dataset. The same procedure was also followed for the Thames River Basin region data, but this time using the 1904-10 drought. This is the former historic design event for the Eastern area.

3.6.3 Sampling of climate change perturbations

Once the HER drought indicator response variables were calculated the range of the data could be evaluated and appropriately sampled to a smaller number of replicates for water resource modelling.

The calculated 24 month HER drought indicator variables were ranked. The “Wet”, “Mid” and “Dry” climate change scenarios were then sub-sampled directly from the ranked data as the 10th, 50th and 90th percentiles (Figure 18). The upper and lower 10% were discarded as these cases are considered least likely, and generally data in the upper and lower 10th percentiles are of lower confidence and sensitive to assumptions in the UKCP09 methodology (Murphy et al, 2009). The “Wet”, “Mid” and “Dry” case therefore reflects the range and central estimate of the most likely data. Note that the “Mid” case does not reflect the most likely estimate, it simply represents the central estimate with half the scenarios being wetter, and the other half drier.

Figure 18 Distribution of 24 Month HER, PET and Rainfall from the Rapid Drought Indicator Assessment and Latin Hypercube Samples



An extra17 samples were then taken from the large dataset. This employed a Latin Hypercube “smart” procedure on the 24Month rainfall and PET totals in order to reflect the variability of these two datasets. We have shown the resulting samples for the South East River Basin in terms of 24 Month HER on Figure 18 and in their parent data on Figure 19.

These plots indicate some of the underlying variability and interactions of different climate change temperate and rainfall impacts. For example, the “dry” case has both relatively low rainfall and high PET. The “wet” case has both high rainfall and high PET, but as much of the “wet” case rainfall occurs in winter months when PET is low, the overall drought indicator response is much greater.

Figure 19 Range of UKCP09 Rainfall and Temperate Data and distribution of "smart" Latin hypercube samples (note upper and lower 10% excluded from sampling)

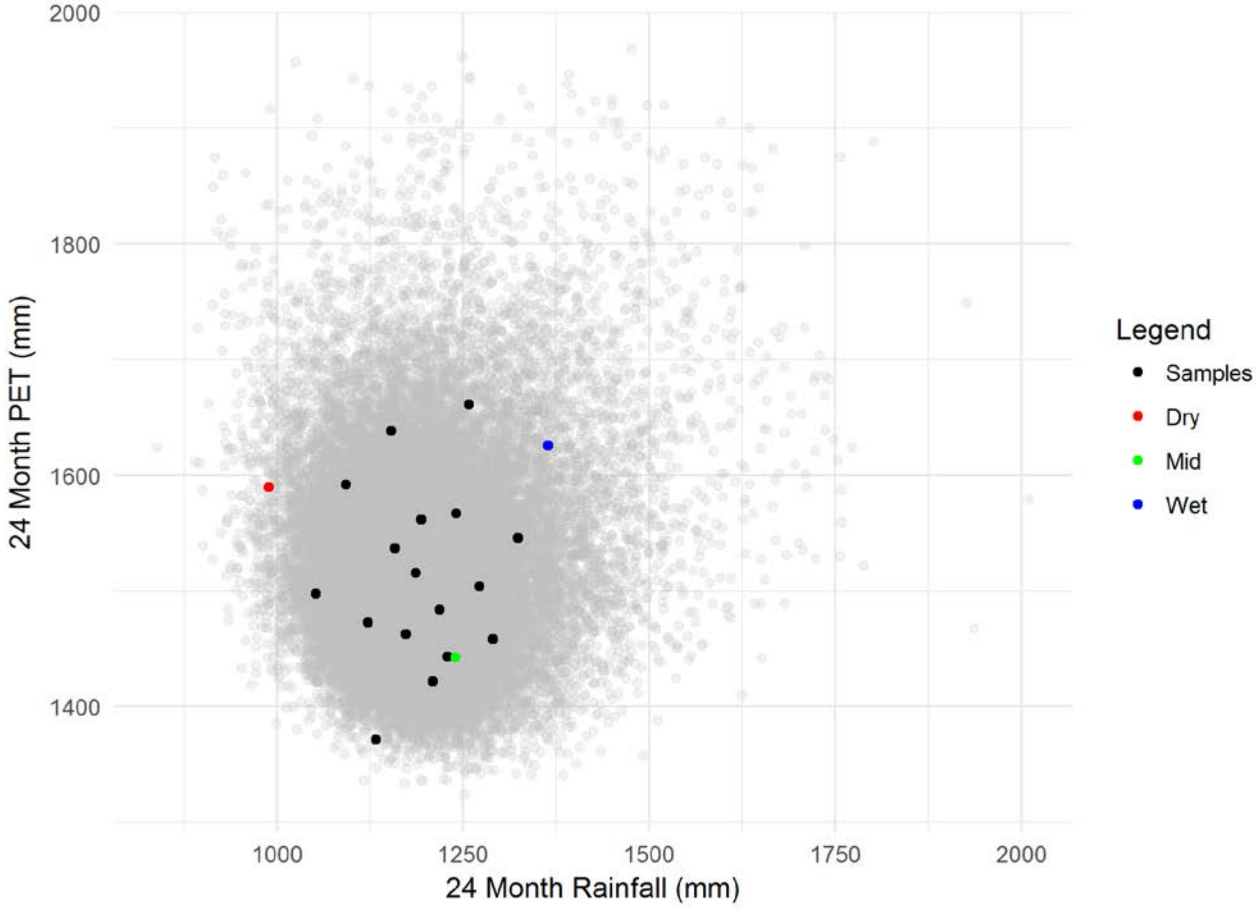
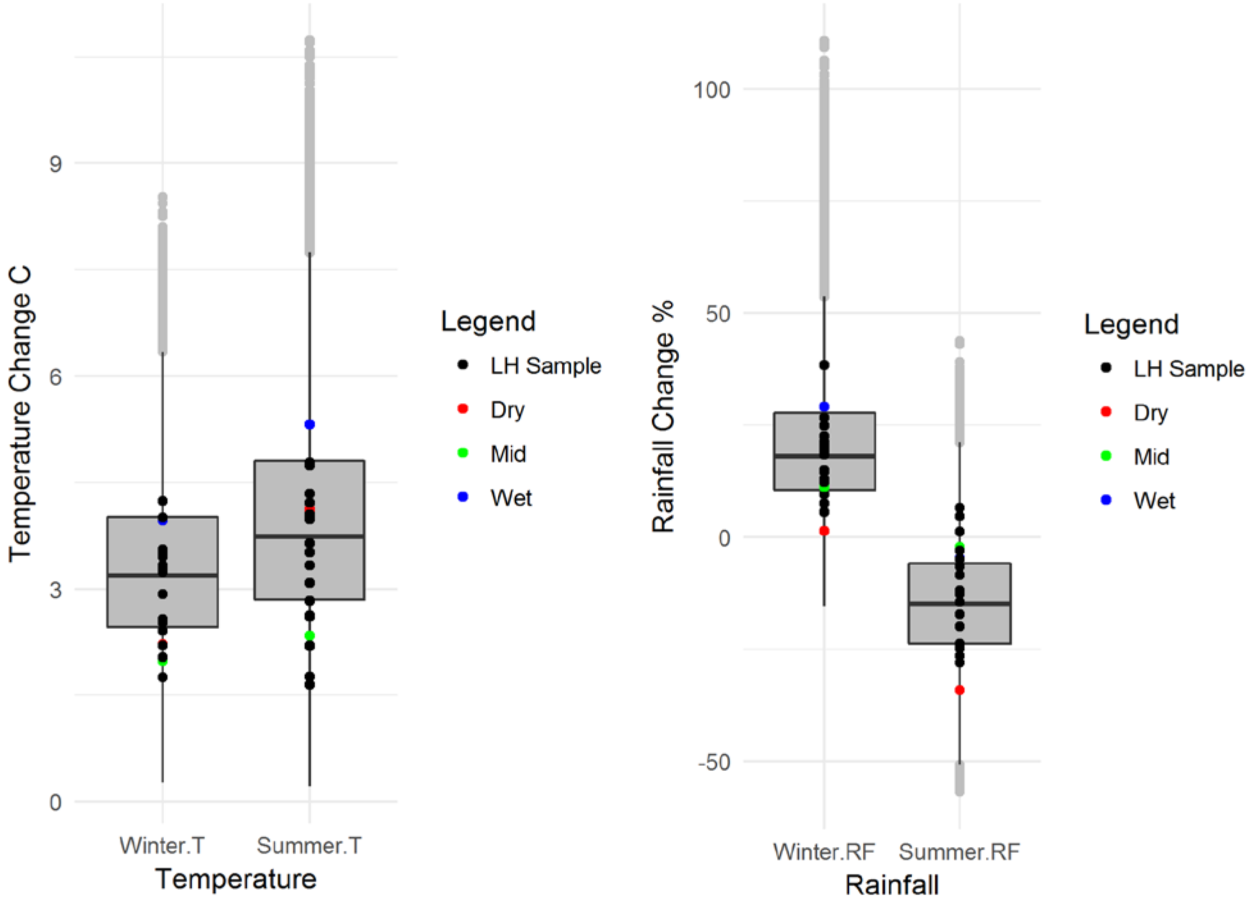


Figure 20 shows a final comparison between the selected samples and the parent UKCP09 Dataset. This shows that the range of summer and winter rainfall and temperature variations in the samples broadly reflects the range of the full UKCP09 dataset and covers the entire interquartile range of the data. Generally winter rainfall is forecast to increase while summer rainfall decreases. Both winter and summer temperatures are predicted to increase, translating to an overall increase in PET., as Changes to rainfall appear to be the most critical factor in terms of the drought indicator response. Consequently, if climate change follows the mid to wet trend forecast increases to winter rainfall may lead to improved water resource forecasts by the mid-2080s.

Figure 20 Box and whisker plots showing the range of the UKCP09 Temperature and Rainfall changes for the 2080s (South East England River Basin) in grey. Our Climate samples are overlain as points



3.6.4 Application to water resource models

As the UKCP09 impact data sets are available on a monthly basis the subset samples from the probabilistic data were converted to monthly perturbation factors on Rainfall and PET. We have applied these data as scaling factors to the synthetic 2000-year daily rainfall and PET sequence generated by the daily disaggregation step.

This process was repeated for each climate change scenario in order to create 20 new daily input time series. These data are in the same daily time series format to those produced by the synthetic weather generator and hence can be directly used by the existing water resource models.

Owing to the run time required and computational resources, it was not possible to run all 20 climate change scenarios through the majority of our water resource models. Instead, as a minimum, the “dry”, “mid” and “wet” scenarios were run through each of the groundwater and Aquator water resource models, in line with the same procedures as outlined in Sections 3.3, 3.4 and 3.5. This step allowed us to recalculate DOs taking account of the impacts of climate change.

We have aggregated these data up to a WRZ level and compared with the baseline DOs in order to estimate the overall impacts of climate change.

3.6.5 Scaling of climate change impacts

Scaling factors have been applied to each of the three climate change scenarios for WRZ estimate of DO. The scaling factor has been calculated in accordance with the EA guidance (Environment Agency, 2013) modified by the revised methodology set out by Charlton and Watts (2017).

Our climate change projections have used the UKCP09 probabilistic data sets for the period 2070-2099. This period includes the entire duration of our 50 year plan. The climate change perturbations and our assessment of DO for each scenario reflect the possible future DOs that we might expect, assuming that no other changes to our sources or new DO constraints emerge.

In order to incorporate the transient effects of climate change and to avoid large step changes in DO a linear scaling factor is employed that translates the forecast DO for the 2080s (2085), consistent with the UKCP09 projections, back to the base year of the WRMP (2016). The equation for this linear scaling factor is shown in Equation 2.

Equation 2 Equation for Scaling Climate Change Impacts (Charlton and Watts, 2017)

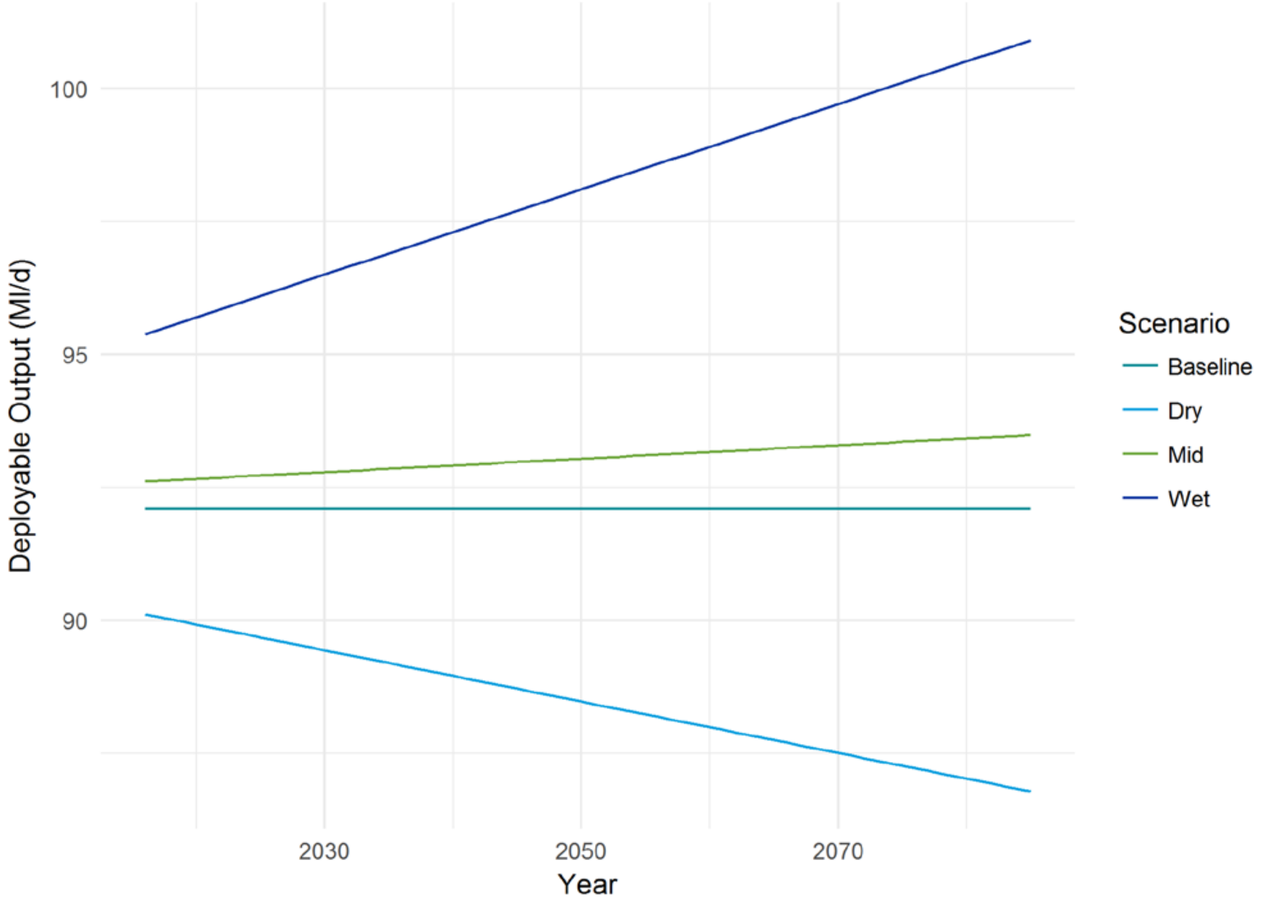
$$Scale\ Factor = \frac{Year - 1975}{2085 - 1975}$$

Where Year = the year of interest

Application of this scaling factor to our climate change projections recognises that UKCP09 projections are expressed as changes relative to as baseline of average conditions for the period 1961-1990. The years 1975 and 2085 represent the mid-point of the UKCP09 30 year time slices for the baseline and future projections respectively. The scale factor is such that 0% of climate change impacts occur in 1975 and 100% of forecast impacts occur by 2085. The calculation therefore recognises that some climate change has already occurred relative to the plan base year (2016) and allows climate impacts to be smoothly applied over the rest of the planning period.

The climate change impacts for each WRZ have been assessed according to this equation and are reported in the planning tables (. An example illustrating how the scale factor has been applied to an example WRZ (Sussex Brighton) is shown in Figure 21.

Figure 21 Example of Climate Change Scaling applied to 1 in 200 Year MDO for Sussex Brighton WRZ



3.6.6 Future climate change modelling approach

A requirement of the “Stochastic Refinement Plan” (Southern Water, 2014 – Appendix C03) was to consider if any improvements to the method for incorporating the effects of climate change within the weather generator were possible. In the 2014 WRMP climate change was considered through post processing perturbation of the long rainfall and PET time series based on factors derived from the UKCP09 probabilistic data sets (see Annex 1).

Newcastle University (Chris Kilsby, pers. comm.) have advised us of two potential methods for incorporating a climate change perturbation capability into the existing weather generator modelling:

> *“Neither is ideal, as they are both simplifications and it is currently not feasible to credibly achieve (a) reproducing the overall statistics of rainfall (e.g. monthly mean) obtained from climate models (GCMs) and (b) generating realistic inter-annual variability (IAV) and rainfall extremes as are found in the observed record.*
>
> *Method 1. Incorporate perturbations of covariates (e.g. sea level pressure patterns and sea surface temperatures) from the most recent climate models (CMIP5) to account for climate change within the rainfall modelling. Advantages include coherent changes of behavior of the rainfall model, but with no guarantee that the final rainfall statistics will match those of the GCM outputs.*
> *Method 2. To incorporate change factors of rainfall obtained from GCMs directly into the rainfall model. This could be done post-generation, i.e. as a forced bias-correction, with unpredictable effects on IAV and extremes. It would be more*

> *coherent to be done within the model parameterisation, but a suitable method has not currently been developed.*
>
> *A credible method for such an approach is a significant research task, which is nonetheless aligned with NU's research strategy"*

Given the timescales available to develop the method this approach will not be achievable for WRMP19. There may also be regulatory acceptance hurdles with both new methods as they are untested approaches to assessment of climate change impacts. It is anticipated by the end of AMP7 that ongoing research (e.g. MaRIUS, UKCP18) will be the foundation for greater advances in climate change impact assessment and therefore a watching brief should be maintained on the outcome of these projects with a view to refining the methodology for WRMP 2024.

We intend to enhance our Climate Change modelling approach in 2018/2019 pending the outcome of both the UKCP18 and MaRIUS research projects. A detailed method statement has not yet been developed but we expect to collaborate with existing consultants and Newcastle University in order to develop the most appropriate approach. The outcome of this project will inform our climate change modelling for our next Water Resource Management Plan.

3.7 Water quality impacts on deployable output

A number of our sources are at risk of a deterioration in raw water quality that could result in a loss of DO. Primarily these risks are from rising nitrate or pesticide concentrations that either cannot be effectively treated to required drinking water standards or where current treatment is forecast to be inadequate in the future because of rising concentrations. Either situation would require us to write down DO as it would result in that resource being unusable.

Nitrate trend modelling was undertaken as part of the AMP6 water quality NEP investigations. The modelling considered historic water quality data along with hydrographs from observation boreholes. The modelling produce a simulation of the observed seasonal variability and short and long-term water quality trends. We have used the outputs from the nitrate modelling, which takes into account the average age of water, to predict when the raw water abstractions would exceed the drinking water limit for nitrate concentrations.

These data were used in conjunction with a separate analysis undertaken by our Drinking Water Safety Plan team forecasting nitrate trends to predict impacts on water quality.

A predicted list of affected sources and the predicted timing and impacts on our DO are summarised in Table 33.

The final list incorporates the results of both modelling methods to forecast a date that water quality may be compromised. Assessing the current levels and the forecasted trend, a range of catchment management solutions were proposed depending on the scale of the issue and the strategic importance of the source.

Pesticides have the potential to affect a number of our surface water sources. Most pesticides can be treated using advanced treatment techniques (GAC) but metaldehyde is a pesticide which cannot be completely removed using current standard treatment technologies. Where we have assessed pesticides having the potential to affect surface water sources, we propose to manage the sources on a risk basis.

Public Health England have confirmed that the current metaldehyde concentrations seen in raw water pose no threat to public health but we must abide by the Water Supply (Water Quality) Regulations and the 0.1µg/l limit for metaldehyde.

To this end, where pumped-storage systems are at risk of metaldehyde, we have assumed that a smart abstraction approach would be implemented whereby reservoir refill would not be undertaken during October and November, which are the months when metaldehyde breaches are most likely to occur. Ceasing pumped reservoir refill if metaldehyde spikes will prevent accumulation of pesticide in the reservoir water bodies. The reservoir systems have been re-modelled with these restrictions to calculate the resulting loss in DOs.

Some of our run-of-river abstractions and on-line reservoirs have several days' capacity bank-side storage, others are direct abstraction from the river and cannot be switched off for more than 24 hours without customers going without water. Given this there are limited abstraction related remedial actions which can be taken to ameliorate the pesticide risk.

We are managing the risk as far as possible by trailing new treatment technologies, implementing smart abstraction to reduce the impact on our raw water resources from the initial metaldehyde peak after the first flush rainfall events. Blending with other lower metaldehyde concentration water is an option where available. We are delivering catchment management schemes to improve the resilience of our sources and to reduce the risks to water quality of all pesticides and these are automatically selected in our investment model. Given the complexities around treatment, the variables that can affect metaldehyde concentrations (application, rainfall events, hydrogeology etc.) and the drive from the company to manage the risk at source within the catchment we have not written down the DOs of our run-of-river sources, and therefore it is critical that this risk is controlled through catchment interventions.

These reductions in DO have been included in our baseline supply demand balance (Annex 5). Any catchment management or treatment solutions required to offset these losses in DO have been included as options in our options appraisal (Annex 6).

Table 33 Forecast Losses in deployable output because of raw water quality

Area	WRZ	Source	Year of DO Loss	Reason	Loss in DO (Ml/d)
Western	HR	Romsey	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO	10.8Ml/d
	HSE	Twyford	2021	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 23Ml/d
	HW	Winchester	2027	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 18.2Ml/d
	HSW	River Test Surface Water	2024	Deterioration in raw surface water quality from pesticides. Assume no DO loss but catchment management scheme selected anyway.	none
	IOW	Sandown	2024	Deterioration in raw surface water quality from pesticides. Assume no DO loss but catchment management scheme selected anyway.	none
Central	SN	Steyning	2034	Deterioration in raw groundwater quality from nitrate. Total loss of DO	1.3Ml/d
	SN	Pulborough Surface Water	2024	Deterioration in raw surface water quality from pesticides. Assume no DO loss but catchment management scheme selected anyway.	Deterioration in raw surface water quality from pesticides. Assume no DO loss but catchment management scheme selected.
	SN	River Arun Surface Water	2024	Deterioration in raw surface water quality from to pesticides. Assume no DO loss but catchment management scheme selected anyway.	none
	SN	Weir Wood Reservoir	2024	Deterioration in raw surface water quality from pesticides. Assume no DO loss but catchment management scheme selected anyway.	none
	SW	North Arundel	2027	Deterioration in raw groundwater quality from nitrate. Total loss of DO	4.1Ml/d
	SW	Long Furlong B	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 3.6Ml/d

Area	WRZ	Source	Year of DO Loss	Reason	Loss in DO (Ml/d)
	SB	North Falmer A	2027	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 6Ml/d
	SB	North Falmer B	2025	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 14.75Ml/d
	SB	Brighton A	2027	Deterioration in raw groundwater quality from nitrate. Total loss of DO	Up to 9Ml/d
Eastern	KMW	Strood	2027	Deterioration in raw groundwater quality from nitrate. Total loss of DO	2.3Ml/d
	KMW	River Medway Scheme	2024	Deterioration in raw surface water quality from pesticides. Restriction of pumped reservoir refill partially constrains DO.	Up to 4.45Ml/d
	SH	Darwell Reservoir	2024	Deterioration in raw surface water quality from pesticides. Restriction of pumped reservoir refill partially constrains DO.	Up to 1.32Ml/d
	SH	Powdermill Reservoir	2024	Deterioration in raw surface water quality from pesticides. Restriction of pumped reservoir refill partially constrains DO.	Up to 0.43Ml/d
	KT	Near Canterbury	2025	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 22Ml/d
	KT	Deal	2022	Deterioration in raw groundwater quality from nitrate, partial loss of DO owing to blending constraint.	Up to 4.32Ml/d
	KT	West Sandwich	2025	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 9.45Ml/d
	KT	Manston2	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 5.22Ml/d
	KT	North Dover	2030	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 1.2Ml/d
	KT	Ramsgate B	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 5.9Ml/d
	KT	Birchington	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	Up to 2.3Ml/d

Area	WRZ	Source	Year of DO Loss	Reason	Loss in DO (Ml/d)
	KT	North Deal	2022	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	4.9Ml/d
	KT	Sandwich	2025	Deterioration in raw groundwater quality from nitrate. Total loss of DO.	2.5Mld

4. Deployable outputs

This section summarises our outturn DOs that we have estimated for each WRZ resulting from the analysis and modelling described in Section 3.

Our review is summarised by WRZ and across our three main supply areas (see the Technical Overview and Annex 1).

In compiling this summary we have also highlighted where there are significant changes in Dos compared to our previous plan, for example because of licence changes, infrastructure constraints or deterioration in water quality.

For our fully risk based plan we have derived estimates of DO under a range of drought events of differing probability. In our DO summary we have presented DO for 5 different planning scenarios:

Normal dry year (50% annual probability)
1 in 20 year drought (5% annual probability)
1 in 100 year drought (1% annual probability)
1 in 200 year drought (0.5% annual probability)
1 in 500 year drought (0.2% annual probability)

4.1 Deployable outputs - effect of drought measures

4.1.1 Effect of supply side measures

Supply side drought measures, such as Environmental Drought Permits and Orders to temporarily relax licence conditions and increase abstractions have not been included in our baseline DO. This is consistent with the Water Resource Planning Guidance (Environment Agency, 2017).

Instead these supply side drought measures are included as options within our investment model. Each of the supply side measures is discussed in detail in Annexes 9 to 11.

4.1.2 Effect of demand restrictions

The Water Resource Planning guidelines (Environment Agency, 2017) allow water companies to take account of the benefit of demand restrictions in their DO forecasts. These benefits reflect that storage, either reservoir or groundwater, can be conserved by reducing demand in drought by implementing restrictions.

The assumptions made about the benefits of demand restrictions for drought interventions were reviewed and updated from our last plan. This analysis is described in full in Appendix E (Atkins, 2017b).

An empirical analysis was carried out to review the impacts of demand restrictions that were observed when restrictions were applied during the 2005-06 drought. The 2011-12 event was not considered suitable because of the exceptionally high rainfall that occurred almost immediately after the TUB was introduced. The methodology followed was broadly in line with the Drought Demand Modelling Guidance (Environment Agency, 2014). Some modifications were made with a minor change surrounding the inclusion of time of year/sunshine hours as an explanatory factor as well as a significant enhancement to allow a quantified analysis of the impact of metering on summer peak demand.

The modelling demonstrated that the ratio of summer demand to underlying (winter) demand has decreased because of the universal metering. The size of the summer peak (as calculated relative to winter 'MDO' demand) is about 35% smaller for the Western and Central areas and 60% smaller for the Eastern area than it was in the early to mid-2000s. This reduces the effectiveness of demand restrictions because discretionary use is now a smaller percentage of total demand (it is worth noting that there was no observable response to the 2005 hosepipe ban on the fully metered Isle of Wight).

The demand reduction factors for TUBs and non-essential use (NEU) bans are shown in Table 34 below.

Table 34 Assumed demand reduction benefits of TUBs and NEU drought restrictions (Appendix E)

	Eastern area		Central area		Western area	
Month	**TUBS**	**NEU**	**TUBS**	**NEU**	**TUBS**	**NEU**
Jan-April	0%	1%	2%	3%	1%	3%
May-June	1%	1%	3%	5%	2%	4%
July-Aug	3%	4%	5%	8%	5%	8%
Sep	2%	2%	3%	5%	3%	4%
Oct-Dec	0%	1%	2%	3%	1%	3%

In our zones dominated by surface water storage, the benefits of TUBSs on DOs are assessed using Aquator models which reduce the overall demand by the amounts set out in Table 34. This approach is described in Section 3.5.11.

For groundwater sources the benefits of restrictions must be applied with caution and will not apply universally. For examples, sources which are infrastructure or licence constrained cannot increase their DO under these conditions even if groundwater storage is conserved. There may also be hydrogeological characteristics of some aquifers that limit the effectiveness of storage, for example, the pattern of seasonal leakage in the coastal aquifer of the Brighton and Worthing Chalk.

For our draft plan we included the DO benefits of TUBs, where relevant, in our baseline DO forecasts. For our revised plan we have changed our approach. Instead of including the marginal benefits of demand restrictions within baseline DO we have instead calculated them separately. Both TUBs and NEU marginal benefits are instead included within the investment modelling as options (see Annex 6). For our draft plan only NEU bans were considered as options. This change was made so that we could assess sensitivity scenarios to our plan where demand restrictions would be unavailable.

Where relevant we have estimated the benefits of demand restrictions on DO for both surface water and groundwater sources. These have been calculated applied according to these criteria:

Only for drought events at return periods consistent with our levels of service, i.e. they are not applied to normal year DO, only for drought events (i.e. 1 in 20 year or less).
The magnitude of TUBs benefits for each area has been set according to the estimated benefits set out by Atkins (2017b). This assessed the effectiveness of restrictions for each WRZ given the high level of metering present.
Where sources are licence or infrastructure constrained no demand benefits are applied.
If a hydrogeologically constrained source has demand benefits applied the magnitude of the benefits is capped at the licence or infrastructure constraint and hence may not be fully realised.
Demand restrictions show differing seasonal impacts, and have been applied as follows (after Atkins, 2017b):
Peak demand benefits (at PDO) are based on the July-August assessment of effectiveness

MDO demand saving benefits are based on the October-December benefit, reflecting that minimum groundwater levels most commonly occur in the autumn.

For the Isle of Wight WRZ, which has been metered for substantially longer than other areas, the effectiveness of restrictions is likely to be less (Atkins, 2017b) and the profile for Eastern area has been used instead

Groundwater sources with an MRF or HoF constraint have been assumed to show some benefit, as groundwater storage is likely to serve to delay any flow constraint being reached.

The magnitude of demand restrictions, expressed as a percentage of DO are presented in Table 35.

Table 35 Summary of the effectiveness of demand restrictions, as applied to deployable output benefits (after Atkins, 2017b, Appendix E). Benefits are shown for TUBs and NEUs)

	Scenario	Western		Central		Eastern and Isle of Wight	
		TUBs	NEUs	TUBs	NEUs	TUBs	NEUs
	PDO	5%	8%	5%	8%	3%	4%
	MDO	1%	3%	2%	3%	0%	1%
	Return period	**TUBs**	**NEU + TUBs**	**TUBs**	**NEU + TUBs)**	**TUBs**	**NEU + TUBs**
DO Benefits at MDO / ADO (Ml/d)	**1 in 2 year**	0.00	0.00	0.00	0.00	1.00	1.33
	1 in 20 year	0.75	4.31	2.41	3.68	1.22	1.84
	1 in 50 year	0.61	2.97	3.01	4.68	0.97	
	1 in 100 year	0.72	2.24	4.62	7.26	0.97	1.76
	1 in 200 year	0.42	1.33	4.25	6.67	0.21	0.75
	1 in 500 year	0.14	0.47	5.18	8.17	0.70	1.38
	1 in 1000 year	0.04	0.17	1.12	1.67	0.71	2.27
DO Benefits at PDO (Ml/d)	**1 in 2 year**	0.00	0.00	0.00	0.00	0.00	0.00
	1 in 20 year	0.42	0.57	3.37	5.39	1.99	2.39
	1 in 50 year	0.41	0.56	3.19	5.10		
	1 in 100 year	7.47	11.87	3.04	4.86	1.97	2.44
	1 in 200 year	4.61	7.30	2.92	4.67	1.97	2.48
	1 in 500 year	2.40	3.75	2.75	4.39	1.90	2.38
	1 in 1000 year	1.46	2.26	2.55	4.07	1.90	2.36

These WRZ’s are where sources are entirely licence or infrastructure constrained have not been assigned any DO benefit from restrictions to demand:

Hampshire Kingsclere
Hampshire Rural
Hampshire Winchester

4.2 Western area

4.2.1 Isle of Wight WRZ

The baseline DOs for the Isle of Wight WRZ are shown in Table 36. For all zones we have calculated DO for our two critical scenarios, MDO and PDO. These are expressed in the tables for a range of probabilities/return periods but specific reference should be made to our baseline “Design” event of 0.5% annual probability, equivalent to a 1 in 200 year return period. There is around a 22% chance we would see at least one event of this severity within the lifetime of our 50 year plan. Table 28.

Note that for our previous plan our assessment of level of service for Drought Orders estimated that the necessary design DO was around 1 in 125 years in our Western area. For an easier comparison with our previous plan we have compared these data to our new 1 in 100 year DO estimates. Other minor changes reflect the inclusion of TUBs benefits into the baseline DO.

We have included zero DOs for four sources - Shalcombe, Ventnor1, Ventnor2 and Ventnor3. Ventnor2 and Ventnor3 were previously written down to zero in WRMP14 owing to low yields and poor water quality. Water quality constraints, low yields and overall network rationalisation will also result in the mothballing and abandonment of Shalcombe and Ventnor1 in AMP6 by 2020. Consequently, no DO is estimated for these sources.

We are building a new groundwater model of the Isle of Wight WRZ aquifers with a view to enhancing our DO assessment methodology for the WRZ. This will be most relevant for those sources which are constrained either by flow conditions or hydrogeological yield. We anticipate this groundwater model will be available to support our DO estimates for WRMP24.

Note that at Newport, the DO contribution from the gravity-fed collecting main was previously estimated using a minimum predicted groundwater level (i.e. the worst synthetic drought). Here it is compared to the newly estimated 1:100 drought event which has led to a slight increase in DO relative to our previous WRMP14 assessment.

4.2.2 Hampshire Southampton West WRZ

The DO for Hampshire Southampton West WRZ is supplied entirely from surface water on the River Test. This source is subject to licence changes under the EA RSA programme. The DO presented in Table 37 also shows that because of the 2017 licence changes, another licence condition will come into force occur in 2027. The impact of these sustainability reductions is discussed in Section 5.

4.2.3 Hampshire Southampton East WRZ

As with Hampshire Southampton West WRZ, sources in our Hampshire Southampton East WRZ are subject to licence changes under the EA RSA programme that has reduced their DO (Table 38).

There have also been changes to both our synthetic drought generation methodology, and the groundwater model used to derive DO for these sources. In combination these factors have led to substantial changes in DO, the vast majority of which is a consequence of the licence change. The impact of these sustainability reductions is discussed in Section 5.

4.2.4 Hampshire Winchester WRZ

For our Hampshire Winchester WRZ, a major change in DO relative to our previous plan is a reduction in the PDO of our Winchester source (Table 39). This reflects long term constraints on the treatment capacity of the works. Our review of past source performance also suggested its previous PDO at the licensed rate could not have been achieved.

DO from the other two sources in this WRZ are constrained by their abstraction licences. A previous demand constraint on Barton Stacey has been removed but there is limited network capacity to allow the water to be used efficiently away from the local supply area.

4.2.5 Hampshire Rural WRZ

For the Hampshire Rural WRZ, both sources are licence or infrastructure constrained. Long term outage, because of raw water quality, at our Romsey Source has resulted in a reduction in overall DO (Table 40).

4.2.6 Hampshire Andover WRZ

In our Hampshire Andover WRZ, Andover, Overton and Whitchurch sources are constrained by infrastructure of abstraction licences and hence there is little overall change to their DO (Table 41).

The most notable change is at Chilbolton, here DO has been reduced to zero to reflect problems with raw water quality owing to high nitrates that cannot be treated at the supply works.

The DO of our Near Whitchurch source has also been reduced owing to demand constraints. In this case, the source is capable of producing higher yields but these cannot be used at the moment because of the source location and existing infrastructure and network constraints.

4.2.7 Hampshire Kingsclere WRZ

There are only two sources in our Hampshire Kingsclere WRZ and under most conditions both are constrained by the existing infrastructure or abstraction licence. During the most severe drought event modelling has indicated that the Newbury source might become drought sensitive leading to a very small reduction in DO (Table 42).

4.2.8 Western area summary

The overall DO for our Western area is presented in Table 43. For most zones the changes to DO are relatively minor and generally reflect changes to infrastructure or raw water quality issues that have emerged since our previous plan. Some other minor changes reflect our updated synthetic drought and modelling methodology, but generally these are small compared to other constraints.

The most significant reductions in DO have occurred in the Hampshire Southampton East and Hampshire Southampton West WRZs because of major licence changes. Section 5 describes these licence changes and their impacts in greater detail and the uncertainty and challenges they introduce for our future planning is also discussed in greater detail in Annex 6.

Table 36 Summary of deployable outputs for Isle of Wight (IoW) WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Lukely Brook	1.50	1.50	1.50	1.50	1.50	1.50	3.00	3.00	3.00	3.00	3.00	3.00	Prescribed River Flow	Prescribed River Flow	0.00	0.00
Caul Bourne	0.97	0.97	0.97	0.97	0.97	0.97	1.05	1.05	1.05	1.05	1.05	1.05	Prescribed River Flow	Prescribed River Flow	0.00	0.00
Newport	10.66	10.56	10.41	10.36	10.32	10.26	13.17	12.37	11.90	11.82	11.67	11.41	Gravity flow & Pump Capacity	Gravity flow & Pump Capacity	-0.60	-1.33
Rookley	1.00	1.00	1.00	1.00	1.00	1.00	1.23	1.23	1.23	1.23	1.23	1.23	Prescribed River Flow	Prescribed River Flow	0.00	0.00
Newchurch (Chalk)	1.00	1.00	1.00	1.00	1.00	1.00	1.97	1.97	1.97	1.97	1.97	1.97	Pump Cut-off	Pump Cut-off	0.00	0.00
Newchurch (LGS)	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	Pump Capacity	Pump Capacity	0.00	0.00
Shalcombe	0	0	0	0	0	0	0	0	0	0	0	0	Source Mothballed	Source Mothballed	0.13	0.04
Ventnor1	0	0	0	0	0	0	0	0	0	0	0	0	Source Mothballed	Source Mothballed	1.00	0.97
Sandown	8.0	8.0	8.0	8.0	8.0	8.0	12.0	12.0	12.0	12.0	12.0	12.0	Treatment Capacity	Treatment Capacity	0.00	0.00
Total	**27.48**	**27.38**	**27.23**	**27.18**	**27.14**	**27.08**	**36.77**	**35.97**	**35.50**	**35.42**	**35.27**	**35.01**			**0.53**	**-0.32**

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Table 37 Summary of deployable outputs for Hampshire Southampton West WRZ, including s.52 sustainability reductions for the River Test

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	**Normal Year**	**1 in 20 Year**	**1 in 100 Year**	**1 in 200 Year**	**1 in 500 Year**	**1 in 1000 Year**	**Normal Year**	**1 in 20 Year**	**1 in 100 Year**	**1 in 200 Year**	**1 in 500 Year**	**1 in 1000 Year**	**MDO**	**PDO**	**MDO**	**PDO**
River Test Surface Water	79.78	66.66	19.60	0.00	0.00	0.00	79.78	79.78	61.90	26.74	2.89	0.00	Prescribed River Flow	Prescribed River Flow	105.00	78.26
Total	**79.78**	**66.66**	**19.60**	**0.00**	**0.00**	**0.00**	**79.78**	**79.78**	**61.90**	**26.74**	**2.89**	**0.00**			**105.00**	**78.26**

Table 38 Summary of deployable outputs for Hampshire Southampton East, including s.52 sustainability reductions for the River Itchen

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	**Normal Year**	**1 in 20 Year**	**1 in 100 Year**	**1 in 200 Year**	**1 in 500 Year**	**1 in 1000 Year**	**Normal Year**	**1 in 20 Year**	**1 in 100 Year**	**1 in 200 Year**	**1 in 500 Year**	**1 in 1000 Year**	**MDO**	**PDO**	**MDO**	**PDO**
River Itchen Groundwater	54.75	52.00	31.64	21.04	0.00	0.00	62.00	62.00	52.00	34.58	14.23	0.00	Prescribed River Flow and Daily Licence	Prescribed River Flow and Daily Licence	22.96	20.21
River Itchen Surface Water	0.75	1.11	0.00	0.00	0.00	0.00	42.10	28.21	4.49	0.00	0.00	0.00	Prescribed River Flow and Daily Licence	Prescribed River Flow and Daily Licence	44.46	44.46
Twyford	20.50	20.10	19.70	19.60	12.05	2.09	23.00	23.00	23.00	23.00	23.00	21.62	Prescribed River Flow and Daily Licence. Pump capacity at high frequency return periods	Prescribed River Flow and Daily Licence	-2.10	-0.20
Total	**76.00**	**73.21**	**51.34**	**40.64**	**12.05**	**2.09**	**127.1**	**113.21**	**79.49**	**57.58**	**37.23**	**21.62**			**65.32**	**64.47**

Table 39 Summary of deployable outputs for Hampshire Winchester WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Barton Stacey	1.12	1.12	1.12	1.12	1.12	1.12	1.28	1.28	1.28	1.28	1.28	1.28	Annual Licence	Demand Constraint	0.00	0.54
Winchester	18.17	18.17	18.17	18.17	18.17	18.17	19.30	19.30	19.30	19.30	19.30	19.30	Annual Licence	Treatment Capacity	0.00	8.00
Alresford	4.54	4.54	4.54	4.54	4.54	4.54	4.55	4.55	4.55	4.55	4.55	4.55	Annual Licence	Daily Licence	0.00	0.00
Total	**23.83**	**23.83**	**23.83**	**23.83**	**23.83**	**23.83**	**25.13**	**25.13**	**25.13**	**25.13**	**25.13**	**25.13**			**0.00**	**8.54**

Table 40 Summary of deployable outputs for Hampshire Rural

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Kings Sombourne	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	Network/ Infrastructure Capacity	Network/ Infrastructure Capacity	0.00	0.00
Romsey	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	10.80	Treatment Capacity	Treatment Capacity	2.20	2.80
Total	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**	**12.30**			**2.20**	**2.80**

Table 41 Summary of deployable outputs for Hampshire Andover WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Andover	16.02	16.02	16.02	16.02	16.02	16.02	19.88	19.88	19.88	19.88	19.88	19.88	Annual Licence	Daily Licence	0.00	0.00
Chilbolton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Written Down, poor water quality	Written Down, poor water quality	0.49	0.49
Near Whitchurch	2.24	2.24	2.24	2.24	2.24	2.24	2.96	2.96	2.96	2.96	2.96	2.96	Demand Constraint	Demand Constraint	0.70	1.79
Overton	1.60	1.56	1.54	1.53	1.53	1.53	1.64	1.60	1.60	1.59	1.56	1.55	Operational Pump Capacity	Operational Pump Capacity	0.04	0.04
Whitchurch	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	Annual Licence	Daily Licence	0.00	0.00
Total	**21.50**	**21.46**	**21.44**	**21.43**	**21.43**	**21.43**	**26.12**	**26.08**	**26.08**	**26.07**	**26.04**	**26.03**			**1.23**	**2.32**

Table 42 Summary of deployable outputs for Hampshire Kingsclere WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Newbury	3.00	3.00	3.00	3.00	3.00	2.99	3.80	3.80	3.66	3.60	3.48	3.45	Annual Licence	Operational Pump Capacity	0.00	0.14
Near Basingstoke	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68	Annual Licence	Daily Licence	0.00	0.00
Total	**8.68**	**8.68**	**8.68**	**8.68**	**8.68**	**8.67**	**9.48**	**9.48**	**9.34**	**9.28**	**9.16**	**9.13**			**0.00**	**0.14**

Table 43 Summary of deployable outputs for the Western area, assumes implementation of proposed sustainability reductions for the River Itchen and River Test abstractions in Hampshire Southampton East and Hampshire Southampton West WRZs

	MDO (Ml/d)						PDO (Ml/d)						Decrease from WRMP14 (Ml/d)	
WRZ Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO
Isle of Wight	27.48	27.38	27.23	27.18	27.14	27.08	36.77	35.97	35.50	35.42	35.27	35.01	0.53	-0.32
Hampshire Southampton West	79.78	66.66	19.60	0.00	0.00	0.00	79.78	79.78	61.90	26.74	2.89	0.00	105	78.26
Hampshire Southampton East	76.00	73.21	51.34	40.64	12.05	2.09	127.10	113.21	79.49	57.58	37.23	21.62	65.32	64.47
Hampshire Winchester	23.83	23.83	23.83	23.83	23.83	23.83	25.13	25.13	25.13	25.13	25.13	25.13	0.00	8.54
Hampshire Rural	12.30	12.30	12.30	12.30	12.30	12.30	12.30	12.30	12.30	12.30	12.30	12.30	2.20	2.80
Hampshire Andover	21.50	21.46	21.44	21.43	21.43	21.43	26.12	26.08	26.08	26.07	26.04	26.03	1.23	2.32
Hampshire Kingsclere	8.68	8.68	8.68	8.68	8.68	8.67	9.48	9.48	9.34	9.28	9.16	9.13	0.00	0.14
Total	249.57	233.52	164.42	134.06	105.43	95.4	316.68	301.95	249.74	192.52	148.02	129.22	**174.28**	**164.43**

4.3 Central area

Our Central area is comprised of three WRZs, Sussex North, Sussex Worthing and Sussex Brighton WRZs (See the Technical Overview and Annex 1).

4.3.1 Sussex North WRZ

For Sussex North WRZ there are a number of notable changes to our DO (Table 44).

We are planning to implement enhancements to our Pulborough groundwater sources as an outcome from the 2014 WRMP. It is expected to result in an enhancement to our MDO which has been assumed in our assessment. Modelling of the source has shown 90-day yields of 20Ml/d should be achievable under extreme stochastic drought. Minimum Deployable Output and annual ADO will still not exceed the long term recharge rate to the aquifer of 13Ml/d.

Our plan for reconfiguration of the Pulborough groundwater sources involves drilling new boreholes and the rehabilitation of existing wells. We have . . . identified locations for the new boreholes but borehole drilling, well testing and construction has yet to commence as discussions are ongoing with Natural England about the relationship of the scheme with nearby designated sites.
Ml/d
We recognise the risk that the scheme will not deliver in time as well as the possibility that the yield from the proposed new and rehabilitated boreholes will be insufficient to meet our planned MDO. This may have knock on effects by leading to a deficit in Sussex North WRZ and potentially impact the timing of other related preferred options, most significantly the Pulborough Groundwater licence variation. To assess the risk of this potential outcome we have considered a sensitivity scenario of our investment model for our Central area. In this scenario we have assumed that only the present 90 day MDO of 16Ml/d will be available. For details of this alternative planning scenario see Annex 10.

The DO of two sources, Petersfield and West Chiltington have been reduced to zero to reflect long term outage at both sources because of poor raw water quality from aggressive Lower Greensand Aquifer that has led to asset deterioration. Borehole rehabilitation and enhanced treatment would be required to return both to service. We have included these schemes as options in our investment modelling (Annex 10).

The other major change is for Pulborough Surface Water. Here we have implemented an updated and refined surface water runoff model and used new synthetic drought sequences (see Section 1.2.1). The combined effect of these changes has been a reduction in our surface water yield forecast for the 0.5% (1 in 200 year) drought event.

4.3.2 Sussex Worthing WRZ

DOs for our Sussex Worthing WRZ are shown in Table 45.

A long term outage at our Littlehampton Source is expected to be resolved during AMP6 which will increase the overall DO of this source, changing the constraint back to previous licenced quantities as it was under the 2009 WRMP.

Relatively minor changes to source yields and DOs at Worthing and Long Furlong B reflect enhancements to our synthetic drought sequences and modelling methodology (Section 3). Other minor increases to DO also reflect the inclusion of expected TUBs benefits in the baseline DO scenario.

For our North Arundel source, treatment capacity has reduced owing to process restrictions leading to a small reduction in DO.

4.3.3 Sussex Brighton WRZ

DOs for our Sussex Brighton WRZ are shown in Table 46.

This WRZ is especially vulnerable to drought as it contains a number of hydrogeologically constrained sources where source yields become limited under low groundwater levels. Changes to our synthetic drought sequences and modelling methodology (Section 3) have indicated minor changes (typically <1Ml/d) in DO for several sources.

Our Lewes Road source has been subject to a long term outage and the DO has been assessed as zero for this plan. The outage has arisen owing to poor raw water quality and insufficient treatment capacity and requires a complex infrastructure solution to resolve.

We anticipate return to service of our Brighton B source by 2020. Raw water from Brighton B will be treated in combination at our Brighton A works and DO for both will be constrained by the total works capacity. For Brighton B we have assumed a DO based on previous source performance though this is uncertain and subject to future well testing. The updated Brighton and Worthing groundwater model suggested a reduction in the severe drought yield and the total DO from Brighton A. The combined output from both Brighton A and B sources is constrained by the current treatment capacity at Brighton A.

Refurbishment and enhancement of the treatment works at Hove B has led to an increase in DO as previous nitrate water quality constraints have been removed.

The net effect of these changes is a minor (<1Ml/d) increase in WRZ DO for both the MDO and PDO conditions under the 1 in 200 year event.

4.3.4 Central area summary

The overall DOs for our Central area are presented in Table 47. The overall changes to DO are relatively minor but reflect changes to infrastructure and our updated synthetic drought and modelling methodology.

The largest change occurs in Sussex North WRZ owing to the reduction in surface water yield. Small increases in DOs for Sussex Brighton and Sussex Worthing WRZs reflect changes to modelling methods and the inclusion of TUBs benefits in our baseline DO.

The effect source write downs (from outage) is largely offset by returning other sources to service in the Sussex Brighton and Sussex Worthing WRZs leading to a small overall net effect in available supplies.

Table 44 Summary of deployable outputs for Sussex North WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Pulborough Groundwater	20.00	20.00	20.00	20.00	0.00	0.00	27.00	27.00	27.00	27.00	0.00	0.00	Sustainable Yield (90 day)	Pump Capacity	-7.00	0.00
Pulborough Surface	30.58	17.22	4.19	1.17	0.00	0.00	33.00	22.91	8.07	3.81	1.08	1.08	Yield above Prescribed River Flow	Yield above Prescribed River Flow	6.58	0.50
River Arun	10.00	10.00	10.00	10.00	10.00	10.00	15.00	15.00	15.00	15.00	15.00	15.00	Licence	Licence	0.00	0.00
Weir Wood Reservoir	8.00	7.50	7.00	5.40	1.95	0.96	17.00	17.00	17.00	17.00	17.00	17.00	Yield	Treatment works	0.00	0.00
Petworth South	2.14	2.14	2.14	2.14	2.14	2.14	2.43	2.43	2.43	2.43	2.43	2.43	Annual Licence	Daily Licence	0.00	0.00
Petersfield	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Written down (needs treatment upgrade)	Written down (needs treatment upgrade)	1.60	1.96
Midhurst	2.19	2.19	2.19	2.19	2.19	2.19	2.88	2.88	2.88	2.88	2.88	2.88	Annual Licence	Daily Licence	0.00	0.00
West Chiltington	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Written down (needs treatment upgrade)	Written down (needs treatment upgrade)	3.12	3.12
Steyning	1.20	1.20	1.20	1.20	1.20	1.20	1.30	1.30	1.30	1.30	1.30	1.30	Demand constraint	Pump capacity	0.00	0.00
Total	**74.11**	**60.25**	**46.72**	**42.10**	**17.48**	**16.49**	**98.61**	**88.52**	**73.68**	**69.42**	**39.69**	**38.61**			**4.30**	**5.58**

Table 45 Summary of deployable outputs for Sussex Worthing WRZ

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Littlehampton	3.90	3.90	3.90	3.90	3.90	3.90	4.00	4.00	4.00	4.00	4.00	4.00	Annual Licence	Pump Capacity	-1.90	-1.90
Arundel	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	Treatment Capacity	Treatment Capacity	0.00	0.00
Worthing	17.00	11.64	10.19	9.80	9.59	9.19	17.00	14.07	12.02	11.35	10.60	9.76	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	0.83	-0.20
South Arundel	9.50	6.99	6.71	6.64	6.28	5.63	11.00	9.81	9.36	9.16	8.72	8.23	Turbidity / Water Quality	Turbidity / Water Quality	0.07	-0.65
South Arundel A	5.00	4.94	4.75	4.70	4.61	4.46	5.00	5.00	5.00	5.00	5.00	5.00	DAPWL	Annual Licence	-0.15	0.00
Long Furlong A	2.30	2.30	2.30	2.30	2.30	2.30	2.80	2.80	2.80	2.80	2.80	2.80	Infrastructure (Distribution) Constraint	Infrastructure (Distribution) Constraint	0.00	0.00
North Worthing	6.50	6.25	6.19	6.18	6.17	6.14	8.68	8.68	8.68	8.68	8.68	8.68	DAPWL	Predicted sustainable DO (BH1 + BH2)	-0.07	0.00
North Arundel	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	Treatment Capacity	Treatment Capacity	0.40	0.40
East Worthing	4.50	4.50	4.50	4.50	4.50	4.50	7.00	7.00	7.00	7.00	7.00	7.00	Daily Licence (Oct-Dec)	Daily Licence	0.00	0.00
Long Furlong B	3.59	2.39	2.08	2.00	1.91	1.76	3.59	2.39	2.08	2.00	1.91	1.76	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	-0.12	-0.20
Durrington	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	Daily Licence	Daily Licence	0.00	0.00
Total	**66.89**	**57.51**	**55.22**	**54.62**	**53.86**	**52.48**	**73.67**	**68.35**	**65.54**	**64.59**	**63.31**	**61.83**			**-0.94**	**-2.55**

Table 46 Summary of Deployable Outputs for Sussex Brighton

	MDO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	MDO	PDO	MDO	PDO
Rottingdean	12.89	12.22	11.59	11.42	11.17	10.70	16.80	16.72	16.31	16.13	15.74	15.30	Salinity	Treatment capacity in Normal Year, Salinity otherwise	-0.12	0.33
Falmer	5.00	3.26	2.35	2.10	1.81	1.27	5.18	4.10	3.14	2.83	2.50	2.13	DAPWL (Adit Roof)	DAPWL (Adit Roof)	-0.21	0.00
Hove	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	Licence	Licence	0.0	0.0
North Falmer A	3.79	3.23	2.66	2.50	2.38	2.15	6.00	6.00	6.00	6.00	6.00	6.00	Licence in Normal Year, else DAPWL	Pump Capacity	-0.03	0.00
Lewes Road	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Written Down (Long term outage)	Written Down (Long term outage)	2.30	2.30
Hove B	10.00	9.65	9.53	9.50	9.41	9.26	11.50	10.81	10.40	10.28	10.20	10.11	Yield at DAPWL	Yield at DAPWL	-2.50	-3.28
North Shoreham	3.30	2.52	1.78	1.58	1.30	3.30	2.82	2.29	2.13	1.98	1.81	3.30	DAPWL	DAPWL	-0.15	0.26
North Falmer B	14.75	13.90	11.54	10.89	9.55	7.07	14.75	14.36	12.47	11.67	10.01	8.14	DAPWL	DAPWL	-0.62	2.07
Brighton A	8.10	8.10	8.10	8.10	8.10	8.10	9.00	9.00	9.00	9.00	9.00	9.00	Sustainable Yield	Sustainable Yield	3.90	3.00
Brighton B	2.50	2.50	2.50	2.50	2.50	2.50	3.00	3.00	3.00	3.00	3.00	3.00	Treatment / Pump Capacity with Brighton A	Treatment / Pump Capacity with Brighton A	-2.50	-3.00
Shoreham	7.00	5.68	5.30	5.20	5.03	4.71	7.00	7.00	7.00	7.00	7.00	7.00	DAPWL	Daily Licence	-0.22	0.0
Lewes	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45	Pump Capacity	Pump Capacity	0.0	0.0
Sompting	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50	11.50	Annual Licence	Annual Licence	0.0	0.0
Total	**104.28**	**98.01**	**92.30**	**90.74**	**88.2**	**86.01**	**113.00**	**110.23**	**106.4**	**104.84**	**102.21**	**100.93**			**-0.15**	**1.68**

Table 47 Summary of deployable outputs for the Central area

Water Resource WRZ Name	MDO (Ml/d) Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	PDO (Ml/d) Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Decrease from WRMP14 (Ml/d) MDO	PDO
Sussex North	74.11	60.25	46.72	42.1	17.48	16.49	98.61	88.52	73.68	69.42	39.69	38.61	4.30	5.58
Sussex Worthing	66.89	57.51	55.22	54.62	53.86	52.48	73.67	68.35	65.54	64.59	63.31	61.83	-0.94	-2.55
Sussex Brighton	104.28	98.01	92.30	90.74	88.20	86.01	113.00	110.23	106.4	104.84	102.21	100.93	-0.15	1.68
Total	**245.28**	**215.77**	**194.24**	**187.46**	**159.54**	**154.98**	**285.28**	**267.10**	**245.62**	**238.85**	**205.21**	**201.37**	**3.21**	**4.71**

4.4 Eastern area

Our Eastern area is composed of four WRZs - Kent Medway West, Kent Medway East, Sussex Hastings and Kent Thanet WRZs. The arrangement and relative supply components of these WRZs is indicated in the Technical Overview and Annex 1.

4.4.1 Kent Medway West WRZ

The DOs for Kent Medway West WRZ are presented in Table 48

The majority of groundwater sources in this WRZ are infrastructure constrained and hence there is little overall change in DO for many sources compared to our previous plan. Some minor increases <0.5Ml/d reflect the inclusion of TUBs benefits and slight adjustments to the curve shifting because of the updated synthetic drought methodology (Section 3).

There are a number of larger reductions in DO because of both infrastructure and hydrological effects.

At Strood, a long-term reduction in pump capacity has occurred owing to equipment failure leading to a reduction in the source DO.

DO has been reduced to zero at Gravesend because of a deterioration in raw water quality (nitrates) and a treatment solution would be required to restore DO here.

The River Medway Scheme (RMS) includes our abstractions from the River Medway together with storage in Bewl Water and another water company’s abstraction from Bewl Water. The DO is calculated for the combined yield of the sources.

As described in Section 3.4, there have been a number of changes in approach and circumstance since our assessments for WRMP14, which may have affected the calculated DO for the RMS. These changes have included:

Re-parameterisation of hydrological models based on updated of calibration/validation period to include extra data from 2005 to 2014 with longer dataset of observed naturalised flow data, including greater period of low flows
Improved approach for modelling Weir Wood and Bough Beech reservoirs using Aquator as part of the denaturalisation process to dynamically estimate abstractions and releases
Improved mechanism for denaturalisation of flows
Revised calibration of reservoir inflow sequences
Use of GEAR gridded rainfall datasets
Updated methodology for the calculation of stochastic rainfall and PET sequences
Changes to the demand profiles
Changes to the demand reduction factors in relation to the imposition of TUBS

The ADO of the RMS has increased by 6Ml/d because of the changes in approach outlined above. Of these, it is the first, the re-parameterisation of the hydrological models, which we believe has had the most significant impact on DO.

The licence for the RMS has recently been subject to formal variation as planned for in our 2014 WRMP, with a new licence in place from November 2017. The new licence for the RMS was included in the modelling but the expected DO benefit of the new licence was removed from our DO calculations, because of supplementary licence conditions which would revert the licence to its original conditions (without the DO benefit) if water quality issues occur in the River Medway. This cannot be ruled out during the severe design droughts.

The PDO of the RMS is constrained by treatment capacity, which is 5 Ml/s lower than as in the 2014 WRMP because of asset deterioration. There are plans to increase the treatment capacity back to the original design capacity, which is discussed in Annex 6.

4.4.2 Kent Medway East WRZ

Kent Medway East WRZ is supplied entirely from groundwater sources. Overall the changes to DO compared to our previous assessment are relatively small as many sources are infrastructure or licence constrained. Where differences occur these reflect a combination of adjustments to the synthetic drought sequence used and the inclusion of TUBs benefits in the DO assessment.

For three sources with seasonal licences (Faversham 1 and 2 and Millstead) there has been an increase in apparent ADO. This does not reflect any change in source yield or infrastructure but simply that the calculation method has been adjusted to properly reflect the annual ADO over the full calendar year. Previously these sources, which are licenced for summer operation only had an ADO of zero. This accounts for the majority of the increase in ADO.

The other major change occurs at Sittingbourne2 where DOs have increased. This reflects infrastructure changes from the 2010-2015 source improvement investigations.

The consequence of these changes is an overall increase in DO for both the ADO and PDO assessments.

4.4.3 Sussex Hastings WRZ

The Sussex Hastings WRZ is relatively small but contains two large reservoir sources and a single combined groundwater surface water source (Table 50). The ADO for Darwell has decreased by 1Ml/d while the ADO for Powdermill has increased by 3Ml/d. These two reservoirs are closely connected in the supply network and are also connected to the River Medway Scheme by the Bewl-Darwell transfer. The DO of the combined reservoir system was calculated for all three reservoirs together in combination. The DO to be attributed to the RMS versus Darwell and Powdermill was calculated by running the individual components in isolation (i.e. separate runs for the RMS and Darwell) to calculate an overall apportionment factor for different return period droughts. The combined overall increase in DO for Darwell and Powdermill reservoirs amounts to 2Ml/d and is a result of the changes approach to the hydrological modelling set out in Section 3.4.

For the groundwater source, DO is dependent on long term average recharge to the catchment, which is not forecast to change from our previous assessment.

4.4.4 Kent Thanet WRZ

Kent Thanet WRZ DOs are presented in Table 51. This WRZ is dominated by groundwater with only a single surface water source. There were a number of changes to the DO assessment method for this WRZ, most notably using the corrected East Kent Groundwater Model and the new synthetic rainfall and PET time series DO

The single surface water source at Stourmouth has had its DO reduced to zero. This reflects long term outage at this site and the fact that substantial asset replacement and refurbishment would be required to bring the source back into use.

The majority of sources show only minor changes in DOs reflecting the in-combination effects of changes to the groundwater model and the input rainfall and recharge sequences. The greatest differences occur for the source near Canterbury and at Birchington. The near Canterbury source was the subject of refinement in the updated groundwater model and the reductions in DO reflect revised curve shifting using the full synthetic rainfall and PET sequences (see Section 3).

4.4.5 Eastern area summary

A summary of the DOs for all WRZs in the Eastern area is given in Table 52

Overall there has been a general increase in zonal level DOs across the Eastern area. This reflects:

Increased yield of the River Medway scheme because of a licence variation and refinements to our surface water modelling approach for Kent Medway West and Sussex Hastings WRZ
Source improvement and changes to the ADO calculation method for Kent Medway East WRZ
Inclusion of TUBs benefits in baseline groundwater DOs.

Kent Thanet WRZ shows a moderate decline in DO reflecting both the write down of the surface water source and changes to the modelling methodology. More write-downs in DO for Kent Thanet WRZ are forecast as consequence of deterioration in raw water quality, largely because of groundwater nitrates in the short to medium term.

Table 48 Summary of deployable outputs for Kent Medway West WRZ

	ADO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	ADO	PDO	ADO	PDO
Strood	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	Pump Capacity	Pump Capacity	0.96	1.00
Rochester	0.48	0.48	0.48	0.48	0.48	0.48	0.70	0.70	0.70	0.70	0.70	0.70	Lower Adit Roof	Lower Adit Roof	0.00	0.00
Gravesend	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Written Down (poor water quality, needs treatment upgrade)	Written Down (poor water quality, needs treatment upgrade)	1.20	2.65
Higham	0.79	0.74	0.51	0.46	0.39	0.39	1.27	0.79	0.73	0.71	0.68	0.66	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	-0.06	-0.05
Meopham	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90	Pump Capacity	Pump Capacity	0.00	0.00
Longfield	6.90	6.88	6.87	6.87	6.86	6.86	7.50	7.30	7.17	7.15	7.12	7.10	Annual Licence	Pump Capacity	-0.01	-0.05
Cuxton	5.58	5.57	5.46	5.37	5.27	5.25	9.40	9.30	9.30	9.30	9.30	9.30	Yield at DAPWL (Adit Roof)	Pump Capacity	-0.07	0.00
Gravesend South	5.62	5.62	5.51	5.42	5.33	5.32	5.80	5.79	5.76	5.76	5.75	5.75	Pump cut out, set at DAPWL	Pump Capacity	-0.07	-0.01
North Cuxton	4.82	4.81	4.75	4.70	4.65	4.65	5.00	4.88	4.82	4.81	4.80	4.80	Pump Capacity	Pump Capacity	-0.03	-0.01
Northfleet Chalk	7.30	7.23	7.18	7.10	7.05	7.05	7.70	7.48	7.45	7.45	7.45	7.45	Pump Capacity	Pump Capacity	-0.05	0.00
River Medway	59.29	59.29	54.85	48.93	43.74	39.98	60.00	60.00	60.00	60.00	60.00	60.00	Yield	Treatment Capacity	-6.03	5.00
Total	**95.98**	**95.82**	**90.81**	**84.53**	**78.97**	**75.18**	**102.57**	**101.44**	**101.13**	**101.08**	**101.00**	**100.96**			**-4.16**	**8.53**

Table 49 Summary of deployable outputs for Kent Medway East WRZ

Name	ADO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	ADO	PDO	ADO	PDO
Hartlip Hill	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	Annual Licence	Booster Pump Capacity	0.00	0.00
Newington	0.52	0.52	0.52	0.52	0.52	0.52	0.65	0.65	0.65	0.65	0.65	0.65	Demand	Demand	0.81	0.88
Faversham3	7.28	7.28	7.28	7.28	7.28	7.28	9.50	9.50	9.50	9.50	9.50	9.50	Pump Capacity / Water Quality	Pump Capacity / Water Quality	0.00	0.00
Hartlip	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	Operational Pump Capacity	Operational Pump Capacity	0.00	0.00
Capstone Chalk	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	Booster Pump Capacity	Booster Pump Capacity	0.00	0.00
Capstone Greensand	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	Booster Pump Capacity	Booster Pump Capacity	0.00	0.00
Gillingham	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	Booster Pump Capacity	Booster Pump Capacity	0.30	0.30
Chatham West	4.61	4.60	4.53	4.51	4.47	4.46	4.73	4.57	4.47	4.45	4.42	4.40	Pump Capacity	Pump Capacity	-0.01	0.05
Chatham	4.43	4.24	3.20	2.92	2.49	2.39	6.30	4.60	3.57	3.35	3.04	2.89	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	-0.29	-0.45
Sittingbourne1	4.43	4.38	4.27	4.26	4.24	4.24	4.70	4.58	4.54	4.52	4.51	4.50	Annual Licence	Annual Licence	0.74	0.48
Sittngbourne2	6.62	6.39	4.88	4.12	3.47	3.43	7.00	6.60	5.35	4.90	4.29	4.00	Yield at DAPWL	Yield at DAPWL	-0.12	-0.90
Millstead	1.37	1.37	1.37	1.37	1.37	1.37	4.75	4.75	4.75	4.75	4.75	4.75	ADO at Seasonal Licence	95% of Daily Licence	-0.89	-0.42
Sheldwich	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	Apportioned Annual Licence / Pump Capacity	Apportioned Annual Licence / Pump Capacity	0.00	0.00
Faversham2	1.89	1.89	1.89	1.89	1.89	1.89	4.50	4.50	4.50	4.50	4.50	4.50	ADO at Seasonal Licence	Pump Capacity	-1.89	0.50
Faversham1	2.09	2.09	2.09	2.09	2.09	2.09	5.00	5.00	5.00	5.00	5.00	5.00	ADO at Seasonal Licence	Annual Licence	-2.09	0.00
Faversham4	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	Pump Capacity	Pump Capacity	0.00	0.00
Total	**88.14**	**87.66**	**84.93**	**83.86**	**82.72**	**82.57**	**102.03**	**99.65**	**97.23**	**96.52**	**95.56**	**72.09**			**-3.44**	**0.44**

Table 50 Summary of deployable outputs for Sussex Hastings

	ADO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	ADO	PDO	ADO	PDO
Darwell Reservoir	29.59	29.59	17.56	15.98	14.66	13.67	34.00	34.00	34.00	34.00	34.00	34.00	Yield	Daily licence	0.22	4.00
Powdermill Reservoir	5.94	5.94	4.95	4.20	3.47	2.97	10.00	10.00	10.00	10.00	10.00	10.00	Yield	Treatment Capacity	-2.20	0.00
Rye	1.23	1.23	1.23	1.23	1.23	1.23	1.50	1.50	1.50	1.50	1.50	1.50	Annual Recharge to Aquifer	Operational Pump Capacity	0.00	0.00
Total	**36.76**	**36.76**	**23.74**	**21.41**	**19.36**	**17.87**	**45.50**	**45.50**	**45.50**	**45.50**	**45.50**	**45.50**			**-1.98**	**4.00**

Table 51 Summary of deployable outputs for Kent Thanet WRZ

	ADO (Ml/d)						PDO (Ml/d)						DO Constraints		Decrease from WRMP14 (Ml/d)	
Name	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	ADO	PDO	ADO	PDO
Stourmouth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Written Down (needs infrastructure upgrade)	Written Down (needs infrastructure upgrade)	3.50	3.50
Deal	4.32	4.30	4.21	4.13	4.06	4.03	4.32	4.30	4.21	4.13	4.08	4.03	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	0.08	0.04
West Langdon	6.82	6.82	6.82	6.82	6.82	6.79	6.82	6.82	6.82	6.82	6.82	6.79	Annual Licence	Daily Licence	0.00	0.00
Manston2	2.80	1.75	1.05	0.93	0.73	0.60	5.22	3.69	2.42	2.06	1.43	1.40	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	0.71	0.69
Ramsgate B	5.81	5.81	5.74	5.73	5.72	5.62	5.90	5.90	5.88	5.84	5.81	5.79	Yield at DAPWL (Fissure Zone)	Yield at DAPWL (Fissure Zone)	0.08	0.06
Kingsdown	3.64	3.64	3.64	3.64	3.64	3.64	4.25	4.25	4.25	4.25	4.25	4.25	Annual Licence	Pump Capacity	0.00	0.00
North Deal	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	Pump Capacity	Pump Capacity	0.00	0.00
Sandwich	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49	Annual Licence	Annual Licence	0.03	0.24
West Sandwich	8.92	8.39	8.13	8.10	8.09	8.08	9.45	8.64	8.53	8.50	8.48	8.45	BHA Yield / Pump Capacity	BHA Yield / Pump Capacity	0.16	0.27
North Dover	1.02	0.99	0.94	0.92	0.90	0.89	1.20	1.05	0.96	0.93	0.91	0.89	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	0.04	0.08
Near Canterbury	14.90	12.77	10.62	10.45	9.74	9.69	22.04	15.34	13.59	13.06	11.39	11.24	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	1.36	1.24
Birchington	2.30	1.67	0.78	0.64	0.54	0.41	2.30	1.70	0.78	0.64	0.54	0.46	Yield at DAPWL (Adit Roof)	Yield at DAPWL (Adit Roof)	1.16	1.16
Total	**57.99**	**53.60**	**49.39**	**48.82**	**47.70**	**29.32**	**68.89**	**59.08**	**54.83**	**53.62**	**51.10**	**32.26**			**7.12**	**7.28**

Table 52 Summary of deployable outputs for Eastern area

WRZ Name	ADO (Ml/d)						PDO (Ml/d)						Decrease from WRMP14 (Ml/d)	
	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	Normal Year	1 in 20 Year	1 in 100 Year	1 in 200 Year	1 in 500 Year	1 in 1000 Year	ADO	PDO
Kent Medway West	95.98	95.82	90.81	84.53	78.97	75.18	102.57	101.44	101.13	101.08	101.00	100.96	-4.16	8.53
Kent Medway East	88.14	87.66	84.93	83.86	82.72	82.57	102.03	99.65	97.23	96.52	95.56	72.09	-3.44	0.44
Sussex Hastings	36.76	36.76	23.74	21.41	19.36	17.87	45.50	45.50	45.50	45.50	45.50	45.50	-1.98	4.00
Kent Thanet	57.99	53.60	49.39	48.82	47.70	29.32	68.89	59.08	54.83	53.62	51.10	32.26	7.12	7.28
Total	**278.87**	**273.84**	**248.87**	**238.62**	**228.75**	**204.94**	**318.99**	**305.67**	**298.69**	**296.72**	**293.16**	**250.81**	**-2.46**	**20.25**

4.5 Our design droughts and drought vulnerability

The deployable outputs summarised in this section are presented for a selection of different probabilities and are expressed as a return period. These have typically been derived from frequency analysis of a time series of DO generated by our Water Resource Modelling.

A return period definition can sometimes be misleading. For example, a 1 in 200 years return period could easily be misinterpreted as meaning that such an event might only occur once every 200 years. The mathematically correct meaning is that on average there is a recurrence interval of two hundred between events, with "*on average*" being a critical qualifier.

In reality it is entirely possible, though unlikely, that events of this return period could occur in consecutive years. An alternative way of considering the probability of these events is to consider either the annual probability or the probability that a given event will occur within a set interval. Of these, the latter method is probably the most useful and gives more tangible descriptions of probability to which it is easier to relate. For example, a 1 in 200 years return period event, equivalent to our design DO, could also be considered as having a 0.5% annual probability of occurrence. Alternatively, the same event could be expressed as having a 22% (around 1 in 5) chance of occurring within the 50 years' lifetime of our Water Resource Management plan. These probabilities can all be readily calculated from each other and hence are somewhat interchangeable.

Table 53 summarises the return period, annual probability and probability of occurrence within the lifetime of our plan for a number of example major water resource planning events consistent with our levels of service and planning scenarios (see also Annex 1). It is also possible to estimate how many of each event might occur within the fifty years' lifetime of our plan.

Table 53 Estimate of probability and return periods for water resource planning design events based on our target levels of service (see Annex 1)

			Probability of at least one event of this severity within the next…		Probability of exactly n events in the next 25 years				
Return Period (years)	**Example Planning Event**	**Annual Probability**	**25 Years**	**50 Years**	**1**	**2**	**3**	**4**	**5**
1 in 2	Normal Dry Year	50%	100%	100%	0.0%	0.0%	0.1%	0.4%	0.9%
1 in 5	Publicity to reduce demand	20%	99%	100%	3.4%	8.4%	14.0%	17.5%	17.5%
1 in 10	TUBs[1]	10%	92%	99%	20.5%	25.7%	21.4%	13.4%	6.7%
1 in 20	Drought Orders restricting NEU[1]	5%	71%	92%	35.8%	22.4%	9.3%	2.9%	0.7%
1 in 100	The worst historic drought	1%	22%	39%	19.5%	2.4%	0.2%	0.0%	0.0%
1 in 200	Severe Design Drought	0.5%	12%	22%	11.0%	0.7%	0.0%	0.0%	0.0%
1 in 500	Extreme Design Drought / Emergency Drought Order to restrict water use	0.2%	5%	10%	4.8%	0.1%	0.0%	0.0%	0.0%

[1] Frequency of first implementation but would be introduced via a phased approach

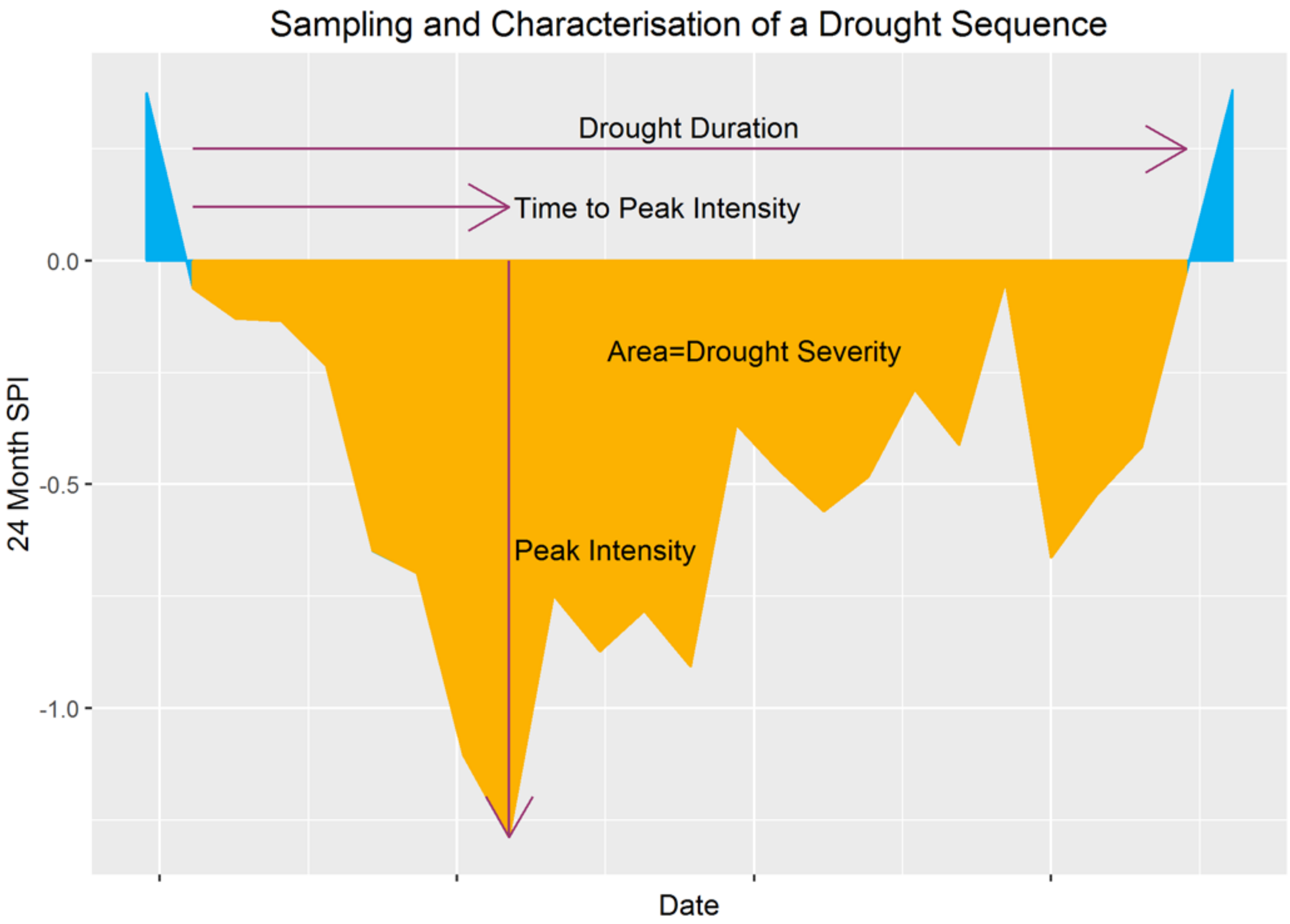
4.5.1 Drought metrics

The process we have employed to generate our synthetic drought sequences (Section 3.2) allows us to generate extremely long time series of rainfall and PET. These can be interrogated by statistical analysis in order to derive metrics and classification of each drought event. As we have generated a coherent time series of DO, the drought metrics can also be compared directly to DO in order to improve understanding of the vulnerability of each WRZ to different styles of drought.

These key metrics (also see Figure 22) are calculated for each period of rainfall deficit in the full synthetic sequence:
Event start date and end date, useful for understanding how seasonal timing of rainfall deficits affect total resource availability
Total drought duration (in months) between the start and finish of accumulated rainfall deficits (Figure 22)
The Peak rainfall deficit (from long term average) reached during each event (Figure 22)
The Standard Precipitation Index (SPI) both as a time series and as a peak value for each drought. This index has been calculated according to the methodology of Mckee et al (1993). This index is useful as it allows more direct comparison between different rainfall sites as differences in the magnitude of rainfall are effectively normalised.
Drought severity, a measure of the total accumulated Standard Precipitation Index over the duration of the rainfall deficit (Figure 22).
Estimates of annual probability, return period, and the overall likelihood of a given event of such rainfall deficit or severity occurring within our 50 years planning horizon.

These metrics can be calculated for different accumulation periods of rainfall deficit and therefore reflect different drought vulnerability, for example short sharp periods of rainfall deficit of fewer than six months, through to longer period “slow burn” events of small rainfall deficits accumulating over several years. Specifically for our analysis we have considered 8 rainfall accumulation periods: 6, 12, 18, 24, 30, 36, 48 and 60 months. A number of these are equivalent to our existing drought triggers and hence would allow comparison with our drought plan.

Figure 22 Summary statistics used to characterise each period of rainfall deficit for an example drought event



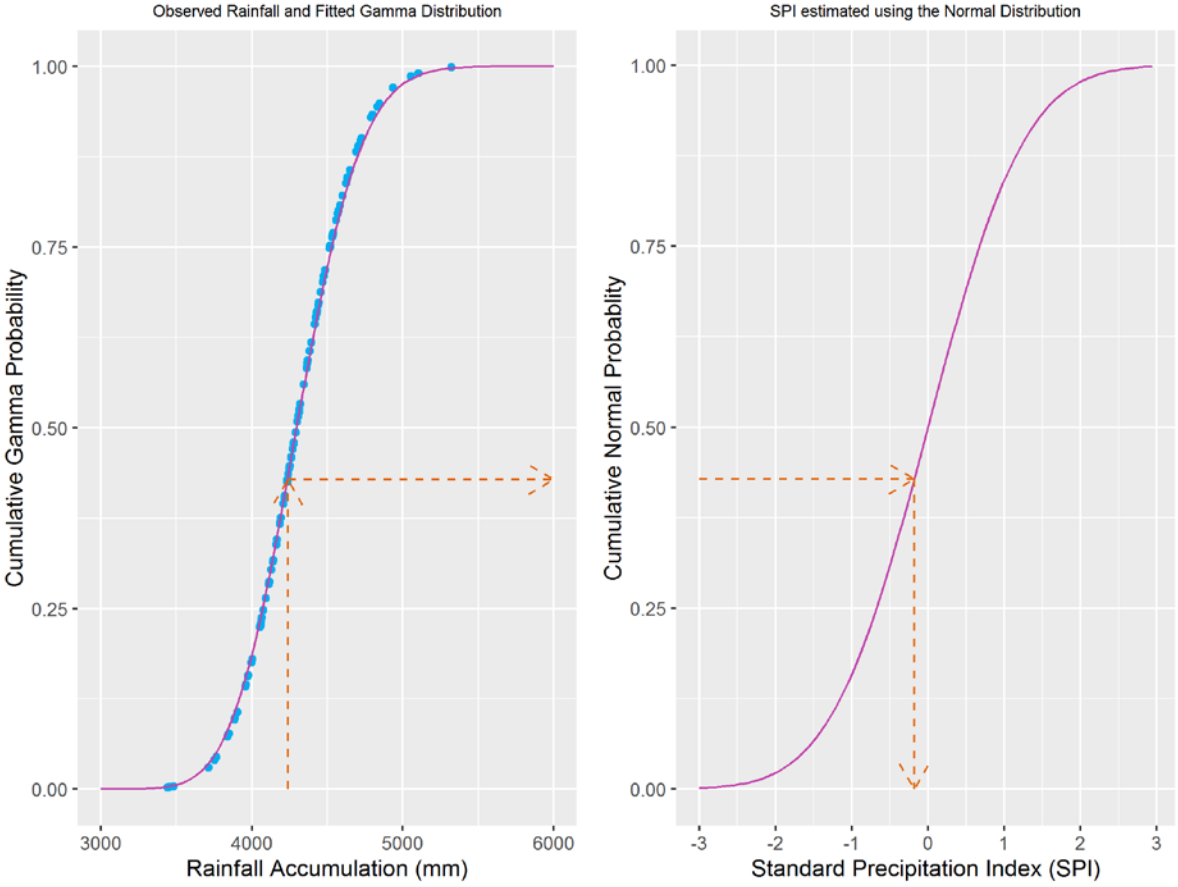
4.5.2 Standard precipitation indices

We consider the standard precipitation index (SPI) to be a particularly useful measure of drought severity. The SPI is recommended by the World Meteorological Association (WMO, 2012) as the preferred measure for characterising meteorological drought. The SPI aggregates the total rainfall over a given distribution period (e.g. 6 months, 12 months, etc.) and calculates the accumulated deviation from a mean value derived from a standard period (e.g. 1961-1990). As it is effectively a normalised indicator, a key advantage of the SPI is that it allows comparison of drought severity between different catchments and timescales as it is insensitive to the overall magnitude of rainfall deficit, instead being a measure of the overall departure (in terms of standard deviation) from long term average conditions for the catchment of interest. Consequently, both historic and stochastic drought sequences can be compared using a consistent metric. As it is a probabilistic parameter the SPI can also be used to estimate the probability of a given event within a given time interval as a function of the duration of the input data.

Standard Precipitation Indices are calculated by aggregating rainfall totals over a period of interest and then fitting a probability distribution (most commonly a gamma distribution) to the data. The quantile describing the accumulate rainfall total is converted to an equivalent normal distribution variate (z-score) (after McKee et al, 1993). Alternative metrics for the SPI are available, for example the Standard Precipitation and Evapotranspiration Index (SPEI). These can be useful in groundwater dominated WRZs as it allows inclusion of the role of effective rainfall and recharge on resources.

The Water Resources Act (1991) specifically refers to demonstrating *"an exceptional shortage of rain"* for the purpose of satisfying tests relating to approval of Drought Orders. Rainfall alone is therefore central to defining what might be considered a legal definition of drought. Consequently, we consider that SPI is a useful metric for this purpose but this is still problematic as there is no widely accepted definition of what might constitute an "exceptional shortage" of rain.

Figure 23 Illustrated Example indicating how SPI's are calculated from a gamma distribution fitted to observed rainfall accumulations and translated to an equivalent standard normal variate with the same cumulative probability



4.5.3 Our design droughts

The outturn DO forecasts for each WRZ that exhibits a degree of supply variability (as a function of hydrological or hydrogeological yield) have been compared to our calculated drought metrics. This has suggested a number of key 'design' drought events that constrain DO at the differing probability estimates used in our risk based plan. Some events are relatively local to a single WRZ, others are more widespread across different WRZs but may differ in terms of their overall severity.

To allow easier comparison each drought event has been randomly named according to a similar system of male and female names employed for storm and hurricane forecasting. A summary of these key drought events is presented in Table 54.

It should be noted that these events reflect only a small proportion of the synthetic drought events which have been processed through our water resource models. It is simply that these are the selection of events that define DO at each arbitrary probability interval. As each drought event can be assessed over each rainfall accumulation metric there is often a degree of variability in the data. The metrics presented represent the most severe set, in terms of the minimum SPI reached.

In comparing these datasets, it is important to remember that probability estimates of a system stress metric, such as DO do not necessarily directly reflect those for the rainfall event itself. Climatological metrics only give an indirect indication of risks to customers, and require comparisons of pre-defined drought duration and magnitude to estimate their probability (UKWIR, 2016b). This issue is discussed in Sections 4.5.5 and 4.5.6

Western area

In the Western area the most drought vulnerable WRZs are Hampshire Southampton East and West under planning scenarios where sources on the River Test and River Itchen are subject to sustainability reductions.

A summary of the major ‘design’ events affecting the Western area is presented in Table 54 and Figure 24. This shows that the most critical events are generally rainfall deficits over 12-24 month accumulations. The key historic style of drought that has greatest impact in the Western area is the 1918-1922 event which is the worst event on record. These types of event feature rainfall deficits accumulating over one to try dry winters and also include the synthetic events of Andrea, Connor, William and Michael. Drought Severity tends to increase with overall rainfall deficit and duration such that the more extreme droughts will include lower autumn and spring rainfall and tend to last well over two years.

The relative timing and duration of rainfall deficits is also important, for example Table 54 indicates comparable rainfall deficits across several drought events but with differing out DO reflecting the timing of antecedent rainfall. This is expected in groundwater (baseflow) dominated resource WRZs which tend to be more sensitive to autumn – spring rainfall deficits when soil moisture deficits are low. Such WRZs are generally insensitive to dry summers.

These events reflect what is generally considered to be the typical design drought for Chalk groundwater dominated resources in South East England, the “three dry winter” event. Our modelling has indicated that even in extreme droughts three sequential severely dry winters are statistically unlikely. It is more likely that the most keenly felt impacts would occur in the second year after two severe winters (which is a more probable occurrence).

Hampshire Southampton West WRZ is overall more vulnerable to drought than Hampshire Southampton East WRZ owing to sensitivity to the proposed HoF condition on the River Test. DO from this WRZ can fall to zero rapidly even in relatively moderate shorter duration droughts, for example the historic 1976 event

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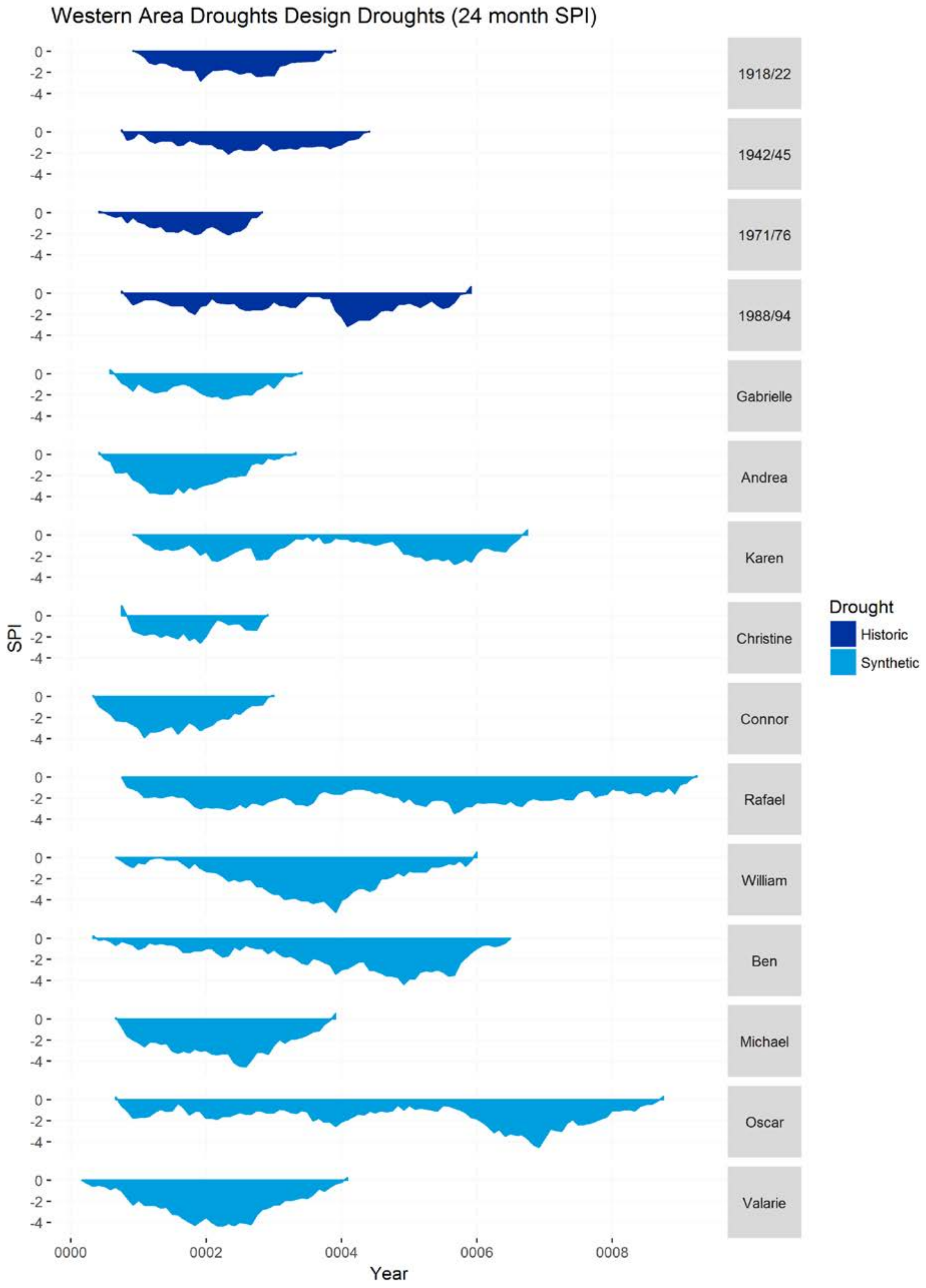
Table 54 Summary of ‘design’ drought events for the Western area

Drought Event	Duration (Months)	Critical SPI/Deficit Period (Months)	Minimum SPI	Peak Rainfall Deficit (mm)	Estimated DO Return Period	Total HSE and HSW DO
1918/21	24	12	-3.85	-393 (52% of LTA)	1 in 100 to 1 in 200*	39.3
1941/45	35	24	-2.77	-302 (63% of LTA)	1 in 50	57.2
1971/76	26	18	-2.81	-406 (68% of LTA)	1 in 50	58.3
1988/92	61	24	-3.14	-508 (69% of LTA)	1 in 50	59.7
Gabrielle	33	24	-2.39	-402 (76% of LTA)	19	107.0
Andrea	30	18	-4.87	-618 (50% of LTA)	48	67.4
Karen	33	12	-2.54	-292 (64% of LTA)	96	49.9
Christine	24	12	-3.09	-342 (58% of LTA)	105	48.3
Connor	25	12	-4.33	-442 (46% of LTA)	167	31.5
Rafael	95	12	-3.65	-389 (53% of LTA)	200	25.2
William	63	24	-5.19	-710 (57% of LTA)	285	12.0
Ben	73	24	-4.35	-615 (63% of LTA)	400	10.0
Michael	43	18	-5.07	-665 (49% of LTA)	1000	2.1
Oscar	96	24	-4.51	-665 (60% of LTA)	1000 - 2000	0.0
Valerie	44	18	-4.51	-574 (51% of LTA)	1000 - 2000	0.0

Figure 24 Example time series of Western area Historic and Synthetic Design Drought Evolution (24 month SPI shown)



Central area

The three WRZs of the Central area show different drought vulnerability to the Western area but also some variation between WRZs (Table 55, Figure 25, and Figure 26). This reflects the differing composition of the available water resource supplies within each WRZ: contrasting the Lower Greensand Aquifer and surface water resources of Sussex North WRZ with the Chalk groundwater dominated Sussex Brighton WRZ and Sussex Worthing WRZ.

Sussex North WRZ is vulnerable to surface water droughts (Table 56) that affect flows in the Western Rother and River Arun. Some surface water storage is also available in Weirwood reservoir. Our surface water and Aquator modelling of this WRZ has shown that the DO in this WRZ is most vulnerable to mid to long period droughts with rainfall deficits accumulating over 18 to 30 months and with the greatest impact occurring over 24 to 30 months (Figure 25).

In terms of historic events, the multiple dry winter 1918/22 drought event appears to be particularly severe in Sussex North WRZ in terms of overall rainfall deficit. Of the stochastic droughts the key surface water design events (Figure 25, Table 56) general show a similar overall patter to the 1918/22 event but with overall rainfall deficits in the first 24 months increasing in severity, for example the named droughts of Karen, Glenn and William.

Groundwater sources in Sussex North WRZNorth are supplied from the Lower Greensand aquifer which underlies most of the WRZ. This aquifer is somewhat drought resilient having relatively high storage and so is capable of sustaining baseflows in the River Rother over multiple season droughts. The Pulborough groundwater source is also presently coupled to the surface water MRF licence constraint and hence loss of this source can result in a sizable loss of DO once that MRF condition is reached despite there likely being water available in the aquifer.

The WRZ can also be vulnerable to ‘double-dip’ events where two or more periods of severe drought occur in sequence with only a short period of recovery between them. The 1988-1993 historic drought would be considered such an event, and the synthetic droughts of Oscar, Valerie and Melissa also match this style of drought (Figure 25).

Sussex Brighton and Sussex Worthing WRZs (the ‘Sussex Coast’) sources are both dominated by groundwater resources from the Chalk aquifer. Many are drought sensitive and overall show similar characteristics to the Hampshire WRZs in being most vulnerable to multiple dry winter events, typically two to three years in length with cumulative rainfall deficits over 18-24 months. Typical events include the historic drought of 1921 and similar synthetic droughts of Jerry, Aisha, Kirk (Figure 26) which are similar in style but more severe.

Like the western area the “three dry winter” event appears statistically unlikely but there are examples of severe and extreme droughts with multiple consecutive winters several years in length though often one or more winters tends to be more moderate, though still below average. These include the 1988/92 event and the synthetic events of Rafael, Tony, Aisha and Oscar. Generally in these cases it is still the second year after the two most severe winters that constrains DO most of all, i.e. the key feature is still consistent with a 1918/22 style event.

Eastern area

In the Eastern area, drought vulnerability varies between WRZs (see Figure 27 and Figure 28), with substantial differences between the groundwater dominated Kent Thanet WRZ and the Kent Medway East and Kent Medway West WRZs reflecting the contribution of surface water from the River Medway Scheme (see Table 48).

Kent Medway West WRZ appears to show a relatively high degree of drought resilience. Groundwater in Kent Medway West WRZ tends to be relatively drought resilience with licence or infrastructure constraints dominating. The storage in Bewl Reservoir also gives some resilience to long duration drought events. The WRZ can maintain close to normal year DOs up to around 1 in 100 year drought events. Drought impacts on DO, which primarily impact yields from the River Medway Scheme are greatest for severe and extreme droughts with deficits accumulating over periods 18 to 30 months in duration. These events (Table 57 and Figure 27) which include 1918/22, 1933/35, Brooke, Kirk , William and Andrea tend to develop relatively large rainfall deficits over a single or pair of winters that reduce the winter refill of the reservoir impacting on available yield in the next summer and autumn. Droughts become more extreme (e.g. Melissa, Dorian) as these rainfall deficits persist into a second or third year. For even longer duration events (48 month+) sufficient rainfall, on average, is likely to occur to allow some partial or complete refill of the reservoir even during extreme droughts.

There appears to be a substantial degree of overlap in terms of the more severe drought events with the Kent Medway West WRZ surface water droughts and Central area droughts (for example the synthetic droughts Michael, Oscar, Patty, William). In particular, William and Oscar and Patty (combined) are also keenly felt in Sussex North WRZ, reflecting that these events lead to substantial surface water impacts.

Kent Medway East WRZ tends to less drought sensitive than Kent Medway West WRZ owing to a greater proportion of licence and infrastructure constrained sources. The small proportion of drought sensitive sources be most vulnerable to long duration two to five-year periods of rainfall deficit that comprise multiple consecutive dry seasons. Some of the principal synthetic events (Table 57 and Figure 27) include Valerie, Patty and Oscar but their impact on groundwater is generally less severe than corresponding surface water events in Kent Medway West WRZ.

There appears to be a substantial degree of overlap in terms of the more severe drought events with the Kent Medway West surface water droughts and Central area groundwater droughts (for example the synthetic droughts Michael, Oscar, Patty, William). In particular the extreme events of William, Kirk Oscar and Valerie are also keenly felt in Sussex North WRZ, reflecting that these events lead to substantial surface water impacts.

Some of these more extreme events (e.g. Oscar) represent extended periods of rainfall deficit approaching a decade or more in length with a more discrete severe 3-4 drought embedded within. This style of event is somewhat akin to the early twentieth century ‘Long Drought’ of the Thames basin from 1890-1910 (Marsh et al, 2007) comprising a series of clustered very dry winters.

The droughts affecting Kent Thanet WRZ (Figure 28) tend to be distinct from those affecting the Medway WRZs. Typically these are shorter, three to four-year periods of rainfall deficit predominantly impacting winter rainfall. There is limited overlap of drought events with the groundwater droughts affecting the Western area and Sussex Brighton and Kent WRZs. These include Gabrielle, Valerie and Melissa. Broadly they are similar in style to the early 1970s drought (1971-73) and mid 1990’s drought. The difference in the drought events possibly reflects the geographic separation from other WRZs and the greater dependence of our Kent Thanet WRZ on drought vulnerable groundwater sources.

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Figure 25 Time series of Sussex North WRZ Historic and Synthetic Design Drought Evolution (24 month SPI shown)

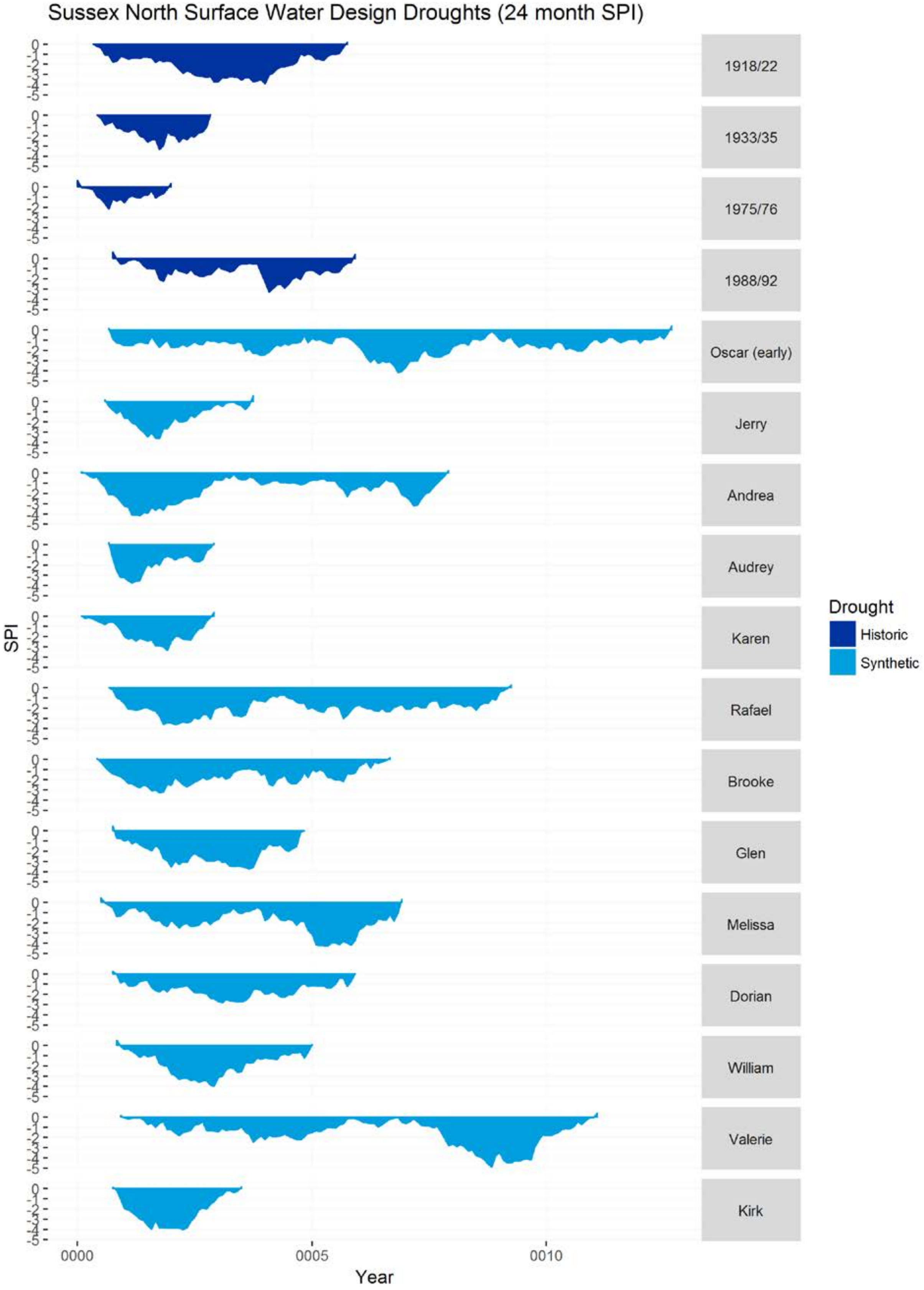


Figure 26 Time series of Sussex Brighton and Sussex Worthing WRZs historic and synthetic design drought evolution (18 month SPI shown)

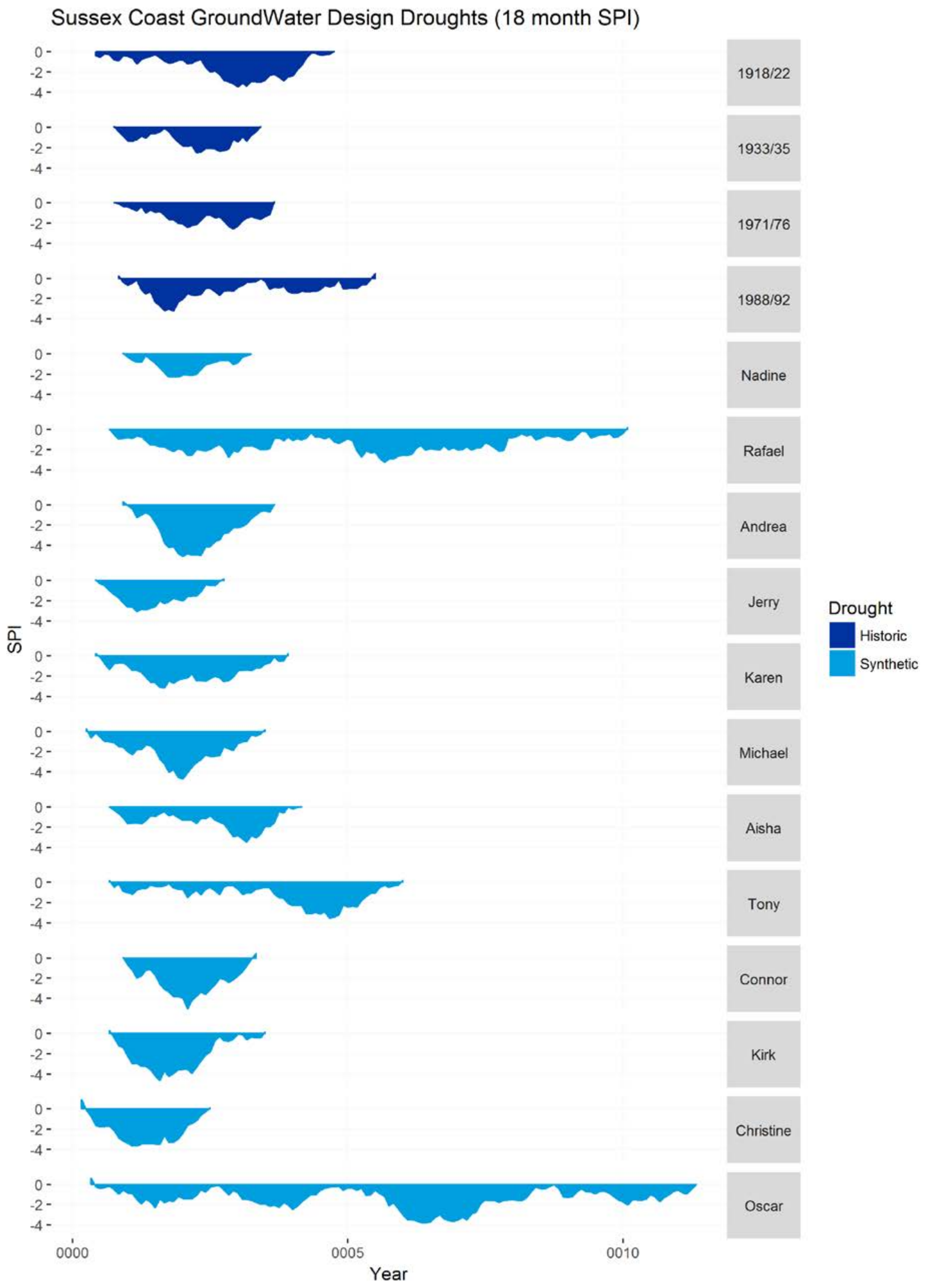


Table 55 Summary of ‘design’ drought events for the Sussex coast groundwater sources

Drought Event	Duration (Months)	Critical SPI/Deficit Period (Months)	Minimum SPI	Peak Rainfall Deficit (mm)	Estimated DO Return Period (years)	Total Coast DO (Ml/d)
1918/21	48	30	-3.54	-668 (69% of LTA)	1 in 100 to 1 in 200*	
1933/35	35	24	-2.99	-498 (70% of LTA)	1 in 20	
1971/76	32	30	-2.92	-560 (74% of LTA)	1 in 20 to 1 in 50	
1988/92	55	18	-3.21	-455 (64% of LTA)	1 in 50	
Nadine	27	18	-2.30	-348 (73% of LTA)	21	157.5
Rafael	115	30	-3.50	-656 (70% of LTA)	49	152.6
Andrea	32	18	-5.05	-675 (50% of LTA)	51	152.4
Jerry	27	24	-3.16	-522 (69% of LTA)	100	149.8
Karen	78	30	-3.92	-715 (66% of LTA)	143	148.3
Michael	38	18	-4.70	-639 (52% of LTA)	182	147.7
Aisha	41	18	-3.48	-497 (62% of LTA)	222	147.3
Tony	63	18	-3.55	-475 (60% of LTA)	250	146.9
Connor	28	18	-5.02	-670 (50% of LTA)	400	145.0
Kirk	33	18	-4.64	-581 (50% of LTA)	500	144.4
Christine	39	30	-4.04	-724 (65% of LTA)	1000	138.3
Oscar	140	24	-4.55	-708 (58% of LTA)	2000	137.5

Table 56 Summary of ‘design’ drought events for surface water in the Central area (Sussex North WRZ)

Drought Event	Duration (Months)	Critical SPI/Deficit Period (Months)	Minimum SPI	Peak Rainfall Deficit (mm)	Estimated DO Return Period (years)	Total DO (Ml/d)
1918/21	67	18	-4.28	-615 (57% of LTA)	1 in 100 to 1 in 200*	
1933/35	28	24	-3.34	-566 (68% of LTA)	1 in 20	
1975/76	17	18	-3.96	-528 (57% of LTA)	1 in 20	
1988/92	61	24	-3.25	-553 (69% of LTA)	1 in 20 to 1 in 50	
Oscar	143	24	-4.15	-678 (62% of LTA)	143	43.4
Jerry	37	24	-3.60	-603 (66% of LTA)	154	42.4
Andrea	43	18	-5.19	-684 (48% of LTA)	167	42.4
Audrey	25	18	-3.76	-554 (61% of LTA)	182	42.4
Karen	25	18	-3.65	-503 (60% of LTA)	200	41.4
Rafael	109	30	-3.75	-695 (68% of LTA)	222	41.4
Brooke	47	18	-3.63	-516 (61% of LTA)	250	41.4
Glen	52	30	-4.00	-766 (67% of LTA)	286	19.5
Melissa	89	30	-4.67	-851 (61% of LTA)	333	17.5
Dorian	63	18	-3.32	-457 (63% of LTA)	400	17.5
William	48	18	-4.07	-560 (56% of LTA)	500	17.5
Oscar	143	24	-4.15	-678 (62% of LTA)	667	17.5
Valerie	52	18	-5.31	-674 (45% of LTA)	1000	16.5
Kirk	26	18	-4.89	-623 (49% of LTA)	2000	15.5

Table 57 Summary of 'design' drought events for surface water in the Eastern area

Drought Event	Duration (Months)	Critical SPI/Deficit Period (Months)	Minimum SPI	Peak Rainfall Deficit (mm)	Estimated DO Return Period (years)	Total RMS DO (Ml/d)
1918/22	52	18	-3.17	-450 (68% of LTA)	~1 in 200*	
1933/35	48	24	-3.62	-570 (68% of LTA)	1 in 50 to 1 in 100	
1971/73	26	18	-1.98	-299 (79% of LTA)	1 in 10 to 1 in 20	
1988/93	17	18	-2.24	-323 (75% of LTA)	1 in 20	
Rosemary	40	24	-4.27	-654 (63% of LTA)	167	71.3
Brooke	44	24	-4.92	-731 (58% of LTA)	182	72.3
Patty	54	18	-4.31	-553 (58% of LTA)	200	71.8
Oscar	138	24	-4.08	-628 (64% of LTA)	250	69.8
Jerry	37	24	-3.98	-618 (65% of LTA)	286	68.3
Kirk	34	18	-4.88	-585 (52% of LTA)	333	65.3
Andrea	30	18	-4.74	-595 (55% of LTA)	400	64.3
William	40	18	-3.63	-504 (64% of LTA)	500	64.8
Tony	51	18	-4.51	-554 (55% of LTA)	667	64.8
Valerie	36	18	-5.24	-647 (51% of LTA)	1000	59.3

*Based on Met Office (2016) Reasonable Drought assessment

Table 58 Summary of ‘design’ drought events for groundwater in Kent Thanet WRZ

Drought Event	Duration (Months)	Critical SPI/Deficit Period (Months)	Minimum SPI	Peak Rainfall Deficit (mm)	Estimated DO Return Period (years)	Total RMS DO (Ml/d)
1918/21	33	24	-2.83	-419 (75% of LTA)	1 in 20	
1933/35	31	24	-2.62	-392 (76% of LTA)	1 in 10	
1971/76	51	24	-2.91	-432 (74% of LTA)	1 in 20 to 1 in 50	
1995/97	49	30	-3.22	-525 (74% of LTA)	1 in 100	
Kirk	58	24	-3.03	-446 (73% of LTA)	21	53.1
William	68	36	-2.60	-489 (80% of LTA)	21	53.0
Joyce	95	30	-2.85	-489 (77% of LTA)	50	50.9
Dorian	68	30	-3.13	-517 (75% of LTA)	100	48.7
Rafael	102	36	-3.44	-623 (75% of LTA)	167	48.5
Gabrielle	47	30	-4.23	-674 (67% of LTA)	200	48.2
Melissa	51	30	-3.32	-550 (73% of LTA)	250	48.1
Leslie	94	30	-3.17	-530 (74% of LTA)	500	47.4
Valerie	68	24	-4.35	-600 (64% of LTA)	1000	47.2
Brooke	61	24	-4.19	-582 (65% of LTA)	2000	46.4

*Based on Met Office (2016) Reasonable Drought assessment

Figure 27 Time series of Eastern area surface water historic and synthetic design drought evolution (18 month SPI shown)

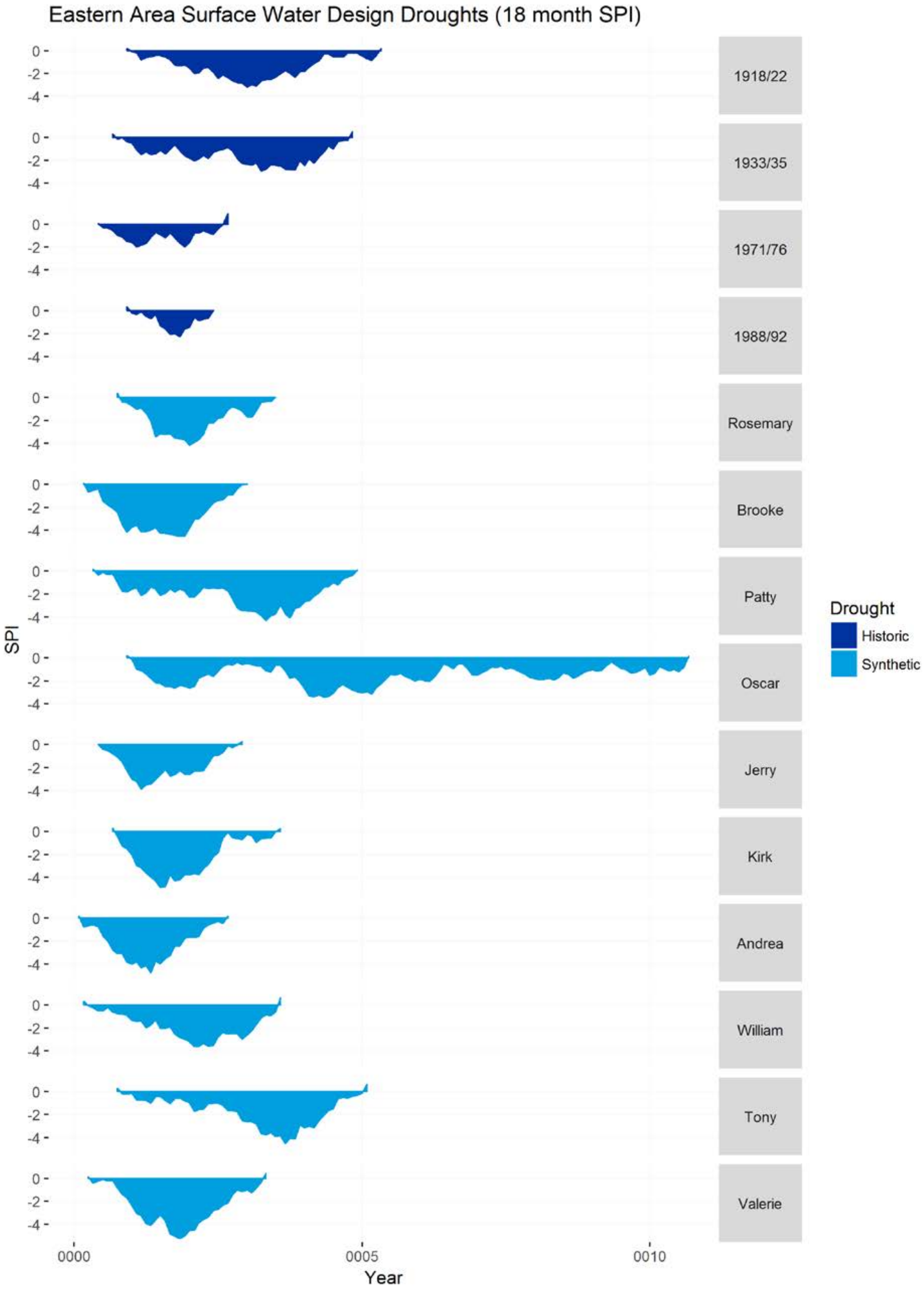
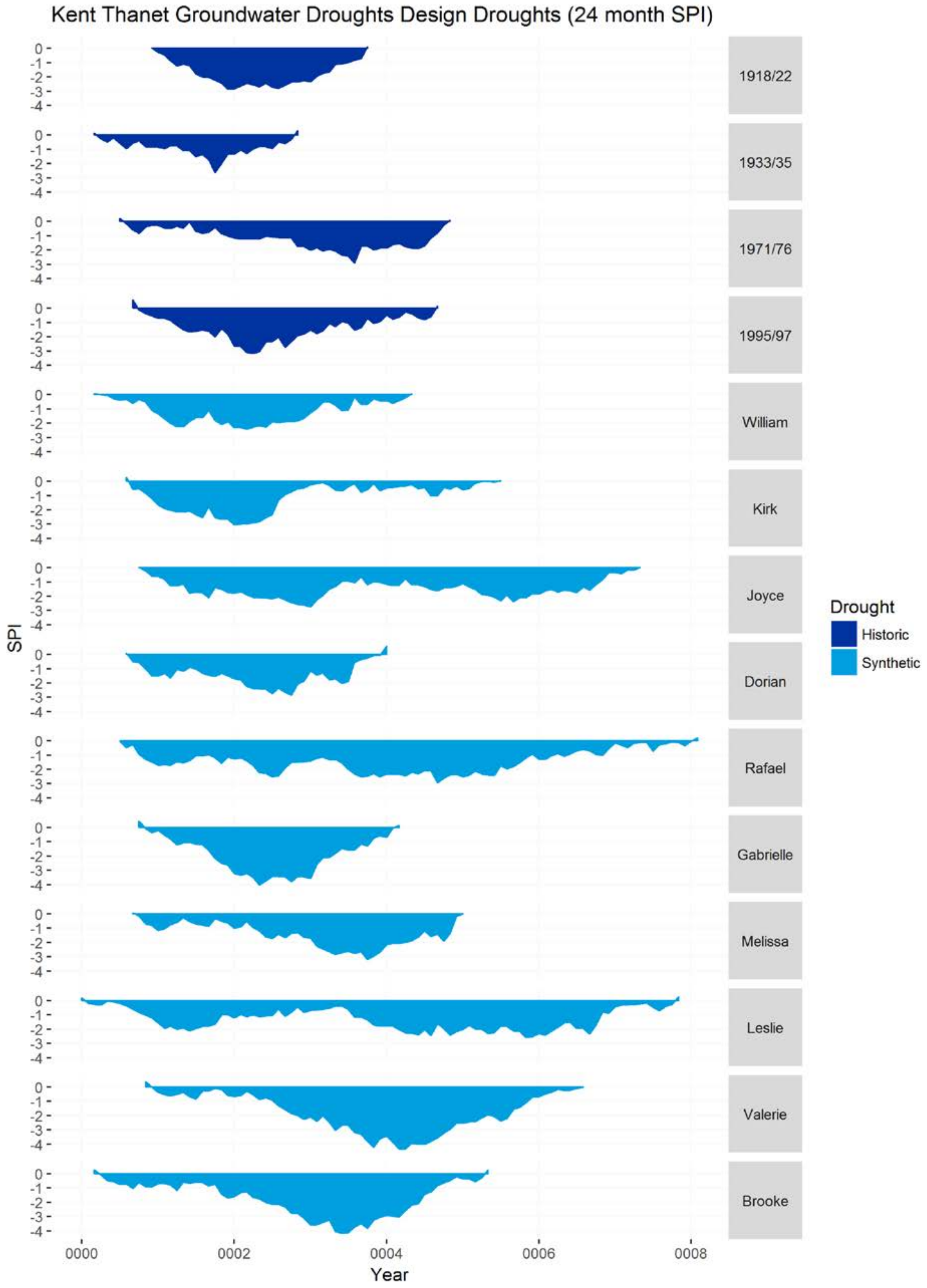


Figure 28 Example time series of Kent Thanet historic and synthetic design drought evolution (24 month SPI shown)



4.5.4 Drought vulnerability

The style of drought to which each WRZ is vulnerable can be generally related to the makeup of water resources within each area. There are a number of design events, particularly of the low probability severe to extreme drought events that impact across all WRZs. Notably, n Michael, Oscar and William, though the overall severity of these events varies between WRZs. Generally the patterns of drought simulated by the synthetic sequence tend to show similar characteristics to historic events in terms of the timing of onset and duration but are often more severe in terms of their absolute rainfall deficits. This validates the credibility of the synthetic weather generator in terms of producing events that are generally consistent with known historic droughts but which are also more severe and exhibit a wider degree of variability. It is also important to note that these named events which generally align with our DO probability estimates represent only a small proportion of the total drought events processed through each water resource model.

4.5.5 Credibility of our stochastic drought events for water resource planning

The difficulty of estimating the true probability of a drought event, given the somewhat limited historical record has previously been discussed in Section 3.2. The large dataset produced for the synthetic rainfall time series can be used to estimate such probabilities but only on the assumption that the previously observed climate (the data for which underpins the synthetic weather generator) gives a reasonable representation of future climate variability.

Given climate change and the short historic record, the extent to which this might be true is unknown. Similar modelling work conducted elsewhere for others (e.g. Met Office, 2016, WRSE, 2016) suggests that this assumption may be reasonable and any uncertainty is at least comparable in magnitude with the uncertainty introduced by hind casting if not smaller.

As well as the direct comparison of synthetic and historic drought events shown in Table 53 to Table 58 and Figure 24 to Figure 28 we have also commissioned an independent study by the Met Office to consider reasonable worst case drought events.

This project (Met Office, 2016), undertaken in 2016 comprised several aspects:

A literature review of historic droughts and potential impact of climate change on drought events
A review of historic rainfall deficits in Southern Water and Met Office held datasets
Extreme value analysis (see also UKWIR, 2016b) using rainfall to consider plausibility of extreme drought events.

The Met Office examined long term rain gauge records and their own rainfall data series across our supply area, for our Western (including Otterbourne rain), Central (including Petworth rain gauge) and Eastern (including Scotney Castle rain gauge) regions. Rainfall deficits over several metrics were calculated and compared to long term averages.

These analyses (Table 59) indicated that the most severe historical drought events across most areas and metrics were usually those of the 1975/76 drought and the 1920/21 drought. In our central and western areas the 1988/89 event was considered more severe over 18 months deficits from April and the 1931-33 event over three hydrological Years. The 1975/76, 1920/21 and 1988/89 events have all been considered as design droughts in our previous Water Resource Management Plans.

Table 59 Summary of worst historical drought events by area After Met Office (2016)

	Worst Historical Drought (% below LTA rainfall)		
Rainfall Measure	**Western Area**	**Central Area**	**Eastern Area**
6 Months (Oct-Mar)	1975/76 (-58.2%)	1975/76 (-54%)	1975/76 (-44.4%)
6 Months (Apr-Sep)	1921 (-52.7%)	1921 (-57%)	1921 (-56.6%)
Hydrological Year (Oct-Sep)	1975 (-47.2%)	1975 (-47.8%)	1920 (-46.4%)
18 Months (Oct-Oct-Mar)	1920/21 (-32.6%)	1920/21 (-35%)	1920/21 (-39.1%)
18 Months (Apr-Apr-Sep)	1988/89 (-25.7%)	1988/89 (-30%)	1920/21 (-28.4%)
2 Hydrological Years	1920/21 (-22.4%)	1920/21 (-25.9%)	1920/21 (-29%)
3 Hydrological Years	1931/33 (-16.1%)	1931/33 (-21.4%)	1919/21 (-22%)
4 Hydrological Years	1918/21 (-11.5%)	1918/21 (-15.7%)	1918/21 (-17.6%)

These events, being the worst on historical record, would imply that by conventional frequency analysis would have the annual probabilities are around 1% (1 in 100 year events). Extreme value analysis of historic rainfall sequences by the Met Office suggested that for some metrics the 1976 and 1921 events might be closer to 0.5% annual probability (i.e. consistent with a 1 in 200 year event).

The Met Office study recognised the difficulty of using worst historic event (~1% annual probability / 1 in 100 return period) for water resource planning. The purpose of this study was to explicitly consider the plausibility of extremely or very low probability drought events (e.g. <<1% annual probability) in order to define what might constitute a '*reasonable worst case'* event to plan for. Recent resilience guidance makes reference to designing public infrastructure for a 'reasonable worst case' but does not explicitly state what that might constitute. Similar limitations apply to the case that needs to be satisfied for the purpose of obtaining Drought Orders under the Water Resources Act which need to satisfy a test that there has been an "*exceptional shortage of rain*" but which is not quantified.

Frequency and extreme value analysis were used to estimate worst case drought events in terms of rainfall deficit over several accumulation periods for each of our three major supply areas. This assessment gives an independent estimate of the likely rainfall deficits of severe to extreme droughts appropriate for water resource planning. These data can therefore be compared to the rainfall deficits estimated for the synthetic weather generator events (Table 60).

The estimates for different rainfall accumulation periods in Table 60 match up relatively well with the estimated deficits for the more severe design droughts. The Met Office estimated that the reasonable range of stress testing to be somewhere between 0.5% and 0.2% annual probability (equivalent to the 1 in 200 to 1 in 500 return period drought events). Overall this assessment suggests that the range of synthetic droughts we have used are credible and broadly consistent with independent empirical estimates derived via an entirely different approach.

Table 60 Estimated reasonable range of rainfall deficits for stress testing (after Met Office, 2016)

Region	Rainfall Deficits (as % of Long Term Average Accumulation)			
	6 Month	12 Month	18 Month	24 Month
Western	30% to 47%	48% to 53%	60% to 74%	78%
Central	30% to 46%	47% to 52%	60% to 70%	74%
Eastern	30% to 54%	48% to 54%	59% to 72%	71%

The Met Office expressed low confidence in their extreme value analysis for rainfall deficits for 1 in 500 years (0.2% annual probability) drought owing to the extrapolation required and limited observation data at these rainfall deficits. This is a general problem when considering extreme droughts owing to the lack of empirical data and reliance on modelling approaches constrained by observations and more research is required.

4.5.6 Drought response surfaces

Another uncertainty when considering the probability of a drought event is which metric(s) are used to define the event. For example, the Met Office (2016) analysis indicated that the 1976/76 event is considered the worst drought on record over short-term rainfall deficits (i.e. 6-12 months). Over longer term measurements, for example 18 months+ the drought is not considered as especially noteworthy in terms of rainfall deficit.

Climate metrics are therefore only partially useful in characterising a drought for water resource planning since the impact of each drought occurs differently because of seasonal timing, antecedent rainfall and the intensity/severity of the deficit accumulated. Consequently, it is possible for a given drought event to exhibit multiple probabilities/return periods dependent on the metric selected. It is for this reason that the UKWIR Risk based planning guidance (UKWIR, 2016) recommends the use of “system stress” metrics for probabilistic drought analysis.

System stress metrics, which include DO and source yield implicitly include the effect of all relevant drought factors (e.g. rainfall deficit, seasonality, potential evapotranspiration and flow/groundwater level) within the metric (UKWIR, 2016b). Return periods of system stress, and probability of failure, can also be directly linked to customer Levels of Service (UKWIR, 2016b).

Our Risk composition (see Annex 1) requires us to produce a “system stress” based metric (DO), and to calculate return periods using that metric for all the droughts. This is because return periods can only be calculated based on a continuous yield/probability curve or by ranking all the droughts that are generated from coherent time series (UKWIR, 2016b). We have undertaken both approaches. We have carried out frequency analysis of our very long rainfall time series output from our stochastic weather generator to estimate climatological metrics. Our water resource modelling also allows us to estimate return periods of DO as a “system stress” metric.

A useful method for visualising the relationship between DOs, rainfall deficit and event probability is through the preparation of “drought response surfaces.” These visualisations were initially developed to support an EA study into the performance of water supply systems during drought (Environment Agency, 2016). The procedure and methodology for preparing the response surfaces has since been refined in two subsequent UKWIR projects looking at both drought vulnerability (UKWIR, 2017) and climate change (UKWIR project CL04). Rather than DO the UKWIR Drought Vulnerability Framework recommends use of an alternative system stress metric that also accounts for demand, and level of service by comparing rainfall deficits with number of days where either abnormal restrictions on demand might be expected, or where Drought Orders and Permits might be implemented (UKWIR, 2017).

The form of a drought response surface is to plot DO (as a colour flood grid) against accumulated rainfall deficit (as a proportion of long term average rainfall) on the y axis and the length of the accumulation on the x axis. Historic rainfall events can then be overlain, and if available, so can estimates of rainfall deficit probability.

This allows rainfall deficits to be directly related to system stress (DO) alongside their likelihood

Several of these visualisations have been prepared, covering each of our main WRZs that are vulnerable to drought. Where DO does not vary substantially during drought no drought response surface has been prepared as such a plot would not be useful.

These plots have been derived from these data:

Historical rainfall at a key indicator observation site within each WRZ
Synthetic rainfall time series for the same indicator observation site, these data are used as input time series to water resource models used to derive DOs and estimate, from frequency analysis, probabilities associated with rainfall deficits
Time series of DO derived from each water resource model

As previously stated DOs are not necessarily directly related to rainfall deficit, especially in high storage WRZs or where the timing of rainfall deficits (e.g. for winter recharge) is important for water resource volumes. Consequently, there are often multiple DO values for each interval of rainfall deficit in these data. Where this is the case the median DO value has been shown in each interval. These data have been derived from the 2000 years output sequences of the water resource modelling and represent the annual MDO in Western and Central areas, and ADO in Eastern area. The absence of shading indicates that a DO has not been calculated for that interval of rainfall deficit and accumulation period. To aid comparison between WRZs, DO is expressed as a percentage of the normal year MDO or ADO.

Point data indicate the observed distribution of historical rainfall deficits. Line data show the probability of a given rainfall deficit for each accumulation period. These probabilities have been derived from frequency analysis of the full (~100,000 year) synthetic drought record produced by our weather generator (see Section 3.2).

Figure 29 and Figure 30 show drought response surfaces for Hampshire Southampton West and Hampshire Southampton East WRZs. Both figures assume the full implementation of the sustainability reductions (Section 5) in the scenarios shown. The full normal year DO is available up rainfall deficits of around 80% of the long-term average. Both WRZs are also relatively resilient to low probability droughts of fewer than six months' duration. 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 Hampshire Southampton East maintains DO for longer but ultimately yield from both WRZs is curtailed entirely by the imposed HoF conditions under severe droughts (<0.5% annual probability).

Figure 29 Drought response surface for Hampshire Southampton West WRZ

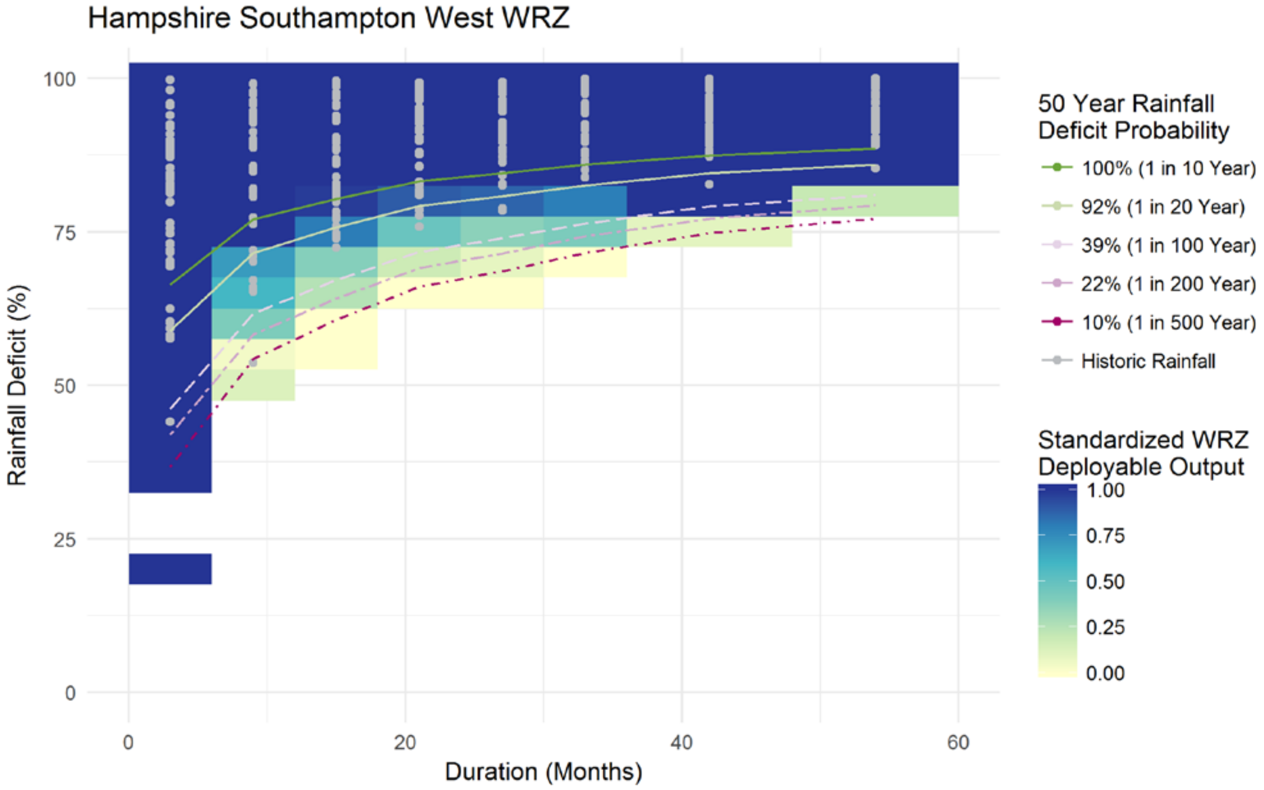
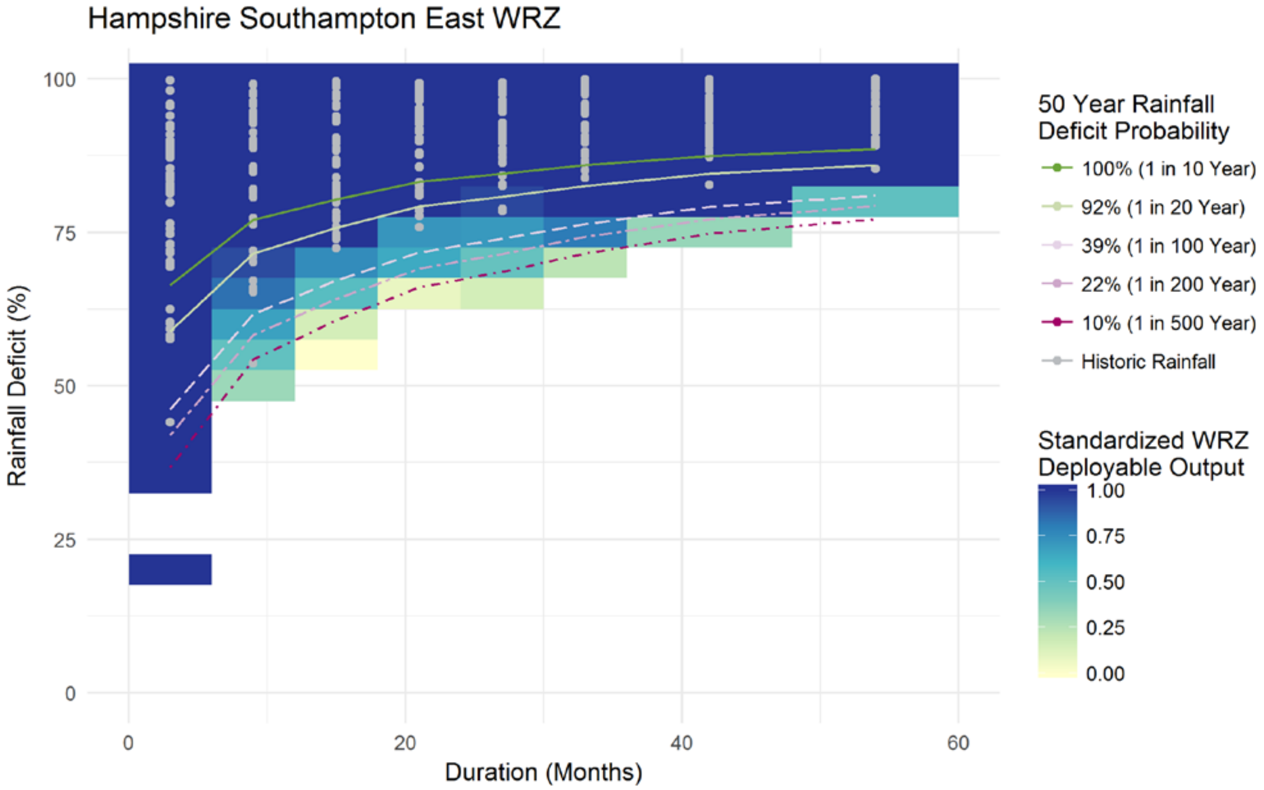


Figure 30 Drought response surface for Hampshire Southampton East WRZ



For the Central area separate drought response surfaces have been produced for Sussex North Sussex Worthing and Sussex Brighton WRZs. The overall pattern for Sussex North WRZ (Figure 31) is generally similar to that in Hampshire though DO is less vulnerable and does not completely drop to zero under extreme droughts. The greatest drought impacts appear to occur for 18 to 36-month rainfall deficits between 50% and 75% of long term average rainfall. This is equivalent to a drought events worse than around a 1 in 20 year rainfall deficit.

Both the Sussex Worthing and Sussex Brighton WRZs (Figure 31 and Figure 32) show similar trends. Overall, the proportion of DO lost during drought is less in Sussex Brighton WRZ and Sussex Worthing WRZ than in Hampshire and Sussex North WRZ owing to a greater number of licence or infrastructure constrained sources. DO starts to reduce at smaller deficits, generally 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 18-30-month rainfall deficits of 50-75% of long term average. These events would be equivalent to around the 1% to 0.2% annual probability drought (1 in 100 to 1 in 500).

Figure 31 Drought Response Surface for Sussex North WRZ

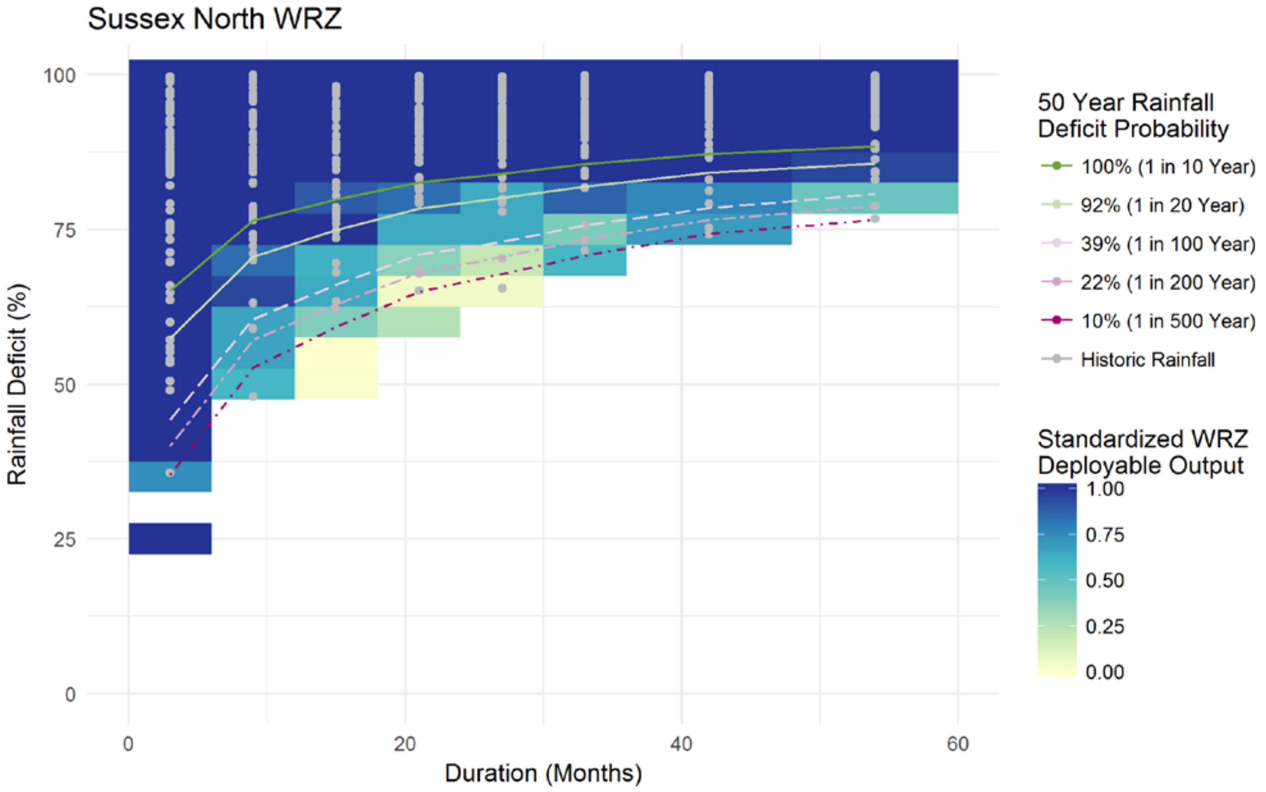


Figure 32 Drought response surface for Sussex Worthing WRZ

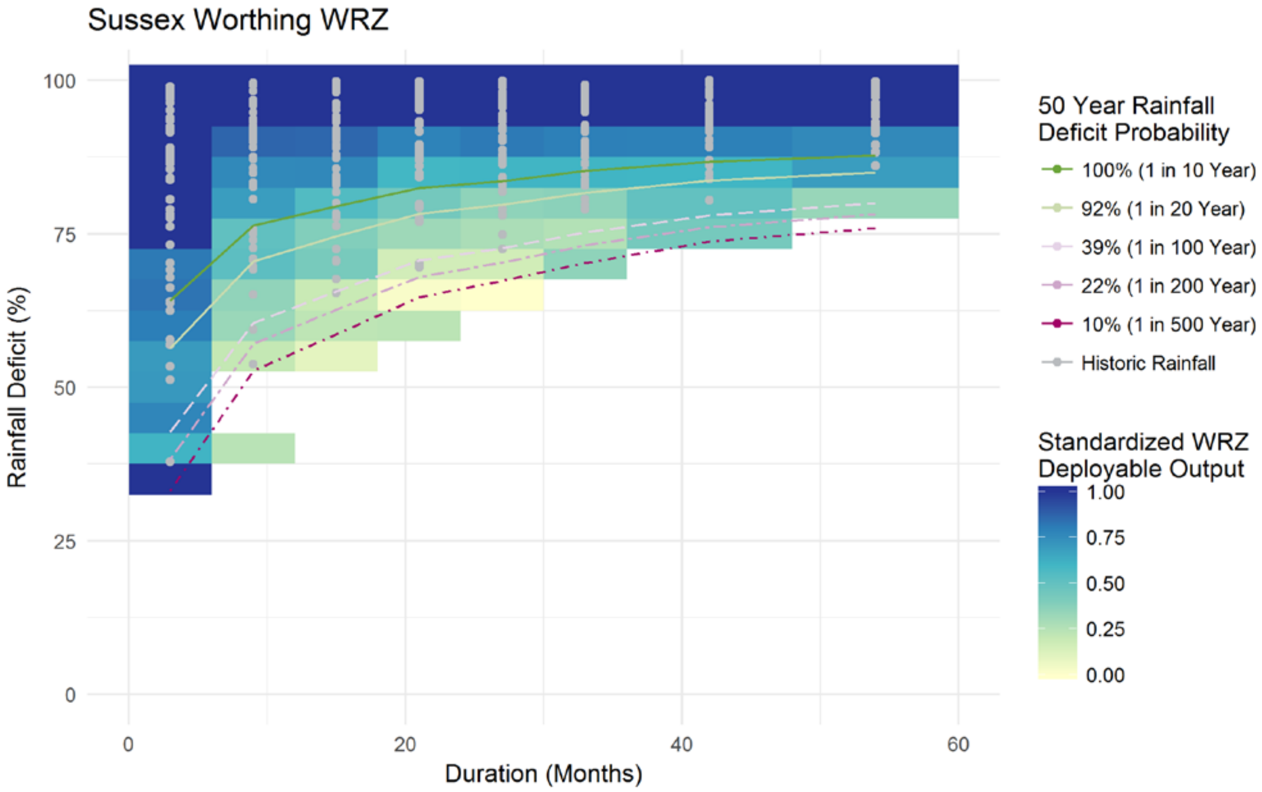
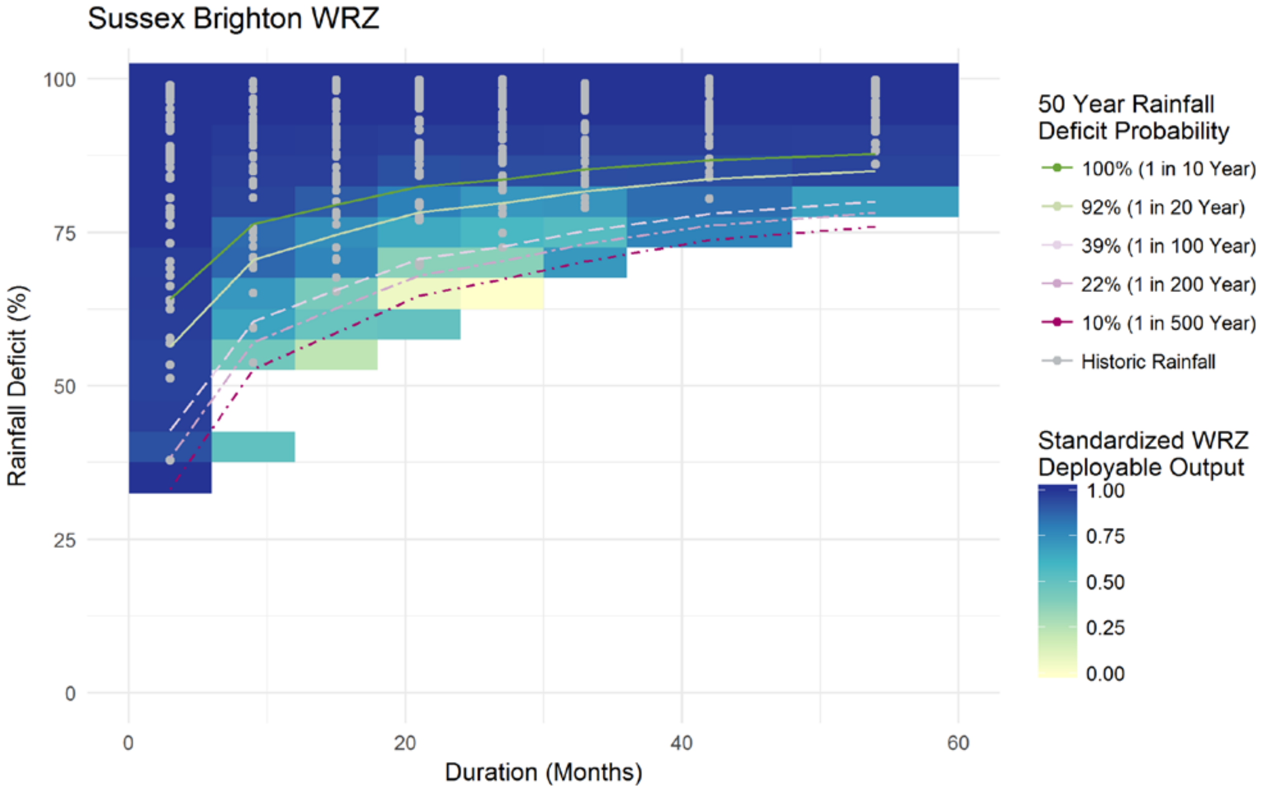


Figure 33 Drought response surface for Sussex Brighton WRZ



Kent Medway East and Kent Medway West WRZs (Figure 34 and Figure 35) are both shown to be relatively drought resilient, reflecting the large number of licence and infrastructure constrained groundwater sources in both WRZs and the high storage available in the River Medway Scheme. Drought impacts are most apparent in Kent Medway West WRZ (Figure 34) and tend to occur when rainfall deficits are between 50 and 75% of long term average accumulations of between 18 and 36 months. This largely reflects depletion of the River Medway Scheme during drought events of less than 1% annual probability (1 in 100 year).

Kent Thanet WRZ (Figure 36) shows the same general pattern to the other groundwater dominated WRZs of Sussex Brighton and Sussex Worthing. Generally rainfall of less than 75% to 80% over periods of longer than 12 months starts to diminish supplies. The greatest impacts are felt at rainfall deficits of less than 75% of the long-term average especially over periods of 18months or longer, equivalent to drought events <1% annual probability.

Sussex Hastings WRZ response (Figure 37) is broadly similar to Kent Medway West WRZ, both WRZs being dominated by large (connected) surface reservoir storage. Sussex Hastings shows a greater drop off in the proportion of DO with increasing drought severity as the reservoirs system makes up the vast majority of the supply. The only alternative being a single small groundwater source. Typically this shows the greatest loss of DO occurs for severe and extreme droughts 18-36 months in duration that effectively deplete the available reservoir storage.

Figure 34 Drought response surface for Kent Medway West WRZ

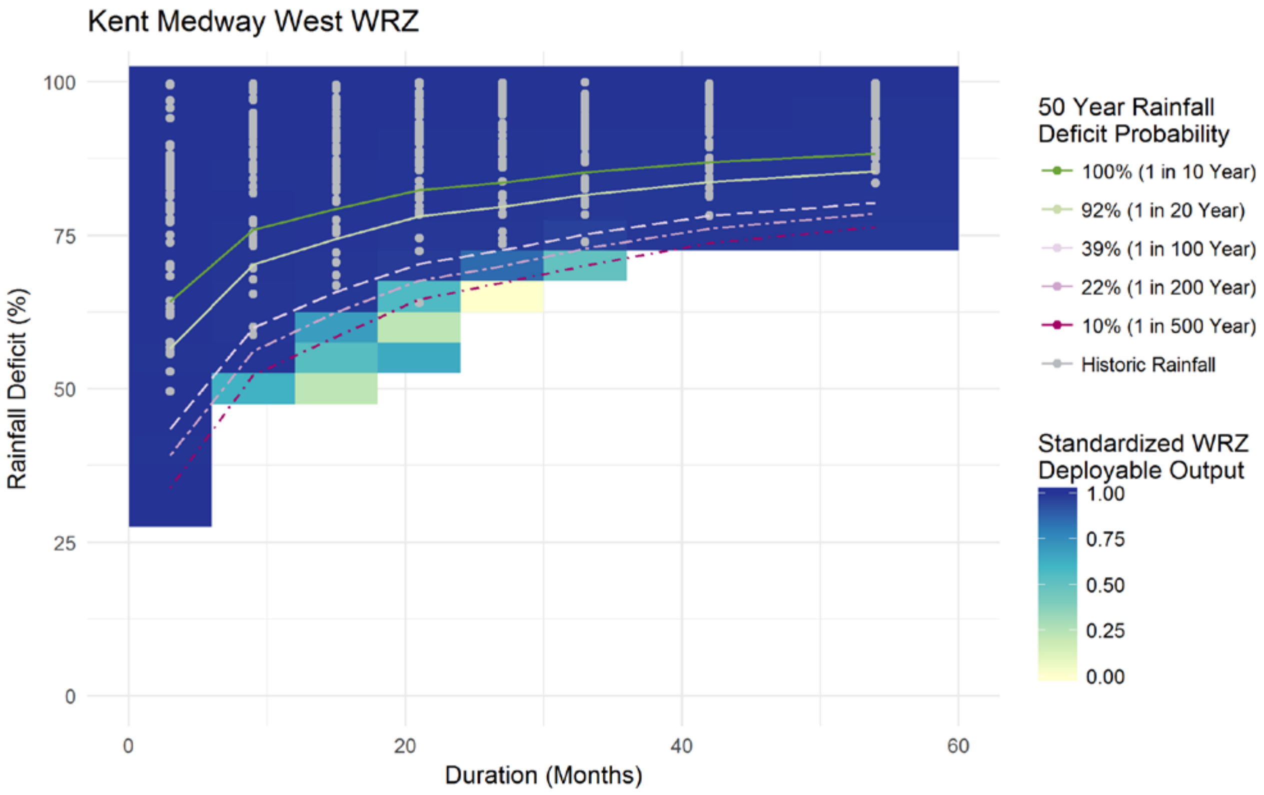


Figure 35 Drought response surface for Kent Medway East WRZ

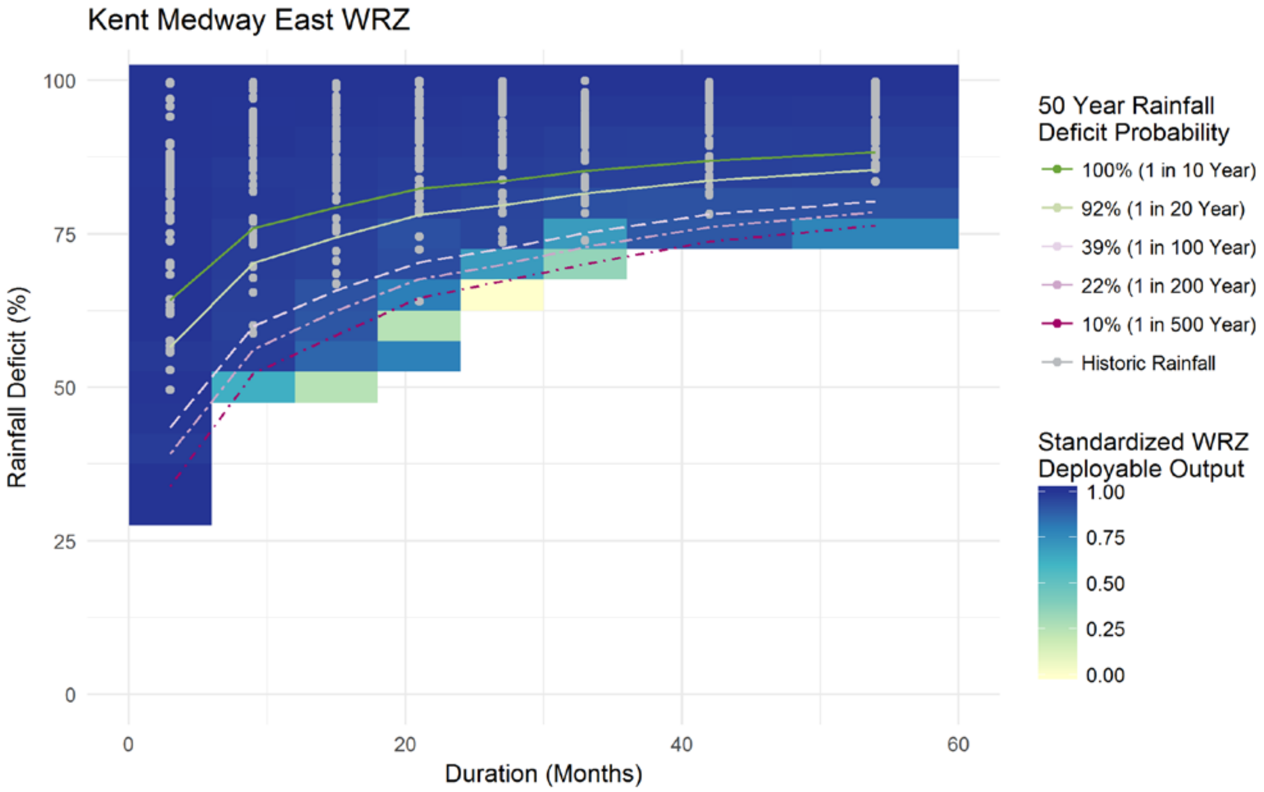


Figure 36 Drought response surface for Kent Thanet WRZ

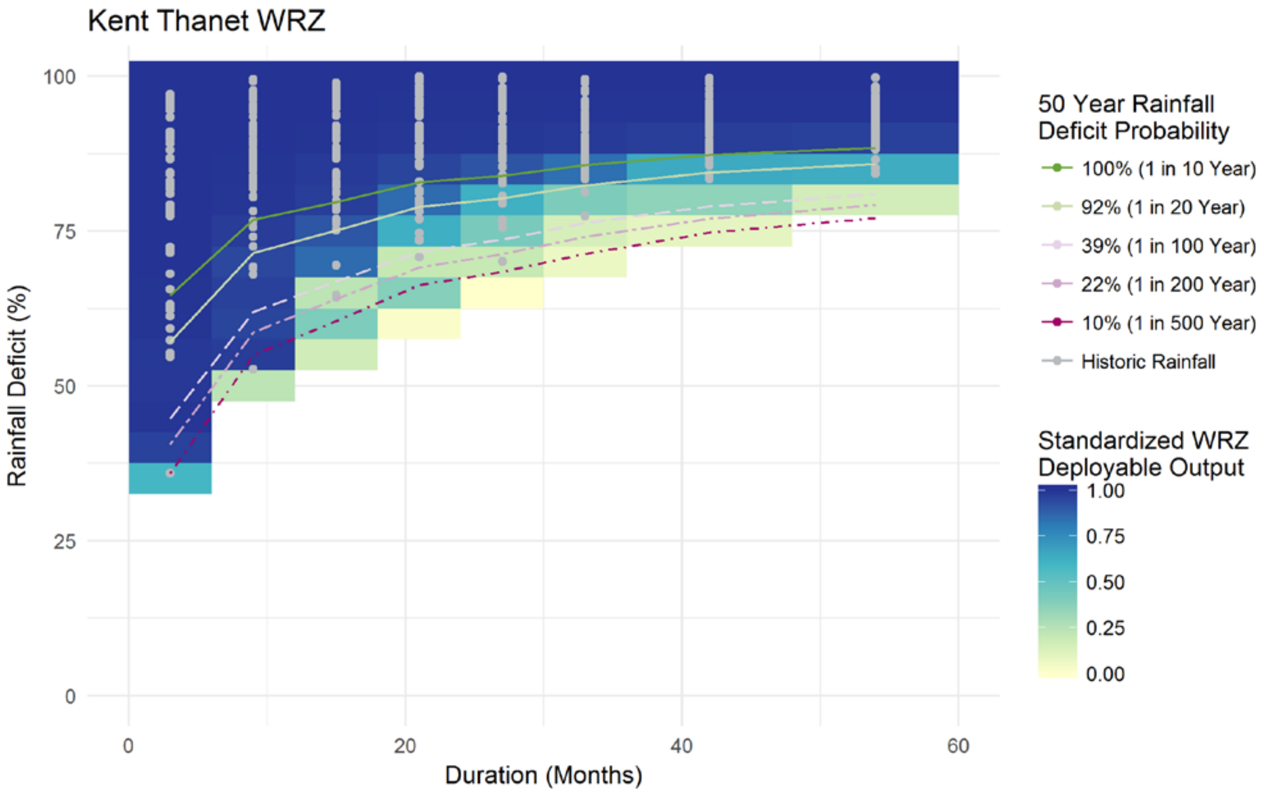
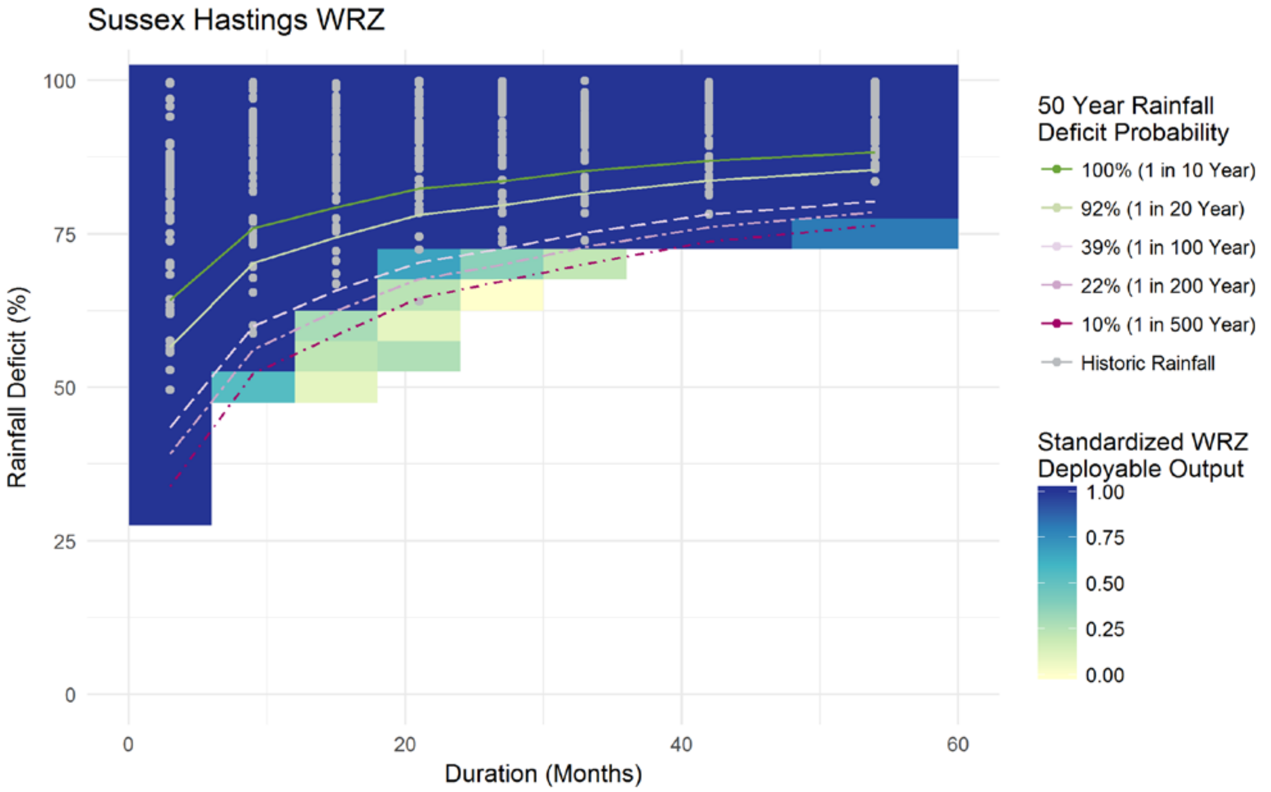


Figure 37 Drought Response Surface for Sussex Hastings WRZ



4.5.7 Links to our drought plan (Table 10)

The drought events set out in Section 4.5.3 (Table 54 to Table 58) represent the associated climatological sequences that correspond to our DOs (as a system stress metric) for different probabilities (return periods).

Consideration of how these drought events constrain DOs and the extra demand and supply side measures we would require to maintain supplies consistent with our levels of service are set out in Table 10 of our Water Resource Planning Tables. In Table 10 we have also considered the worst historical drought events, specifically the 1921-22 drought and, in our western area, the 1976 event.

Our preferred plan (Annexes 9 to 11) describes how our reliance on supply side drought measures changes substantially over the lifetime of our plan. In the short term (2020-2027 in our Western area and 2020-2025 in our Central area) we will require greater reliance on drought permits and orders to maintain supplies (Annex 1). For WRZs where this is the case we have presented alternate versions of Table 10 for these drought events.

Note that as set out in Section 4.1.2, the effects of demand side restrictions as a marginal benefit on DOs are assumed to be available at the levels of service set out in Annex 1. In some WRZs, these marginal benefits to DO are unavailable are the yield of sources are constrained by licence or infrastructure and hence there is no marginal DO benefit available (consistent with UKWIR, 2014).

5. Sustainability reductions

5.1 Achieving sustainable abstraction

Over the last 20 years we have undertaken investigations and implemented schemes to improve the environmental sustainability of our abstractions. We have been an active partner in supporting delivery of the EA's RSA programme and more recently Water Framework Directive (WFD) programme. Both programmes aim to establish a sustainable abstraction regime. Requirements for investigations, options appraisals and implementation schemes have been set out in the EA's NEP which is issued every five years to align with Ofwat's business planning periodic review process to allow funding to be sought.

In recent years we have revoked an abstraction licence in Hampshire (Test valley), reduced licence volumes at a source in Sussex (North Arundel) and implemented river restoration to a stream on the Isle of Wight (Lukely Brook). A summary of the investigations, options appraisal and implementation schemes the company is delivering in AMP6 as part of the current NEP is described in the section below.

We believe it is in the best interest of customers and the environment to address unsustainable abstraction as quickly as possible and to look beyond the five-year NEP / business planning cycle to make sure we address future risks. This will mean more optimal solutions can be implemented taking account of the long-term availability of supplies. As well as being supportive of the EA's most recent 'sustainable catchments' plan, which was disseminated in 2016 and which has influenced the Water Industry National Environment Programme (WINEP) for AMP7, we are also developing a long term environmental forecast. This will consider future scenarios taking account of climate change and its impact on sustainable abstraction as well as other drivers such as behavioural change. The environmental forecast and how we are using it in WRMP19 is set out in Annex 4.

There are a number of drivers that must be addressed in order for a sustainable abstraction regime to be achieved. These include protecting habitats and species designated under the Habitats Directive, safeguarding SSSIs and protecting BAP species. The EA's sustainable catchments programme also strongly emphasises the WFD objective of ensuring water bodies do not deteriorate as well as improving water body status where this is achievable.

5.2 AMP6 water resources national environment programme

We are delivering a number of investigations, options appraisal and implementation schemes in AMP6 (2015-20), which were confirmed in the final NEP phase 5 released to the company in January 2016. A table showing all the schemes is shown in Table 61, with the descriptions of the driver codes in

Table 62. The schemes are summarised below.

New investigations and options appraisals include the Anton and Pill Hill Brook, and Plaish Meadows, both of which have local drivers. In North Kent a joint investigation with South East Water is underway to review the sustainability of a number of groundwater sources against Water Framework Directive objectives.

Implementation schemes include the Lower Test EAand the Lower Itchen sources (Itchen surface water, Itchen groundwater and Twyford) following changes to our abstraction licences in March 2019. Non-licence change implementation schemes consist of the Lukely Brook (Isle of Wight WRZ) and Lewes Winterbourne (Sussex Brighton WRZ) river restoration scheme to address WFD objectives, the 'Wingham and Little Stour habitat restoration scheme' to address Biodiversity 2020 objectives and schemes at Bewl and Weir Wood reservoirs to address Water Framework Directive Heavily Modified Water Body objectives.

EATable 61 AMP6 water resources national environment programme schemes

Site Name	Waterbody ID (NBB)	Driver 1 updated	Licence Name	Type of change
Lower Test	GB107042016840	wrSSS1	River Test Surface Water	Licence Variation
Lukely Brook	GB107101006250	wrWFDs1	Newport GW	Non-licence habitat restoration
Bewl Water	GB106040018500	wrWFDp1	Springfield, Smallbridge, WPS near Maidstone, abstraction from Bewl	Compensation release variation
Bewl Water	GB106040018520	wrWFDp1		
Bewl Water	GB106040018260	wrWFDp1		
Bewl Water	GB30644398	wrWFDp1		
Weir Wood	GB30644310	wrWFDp1	Weir Wood Weir Wood	Compensation release variation
Weir Wood	GB106040018070	wrWFDp1		
Lewes Winterbourne	GB107041012450		Brighton Group	Non-licence habitat restoration
Lower Test	GB107042016840	wrSSS1	River Test Surface Water	Licence Variation
Little Stour	GB107040019590	wrBiod1	Near Canterbury	Non-licence habitat restoration
Wingham River	GB107040019570	wrBiod1	Near Canterbury, West Sandwich, Sandwich	Non-licence habitat restoration
River Itchen	GB40701G0500	wrHD1	Twyford	Licence Variation
River Itchen	GB40701G0500	wrHD1	River Itchen SW	Licence Variation
River Itchen	GB40701G0500	wrHD1	River Itchen GW	Licence Variation
Lower Test	GB107042016840	wrWFDs3b	River Test Surface Water	-

Site Name	Waterbody ID (NBB)	Driver 1 updated	Licence Name	Type of change
Anton & Pillhill Brook	GB107042022780	wrLoc3	Andover	-
Plaish Meadows and Lukely Brook	GB107101006250	wrLoc3	Newport	-
Plaish Meadows and Lukely Brook	GB107101006250	wrLoc3	Lukely Brook	-
Dry valley south of Sittingbourne	GB40601G501700 (linked groundwater body ID)	wrWFDs3	Sheldwich, Faversham3, Faversham4, Faversham1, Faversham2, Beacon Hill, Sittingbourne1, Sittingbourne2, Millstead, London Road, Lomas Road, Tonge	-
White Drain	GB106040018560	wrWFDs3		-
North Kent Swale Chalk	GB40601G501700 (linked groundwater body ID)	wrWFDg3		
North Kent Tertiaries	GB40602G500200 (linked groundwater body ID)	wrWFDg3		-
North Kent Medway Chalk	GB40601G500300 (linked groundwater body ID)	wrWFDg3	Northfleet Chalk, Gravesend, Meopham, Cuxton, Rochester, Higham, Strood, Chatham West, Capstone, Chatham, Gillingham	-
Swale Tributary at Lower Halstow	GB40601G501700 (linked groundwater body ID)	wrWFDs3	Motney Hill, Chatham West, Capstone, Rainham, Chatham, Gillingham, Hartlip, Hartlip Hill, Sittingbourne, Newington	-

Table 62 Water resources driver codes

Driver	Driver Code	Driver Description
Habitats Directive	wrHD1	Action to achieve favourable conservation status
Water Framework Directive	wrWFDs1	Action to help achieve good ecological status (surface water)
	wrWFDp1	Action to achieve good ecological potential
Sites of Special Scientific Interest (SSSI)	wrSSS1	Action to achieve favourable conservation condition
Biodiversity Action Plan (BAP)	wrBiod1	Action to achieve a water resources requirement agreed by the conservation agencies and the EA, beyond the requirements of Habitats Directive and CRoW Act to meet outcomes under Biodiversity 2020 or the NERC Act. This addresses government's Biodiversity driver to "take targeted action for the recovery of priority species, whose conservation is not delivered through wider habitat-based and ecosystem measures"
Water Framework Directive	wrWFDs3b	Investigation to find out the likelihood that abstraction will cause water body deterioration (surface water) and identify effective solutions
Local Priority (Local)	wrLoc3	Investigation to quantify the impact of abstraction on a site

5.3 AMP7 water industry national environment programme

The EA issued a programme for three formal 2019 price review (PR19) WINEP releases between March 2017 and March 2018 (Environment Agency, 2017):

WINEP 1: released on 31 March 2017
WINEP 2: 29 September 2017
WINEP 3: 30 March 2018

In the lead up to WINEP 1, the EA worked with water companies to understand the need for sustainability investigations and reductions through review of EA data. This 'sustainable catchments' programme was initiated at a national workshop in September 2016 and there was an associated release of guidance with a spreadsheet of data for each company. More clarifications and guidance were issued through to January 2017.

In order to complete our draft supply forecast before of the release of WINEP 2, we developed our estimates of sustainability reductions in two main phases which are described in this section:

1. September 2016 – March 2017: Sustainable catchments review to inform WINEP 1
2. March 2017 – August 2018: Sustainability reductions for the supply forecast after the WINEP 1 release

After the release of WINEP 2 and WINEP 3 we have reviewed the need for any changes to our estimates of sustainability reductions for the final WRMP. In WINEP 3 more details were specified for investigations on the River Test and River Itchen. There were also changes in the level of certainty assigned to some investigations or completion dates. After a review we concluded there was no need to change our sustainability reductions assumptions and hence the original assessment undertaken on the formal WINEP 1 release as referred to below in this section still stands.

5.3.1 Sustainable catchments review – EA data and guidance

The spreadsheet issued by the EA to each water company in September 2016 summarised calculations for compliance with the Environmental Flow Indicator (EFI) for Water Framework Directive (WFD) surface water bodies in water companies' supply areas. The spreadsheet also contains data on assumed abstraction rates, for a range of scenarios.

In its guidance on the use of the EFI, the EA states:

EFIs are used to indicate where abstraction pressure may start to cause an undesirable effect on river habitats and species. They do not indicate where the environment is damaged from abstraction. In its guidance in 2013 (EA, 2013b) the EA stated that the EFI is not a target or objective for resolving unsustainable abstractions. It is an indicator of where water may need to be recovered. The decision to recover water in water bodies that are non-compliant with the EFIs should only occur when supported by evidence that gives ecological justification.
In its updated guidance published in January 2018 (EA, 2018) the EA states that when managing abstraction licences to support the objective of good ecological status for the WFD, the EFI will be applied as a default unless there is agreed local information that defines a more appropriate local flow constraint.

The calculations of compliance with the EFI are carried out in an EA assessment tool called the Water Resources GIS. This tool is not shared with water companies so there can be difficulties in understanding the summary data and predicting how changes in abstraction would affect flows.

In the sustainable catchments spreadsheet, the EA estimated the impact of each abstraction point (which may be multiple points for sources with more than one borehole) on up to five WFD surface water bodies. The EA estimated the expected increase in abstraction rates through to 2027 by referring to raw water abstracted (RWA) values from companies' WRMP14 planning tables. Finally, the EA found abstractions that are upstream of protected areas such as Special Protection Areas (SPAs) and Special Areas of Conservation (SACs).

Based on these data, each abstraction point was then attributed a category of deterioration risk from one (highest risk) to four (lowest risk) (Table 63). Water companies were asked to return their spreadsheet by the end of February 2017 and to: a) comment on the category of deterioration risk and b) indicate a delivery option by the end of February 2017, from the pick list shown in Table 64. The EA were to use this information to inform its WINEP 1. As noted above, more guidance on the process was issued by the EA in December 2016 and January 2017.

Table 63 EA sustainable catchments categories and timelines

Category	Criteria	Dataset	Timeline
Category 1	Water bodies suffering from seriously damaging abstraction or protected area deterioration	List of water bodies	Implement in AMP6 or early in AMP7
Category 2	Deterioration likely by 2027 or serious damage but reason not known	Water bodies at high/medium/low risk*1, Future Predicted*2 scenario or serious damage but reason not known	Options appraisal ahead of PR19 and implement early in AMP7
Category 3	Deterioration likely after 2027 and by 2040	Water bodies high risk, Fully Licensed*3 scenario or risk of serious damage Fully Licensed scenario	Options appraisal in AMP7 and implement in late AMP7 / early AMP8
Category 4	No likelihood of deterioration out to 2040	Water bodies medium/low risk, Fully Licensed scenario	Establish 'uncertainty reserve'

Notes:

*1 The EA issued more details of how the risk categories were assigned

*2 Future Predicted = recent actual abstraction rates (from 2007-2012) factored by an EA estimate of abstraction increase by 2027

*3 Fully Licensed = all abstractions assumed at fully licensed rates

The proposed timelines posed significant difficulties for water companies. This was particularly the case for abstractions in Category 2, where the requirement was to appraise options ahead of PR19 and effectively commit to a delivery action by February 2017. A large number of licences were attributed to Category 2 because this potentially included all licences with a predicted growth in abstraction by 2027, no matter how small.

Table 64 EA sustainable catchments delivery options

Delivery option	Description
A	Sustainable licence
B	Voluntary licence reduction
C	Implementation in AMP6
D	Implementation early AMP7
E	Investigation and options appraisal in AMP7
F	Mitigation plus options appraisal in AMP7
G	Options appraisal (by 2022 WRMP) and Implementation in AMP7
H	Options appraisal in AMP7/implementation AMP8

5.3.2 Sustainable catchments – Southern Water's review

Having reviewed the EA guidance and spreadsheet, we shared our proposed approach with EA national co-ordinators and Area staff for comment. No major comments were received so we progressed our assessment and met EA Area teams in November and December 2016 to discuss initial results. Taking account of guidance and discussions with national specialists in January 2017, more meetings were held with Area teams in February 2017.

We had to take a range of factors into account for our assessment. The most significant of these were:

1. the Water Resources GIS tool is not shared with water companies who therefore need to simplify their assessments
2. the timescales for the water company review were short and more guidance was not issued until late January 2017.

The key steps in our review are summarised below.

Step 1: Review of growth factors for abstractions

Southern Water found that the raw water abstracted (RWA) value the EA had used to represent abstraction growth was not the most suitable, and in many cases was likely to under-estimate the long term growth. To address this, growth calculations were carried out by Southern Water for each WRZ and the results were used to revise the quantitative assessment of deterioration risk.

Step 2: Review of Category 1 risk licences (serious damage with abstraction confirmed as cause or protected area risk)

In the EA spreadsheet, no abstractions were found with abstraction being a confirmed cause of 'serious damage'. All of the Category 1 risks were associated with licences being upstream of protected areas. In our review, if the licence had been affirmed (at fully licensed rates) in the Review of Consents process, and there are no known new flow targets or issues to consider, then we have reassigned the abstraction points from Category 1 to Category 2 for review in Step 3.

This screening resulted in all Category 1 licences being reassigned to lower risk categories.

Step 3: Review of Category 2 risk licences (likely risk of deterioration by 2027)

The EA method assigned any licence having a forecast increase in abstraction, no matter how small, as having a likely risk of deterioration by 2027 (unless all the impacted water bodies were all compliant with the Environmental Flow Indicator). Southern Water had indicated in discussions with Area teams that it intended to apply a '*de minimus'* test to this 'likely risk' category. This was done in two steps:

i. The increase in abstraction impact from 'recent actual' to 'future predicted' scenarios was re-calculated by applying Southern Water's revised WRZ growth factors.
ii. The difference between recent actual and future predicted impacts was then calculated as a percentage of natural Q95 flow. If the increase in impact was less than 1% of the natural Q95 flow in the impacted water bodies, then the risk of deterioration by 2027 was considered to be negligible and the point was reassigned from Category 2 to Category 4 (unless the point also qualified as Category 3 risk).

This screening resulted in 33 abstraction points being validated at Category 2 risk.

Step 4: Review of Category 3 risk licences (deterioration likely after 2027 and by 2040)

In the EA guidance, Category 3 risk was assigned based on two criteria:

i. The fully licensed scenario is associated with a risk of serious damage, defined by fully licensed band 3 non-compliance.[1]
ii. The fully licensed scenario results in a high risk of deterioration. This is where the water body has a recent actual compliance band of 3 and the fully licensed scenario results in a change of >10% of Qn95, or where a recent actual compliance band is 2 and the fully licensed scenario results in a change of >15% of Qn95.

In accordance with the EA's statement about the purpose of the EFI (Environment Agency, 2013b), in the absence of any supporting ecological information, it is not accepted that band 3 non-compliance for the fully licensed scenario can be associated with a risk of serious damage and used to drive a sustainability reduction. The difference between recent actual and fully licensed scenarios, expressed as percentage of Qn95, is accepted as an indicator of a risk of deterioration.

Applying this categorisation led to the majority of Category 3 abstraction points being re-categorised as Category 4.

Step 5: Revoked abstraction points and licences

We found a number of abstraction points and licences in the EA dataset which had already been revoked, or where we had confirmed to the EA our intention to revoke. To help the EA remove these points from future versions of the Water Resources GIS they were classified by an extra 'delivery option': Z – Revoked.

Risk categorisation for abstraction impacts on groundwater bodies

The EA high level guidance for abstraction impacts on groundwater bodies was issued at the end of January 2017, so no categorisation had been proposed in the original spreadsheet that was issued in September 2016. The groundwater body risk categorisation is driven mainly by the surface water body classification for the abstraction point - but a Category 5 was included where the groundwater body had an objective of 'poor' by 2027 and the abstraction was linked to a surface water risk category of 4.

Results from our review

Southern Water issued its sustainable catchments return to the EA at the end of February 2017 and completed revisions early in March 2017. The spreadsheet included a justification for the risk category assigned to each abstraction point.

In the surface water body spreadsheet produced by the EA, each line represents the risk for a single abstraction point on one of up to 5 surface water bodies. This level of detail means that the spreadsheet was large and had a total of 362 rows with each entry representing an abstraction point – surface water body combination. The number of entries in each of the risk categories (including 'no risk') in the original EA spreadsheet and in the Southern Water validated return are compared in Table 65.

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[1] Surface water body compliance EFI is calculated at Qn95. Band 3 non-compliance is >50% of Qn95 below the EFI, Band 2 non-compliance is 25-50% of Qn95 below the EFI.

Table 65 Summary of abstraction risk categories – surface water bodies

Category	Original EA spreadsheet	Southern Water's return
1	56	0
2	44	33
3	22	8
4	58	132
No risk	182	189
Total	**362**	**362**

The main reason for the reduction in Category 1 risk was that all these points were assigned Category 1 only because they were upstream of a protected area. We reassigned these to the next highest category because the licences had been affirmed through the Habitats Regulations Review of Consents and there were no known new flow targets or issues to consider. The smaller shifts from Categories 2 and 3 to Category 4 resulted from the validation approach set out in Steps 3 and 4.

For groundwater bodies, in the original spreadsheet issued in September 2016, of the 348 entries 347 were assigned to Category 2 and one point was assigned to Category 1. The lack of a more detailed breakdown is assumed to be because the groundwater guidance had not been completed when the original spreadsheet was issued. The number of licence points in each of the groundwater body categories in our final response is summarised in Table 66.

Table 66 Summary of abstraction risk categories – groundwater bodies

Category	Southern Water's Return
1	0
2	2
3	107
4	74
5	132
No risk	33
Total	**348**

Southern Water wishes to establish a sustainable abstraction base as soon as is realistically possible. To achieve this, even where our review indicated a low risk of deterioration, we intend to investigate and appraise licences by the end of AMP7 so that any actions can be agreed and implemented in AMP8 at the latest. The majority of licences that were not assigned a category of 'no risk' were therefore assigned delivery option H: Options appraisal in AMP7/implementation AMP8.

5.3.3 WINEP 1

WINEP 1 was issued by the EA to water companies as a spreadsheet on 31 March 2017. As for the sustainable catchments data, each Southern Water source is represented by its individual points (for example separate boreholes) and each of these has abstraction impacts allocated to up to 5 WFD surface water bodies and one WFD groundwater body. The dataset also included a categorisation for ongoing investigations but specific sources and water bodies were not necessarily listed against these. The sheet is lengthy with Southern Water's sources being represented by 371 rows of data (excluding 27 rows relating to water quality).

Each point has a type of measure and a level of confidence, the latter being assigned to one of four categories. The EA guidance issued in June 2016 gave more clarification on the confidence (Table 67).

Table 67 PR19 approach to managing uncertainty for Water Industry National Environment Programme (Environment Agency, 2017)

Colour	Status of Measure	Justification
Green	Certain	Evidence that water company action is needed, there is clarity on the required measure, the measure is considered cost beneficial and affordable (where applicable).
Amber	Indicative	Evidence that water company action is needed, there is clarity or developing clarity on the required measure, the measure is considered cost beneficial but awaiting decision on affordability. May turn green during the AMP period.
Red	Unconfirmed	Evidence that water company action is needed but the measure is not yet clear. May turn amber during the AMP period.
Purple	Direction of travel	We know that the water company will need to do this work in the future, e.g. potential change to revised Common Standards Monitoring Guidance but we don't have scheme level evidence.

We have given a summary of the numbers of points in each of these categories in Table 68.

Table 68 Summary of WINEP 1 categorisation

Measure type	Green	Red	Total
Adaptive Management	22		22
Investigation and Options Appraisal	326	9	335
Restoration		10	10
Sustainability Change		4	4
Total	**348**	**23**	**371**

Each entry on the WINEP table represents an individual abstraction point (e.g. borehole) at a Southern Water source in combination with an individual WFD water body (up to 5 surface water bodies and one groundwater body) – except some rows which represent ongoing AMP6 investigations which do not have abstraction sources named.

There were no confirmed sustainability changes in WINEP 1 for Southern Water (Table 68). There were also no 'Indicative' (Amber) or 'Direction of travel' (Purple) sustainability reductions or investigations.

The vast majority of abstraction points are assigned to 'investigation and options appraisal' in the 'certain' category. This is in line with our aim to develop a sustainable abstraction base as quickly as is reasonably possible and hence the need for comprehensive investigations in AMP 7.

The other measure type which is assigned to the 'certain' category is 'adaptive management'. There are 22 'abstraction point – water body' rows in this category and these relate exclusively to four sources in the Brighton WRZ which were included as part of the Lewes Winterbourne (Sussex Brighton WRZ) AMP5 investigation for non-licence change implementation.

No licences were included in the ‘amber’ category of indicative status. Four rows of data were classed as sustainability changes in the ‘red’ category of ‘unconfirmed’. These rows are listed against:
AMP 6 investigations and options appraisals for Anton and Pill Hill Brook, and Plaish Meadows
the Test surface water source.

In summary, there were no sources listed with confirmed or indicative sustainability changes and three investigations covering four sources listed with an unconfirmed sustainability change. This gave Southern Water some limited information on potential sustainability changes to asses.

5.4 Incorporating confirmed and potential sustainability changes into WRMP19

In its guidance issued in June 2017, the EA gave more information about how water companies should assess sustainability reductions in their plans. The guidance asked that companies consider three sustainability scenarios. We refer to these as ‘cases’ to distinguish them from the four alternative sustainability scenarios we considered in the draft WRMP for our Western area:
a lower case that includes only green sustainability changes
a middle case that includes green and amber sustainability changes and a pragmatic estimate of the red sustainability changes
an upper case that includes green, amber and red sustainability changes and a pragmatic estimate of any more sustainability changes that may be required after investigations and options appraisals, or driven by future legislation or requirements.

For extra sustainability changes included in the upper case, the guidance noted that these may be required to:
prevent deterioration of water body status (where investigations are proposed for AMP7)
meet WFD environmental objectives for 2027
meet protected area revised Common Standards Monitoring Guidance requirements for flow
implement requirements of the Salmon 5-point approach.

The EA asked companies to set out the assumptions they used to generate the lower, middle and upper cases.

As indicated by Table 68, WINEP 1 did not have any green or amber sustainability changes and had just four licences listed as red sustainability changes. As well as the generic guidance, we met the EA to discuss specific sustainability reduction scenarios for the Western area in light of the Section 52 notices received.

We considered in combination: the June 2017 guidance, the WINEP 1 spreadsheet, and the discussions on Western area sustainability reductions. Based on these, we set out our proposed approach for assessing sustainability reductions and discussed these with the EA in several pre-consultation meetings between May and October 2017.

A challenge we faced was how to estimate potential DO reductions, particularly for the ‘upper case’ which was to include ‘a pragmatic estimate of any more sustainability changes that may be required after investigations and options appraisals, or driven by future legislation or requirements’.

The approach we took for the sustainability reduction assessment, based on our proposed method and feedback from the EA is summarised in Table 69.

Our sustainable catchments review has considered all our abstraction licences including those which are time limited. Twelve of our abstraction licences include time limited conditions. The consequence of this review is that a large proportion of our abstraction licences will now be subject to an investigation in AMP7 under the WINEP and this includes some of our time limited licences (e.g. Sittingbourne1). Given the thoroughness of our sustainable catchments review and the extent of our abstraction licence investigation programme we believe this sufficiently covers the risk that time limited licences will not be renewed on the same terms. We also considered that for time limited licences which will expire before any investigation will conclude, that the prospect of growth in abstraction that could cause deterioration is very limited.

Table 69 Sustainability reduction scenarios - Southern Water's approach

Sustainability reduction case	EA guidance	WINEP 1 (Changes from WINEP3 highlighted)	Southern Water's approach
Lower case	Green sustainability changes only	None WINEP3: No changes from WINEP1	Eastern and Central areas: None Western area: Test and Itchen licence changes as implemented in March 2019 (Section 20 Agreement)
Middle case	Green and Amber sustainability changes + pragmatic estimate of Red sustainability changes	No Green or Amber. Red: 'Anton and Pillhill Brook', Plaish Meadows and Lukely Brook, Test surface water. WINEP3: No changes from WINEP1	As above, plus: 1) Sources at Andover and on the Isle of Wight at Newport and Lukely Brook: DO reduced 'to achieve the EFI*2'. 2) Sources at Winchester and Alresford: DO limited to recent actual rates (because impacted water bodies are already compliant with the EFI). 3) A future unconfirmed sustainability reduction on the Itchen in 2024*1
Upper case	Above + a pragmatic estimate of sustainability reductions after Investigation / options appraisal or 'future legislation or requirements '	326 entries (relating to ~90 sources) with options appraisal at 'certain' confidence. WINEP3: For some investigations - a change to green 'certainty' or completion date - but no changes made to assumptions relative to the draft WRMP	As above, plus: 1) DO reduced 'to achieve the EFI*2 for all licences impacting on surface water bodies assessed by the EA as being non-compliant with the EFI. 2) For sources not linked to non-complaint surface water bodies, but included in AMP6 investigation, a 10% reduction in DO has been assigned. This principally relates to a large number of sources being considered in the North Kent RSA investigation.

Notes:

*1 More details on the alternative Western area sustainability reduction scenarios and the unconfirmed sustainability reduction on the Itchen are set out later in this section.

*2 The approach to estimating a DO reduction to 'achieve the EFI' is explained below.

Estimating a DO reduction to 'achieve the EFI' is not straightforward from the data produced by the EA. In particular, multiple licences, including those of other water companies, may contribute to flow impacts on non-compliant water bodies. We also needed to consider upstream and downstream impacts.

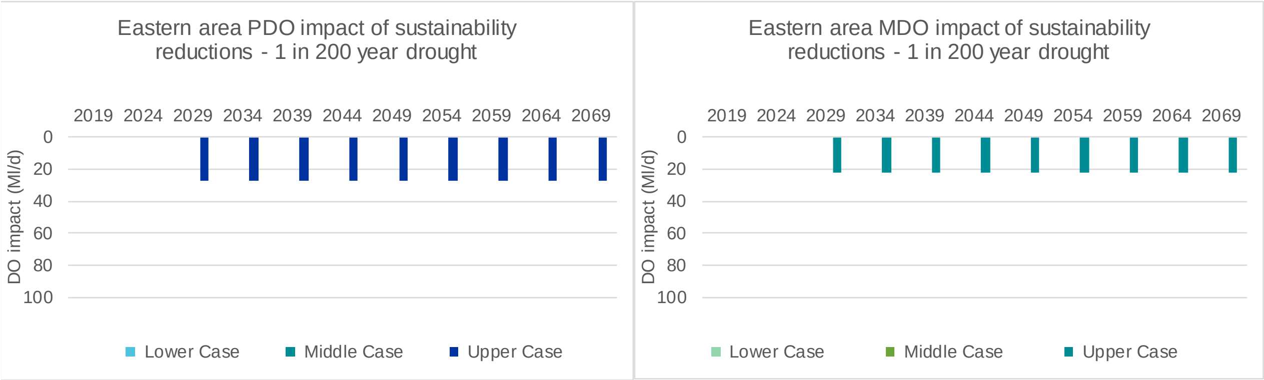
We estimated DO reductions needed to achieve EFIs in surface water bodies through these steps:
1. Flow compliance data were requested from the EA for all WFD surface water bodies in our area. These include values for the water body natural Q95, the EFI (set at 80%, 85% or 90% of natural Q95 dependent on the abstraction sensitivity band) and WRGIS generated estimates of total upstream impacts from abstractions and discharges.
2. For each WFD river water body, the percentage reduction required in upstream abstraction impacts to achieve the EFI was calculated. This was done for the recent actual abstraction scenario.
3. This percentage reduction in recent actual abstraction was then applied to our abstraction points found by the EA as affecting the surface water body. For each source, this generated a resultant ‘abstraction rate to achieve EFI compliance’.
4. Where the abstraction point impacted on multiple water bodies, the lowest ‘abstraction rate to achieve EFI compliance’ was used (since this reduction would also address the contribution to achieving EFI compliance in any other surface water bodies).
5. Downstream water bodies were also classified so that abstraction reductions in upstream water bodies could be accounted for.
6. Where abstraction impacts were assigned to Catchment Management Abstraction Strategy (CAMS) assessment points (for example for the Newport and Lukely Brook sources) then abstraction reductions were calculated for the next downstream WFD water body outflow point (because no flow compliance data were available for CAMS assessment points).
7. The DO (PDO and ADO/MDO as appropriate for the WRZ) was then reduced to the calculated ‘abstraction rate to achieve EFI compliance’.
8. Reduced DOs were then summed by WRZ and area.

In summary, the EFI has been used as a guide in determining a worst case of future sustainability reductions for the WRMP19 and to help us prioritise the investigations that we will need to do in AMP7 to confirm risks and what solutions might be needed. We feel that this is aligned with the EA’s guidance in 2018 that the EFI will be used as a default unless there is agreed local information that defines a more appropriate local flow constraint (EA, 2018).

The resultant sustainability reductions are summarised below and are discussed in more detail in Annex 5 (Baseline supply-demand balance). There were some minor reductions to some of the calculated sustainability reduction values between the draft and revised draft WRMP. These were driven by changes to DO for several sources and a correction to the formula used to calculate the sustainability reduction at Longfield (Kent Medway West WRZ).

For the **Eastern area** (Figure 38), in line with the EA guidance, there are no sustainability reductions in the lower and middle scenarios. For the upper scenario, sustainability reductions are driven by: a) reductions in DO rates to give a proportionate contribution to EFI compliance, and b) an assumed 10% reduction in DO for sources which are being evaluated in the North Kent RSA investigation. The estimated sustainability reductions for the upper scenario, under severe drought conditions, from 2029, are 26.9Ml/d for PDO and 21.8Ml/d for MDO/ADO.

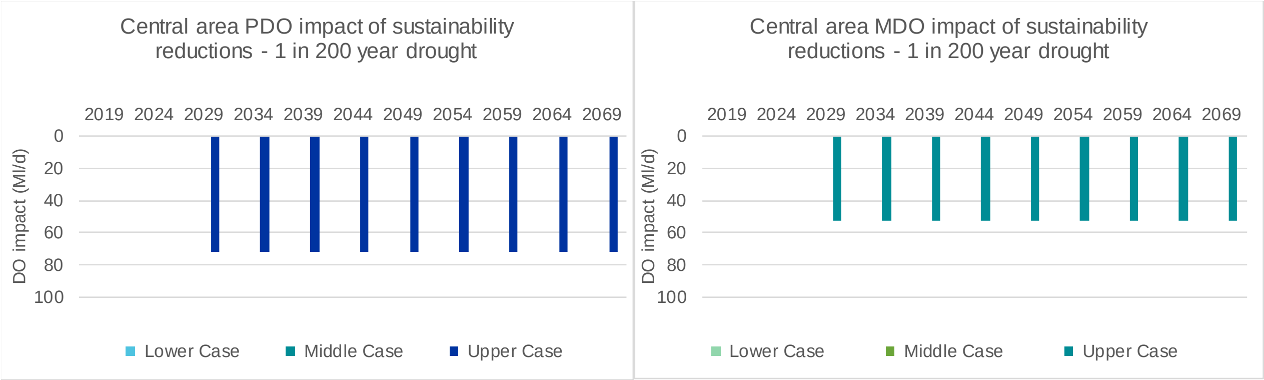
Figure 38 Eastern area impacts of sustainability reductions on PDO and MDO/ADO



For the **Central area** (Figure 39), again there are no sustainability reductions in the lower and middle scenarios. For the upper scenario, sustainability reductions are driven by reductions in DO rates to give a proportionate contribution to EFI compliance. The estimated sustainability reductions for the upper scenario, under severe drought conditions, from 2029, are 72.1Ml/d for PDO and 52.4Ml/d for MDO/ADO. These are substantial reductions and are explained below.

The main abstractions causing the Central area sustainability reductions are the Brighton and Worthing Chalk block licences. These are Chalk groundwater sources associated with relatively small WFD surface water bodies and EA calculations indicate that abstraction impacts are high relative to natural low flows. Recovery to the EFI would have a considerable impact on DO for these sources. In the case of the Brighton block, abstraction impacts were assessed in the AMP6 Lewes Winterbourne investigation. The outcome was that a non-licence change solution would be progressed, including river restoration and adaptive management. For other Southern Water sources, sustainability reductions are still potentially required after a non-licence change solution had initially been agreed. On a precautionary basis we have retained a full recovery to EFI for the Brighton block sources in our upper scenario for sustainability reductions. For the Worthing block we intend to investigate this in AMP7 but at this stage, we have assumed a full recovery to EFI, which again results in significant sustainability reductions for the upper scenario.

Figure 39 Central area impacts of sustainability reductions on PDO and MDO/ADO



For the **Western area** we considered four sustainability reduction scenarios in our draft WRMP, each making different assumptions about the timing and scope of the EA's proposed licence changes (also referred to as sustainability reductions) for the Test surface water source and Lower Itchen sources. This enabled us to explore the sensitivity of the strategy to these different assumptions. Scenario A assumed the EA's proposed licence changes would be implemented in full and immediately. This ended up being the outcome of the River Test, River Itchen and Candover stream abstraction licence Public Inquiry held in March 2018 in which a 'Section 20 Operating Agreement' was reached between Southern Water and the EA. Southern Water's preferred strategy (referred to in the draft WRMP as 'Strategy A') set out in detail in subsequent annexes is based on the Scenario A sustainability reductions.

Scenarios B, C and D were considered as alternatives to demonstrate the impact on option selection and the relative costs of the different solutions of alternative licence change assumptions. These have been retained in Annex 9 only for the purposes of scenario testing of the preferred plan.

The sustainability reductions for the main 'Scenario A' Section 20 Operating Agreement (see Section 5.4.2 below) licence change scenario at the 1 in 200 year return period are presented in Figure 40. These assume the implementation of the Itchen sustainability reductions in 2018 and Lower Test sustainability reductions partially in 2018 and fully in 2027 (second phase of Lower Test licence change). This results in immediate sustainability reductions in the PDO condition of 125Ml/d, rising to 152-227Ml/d across the EA's lower to upper sustainability cases after 2027. The immediate MDO impacts are 166Ml/d, rising to 166-228Ml/d across the three EA cases after 2027.

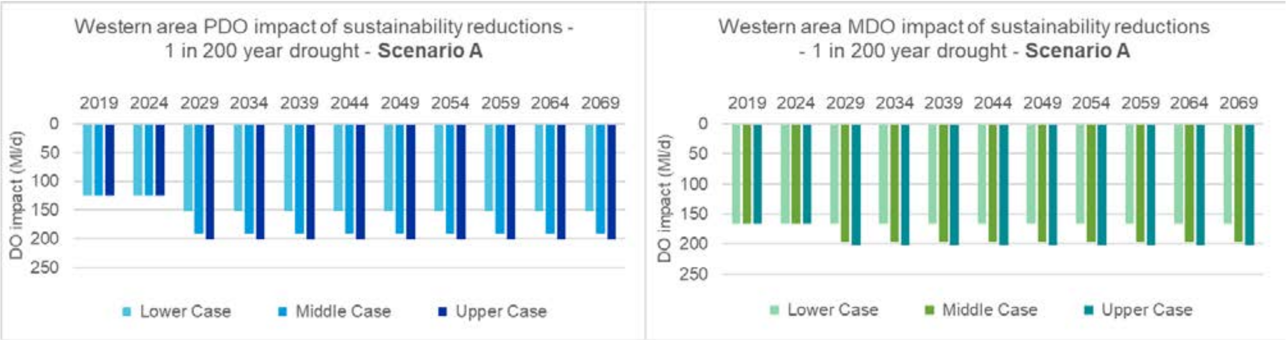
For the revised draft and final WRMP we also included a potential extra sustainability reduction for the Lower Itchen sources after the conclusion of the River Test, Itchen and Candover abstraction licences Public Inquiry in March 2018. In their closing statements at the inquiry, the EA referred to the prospect of future review of the proposed HOF flow conditions on the River Itchen licences at the point of intended licence renewal in 2024 and following WINEP investigations in the next five year period.

We will investigate these revisions during the next five year period (2020-2025). The last independent review (Wilby, 2010) of the Lower Itchen HOF conditions proposed a flow condition of 224Ml/d. This is higher 26Ml/d than the current proposed condition of 198Ml/d.

To have long-term regard to a possible future reduction in abstraction we have used this estimate of 224Ml/d as the potential new HOF condition on the River Itchen licence in order to assess the likely impact on the supply forecast post 2024. We included the impact of this extra sustainability reduction on the River Itchen from 2024 in the baseline supply forecast in our revised draft WRMP. The rationale was to make sure that the solutions we are developing for the Western area are capable of accommodating this change to the licence over and above those that have been proposed and agreed during the Public Inquiry.

As instructed by Defra in its letter dated 19 March 2019, we revised this assumption for the final WRMP, instead including the uncertainty associated with this future Itchen sustainability reduction. This is consistent with the consideration of other uncertain and unconfirmed sustainability reduction in our plan, across all supply areas. This is described in more detail in Annexes 5 and 9.

Figure 40 Western area impacts of sustainability reductions on PDO and MDO for the 1 in 200 year return period



5.4.1 River Itchen, River Test and Candover abstraction licence Public Inquiry

The Public Inquiry was instigated after a challenge by Southern Water to the EA's proposed variations to a series of its abstraction licences. The need for licence changes for more sustainable abstraction was never a principle that was opposed by Southern Water.

Southern Water's concern was that, particularly during times of drought, the conditions were such that they had the potential to impede the ability for the company to meet its statutory duties to supply public water.

The Inquiry hearing opened on March 13, 2018. It focused on a proposed operating agreement between Southern Water and the EA under Section 20 of the Water Resources Act 1991 ("The s20 agreement"). The s20 agreement had been drafted after submissions of evidence to the Inquiry in the preceding weeks and because of both parties reaching a better understanding of the critical issues presented by the other.

During the course of the Inquiry the s20 agreement was completed and an outline package of monitoring, mitigation and IROPI compensation measures prepared.

The s20 agreement was signed and presented to the Inquiry at its closure on 29 March 2018.

We were notified of the determination by the Secretary of State on the outcome of the Inquiry in February 2019, the s20 agreement was upheld and the Lower Test and Lower Itchen licence variations were implemented in March 2019. .

5.4.2 The s20 agreement

The s20 agreement enables a new, positive way forward for both parties, for public water supplies and for the habitats and ecology of the River Itchen and River Test. Southern Water accept the abstraction licences changes. The EA commits to procedural reassurances around how Southern Water can use the drought permit and drought order process to maintain public water supplies pending the implementation of new reliable water supplies to replace the water resource lost by the licence changes.

Southern Water also commits to a significant package of environmental monitoring and mitigation measures associated with the potential drought permits and drought orders that may be needed over the next ten years or so.

The main elements of the s20 agreement are as follows.

Southern Water has agreed to:

Accept all of the EA’s proposed licence changes, to be implemented immediately (on the Secretary of State's determination)

Use all best endeavours to implement the long term scheme for alternative water resources set out in its final Water Resources Management Plan 2019

Rely on the use of Drought Permits and Drought Orders on the River Test and River Itchen during the interim period while long-term resources are developed in line with the procedure set out in the s20 agreement. For the avoidance of any doubt, the agreed procedure does NOT vary the statutory requirements for such applications but agrees the timing of drought permit applications to the EA and a set of principles which mean that this process can be used and relied on more effectively

Make sure that the River Test Surface Water Drought Permit is reviewed every 6 months, to maintain that it is ‘application ready’

Accept that on the basis of current ecological evidence a likely significant effect and adverse effect on the integrity of the Itchen SAC cannot be ruled out from the operation of the Candover Drought Order

Commit a substantial package of environmental monitoring, mitigation and potential IROPI compensation measures in respect of the Drought Permits and Drought Orders.

The EA has agreed to:

A timetable for the acceptance and determination of the River Test Drought Permit (35 days or less in the case of extreme urgency)

Accept that at the time of the application:

(a) Water use restrictions do not have to be in place (and only have to be in place at time of implementing the permit)
(b) The case for ‘exceptional shortage of rain’ can include a forecast component
(c) The refusal of access by landowners for monitoring and/or mitigation is not a detriment to being 'application ready'

Accept that Southern Water's proposed Candover scheme could be implemented under a Drought Order during the interim period.

Accept a ‘force majeure’ clause within the River Test abstraction licence, so that Southern Water will be allowed to abstract above the new licence limits, should certain events or incidents (as defined in the s20 agreement) develop outside of Southern Water's control, and it is necessary to maintain public water supplies.

Use Article 4(6) of the Water Framework Directive in principle to enable the grant of a Test Surface Water Drought Permit authorising abstraction, and to accept that low flows on the River Test of between 355Ml/d and 265Ml/d are capable of constituting exceptional circumstances for the purposes of Article 4(6) WFD.

Accept that subject to a material change of circumstances and until long-term solutions are implemented, Southern Water has a good case that it has no alternative solutions to its Candover and Itchen Drought Order schemes in order to maintain public water supply and that the schemes satisfies the test in Article 6(4) Habitats Directive, for an imperative reason of overriding public interest (IROPI).

The s20 agreement also establishes a number of principles that are agreed between the EA and Southern Water. The most significant being:

The Test, Candover and Itchen Interim Abstraction Scheme – This is the sequencing in which Southern Water plans to implement drought actions. It is subject to the principle that Southern Water will take into account ecological conditions (based on up to date monitoring data) in deciding the order of Drought Orders. This Scheme has been incorporated throughout this Drought Plan.

Southern Water will develop proposals to investigate diurnal variation of abstraction from the River Test to identify any potential impacts on fish migration (to conclude mid-2021, the results of which will aim to be used when preparing future drought and water resource management). We have already asked for this investigation be listed on the National Environmental Programme.

5.4.3 Southern Water's monitoring commitments

The package of measures is documented in Annex 5 of the revised draft Drought Plan.

This includes supplementing existing monitoring by other parties with a network of:

Hydrological monitoring (flows, velocities and groundwater water levels).

Water quality modelling (including temperature).

River, riparian and wetland ecological modelling, including fish monitoring.

The EA has also agreed to perform some of the monitoring commitments.

All of the commitments set out in the respective monitoring packages will be funded by Southern Water.

5.4.4 Southern Water's mitigation commitments

The package of measures is documented in Annex 5 of the revised draft Drought Plan.

Up front mitigation commitments will be implemented by 2023-24. This is irrespective of whether need for the Drought Permits or Drought Orders arises by then. They will improve ecological resilience on a permanent basis on both the River Test and River Itchen, including the Candover.

The schemes are at finalisation stage with the EA and have already been approved by Natural England. They will be included in the final version of the new Southern Water Drought Plan and are intended to be implemented in partnership with the EA and other delivery partners such as the Hampshire and Isle of Wight Wildlife Trust. The majority of implementation will be led by the EA, with some specific enhancements for southern damselfly and white clawed crayfish likely to be delivered by the Wildlife Trust. Again these works will be funded by Southern Water.

The Test and Itchen Catchment Partnership and the Watercress and Winterbournes Landscape Partnership Scheme (operating in the headwaters of the Test and Itchen), will also receive more funding from Southern Water to help deliver some of the agreed mitigation commitments. The organisations involved in these partnerships will prioritise, agree, and implement works across the catchment that are complementary to the mitigation works outlined above.

The package of measures will include:

White Clawed Crayfish habitat and population enhancement

Southern Damselfly habitat and population enhancement

River restoration and general habitat and ecological resilience enhancement.

5.4.5 Southern Water's IROPI compensation commitments

The EA in the s20 agreement has agreed in principle to Southern Water's case for an imperative reason of overriding public interest under the Habitats Directive.

The need for a Drought Order may or may not in reality materialise. Nevertheless, a set of compensation commitments have been agreed in outline and are being refined.

These measures are intended to be put into operation ahead of implementing the Candover and Itchen Drought Orders. Once the detail is completed, the delivery and requisite timetable to can be established in agreement with the EA and Natural England but it is anticipated that not all measures will need to be implemented immediately. Southern Water shall work alongside the EA and Natural England to make sure that the measures are secured. The measures must be at locations which are not directly impacted by the Drought Orders and include:

Extra White Clawed Crayfish habitat and population enhancement

Extra Southern Damselfly habitat and population enhancement

More river restoration and general habitat and ecological resilience enhancement including measures specifically focused on Salmonids.

5.4.6 Incorporating the Section 20 Agreement into the drought plan

The Section 20 Agreement has several key components to it, as outlined above. These commitments have been incorporated throughout Southern Water's final Drought Plan.

5.5 Invasive non-native species (INNS) risks

Southern Water has non-native invasive species (INNS) management plans at existing sites with known risks and is implementing improved biosecurity but we will continue to undertake analysis of current management practices to identify gaps or improvements. We will continue to assess INNS presence and risks, and undertake pathway risk analysis for in-house and supply chain operations.

Southern Water has a planned scheme to alter the existing raw water transfer between Bewl and Darwell reservoirs, to disconnect the transfer into Darwell and instead transfer the raw water from Bewl directly to Southern Water's two water supply works in Sussex Hastings WRZ. This scheme was to be implemented in AMP6 but has been delayed to AMP8, in agreement with South East Water and the EA, to allow South East Water to implement an alternative to the bulk supply it takes from Darwell reservoir which is dependent on the transfer from Bewl.

5.6 Eels regulations

Twenty surface water abstraction sites were noted for Eels Regulation (2009) requirements to be implemented during AMP6 by Southern Water. Extra assessments by Southern Water, and consequent discussions and agreements with the EA, have rationalised this programme: some small abstraction licences have been given up to remove the requirement. Trap and transport arrangements are intended for four reservoirs and several sites have been deferred to 2020-2025. Detailed design and site programming is ongoing for the rest of the sites, with installations of improved intake screens due in 2019.

5.7 Longer term environmental forecast

The five-yearly cycle of the EA's NEP to align with Ofwat's periodic review process means that water companies have generally only had a short term view of how environmental drivers could impact their water resources management plans. Southern Water has learnt from recent experience that a lot can change from one NEP to the next, leading to sustainability reduction challenges that need to be addressed over short timescales in order to maintain secure supplies. This can lead to sub-optimal strategies in order to resolve unexpected supply-demand deficits. While we accept there will always be a degree of uncertainty around the scale and timing of future sustainability reductions, more could probably be done to take a longer term view of potential impacts.

Prompted by recent experience and a desire to develop optimal strategies which are in the best interests of customers and the environment, the company decided it would commission the development of a long term environmental forecast. We have in this plan set out a proposed framework for producing a forecast and undertaken an assessment which has then been used as a sensitivity run in our investment model. More information can be found in Annex 4.

6. Impacts of climate change on supplies

This section summarises the forecast impacts of climate change at a WRZ level for each our three areas. These data have been calculated through the methodology set out in Section 3 and should be compared as impacts to our DO forecasts in Section 4.

Climate change impacts for our three key scenarios used for our integrated risk modelling (Annex 5) comprising a "dry", "mid" and "wet" scenarios are set out for each WRZ and area in the tables below.

As with our other DO assessments the impacts are expressed as a change in WRZ DO for a range of scenarios with different probabilities. This has allowed us to include a probabilistic forecast of the effects of climate change and reflects the uncertain range of outcomes between the dry and wet scenarios. This uncertainty about the outcomes of climate change has been included in our integrated risk model (see Annex 5) in keeping with our risk principle of designing a fully risk-based plan (Annex 1).

In line with our fully risk-based methodology under which we have defined DO under a range of different drought probabilities and severities, climate change impacts can be similarly assessed. That is to say that the full 2000 years' synthetic drought time series were perturbed for a number of climate change scenarios and processed through our hydrological and water resource models. The impact of climate change on drought type (e.g. duration and pattern) was assessed along with the basic DO / severity impact. Each climate change perturbation was evaluated against a generated time sequence that included all of the drought sequences of interest.

The mid-range scenario for each WRZ has been included in our base supply line of the WRMP tables (See Annex 5). The 'minimum' (wet) and 'maximum' (dry) climate change scenarios have then been added to our integrated risk model, based on the deviation from the mid-range 'most likely' scenario. The values all represent the impact at the end of the WRMP planning period – i.e. 2070 – and impacts were assumed to increase linearly from zero in the base year to the assessed value in 2070, in line with the methodology specified in Charlton and Watts (2017).

We shared a summary of our proposed climate change modelling approach with the EA in February 2017. Our approach for climate change assessment (see Annex 1 and Section 3.6) is compliant with the Water Resources Planning Guidelines, as it involves sampling for the UKCP09 climate change scenarios (which are the revised climate change projections published by Defra in 2009) to forecast a range of possible impacts for all WRZs.

6.1 Western area

The impacts of climate change vary substantially across our Western area because of the differing supply composition and DO constraints of each WRZ (see Table 70 and Table 71). Note that the data presented in these tables represent absolute modelled changes for a specific design drought with an annual probability of 0.5% (1 in 200 years). See Annex 5 for a full explanation of how the climate change impacts have been incorporated into our integrated risk and uncertainty modelling.

Table 70 Climate change impacts (Ml/d) for low vulnerability WRZs in our Western area

Planning Conditions	Climate Scenario	HK	HA	HR	HW	IOW
MDO	Dry	<1Ml/d	<1Ml/d	No Impact	No Impact	<1Ml/d
	Wet	No Impact	<1Ml/d	No Impact	No Impact	<1Ml/d
	Medium	No Impact	<1Ml/d	No Impact	No Impact	<1Ml/d
PDO	Dry	<1Ml/d	No Impact	No Impact	<1Ml/d	<1Ml/d
	Wet	<1Ml/d	<1Ml/d	No Impact	<1Ml/d	<1Ml/d
	Medium	<1Ml/d	No Impact	No Impact	<1Ml/d	<1Ml/d

Hampshire Kingsclere, Hampshire Andover and the Isle of Wight WRZs have some limited sources that exhibit vulnerability to drought and therefore climate change. The overall magnitude of these impacts is small and consequently their vulnerability is low.

For the Isle of Wight WRZ, the key treatment constraint at the major surface water source is still the limiting factor under most scenarios. The impact of climate change in this WRZ is therefore small and restricted to groundwater sources only, and of the groundwater sources only one is drought constrained so the overall sensitivity of this WRZ is low and the climate change impacts negligible (<1Ml/d) under all scenarios.

Hampshire Winchester WRZ and Hampshire Rural WRZ are both licence or infrastructure constrainedand here there is no current vulnerability to drought or climate change.

The greatest climate change impacts for our Western area are forecast for Hampshire Southampton West and Hampshire Southampton East WRZs (Table 71). This reflects that in both WRZs DOs are constrained by the available flow in the rivers Test and Itchen respectively. The impacts become greater under scenarios where sustainability reductions are imposed (see Section 5) because of the minimum residual flow conditions imposed by the licence changes.

Table 71 Climate change impacts (Ml/d) for Hampshire Southampton East (HSE) and Hampshire Southampton West (HSW) WRZs for different sustainability reduction scenarios for 2070

Planning Conditions	Climate Scenario	HSE			HSW 2017 s.52	HSW 2027 s.52
		Surface Water	Ground Water	Total	Total	Total
MDO	Dry	No Impact	-35.10	-35.10	No Impact	No Impact
	Wet	No Impact	11.88	11.88	43.96	No Impact
	Medium	No Impact	3.89	3.89	20.34	No Impact
PDO	Dry	No Impact	-33.67	-33.67	-23.09	No Impact
	Wet	27.31	1.84	29.15	45.81	16.98
	Medium	10.64	1.84	12.48	36.78	4.51

The overall magnitude of climate change impacts on DO for both of these WRZs tends to be somewhat limited by the fact that flows in both the River Test and Itchen are close to or below the respective HoFs under severe to extreme low probability drought conditions. While greater flow impacts in both rivers occur because of climate change, they are not reflected in DO forecasts as modelled flows tend to be below the HoF constraint during droughts (i.e. the DO would be zero regardless of climate change impacts). The impact is therefore somewhat limited in overall volumetric terms. However, in terms of the available DO during drought, both WRZs become highly sensitive to climate change since the variability can account for the total baseline DO. Essentially, this means that most of the impacts of climate change are felt under annual probability drought events of 1-10% probability (1 in 100 to 1 in 20).

For Hampshire South East under the Dry climate change scenario, overall impacts are reasonably similar in magnitude between our current plan and those predicted for WRMP14. In both cases the total DO is eliminated by climate change under a dry scenario. For the Mid scenario DO impacts are slightly positive for the current plan and slightly negative for WRMP14. This likely reflects the difference in forecast period, i.e. the broad mid-range climate change impact of wetter winters may have more impact on flows by the 2080s.

Another consideration is that for this plan we have redefined our WRZs. Previously, climate change impacts were considered as a proportion of DO against the whole of the former Hampshire South WRZ in WMRP14. In this plan, much of this WRZ was insensitive to climate change and drought with most sources being licence or infrastructure constrained. Climate change impacts were therefore a small proportion of total WRZ DO.

In this plan we have split Hampshire South WRZ into four smaller WRZs and of these, nearly all of the climate change impacts are only felt in two of those WRZs - Hampshire Southampton East WRZ and Hampshire Southampton West WRZ. In both WRZs under scenarios where sustainability reductions are applied, impacts occur on sources that make up the entire total DO of the WRZ. The overall impacts therefore appear to be a much greater proportion.

6.2 Central area

Forecast climate change impacts for the 0.5% annual probability (1 in 200 years) drought event in our Central area WRZs are shown in Table 72.

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The Sussex North WRZ shows the greatest vulnerability to climate change in our Central area. Impacts here for the MDO and PDO are relatively large compared to the baseline DO. Like the rivers Test and Itchen in Hampshire, these climate change impacts are related to a minimum residual flow condition on the River Rother that impacts on both our Pulborough groundwater and surface Water sources. Combined, these two sources contribute the majority of the WRZ DO. For even lower probability extreme drought events, climate change impacts are negligible as drought flows are already forecast to below the MRF constraint and there would be no available water in this WRZ, which was classified as being of high vulnerability

Sussex Brighton shows a relatively small and positive mid-range impact (~1.4Ml/d). This reflects a slight improvement in DO from the influence of wetter winters on groundwater recharge. There is a relatively large range of uncertainty between the ‘wet’ and ‘dry’ scenarios that accounts for up to ~14Ml/d and hence the WRZ is still of medium vulnerability compared to our original assessment (Annex 1).

Of these three WRZs, climate change impacts and vulnerability are generally smallest in Sussex Worthing WRZ as it has fewer hydrogeologically constrained groundwater sources and this serves to limit the overall magnitude of climate change impacts. The mid-range impacts are relatively small (<1Ml/d for both PDO and MDO). Substantial uncertainty still exists for this WRZ with the range between the ‘wet’ and ‘dry’ scenarios around of ~4.5Ml/d.

Table 72 Climate change impacts (Ml/d) for our Central area for 2070

Planning Conditions	Climate Scenario	SN			SW	SB
		Surface Water	Ground Water	Total	Total	Total
MDO	Dry	-8.81	No Impact	-8.81	-1.36	-4.59
	Wet	10.71	No Impact	10.71	3.14	7.24
	Medium	4.49	No Impact	4.49	1.16	2.93
PDO	Dry	-3.28	No Impact	-3.28	-2.08	-3.60
	Wet	-3.28	No Impact	-3.28	3.84	5.78
	Medium	-3.28	No Impact	-3.28	1.56	2.46

6.3 Eastern area

In our Eastern area the impacts of climate change vary substantially between WRZs. Forecast climate change impacts for the 0.5% annual probability (1 in 200 years) drought event in our Eastern area WRZs are shown in Table 73.

Climate change impacts in Sussex Hastings WRZ have no impact at PDO as the impacts of climate change are offset by the large storage reservoirs on these WRZs. Average impacts are positive, reflecting increased rainfall but are still uncertain. The ‘wet’ and ‘mid-range’ scenarios predict a modest increase in DO (<1Ml/D) but the ‘dry’ scenario has a much more substantial impact in reducing DO.

For Kent Medway West WRZ the majority of climate change impacts occur because of changes to flows in the River Medway. For all three scenarios, this results in a net DO benefit at ADO, though there is some uncertainty as to the size of the benefit. The ‘mid-range’ most likely and ‘dry’ forecasts suggest a modest increase in DO (<2% of total) but the wet case suggests a range of up to 11%.

For Kent Medway East WRZ the overall impacts of climate change are small, reflecting the fact that many sources in this groundwater dominated WRZ are licence or infrastructure constrained. Overall, the impacts as a percentage of the baseline DO are less than 2% of the most likely case and +-3% between the wet and dry scenarios. This is consistent with our previous analysis that showed that groundwater resources in Kent Medway were relatively resilient to climate change.

Kent Thanet WRZ shows a much greater vulnerability than our other eastern WRZs. The forecasts suggest a relatively small impact at both PDO and ADO for the ‘mid-range’ most likely case (<2Ml/d). As with other drought vulnerable groundwater dominated WRZs (e.g. Sussex Brighton and Sussex Worthing) there is a wide range of uncertainty between the ‘wet’ and ‘dry’ scenario impacts that accounts for around 12Ml/d of the total DO.

Table 73 Climate change impacts (Ml/d) for our Eastern area for 2070

Planning Conditions	Climate Scenario	SH			KMW			KME	KT
		Surface Water	Ground Water	Total	Surface Water	Ground Water	Total	Total	Total
ADO	Dry	0.52	0.00	0.52	1.64	0.00	1.64	0.09	-6.83
	Wet	4.32	0.00	4.32	10.02	0.00	10.02	1.64	3.18
	Medium	0.60	0.00	0.60	1.30	0.00	1.30	0.09	-0.29
PDO	Dry	0.00	0.00	0.00	0.09	0.00	0.09	-0.52	-9.79
	Wet	0.00	0.00	0.00	0.26	0.00	0.26	1.64	1.11
	Medium	0.00	0.00	0.00	0.17	0.00	0.17	0.86	-0.18

6.4 Final climate change vulnerability

After our water resource modelling we have considered the final climate change vulnerability of our WRZs by 2045 (the end of a conventional 25 year planning period). This review shows that across our supply areas the forecast impacts of climate change fall into three general categories:

1. Highly Vulnerable Zones where both the ‘mid-range’ forecast impacts and the uncertainty between ‘wet’ and dry scenarios is large. This generally applies to WRZs with minimum residual flow constraints are either imposed already, or forecast, on surface water abstractions, specifically Hampshire Southampton West, Hampshire Southampton East and Sussex North WRZs. All three WRZs are highly vulnerable to climate change following the March 2019 sustainability reductions. Kent Thanet WRZ is also considered to be highly vulnerable owing to the range of uncertainty of climate change impacts between wet and dry scenarios.

2. Medium Vulnerability Zones Those WRZs where the most likely mid-range impact is small (<5% of WRZ DO) but where the range of predictions between the ‘wet’ and ‘dry’ scenarios is suggests substantial uncertainty (up to 15% of WRZ DO). This includes Sussex Worthing, Sussex Brighton, Sussex Hastings Kent Medway West WRZs. These WRZs tend to have a higher proportion of drought or yield constrained sources vulnerable to the effects of climate change.

3. Several WRZs are Low Vulnerability where the impacts of climate change are small and the uncertainty between wet and dry scenarios is also low (<5% of total WRZ DO). These WRZs are therefore considered to be low vulnerability, generally echoing the predictions of our initial vulnerability assessment (Annex 1). This classification includes Hampshire Kingsclere, Hampshire Andover, Hampshire Rural, Hampshire Winchester, sle of Wight and Kent Medway East WRZs. The vulnerability of these WRZs is typically lower as a greater proportion of their sources are licence or infrastructure constrained, reducing their overall sensitivity to drought and climate change.

For the most sensitive WRZs (Hampshire Southampton East, Hamsphire Southampton West and Sussex North), the vulnerability arises because of existing or potential future HoF and MRF conditions on abstraction licences for the rivers Test, Itchen and Rother. Under the modelled drought and sustainability reduction scenarios (Section 3 and Section 5) the DO is directly related to available flow above the HoF constraint. Changes in flow because of climate change perturbations therefore directly translate to impacts on DO. This is exacerbated under the more severe or extreme low probability droughts where the DO is already small, or even zero. The magnitude of the flow changes can account for a large percentage shift in DO.

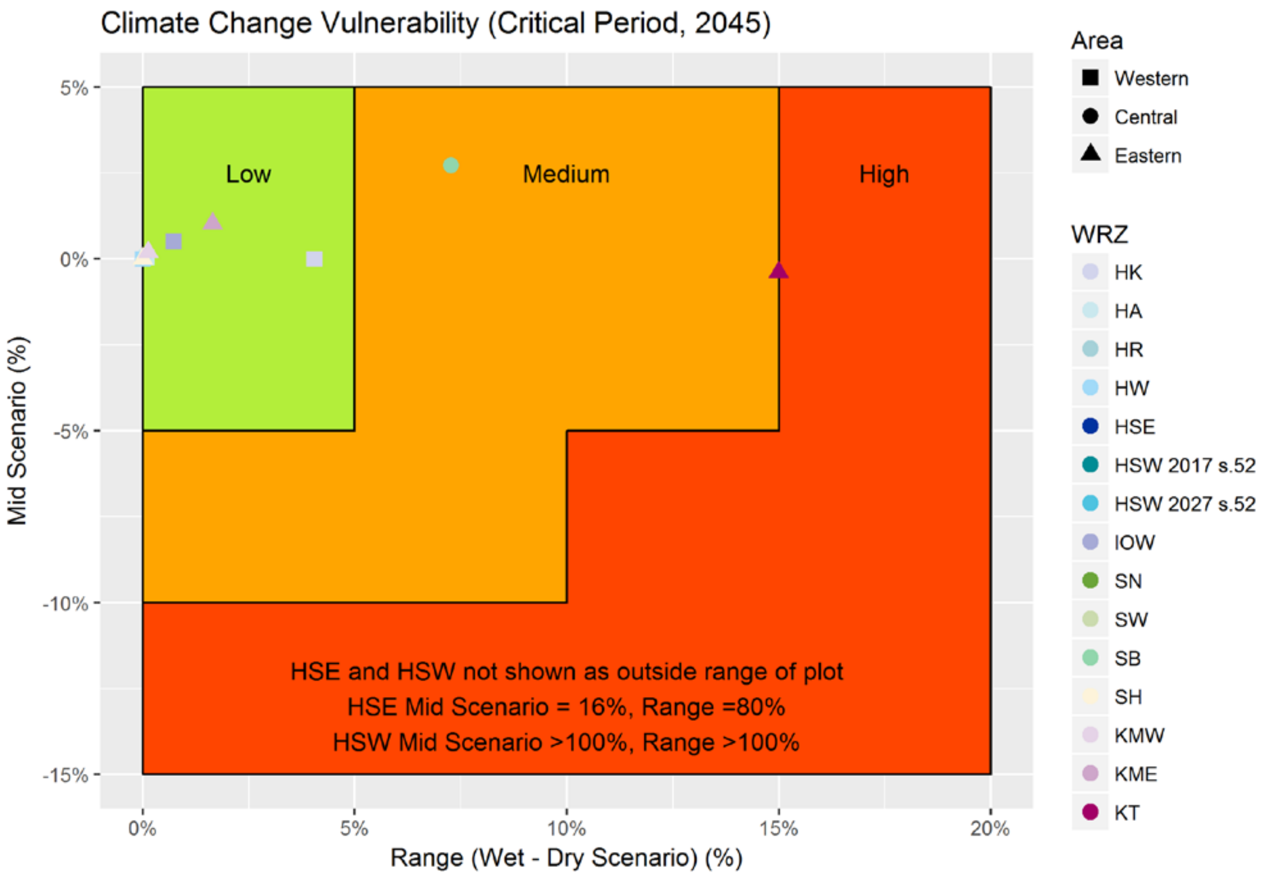
For extreme droughts or if the River Test sustainability reductions are applied in full, the sensitivity to climate change in the severe or extreme drought conditions becomes less significant as no water is available at all under the revised HoF conditions for these events. Under these circumstances climate change impacts are still felt for less severe (1 in 20 years) drought events and can still be large (10s of Ml/d).

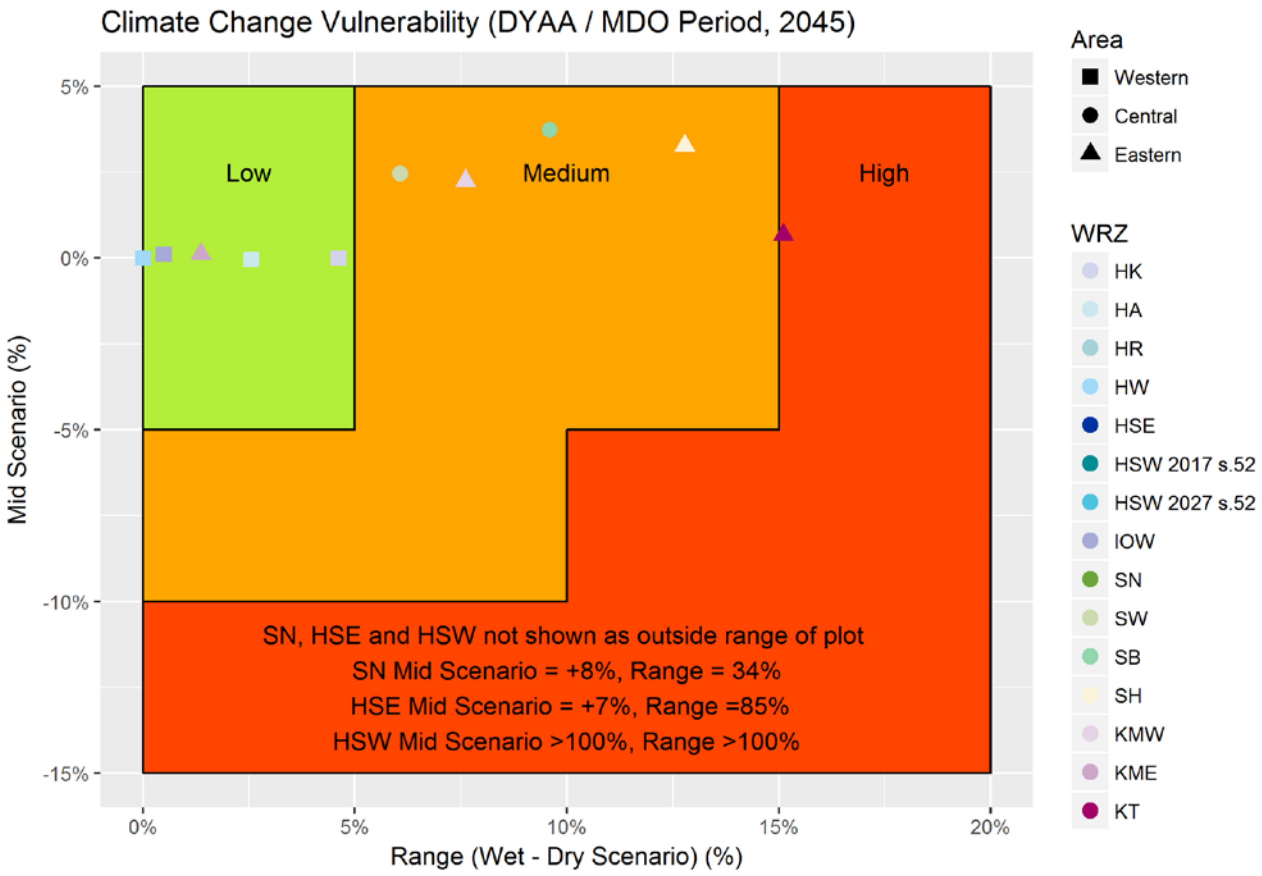
Figure 41 shows revised climate change vulnerability plots including the outcome of our modelling assessment (see Annex 1 for details on how this is produced). This highlights the three key groupings between those of High Vulnerability and uncertainty, those WRZs of medium vulnerability where the mid-range impacts are small but the wet-dry range is large and those least sensitive WRZs where impacts are small.

6.5 Climate change and the integrated risk model

A summary of how we have included the effects of climate change into our supply demand balance, integrated risk modelling and planning scenarios is presented in Annex 5.

Figure 41 Outturn Climate Change Vulnerability (by 2045) post Water Resource modelling





7. Process losses

Process losses account for the loss of water arising from the treatment process between the point of abstraction and where water enters the distribution system. Typically groundwater sources have a simpler treatment process (in some cases only chlorination is required) than surface water sources and so process losses in groundwater dominated WRZs will tend to be lower.

A review of process loss data has been made for all Southern Water's Water Supply Works (WSWs) since WRMP14. Where we have both abstraction and distribution input flow meters, we have been able to quantify the volumes of water that are lost in the treatment process. This gives us a percentage loss figure that can then be used at similar sites (e.g. groundwater sites) where we do not record both flows. On some sites, better data collection at abstraction and DI points has allowed a revision of the variable losses percentage. The variable losses are based on the difference between abstraction and distribution input on sites where the data quality is good. Process scientists agreed that the process losses for surface water sites should be higher than in WRMP14 supporting the data. Where the data quality for a site was not good or either abstraction or distribution input flow meters are unavailable, then the average variable loss is used.

The average variable losses for sites where data appears trustworthy is around 5 but this is a ball park figure. For example, for Test SW, the difference appears to be higher than 5%, but 5% has been used in light of alternative evidence. Because of this the variable loss percentage has increased since WRMP14, in some cases quite significantly. Extra reviews on the data quality for process losses will be carried out during AMP7 in preparation for WRMP24 to address areas where improvements are required.

Since PR09 there have also been changes on site that would increase process losses. These include triple validation instead of single instrument and to a lesser extent desludging and backwashing. It is noted that the impact from the changes in process do not contribute as large a difference as the improved data quality.

Estimates of process losses are summarised for each WRZ in Table 74 below. The resulting update from WRMP14 has seen an increase in process losses for both average and peak scenarios. Another update and review of process losses will be carried out in preparation of WRMP24.

Table 74 updated process losses for the WRMP19

Water Resource Zone	Average	Peak
Isle of Wight	2.42	3.42
Sussex North	2.22	1.48
Sussex Hastings	1.72	1.89
Sussex Brighton	0.57	0.57
Sussex Worthing	0.84	0.84
Kent Medway East	0.67	0.67
Kent Medway West	3.83	2.08
Kent Thanet	0.65	0.65
Hampshire Rural	0.07	0.07
Hampshire Winchester	0.09	0.09
Hampshire Southampton West	5.25	5.25
Hampshire Southampton East	2.33	2.33
Hampshire Andover	0.13	0.13
Hampshire Kingsclere	0.08	0.08

8. Outage allowance

8.1 Background

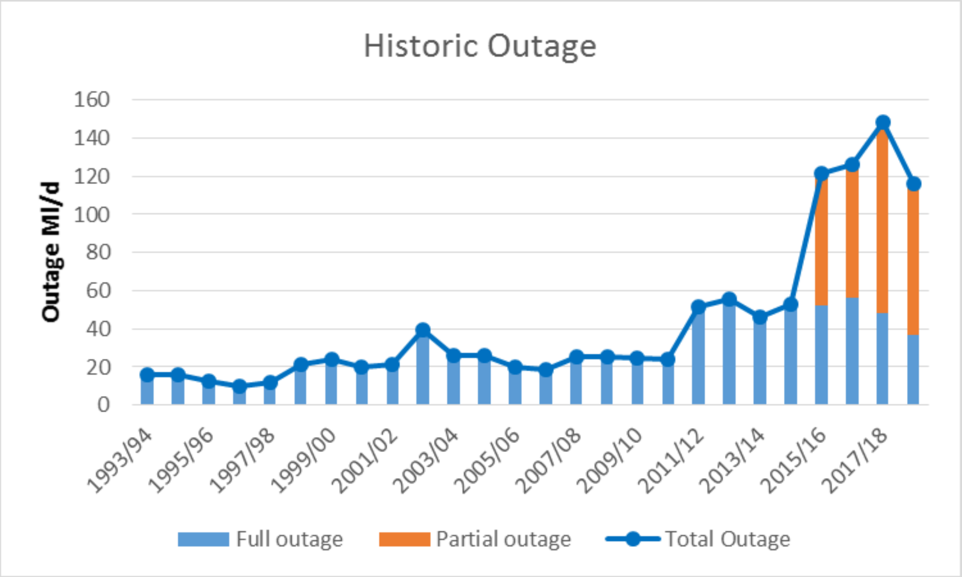
Historically (from 1993 to 2010), our actual outage levels were around 25Ml/d or under. This is based on data comprising **full** outage events i.e. only taking account of sources whose full DO is unavailable. During AMP5 (2010 to 2015), Southern Water introduced a new system of 'triple validation' for water quality monitoring at its water supply works (WSW), which increased the frequency of site shutdowns. Consequently, reported outage increased to just under 60Ml/d for **full** outage events. Another factor which has contributed to higher outage levels is the company's successful customer metering programme which, in helping to reduce the average demand for water by 16%, has led to lower abstraction and source outputs. The lower utilisation of sources has led to more system failures when efforts to increase source outputs above these lower levels have been made. We are using the lessons from this to improve our asset management processes and preparedness for drought events.

In 2015-16 we improved out reporting methodology to give a better picture of resource availability by including **partial** outage events, which is when a site is operational but cannot achieve its full DO. The new methodology for reporting outage was shared with the EA in December 2015 and we reported provisional figures for **partial** outage in the 2016 Annual Review of our WRMP14. At this point the **partial** outage dataset was subject to more investigation to understand whether the causes were legitimate outage events. A meeting was held with the EA in November 2016 to discuss outage definitions and reporting and since the 2017 Annual Review of our WRMP14 we have formally reported **partial**, **full** and **total** outage figures to the EA.

The consideration of **partial** outage events has led to a large increase in our reported **total** outage (consisting of **full** outage plus **partial** outage events). Figure 42 shows the historic outage from 1993 to 2019 and the introduction of the reporting of **partial** and **total** outage in 2015-16.

By including **partial** outage in our assessment of actual outage Southern Water has gone beyond most other water companies in trying to fully quantify our ability to achieve DOs during design drought events to maintain supplies. Our **total** outage levels should not be compared to other companies who have not included **partial** outage in their assessment and only based their assessments on **full** outage events.

Figure 42 Historic actual outage



8.2 Methodology

The methodology and assumptions we have used for the calculation of our outage allowance for the WRMP19 are set out in Appendix F of Annex 3 of the WRMP19.

In line with best practice our initial outage allowance assessment for the WRMP19 followed the UKWIR 1995 outage methodology. The assessment was based on our **full** outage dataset recorded from 2015-17 when sufficiently robust outage data was available. While we have historic outage data before 2015-16 which includes the timing and location of outage events we do not have data on the causes of all these outage events which is needed to apply the methodology.

Monte Carlo analysis was used to develop a company level distribution of **full** outage events for the period from 2015-18 based on the nine WRZs (WRZs) with **full** outage events in that data range. 10,000 simulations were run, across all the outage causes considered, to develop a distribution. This led to a full outage allowance of about 65Ml/d, which is slightly higher than the May 2018 full actual outage figure of 58Ml/d. This was the most up to date full outage figure available at the time of the analysis.

We considered that the results of the Monte Carlo simulation, referred to above, which followed the UKWIR methodology were not representative of an appropriate outage allowance in the long term because of the short dataset used in the analysis and the high actual outage experienced during the period when data was available. The assessed **full** outage allowance figure of 65Ml/d is an overestimate of the actual outage we expect to be able to maintain throughout the course of our WRMP19. We also needed a methodology that could take account of the more accurate actual outage data we were reporting (containing **partial** outage data) and the development and implementation of a focused outage reduction plan that was overseen by a new Operational Resilience group to manage water supply resilience risks.

Because of the need to base the outage allowance on a longer data set we then followed an adapted version of the Monte Carlo methodology that was previously adopted for Southern Water's WRMP14 and our draft WRMP19. This is detailed in Section 3 of Appendix F from Annex 3 and used a minimum period of five years of **full** outage data. An assessment of **partial** outage based on recent actual data was also made and added to the **full** outage allowance calculated using the Monte Carlo method. A **total** outage allowance of 79.6Ml/d was derived by this approach but this was also considered to be too high as a long term outage allowance when compared to other water companies and Southern Water's previous WRMP outage allowances.

The EA's July 2016 technical note 'WRMP19 methods: Outage allowance' highlights that water companies should, where possible, use the UKWIR 1995 outage methodology, but if they decide not to they should discuss their alternative approach with the EA and clearly explain within their WRMP why they have chosen a different approach and the risks and benefits of doing so. The guidance note also urges companies to consider how the outage allowance could vary over the planning period and consider ways to reduce outage to manage supply-demand problems. As such we have developed a hybrid approach in line with this guidance which takes account of our current data availability and recent high **total** outage levels. We discussed aspects of our new approach with the EA in June 2018 as we considered what changes were necessary to our WRMP after the consultation on the draft WRMP19. This included the concept of having a different level of outage allowance for different severities of drought which we have adopted in the WRMP19 (see below).

The outage allowance we have used in the WRMP19 has been calculated based on our outage recovery plan (which is discussed in Appendix F to Annex 3) and the historic **full** outage levels experienced during the 2005-06 drought event. The outage allowance is based on total outage (**full** plus **partial** outage) and on how we have forecast total outage to reduce in line with the outage recovery plan through the end of AMP6 to the end of AMP7.

The outage allowance profile follows a glide path, starting at 76Ml/d at the beginning of AMP7 and reducing to 35Ml/d by the end of AMP7. The outage allowance for the rest of the planning period from AMP8 (2025-26) to 2070 is set at 35Ml/d in the normal and drought (1 in 20 year severity) planning scenarios in our WRMP19. In the severe drought (1 in 200 year severity) and extreme drought (1 in 500 year severity) planning scenarios the allowance for **total** outage is lower (29.5Ml/d) to reflect the levels of outage that we expect to maintain during more severe drought events. This is based on **full** outage data from 2005-06 and includes an allowance for **partial** outage. While the risk of some outage causes may increase in severe drought events (e.g. from deteriorating raw water quality), we would do everything possible to fully use existing source of supply in order to maintain supplies to customers and avoid implementing drought permits and orders which have an environmental impact. The outage event of 2005-06 gave some evidence of the level of outage which could be maintained in such circumstances which is why we have used it as a best estimate of the outage allowance in severe and extreme droughts.

It is important to note that one of the key drivers to the approach we have adopted in this plan is the fact that adopting higher outage allowances would result in larger supply-demand deficits, triggering a need for more or larger water resource schemes to manage the supply-demand balance. These would likely be more expensive than maintaining a lower outage level. However, there will be a point at which it becomes more expensive to maintain a low outage level than to implement a new demand management or supply scheme. We believe applying a similar concept as the economic level of leakage to outage could be explored more for the next round of plans.

8.3 Reporting

Since April 2019 our outage reporting has improved to make sure we are fully compliant with the Ofwat AMP7 outage methodology. This looks at the failure or deterioration of any asset in the water production process which impacts on the ability to achieve the peak week production capacity (PWPC). The PWPC is essentially the maximum sustained capacity output of a WSW and could be the constraint on DO. In other instances, it will be greater than the DO where there are other constraints such as, for example, the hydrological yield of a source in the design drought. The process of collecting data to report against the PWPC also allows us to compare failures against the ADO / MDO to give data consistent with outage reporting to the EA. This produces fully assured data that is directly comparable across both methodologies.

We are concurrently running the old and new reporting methods until the new process is fully established as reliable and accurate. The Water Production Manager owns the process for reporting outage. Monthly updates to the outage recovery plan are reviewed by the Operational Resilience group and we are implementing a new outage reporting system which will be internally assured on a monthly basis.

Telemetry data is used to indicate asset faults or failures, with this being recorded as the start of the outage period. This telemetry data is then linked to SCADA (supervisory control and data acquisition) data, which contains flow volumes and work completion information. Once all required work is complete, the final completion date and time is used as the end of the outage period. This period of outage is then compared to internal records to separate planned outage. Flow data from the site is then used to quantify the volume of water put into supply during the period of outage, ensuring that both full and partial outage are captured.

This flow data is compared against PWPC and MDO to produce comparable figures for both Ofwat and the EA. Extra validation is also carried out against exclusion criteria, and to make sure that if there has been a failure of the telemetry system, any reduction in flow is still captured and investigated to make sure no outages are excluded in error and similarly to make sure that no instances of low demand are incorrectly captured as outage. The reports will be assured on a monthly basis in terms of data accuracy and then again on a yearly basis against reporting requirements.

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Water Resources Management Plan 2019

Annex 3: Supply forecast

Appendix A: Additional technical information on Weather Generator

December, 2019

Version 1

Introduction

This appendix contains additional technical information on the stochastic weather generator we have used to produce our synthetic climate sequences for use with our Water Resource Modelling. The methodology section was prepared by Francesco Serinaldi at the University of Newcastle and details the additional enhancements made to the weather generator.

Methodology

Spatio-temporal rainfall model

The monthly rainfall model builds on other models developed for monthly rainfall (Serinaldi and Kilsby, 2013), radar errors (Villarini et al. 2014), and daily rainfall fields (Serinaldi and Kilsby, 2014). It is based on parametric Generalized Additive Models for Location, Scale and Shape (GAMLSS) and allows embedding exogenous variables such as large scale climate indices, thus making the framework well suited for sensitivity analysis under alternative climate scenarios. The model has been extensively validated on gauge and GEAR data provided by Southern Water Services (SWS).

Referring to Serinaldi and Kilsby (2014) for technical details, the at-site models are GAMLSS allowing the introduction of physical covariates that help adapt the shape of the at-site distribution according to external (climate and geographical) drivers. The spatial dependence is accounted for by both the spatial patterns of the physical covariates and by an underlying meta-elliptical random field that accounts for the stochastic properties of the spatial dependence. Moreover, while the seasonality is introduced by the covariates of the marginal distributions, the short term autocorrelation is embedded in the underlying meta-elliptical random field, which can be thought as a separable spatio-temporal process. In more detail, the modules of the model can be summarized as follows:

At-site univariate model

As mentioned above, the model relies on the combination of univariate at-site distributions and a spatio-temporal random process accounting for spatial correlation as well as short term autocorrelation. Let Y(s,t) be the rainfall value at the site s and day t, and p the probability of zero rainfall. The precipitation can be described by a discrete-continuous distribution $G\big(Y(\boldsymbol{s},t)\big)$. In the GAMLSS framework, G can depend on external covariates via suitable relationships and link functions. Namely, G can be described by a continuous distribution such as the Generalized Gamma (GG) distribution (eg Papalexiou and Koutsoyiannis, 2012):

$$g\big(Y(\boldsymbol{s},t)\big) = \frac{|\nu|\theta^{\theta} z^{\theta}\exp(-\theta z)}{\Gamma(\theta) y}, \qquad (1)$$

for y > 0, where the parameters $\mu > 0$, $\sigma > 0$, and $-\infty < \nu < \infty$, and where $z = (y/\mu)\nu$ and $\theta = (\sigma 2\nu 2)$. The parameters μ, σ, andν can be linked to covariates via suitable functions such as:

$$\begin{cases} \eta_\mu(\mu(\boldsymbol{s},t)) = \boldsymbol{\beta}_\mu(\boldsymbol{s})' X_\mu(\boldsymbol{s},t) \\ \eta_\sigma(\sigma(\boldsymbol{s},t)) = \boldsymbol{\beta}_\sigma(\boldsymbol{s})' X_\sigma(\boldsymbol{s},t), \\ \eta_\nu(\nu(\boldsymbol{s},t)) = \boldsymbol{\beta}_\nu(\boldsymbol{s})' X_\nu(\boldsymbol{s},t) \end{cases} \qquad (2)$$

in which η_μ, η_σ, and η_ν are suitable link functions. Even though the above model is written considering linear relationships between parameters and covariates, nonlinear relationships are allowed as well in the GAMLSS framework.

Spatial dependence structure

The stochastic nature of the spatial dependence of the rainfall process is modelled by using a meta-elliptical random field that can be synthesized by the empirical correlation matrix.

The possible short term (ARMA) autocorrelation exhibited by the monthly rainfall fluctuations can be introduced by allowing for dependence of at-site parameters on the previous observations or by introducing time dependence in the underlying spatial random field. Even though the first approach is deemed more natural, it implies that each simulation depends on the previous one, thus resulting in an inefficient simulating algorithm. In the second approach, the short-term time dependence can be simply introduced by writing (after Podgórski and Wegener, 2012):

$$Z(\boldsymbol{s},t+1)=(\rho-1)Z(\boldsymbol{s},t)+\sqrt{1-\rho^2}\Phi(\boldsymbol{s},t), \qquad (5)$$

where Φ is a meta-elliptical spatially correlated random field and ρ is the lag-1 autocorrelation. As $Z(\boldsymbol{s},t)$ has uniform marginal distribution it can be coupled with the at-site model in a coherent and flexible modelling framework.

Rainfall simulation procedure

The modelling and simulation approach can be summarized as follows (Serinaldi and Kilsby, 2014):

1. A GAMLSS GG cumulative distribution G(y(s,t)) is fitted to every time series at each location to model the (at-site) rainfall marginal distributions accounting for seasonality and covariate effects. Namely, the probability density function is set up as follows

$$g\big(y;\theta(\boldsymbol{s},t),z(\boldsymbol{s},t),\nu(\boldsymbol{s},t)\big)=\frac{|\nu|\theta^{\theta}z^{\theta}\exp(-\theta z)}{\Gamma(\theta)y}$$

   where

$$\mu(\boldsymbol{s},t)=\beta_{\mu,0}(\boldsymbol{s})+\beta_{\mu,1}(\boldsymbol{s})\mathrm{NAO}+\beta_{\mu,2}(\boldsymbol{s})\mathrm{SST}+\sum_{k=1}^{12}d_{m,k}D_{m,k}$$

$$\sigma(\boldsymbol{s},t)=\beta_{\sigma,0}(\boldsymbol{s})+\beta_{\sigma,1}(\boldsymbol{s})\mathrm{NAO}+\beta_{\sigma,2}(\boldsymbol{s})\mathrm{SST}+\sum_{k=1}^{12}d_{m,k}D_{m,k}$$

$$\nu(\boldsymbol{s},t)=\beta_{\nu,0}(\boldsymbol{s})$$

   in which NAO and SST are North Atlantic Oscillation index, and sea surface temperature, while $D_{m,k}$ denote factors identifying calendar months ($D_{m,1}$= Jan, $D_{m,2}$= Feb, etc.).
2. The lag-1 temporal correlation and spatial correlation are estimated through Spearman correlation coefficient ρS and then transformed into Pearson correlation ρ via the formula ρ=2sin(ρSπ/6).

3. A set of temporally independent but spatially correlated Gaussian random fields w(s) covering the spatial domain are simulated and the short term temporal correlation is introduced applying Eq. (5). The resulting random fields y(s,t) are Gaussian and spatio-temporal correlated.

4. The probability transformation u(s,t)=Φ(y(s,t)) is applied to obtain random fields with standard uniform marginals which mimic values of probability ranging in [0,1] with a prescribed spatial and temporal structure.

5. Finally spatio-temporal correlated rainfall fields are simulated by applying the local (at-site) quantile functions (inverse of Eq. (1)) to the meta-Gaussian random fields with uniform marginals u(s,t), ie y(s,t) = G-1(u(s,t)).

Water Resources Management Plan 2019

Annex 3: Supply forecast Appendix B: calibration of the synthetic weather generator

December, 2019

Version 1

Introduction

This appendix contains calibration plots for the synthetic weather generator that compare the distribution of observed rainfall over various accumulation intervals to the range of the synthetic rainfall data.

To demonstrate the “calibration” of the weather generator outputs against the historical climate a series of Quantile-Quantile (Q-Q) plots have been produced. A quantile-quantile plot compares ranked outputs from the model against the equivalent rank of the observed data sets. For example, the rainfall total for fifth driest simulated year would be plotted against the fifth driest observed year.

The grey points show the range and variability of the synthetic weather simulations for 500 different realisations of equal length to the historic record. The solid red dots indicate the mean of that range. If the weather generator simulated the historic climate distribution exactly, then all of the data would plot on the 1:1 line.

However, the point of this modelling is not to exactly reproduce the historic climate but to stochastically simulate alternative, but plausible climate sequences. For a reasonable calibration the pattern of the scatter include the 1:1 line but with a reasonable degree of variability about this line. Generally a roughly even scatter about the 1:1 line across the whole data range would be desirable as this would demonstrate the model is not systematically drier or wetter than observations, especially at either “tail” of the dataset.

To examine the model calibration, rainfall totals are compared over a number of different accumulation periods; 6, 12, 18, 24, 30, 48 and 60 Month rainfall accumulations for months ending in October, November and December. These plots are produced as a single set for each aggregation period across the whole of the rainfall dataset.

Figure 43 Calibration Plots (6-month ending December)

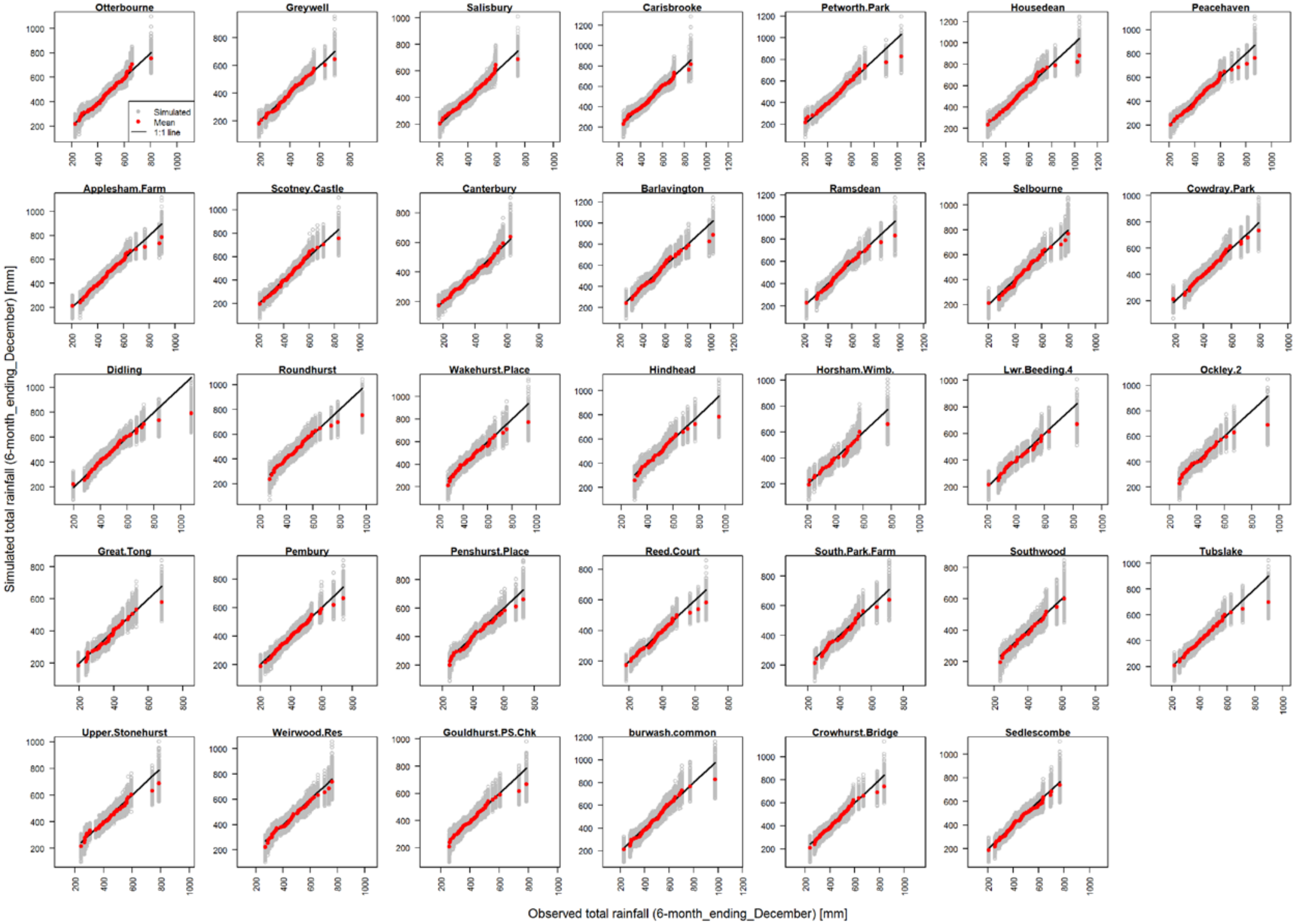


Figure 44 Calibration Plots (6-month ending November)

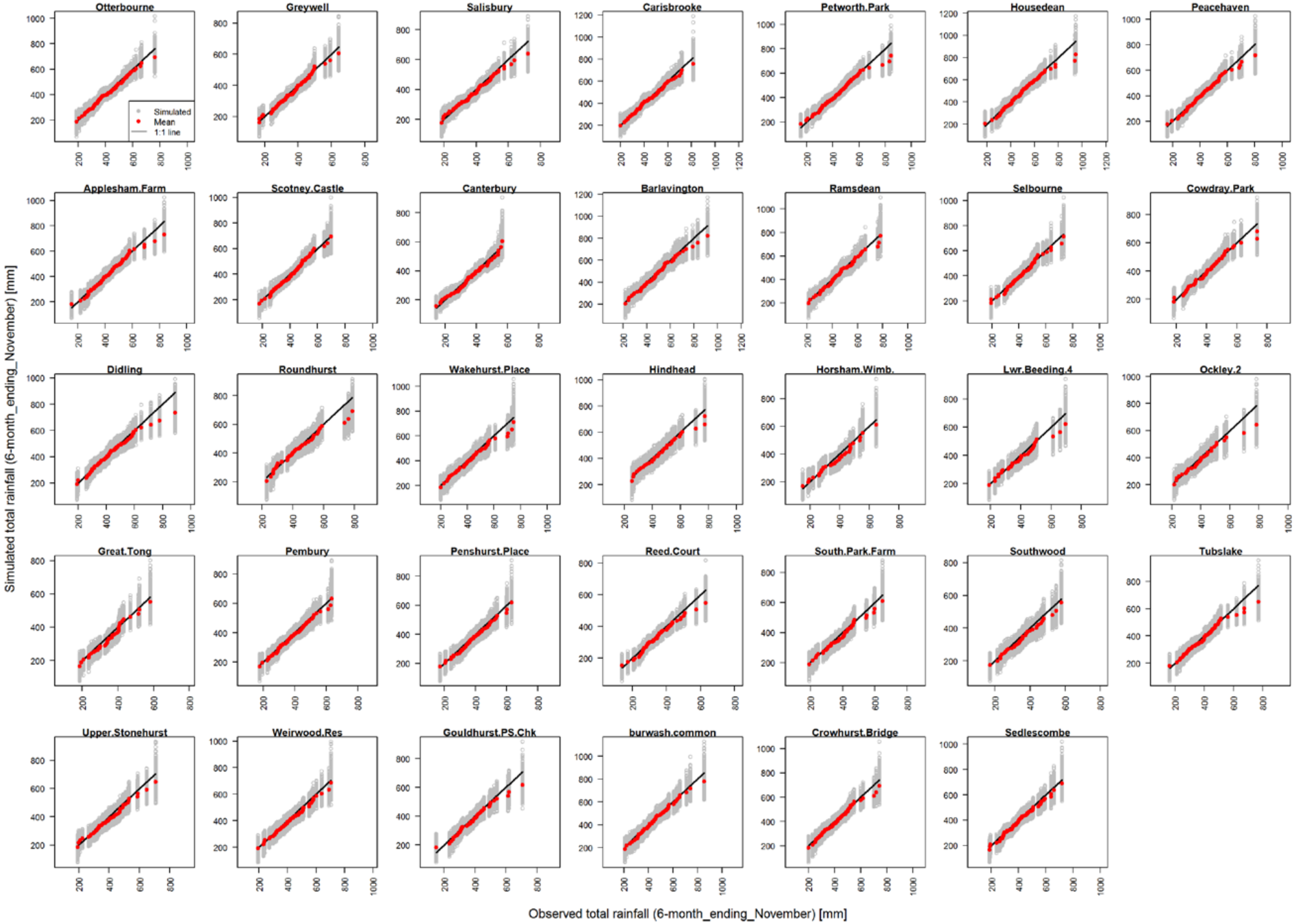


Figure 45 Calibration Plots (6-month ending October)

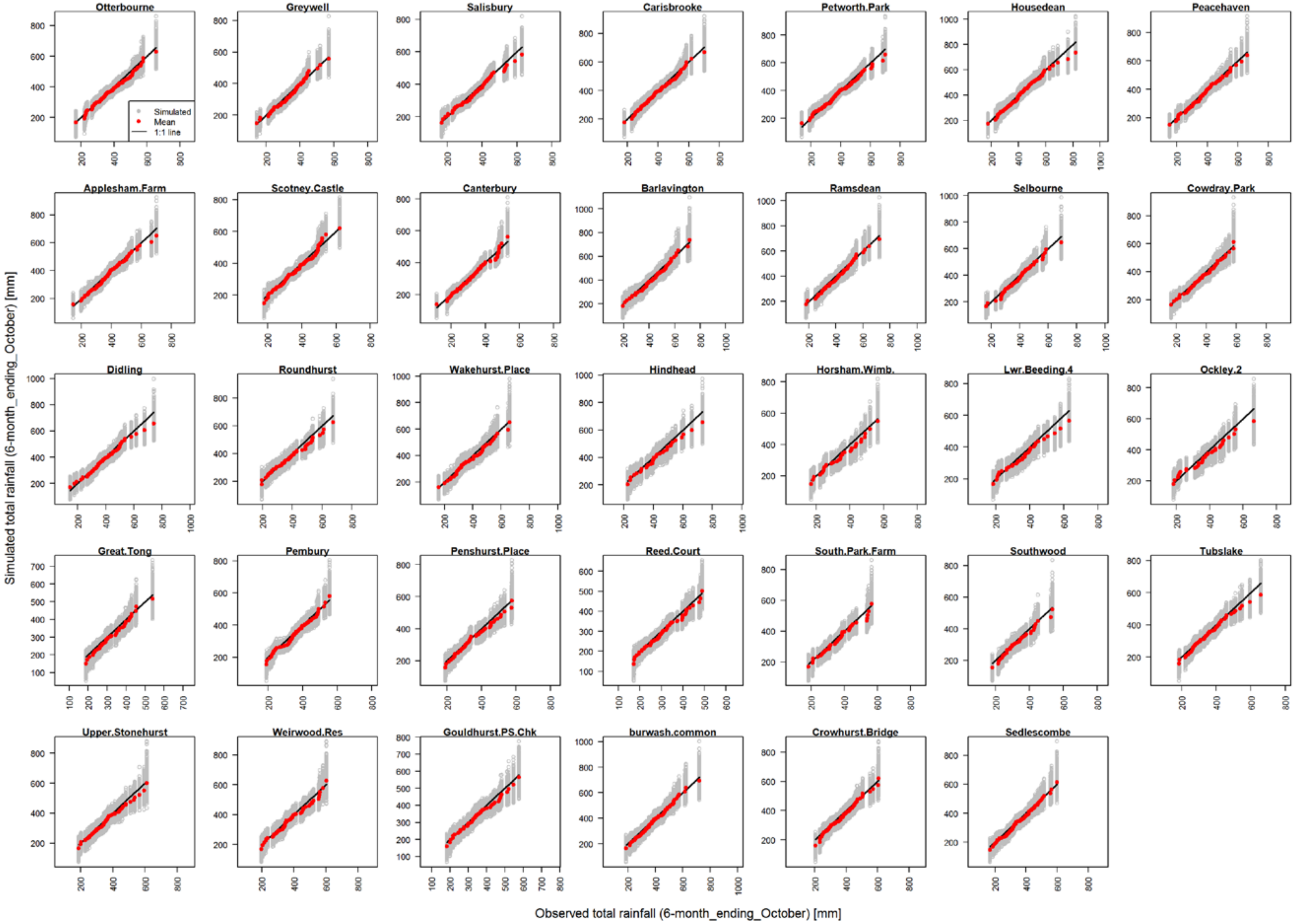


Figure 46 Calibration Plots (12-month ending December)

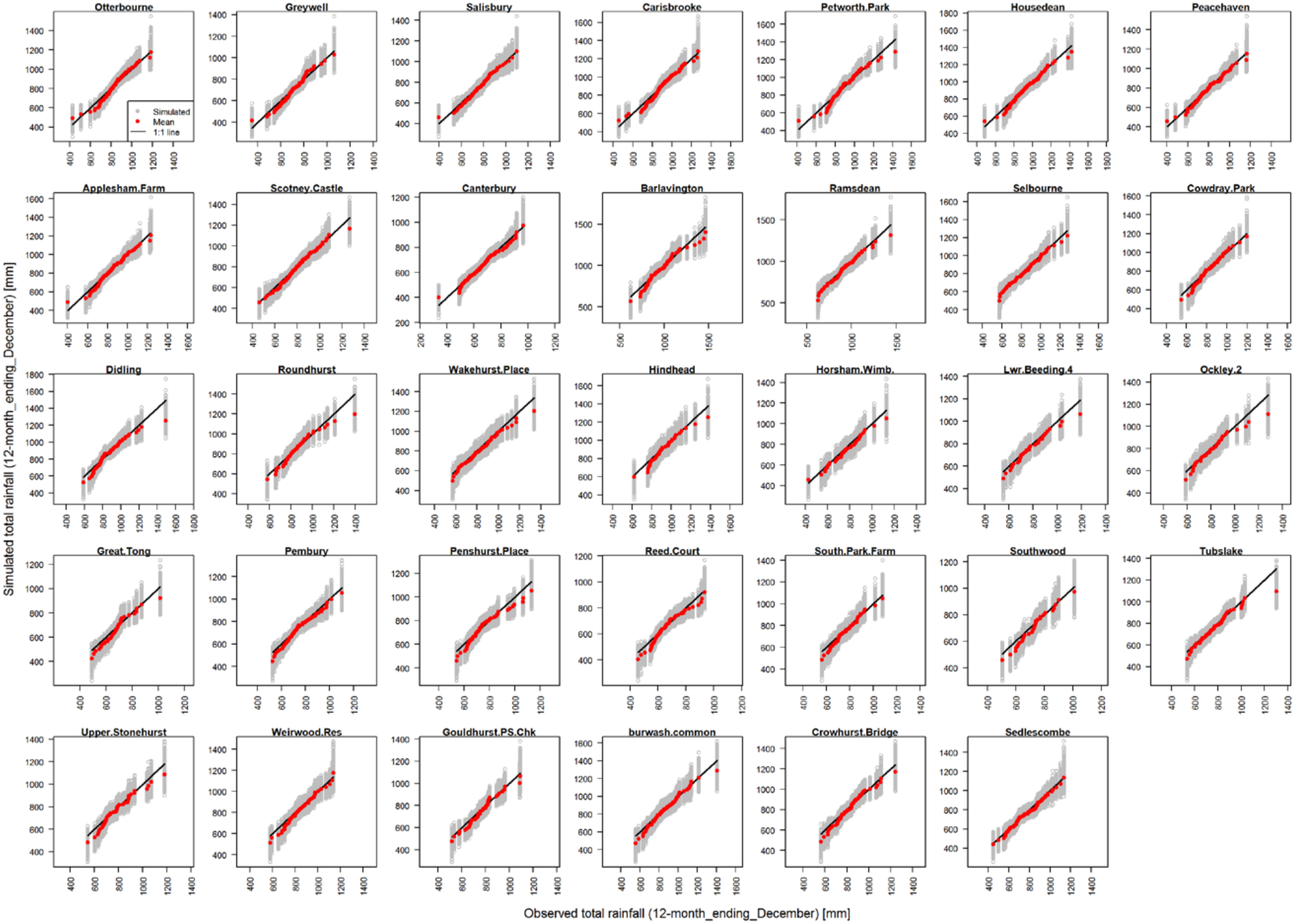


Figure 47 Calibration Plots (12-month ending November)

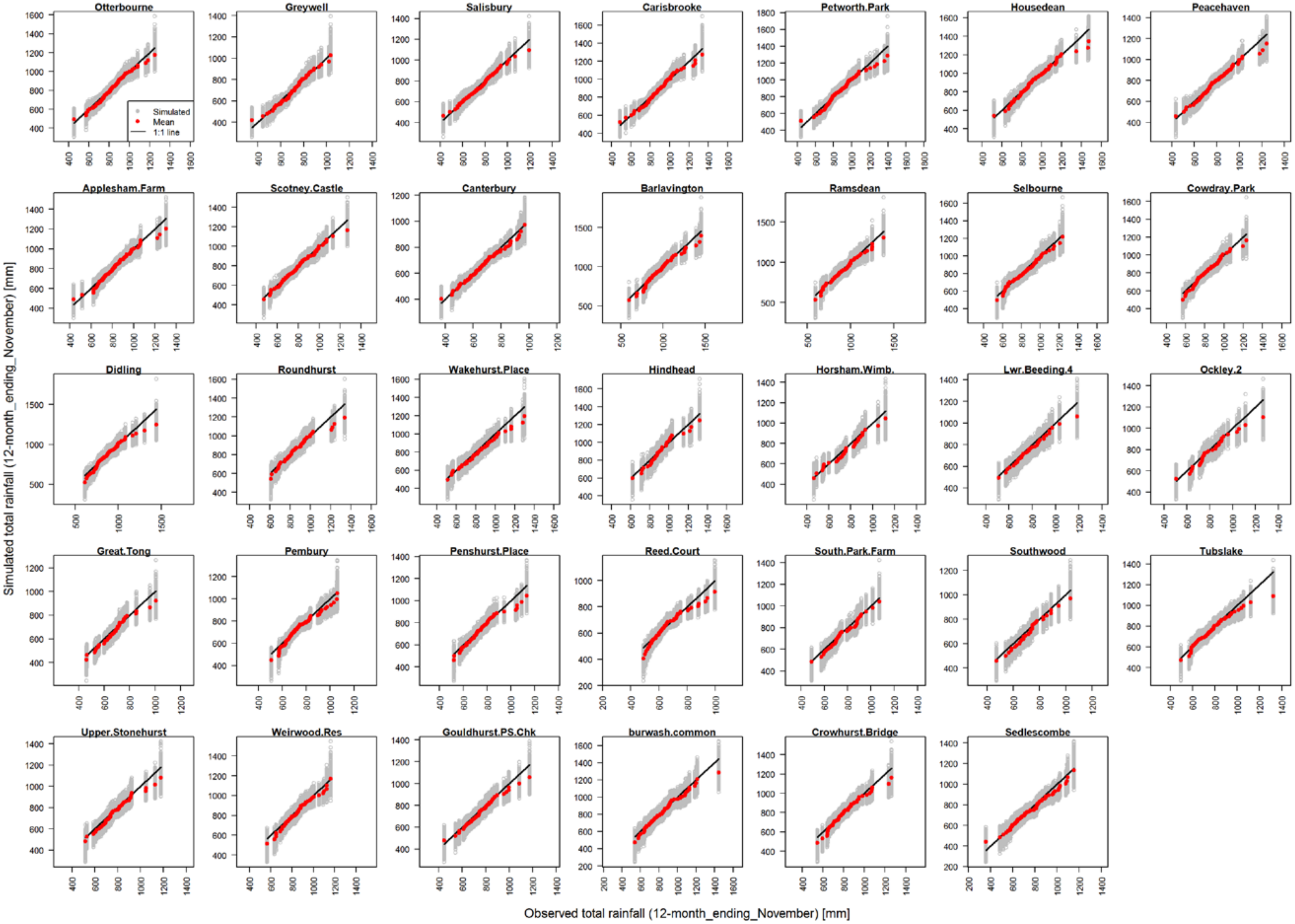


Figure 48 Calibration Plots (12-month ending October)

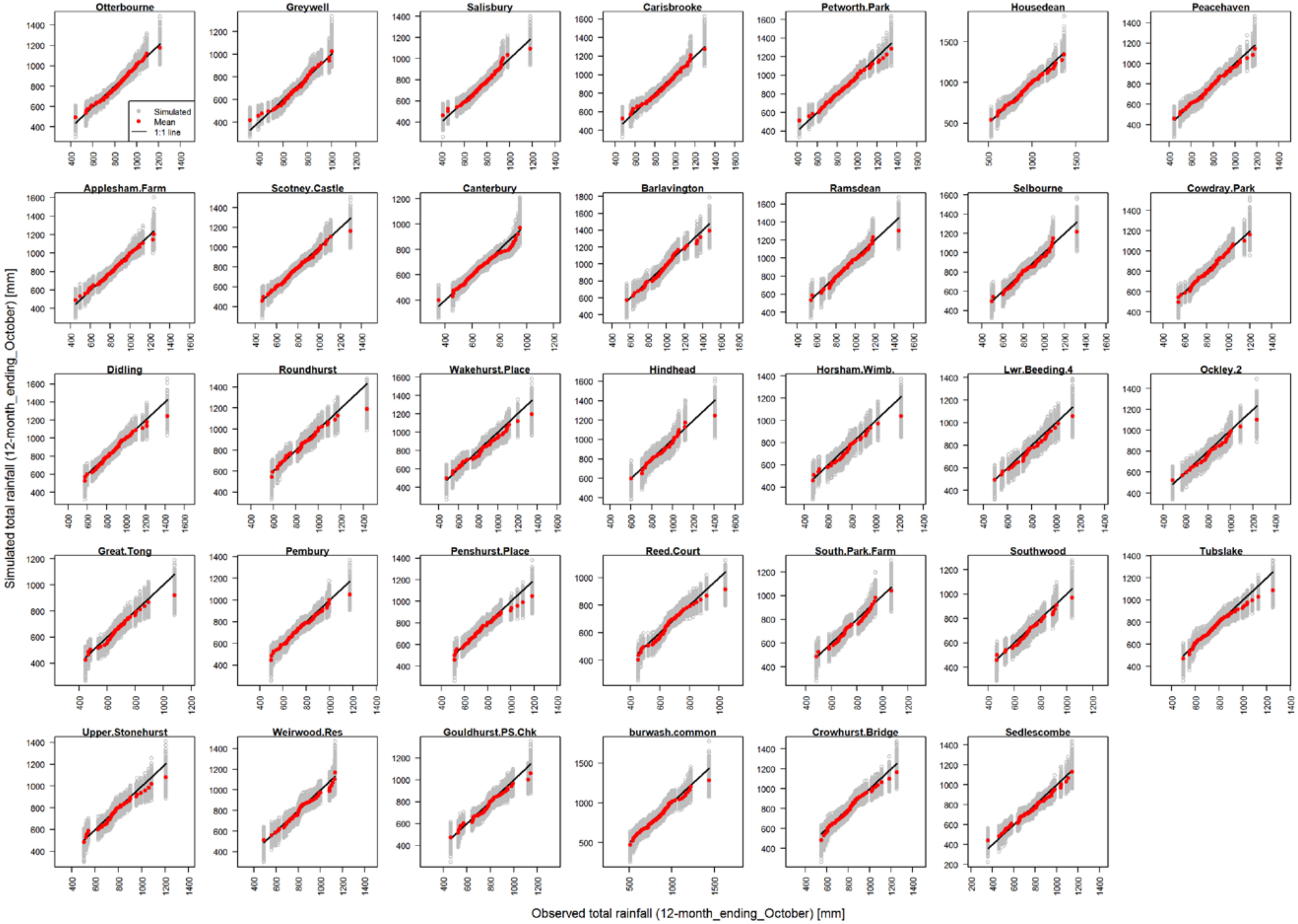


Figure 49 Calibration Plots (18-month ending December)

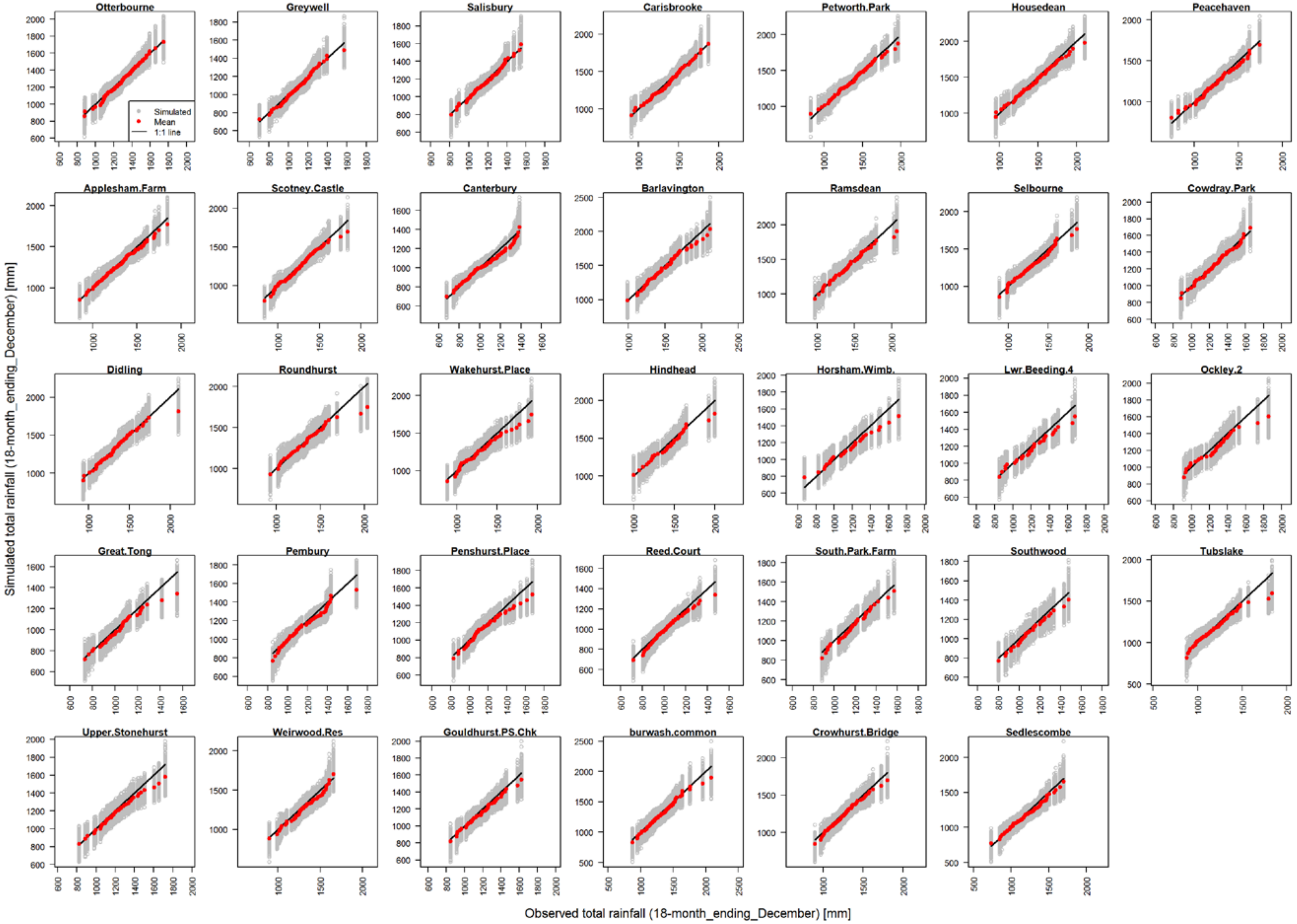


Figure 50 Calibration Plots (18-month ending November)

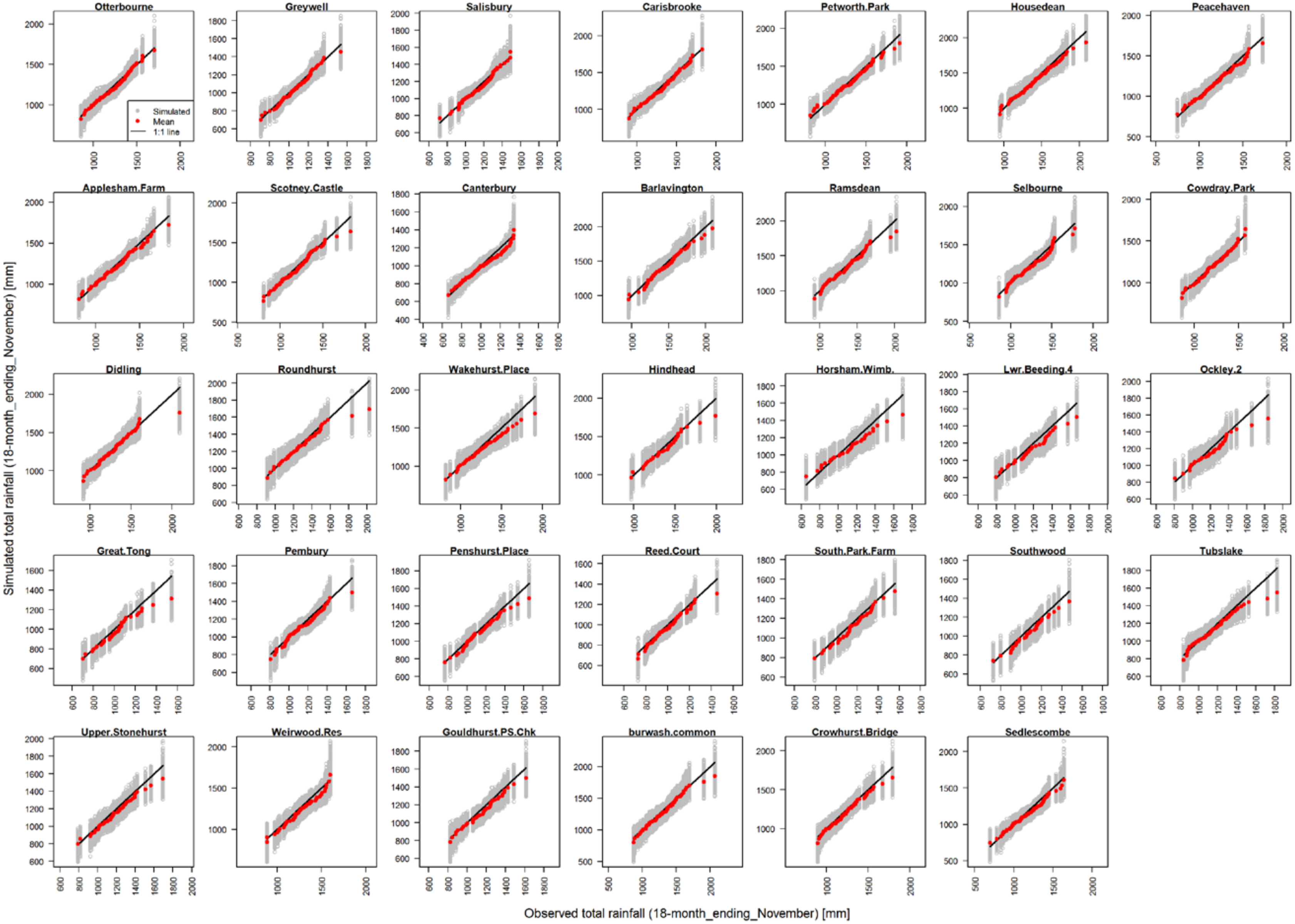


Figure 51 Calibration Plots (18-month ending October)

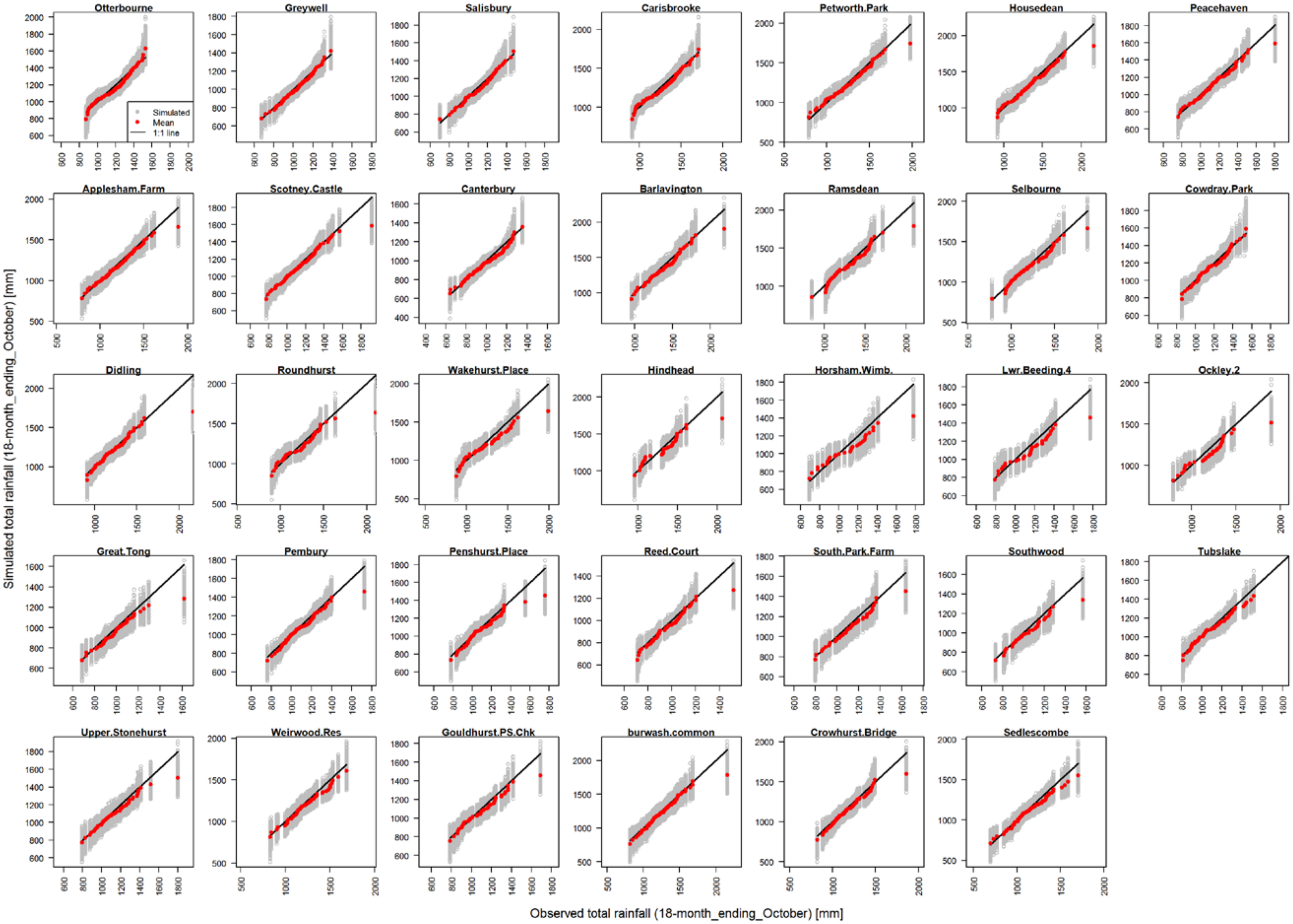


Figure 52 Calibration Plots (24-month ending December)

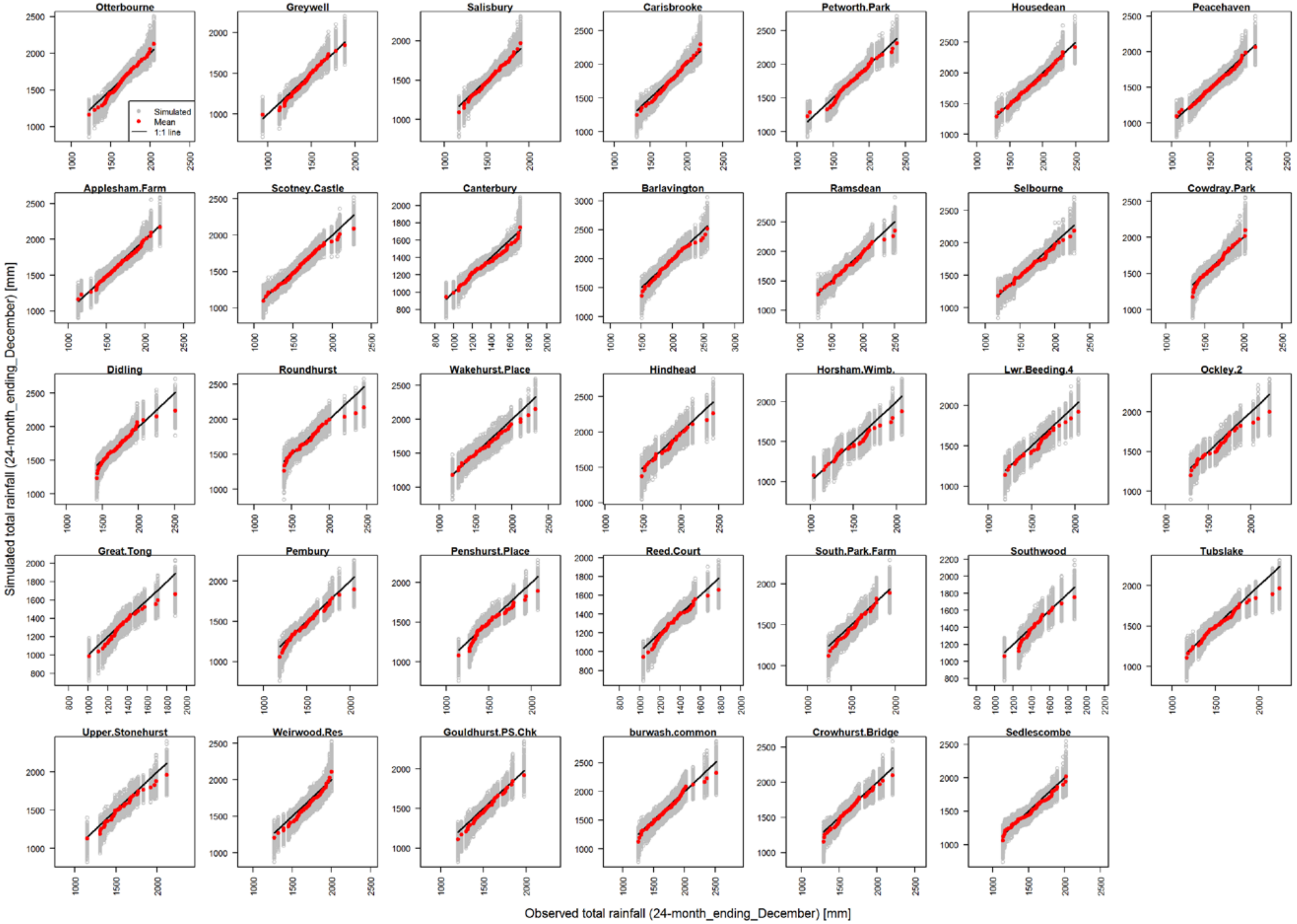


Figure 53 Calibration Plots (24-month ending November)

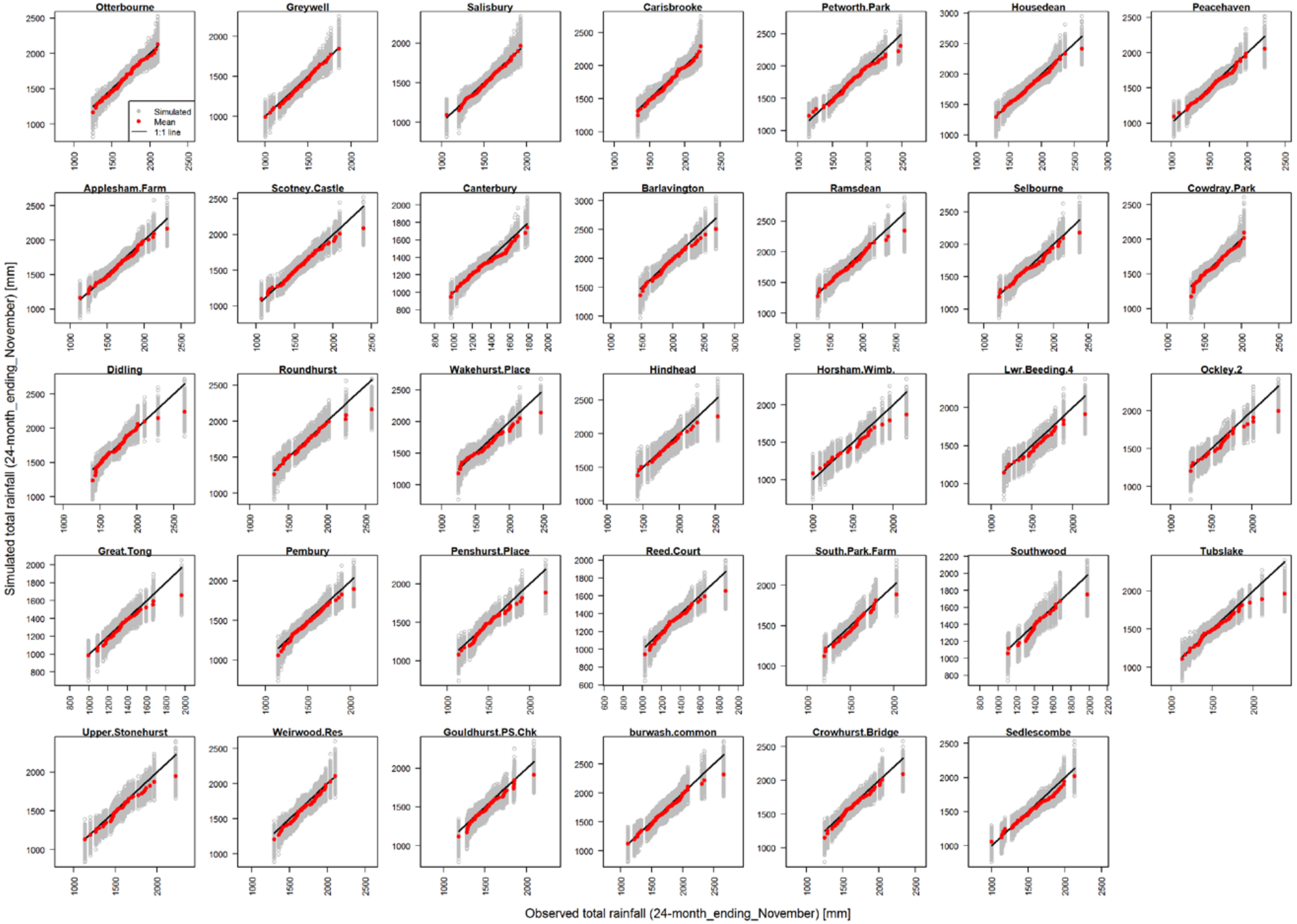


Figure 54 Calibration Plots (24-month ending October

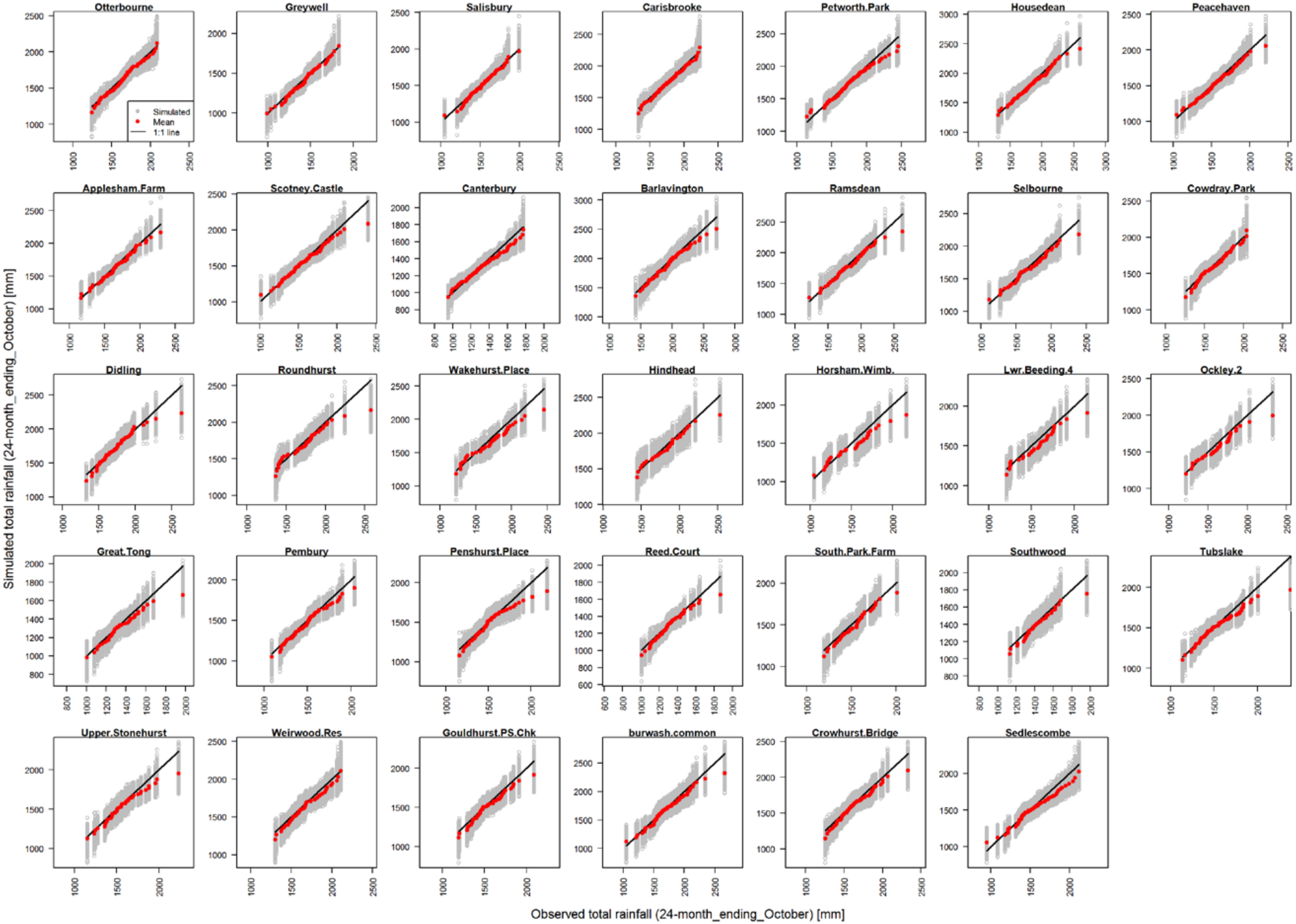


Figure 55 Calibration Plots (30-month ending December)

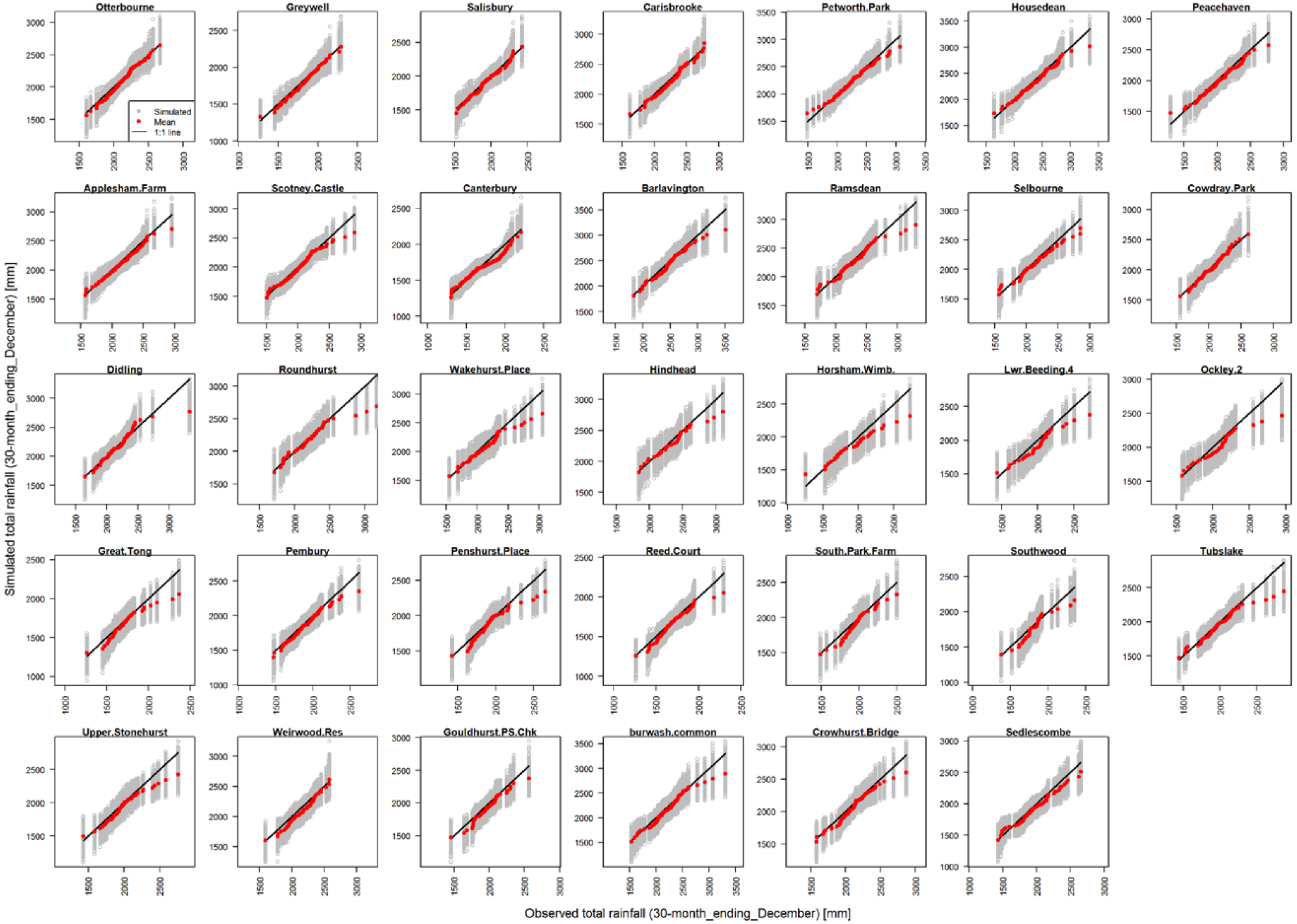


Figure 56 Calibration Plots (30-month ending November)

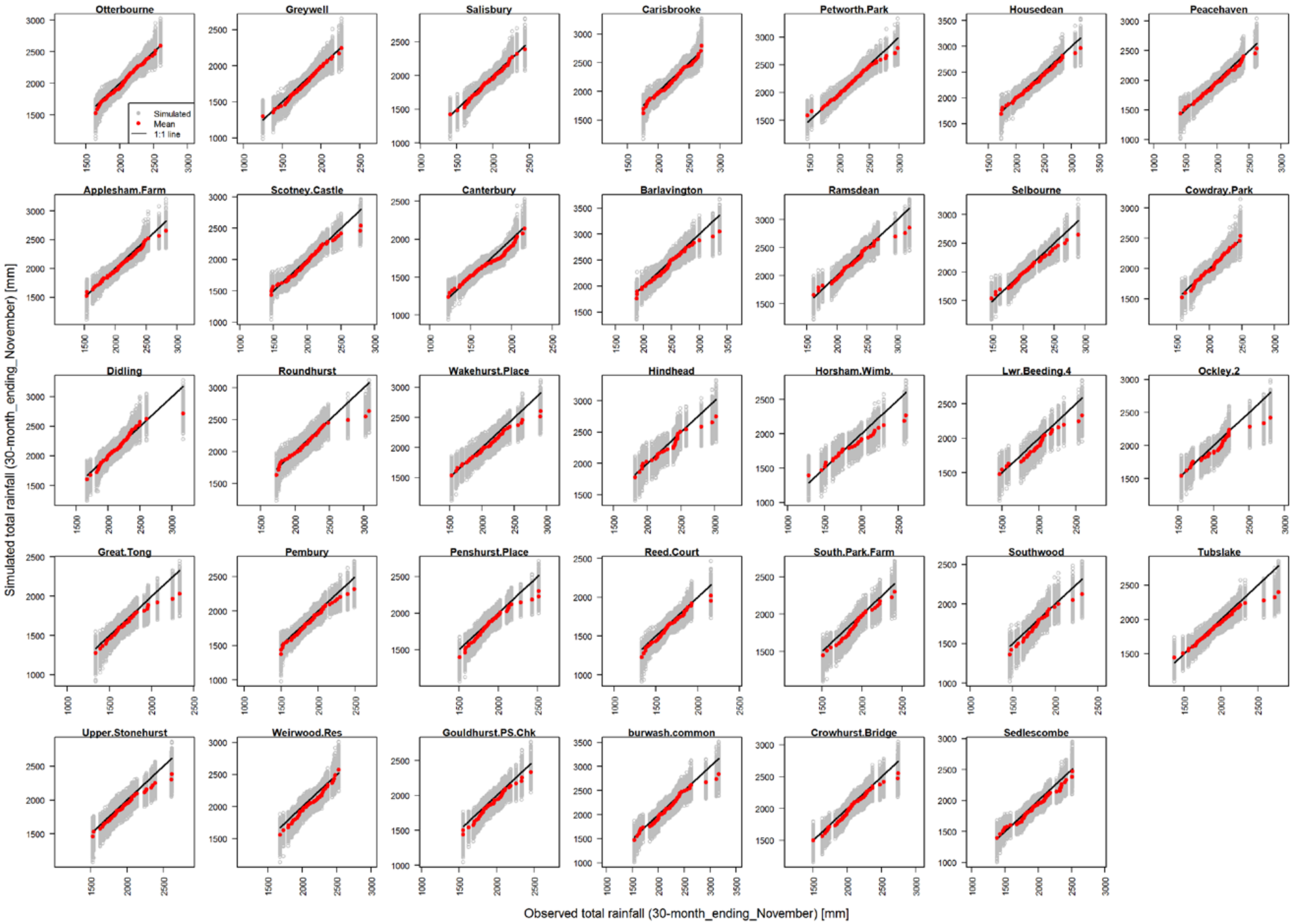


Figure 57 Calibration Plots (30-month ending October)

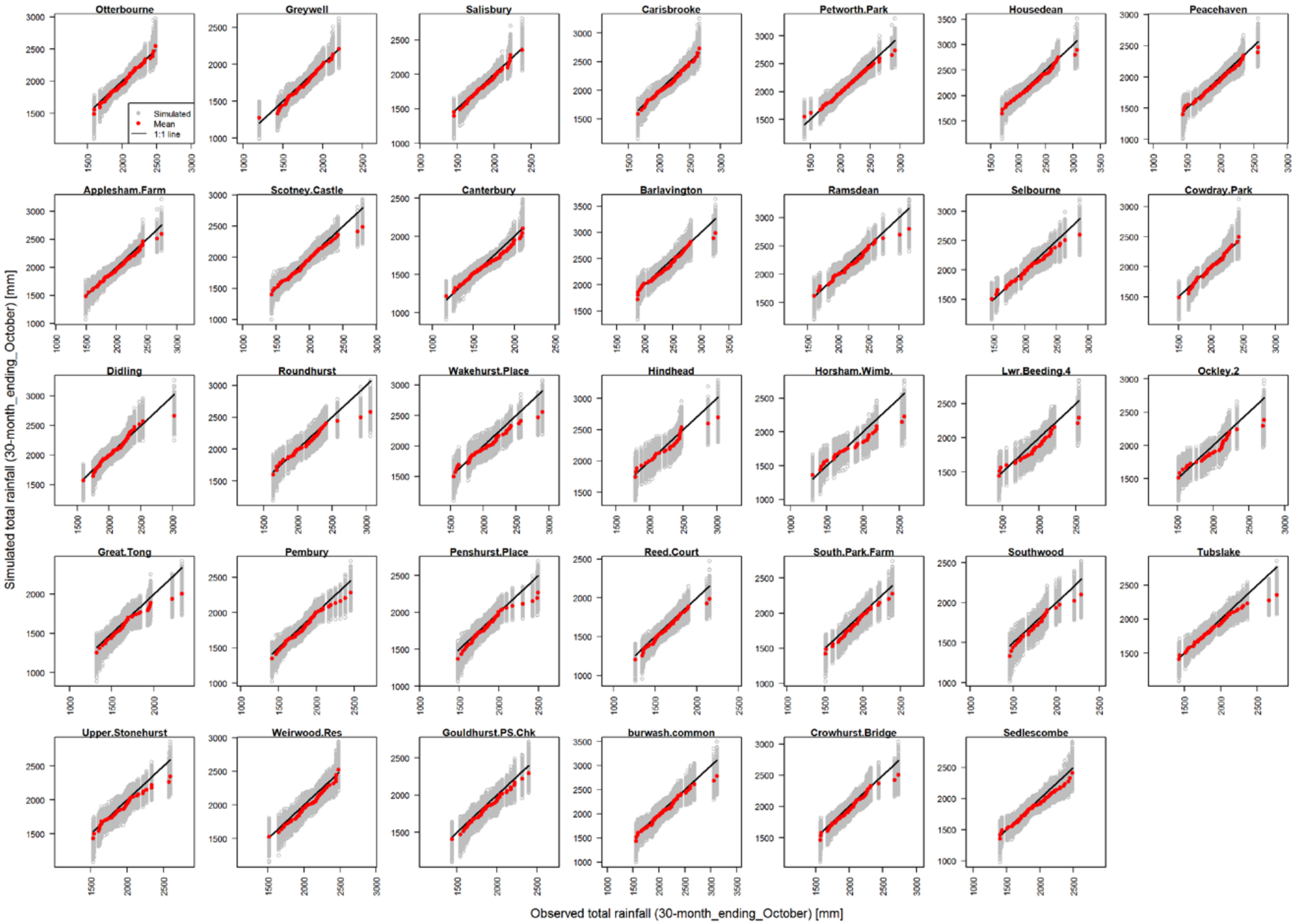


Figure 58 Calibration Plots (36-month ending December)

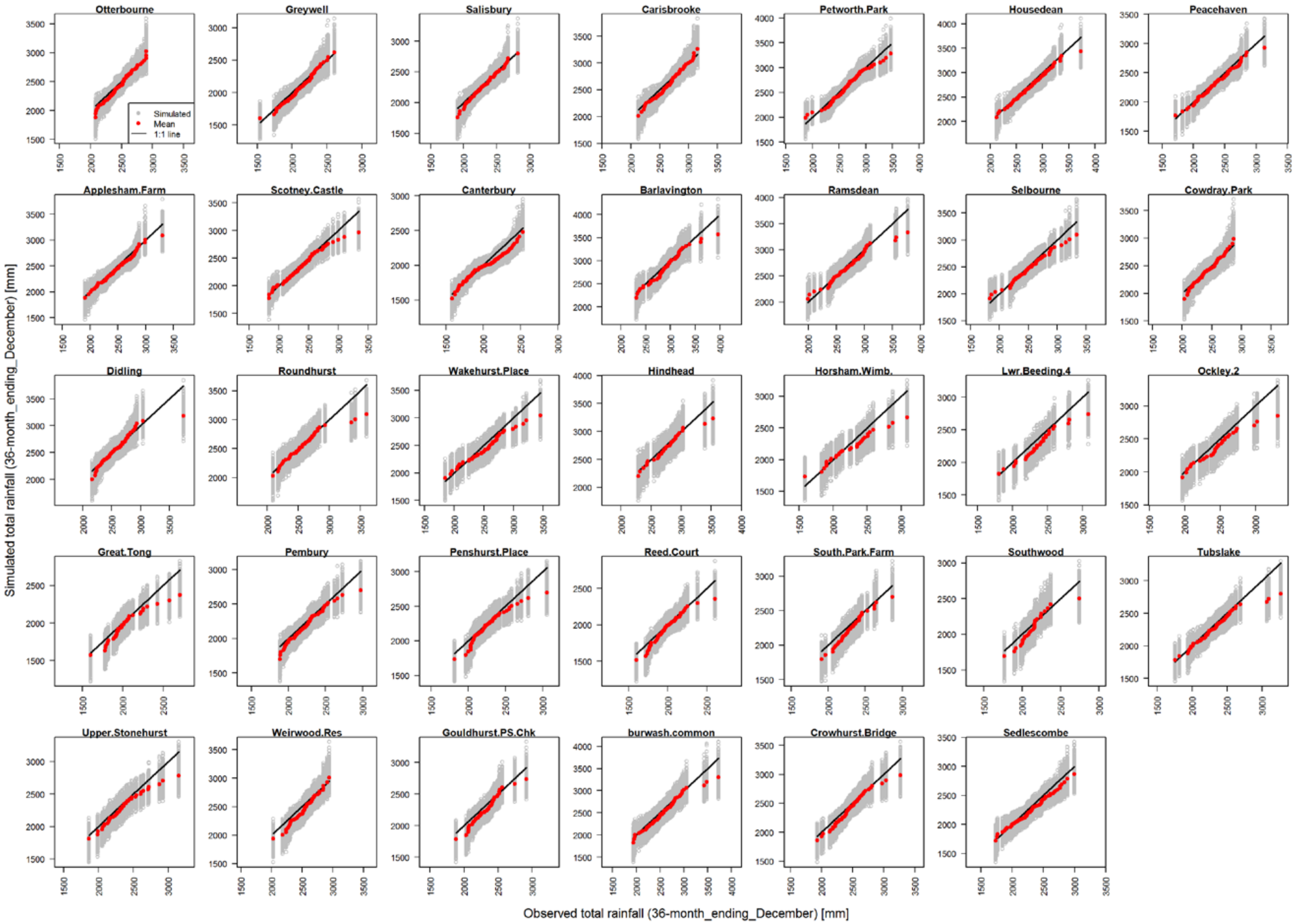


Figure 59 Calibration Plots (36-month ending November)

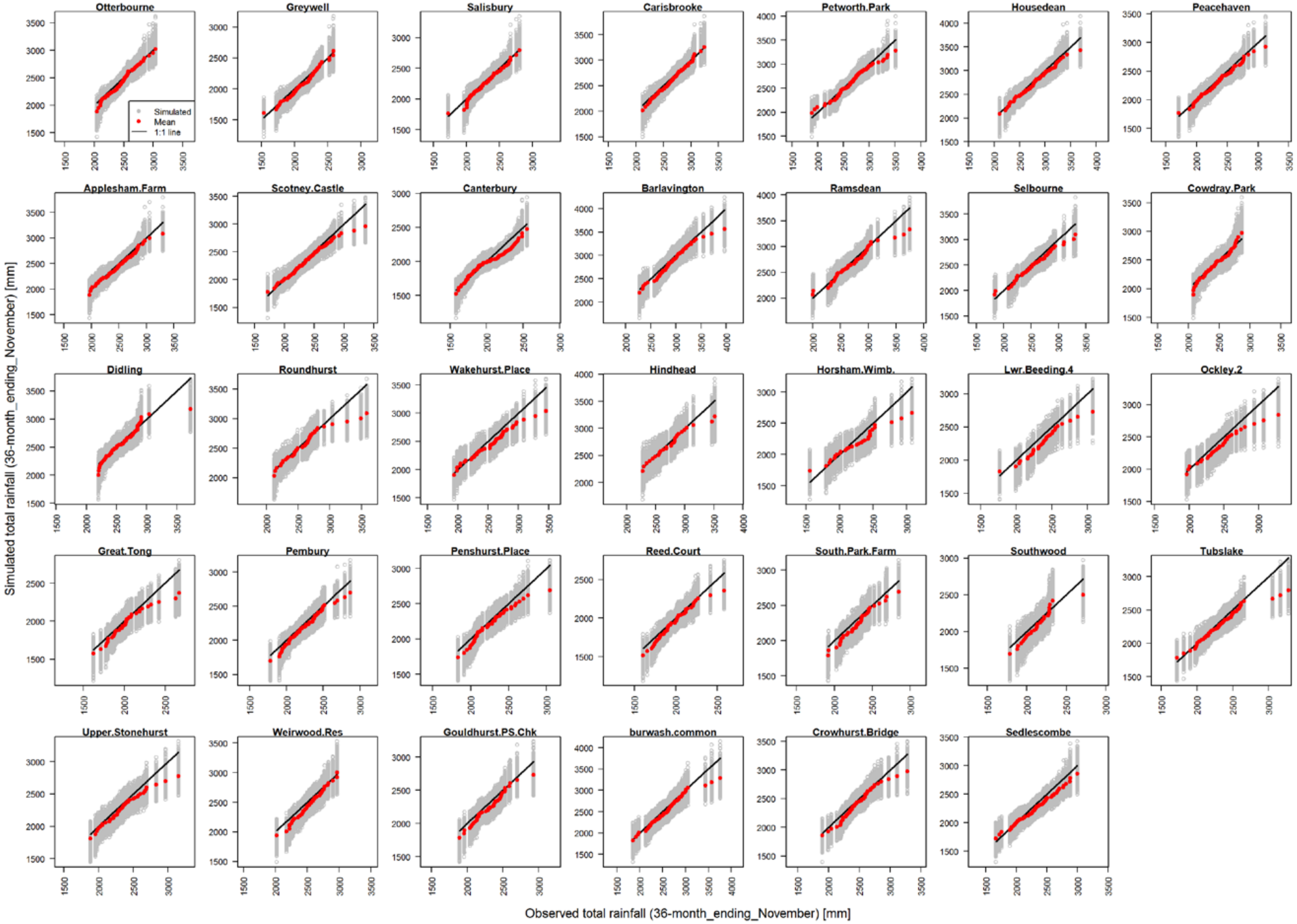


Figure 60 Calibration Plots (36-months ending October)

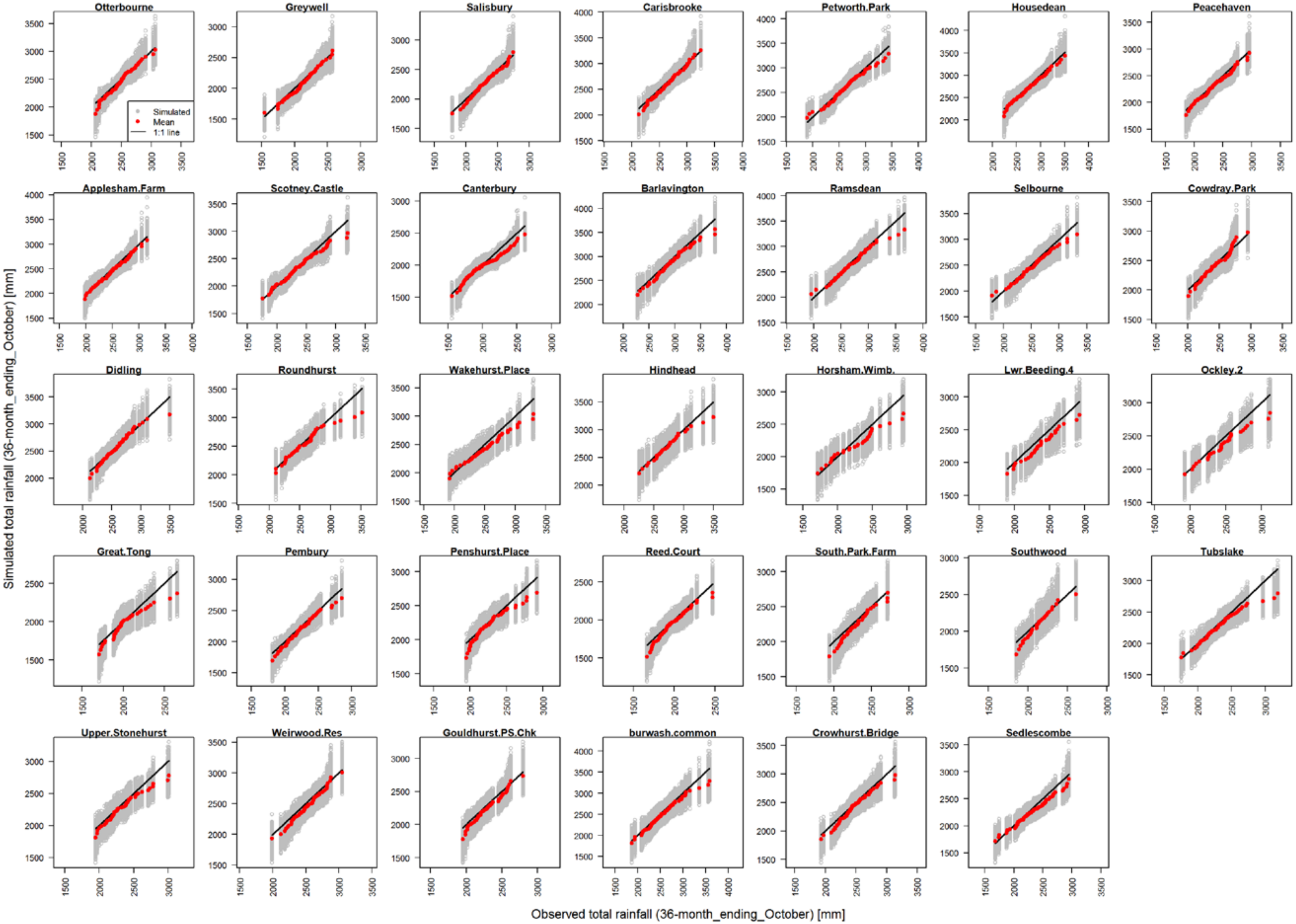


Figure 61 Calibration Plots (48-month ending December)

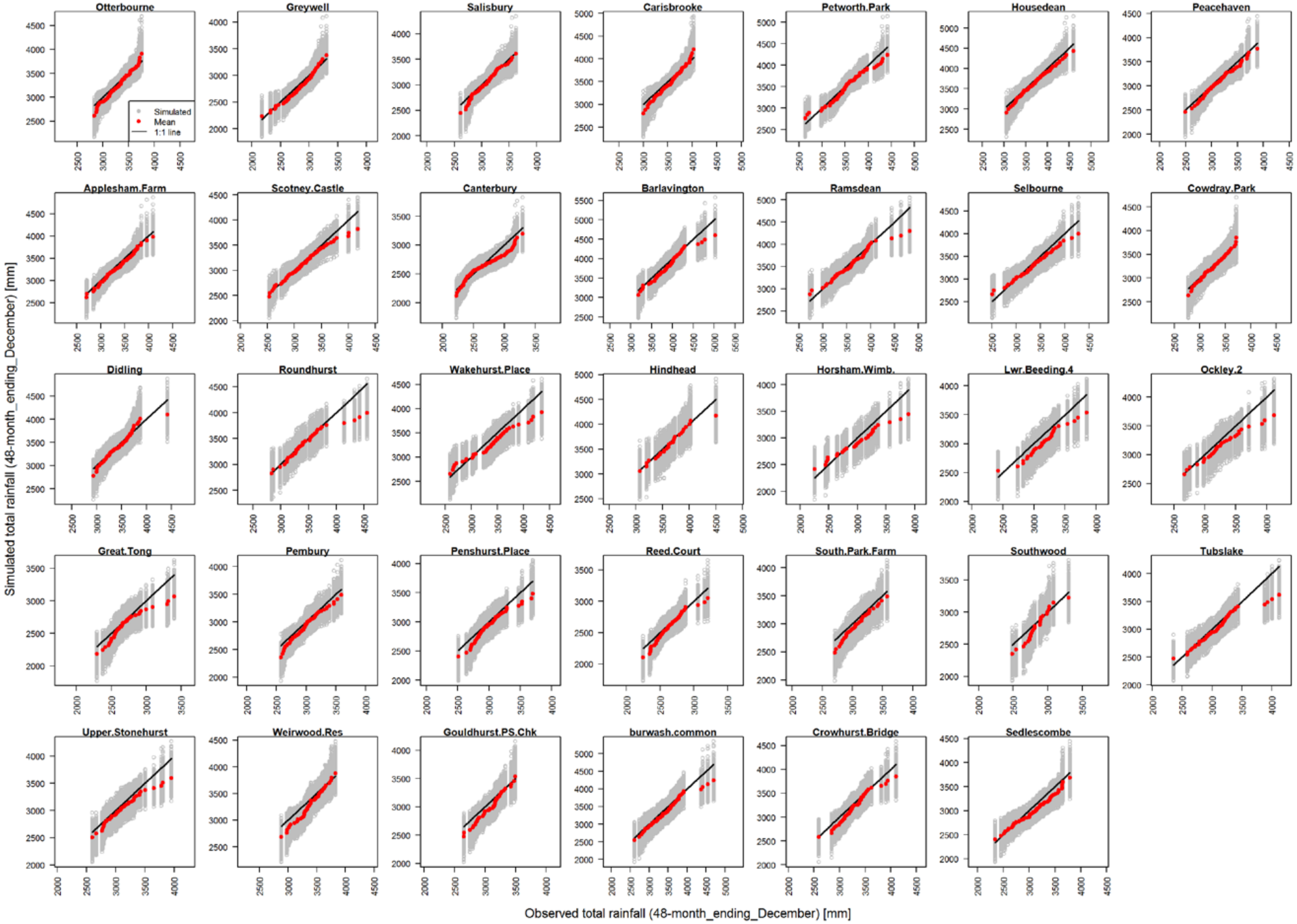


Figure 62 Calibration Plots (48-month ending November)

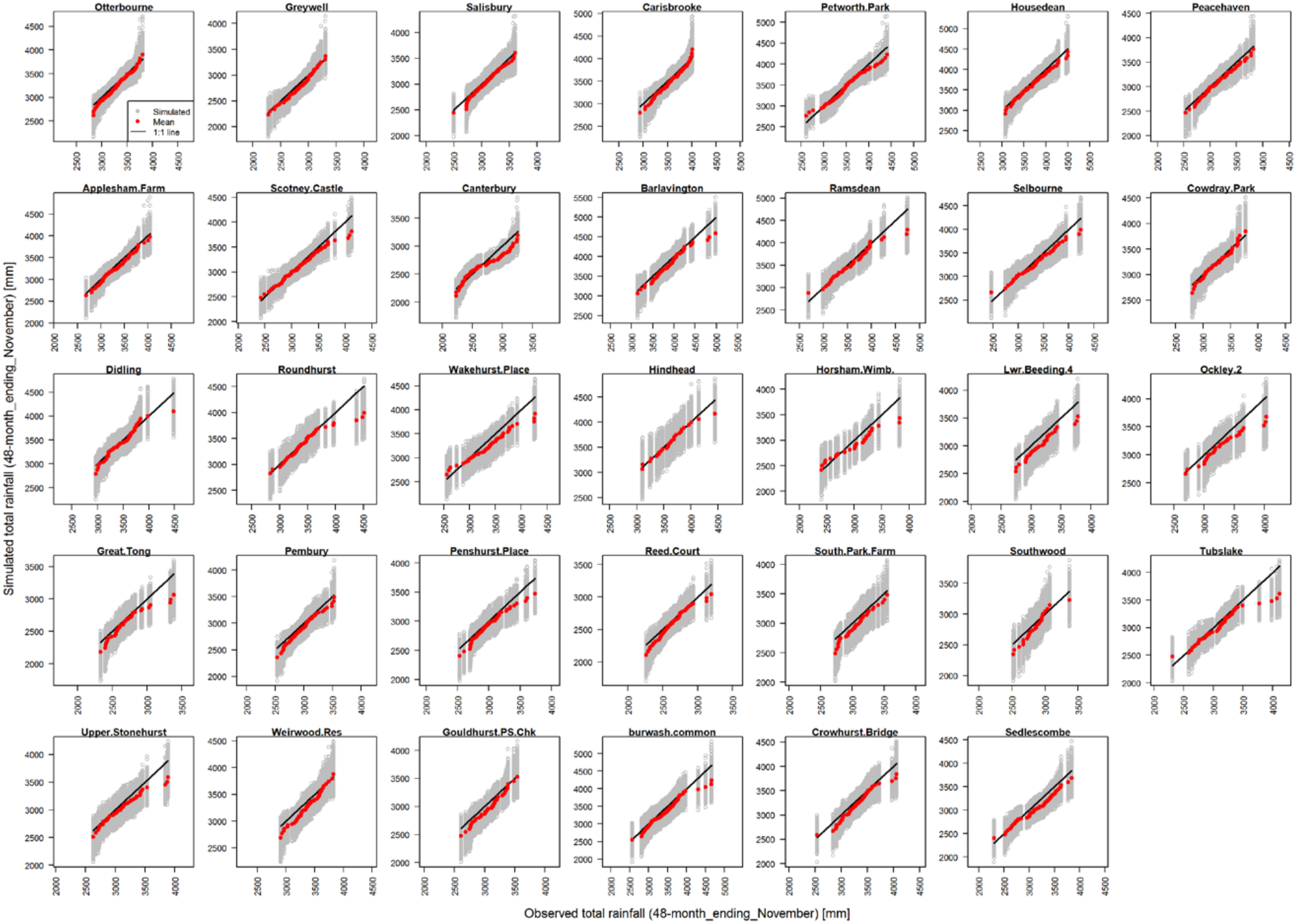


Figure 63 Calibration Plots (48-month ending October)

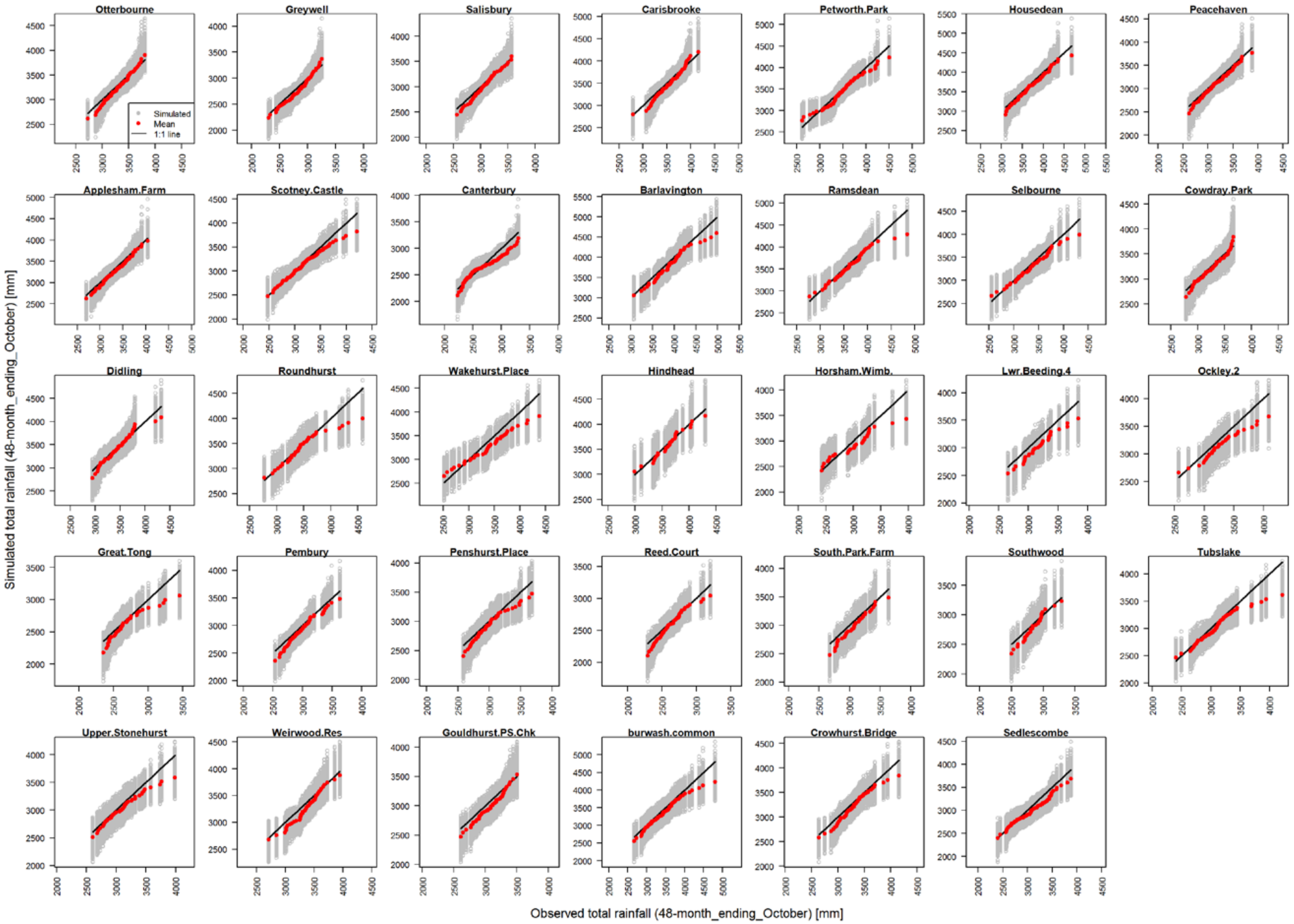


Figure 64 Calibration Plots (60-month ending December)

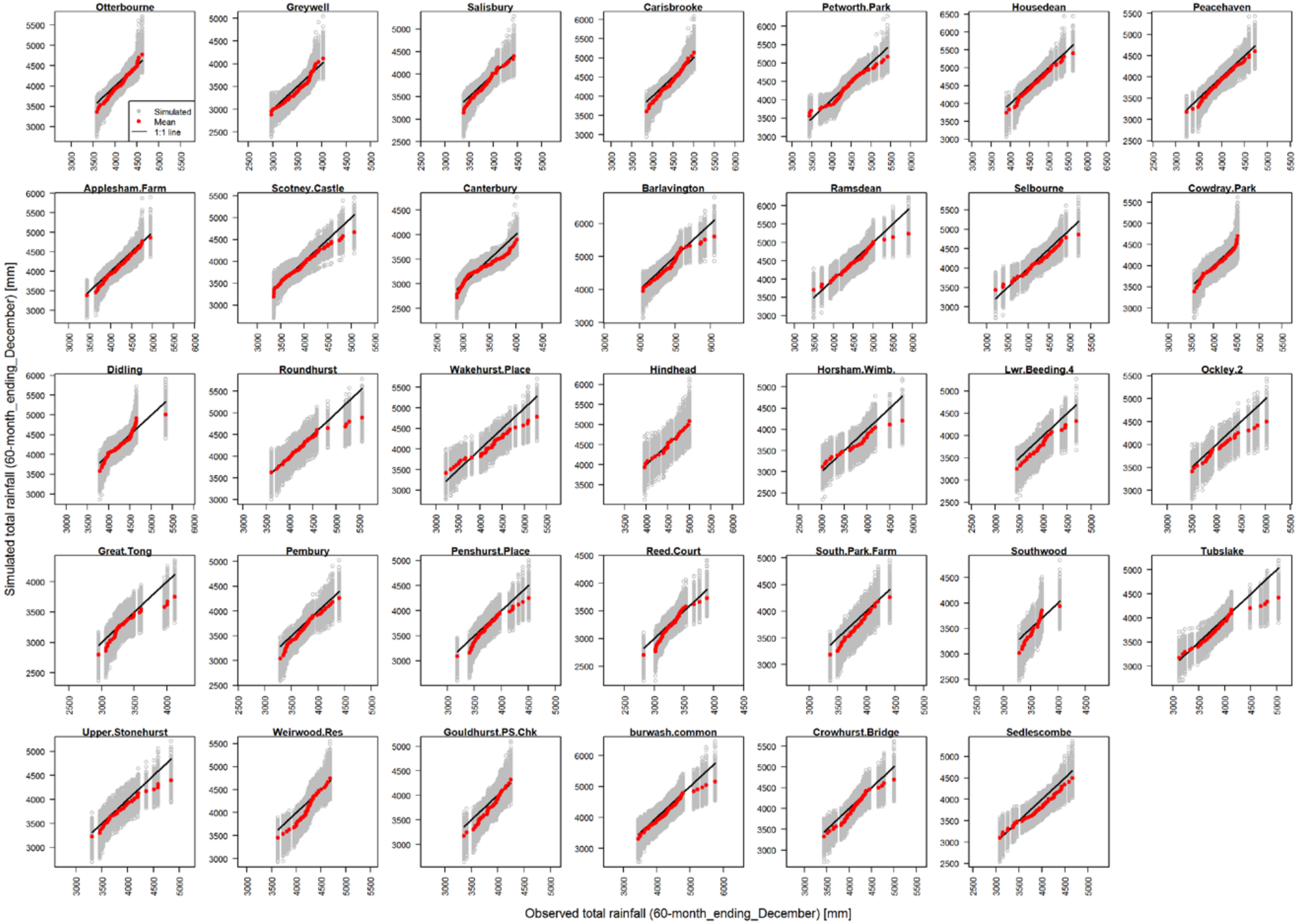


Figure 65 Calibration Plots (60-month ending November)

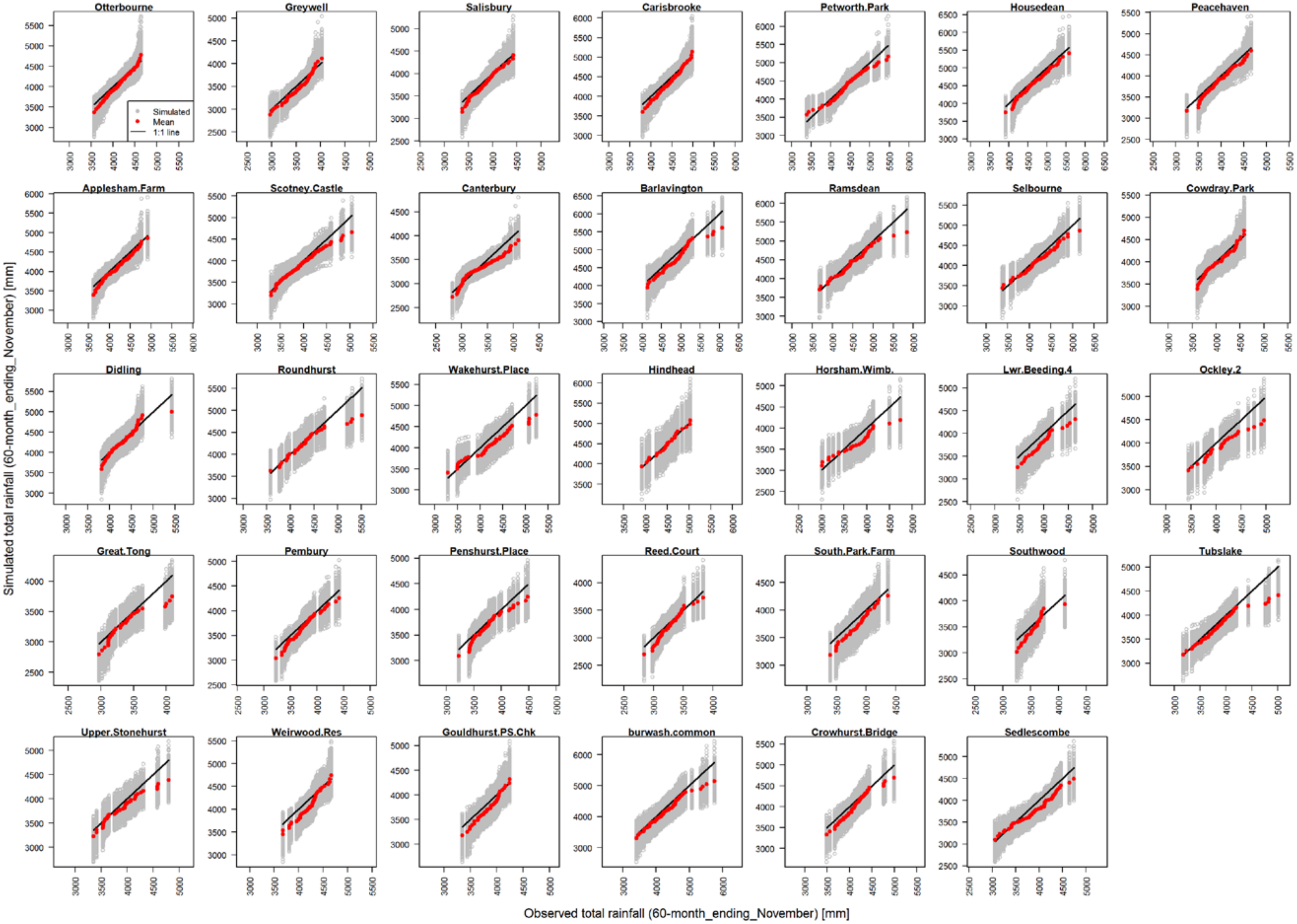
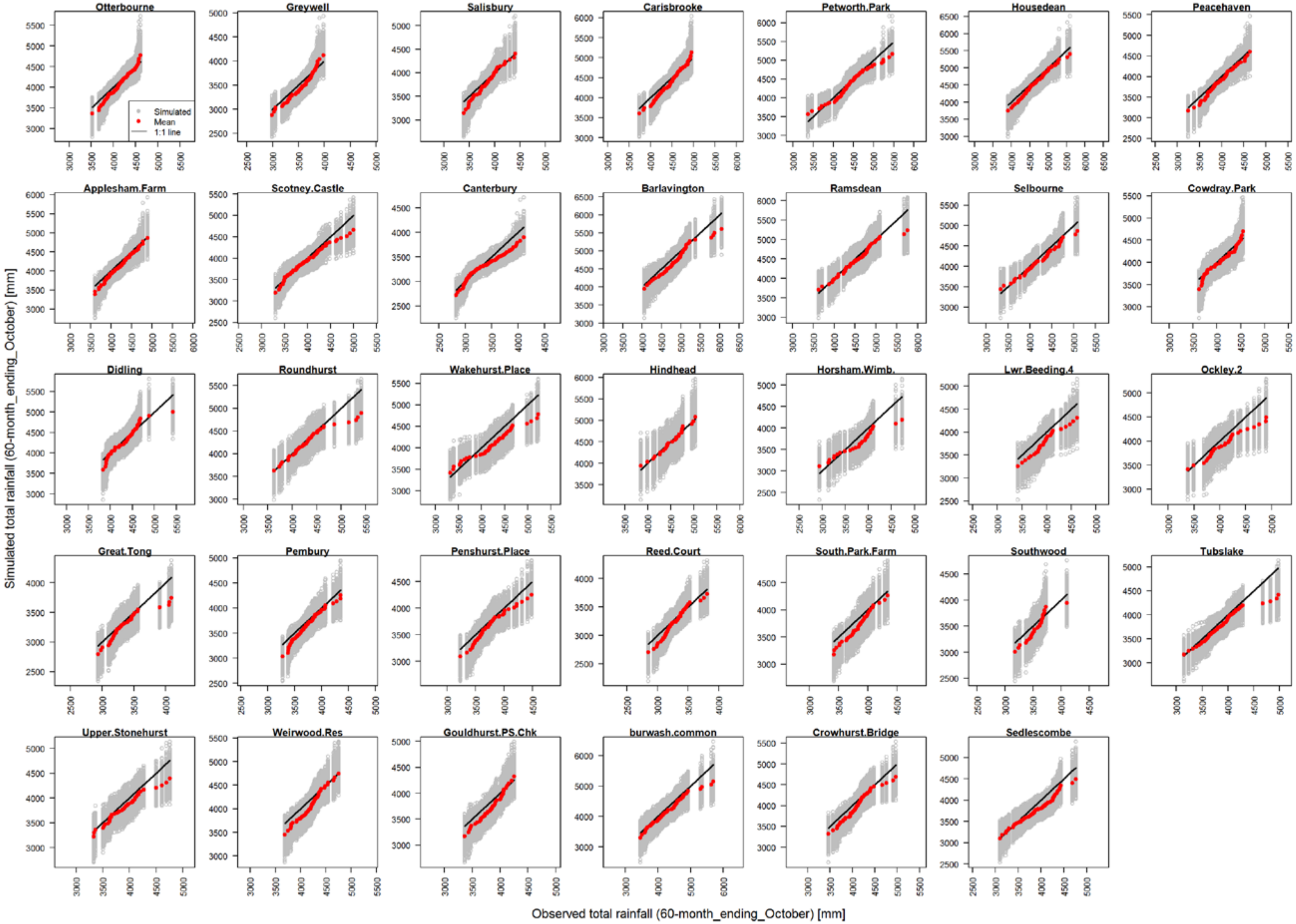


Figure 66 Calibration Plots (60-month ending October)



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Appendix C: Hydrological calibration plots

December, 2019

Version 1

Introduction

CATCHMOD hydrological models are used to model river flows in relation to our surface water sources. The models have been developed to produce flow sequences from the synthetic stochastic rainfall and PET sequences, as well as the historic records of rainfall and PET. These hydrological models have been updated and recalibrated for this plan on the basis of observed data up to 2014. CEH GEAR gridded catchment rainfall data (Tanguy et al, 2015) and MORECS PET data were used for the calibration process. Naturalised flows were generated for the calibration process by decomposition.

An improved denaturalisation module has been developed which dynamically accounts for abstractions in relation to hands off flow (HOF) conditions. The module also automatically aggregates the relevant time series to derive flows in the Medway at Teston. The denaturalisation procedure excludes Southern Water abstractions and reservoir releases; these are modelled separately within the Aquator water resource models.

The methodology used to update the hydrological models is presented in the main text of Annex 3, in the ‘Hydrological modelling’ subsection of the ‘Methodology for developing the supply forecast’ section.

This appendix presents the calibration plots at the key flow gauges for the water resource modelling.

For each gauge, the first figure shows two key pairs of data.

The ‘observed naturalised flows by decomposition’ flows may be compared with the ‘simulated naturalised’ flows. ‘Observed naturalised’ flows are the gauged flows which have been manipulated to account for abstractions and discharges within the catchment. These are used for the calibration of the hydrological models. The ‘simulated naturalised’ flows are the outputs from the hydrological models.
The ‘observed gauged’ flows may be compared with the ‘simulated fully denaturalised’. The ‘observed gauged’ flows are the gauged data, and the simulated fully denaturalised have had all the abstractions and discharges added to the simulated data, to assess how well the modelled data fits back to the gauged data.
The denaturalised flow (excluding SWS impacts – for Aquator) shows the partially denaturalised modelled flows, which excludes the components of Southern Water’s resource system which are modelled in the Aquator resource models. These datasets are used as the input to Aquator.

For each gauge, the second figure compares the AMP4 naturalised and denaturalised flows with the AMP6 naturalised flows. This illustrates how the update and reparameterisation of the models based on recent flow and artificial influence data has changed the flow duration curves of the modelled flow datasets.

Medway at Teston

Figure 67 Medway at Teston: Observed gauged flows vs simulated fully denaturalised and Naturalised flows by decomposition vs Simulated naturalised flows

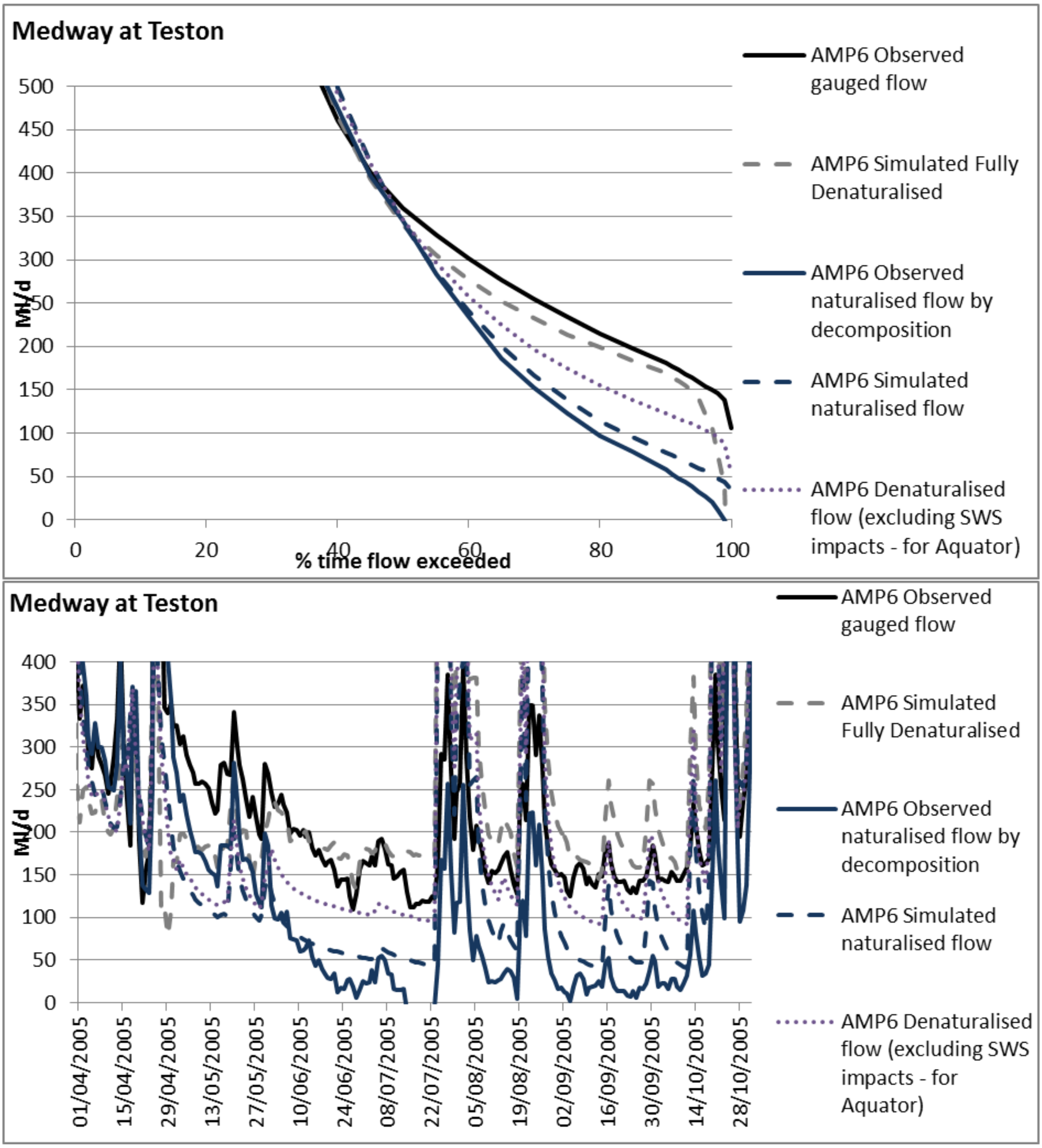
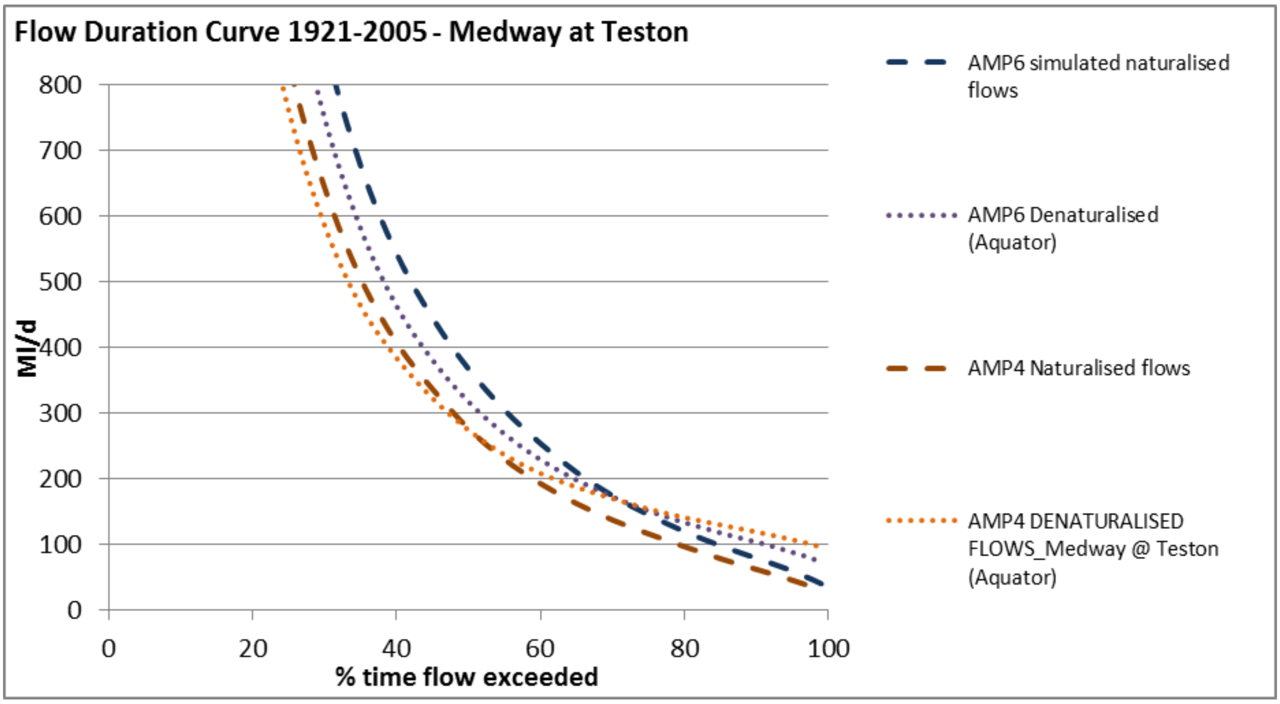


Figure 68 Medway at Teston: AMP6 simulated naturalised flows vs AMP4 simulated naturalised flows and AMP6 denaturalised flows vs AMP4 denaturalised flows



Teise at Stonebridge

Figure 69 Teise at Stonebridge: Observed gauged flows vs simulated fully denaturalised and Naturalised flows by decomposition vs Simulated naturalised flows

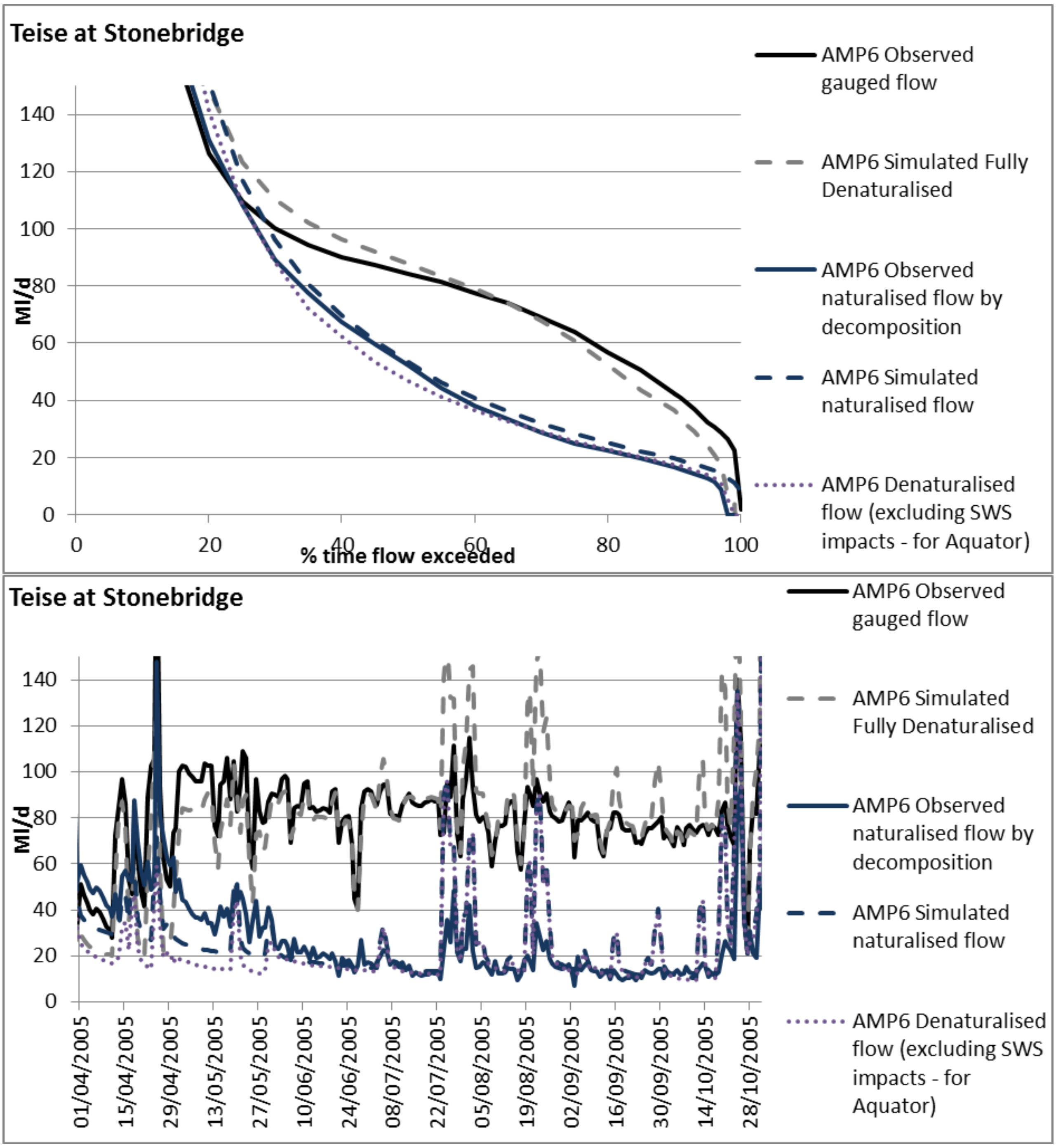
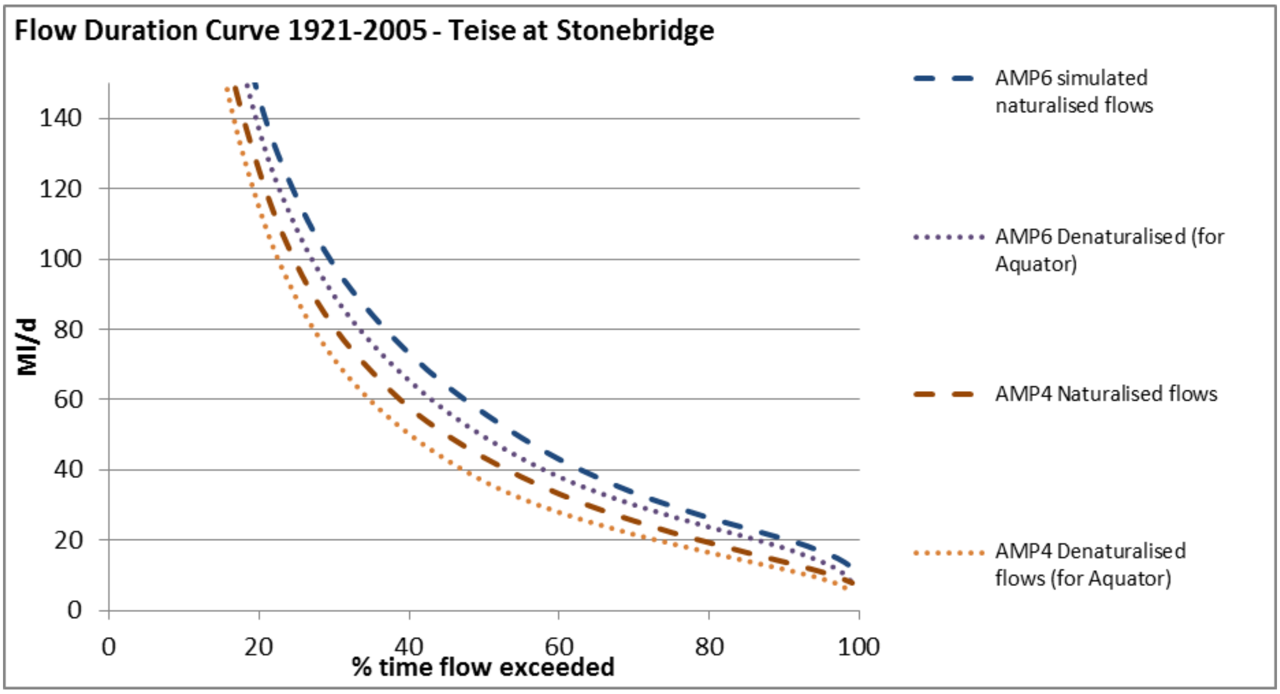


Figure 70 Teise at Stonebridge: AMP6 simulated naturalised flows vs AMP4 simulated naturalised flows and AMP6 denaturalised flows vs AMP4 denaturalised flows



Brede at Brede

Figure 71 Brede at Brede: Observed gauged flows vs simulated fully denaturalised and Naturalised flows by decomposition vs Simulated naturalised flows

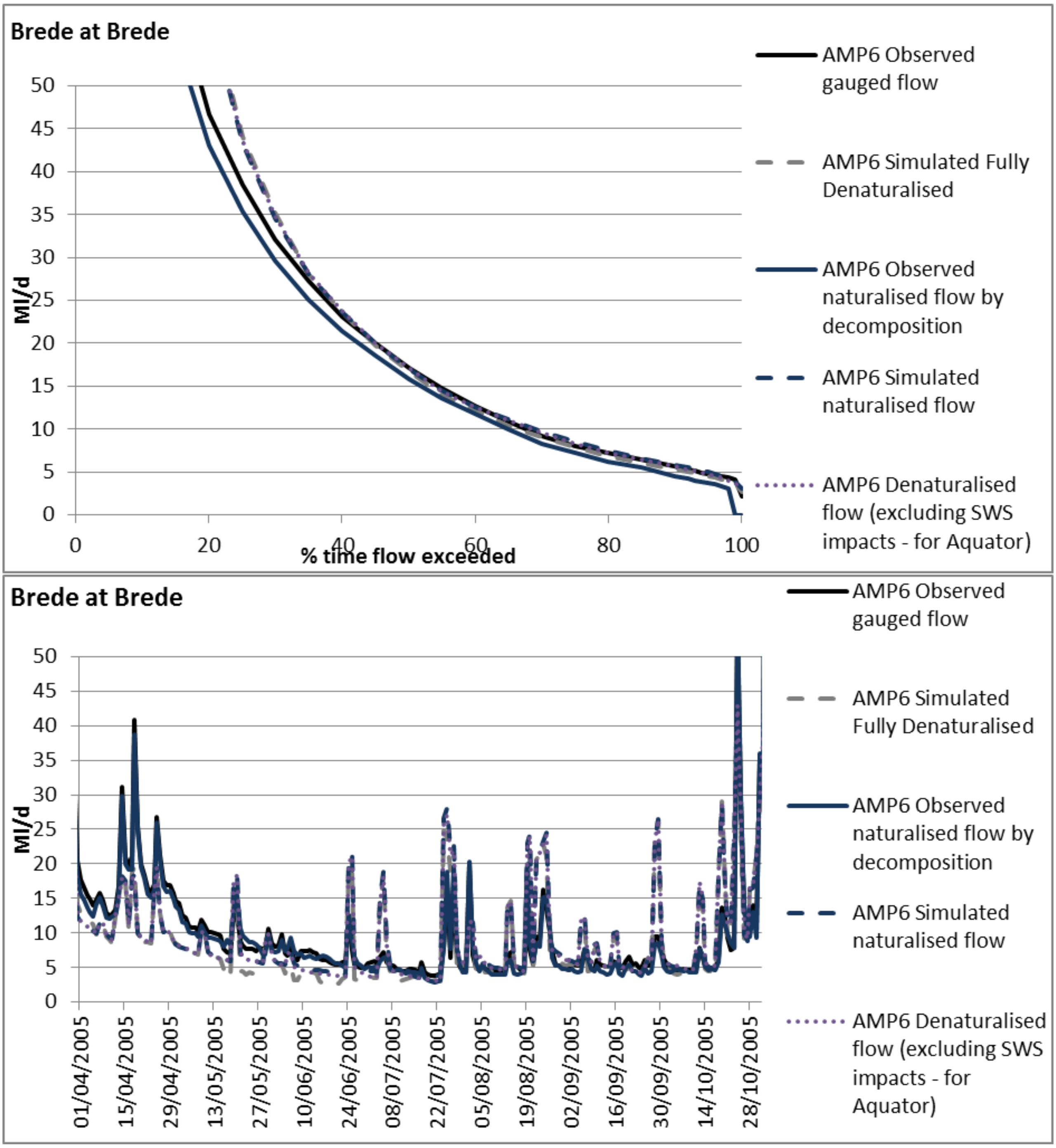
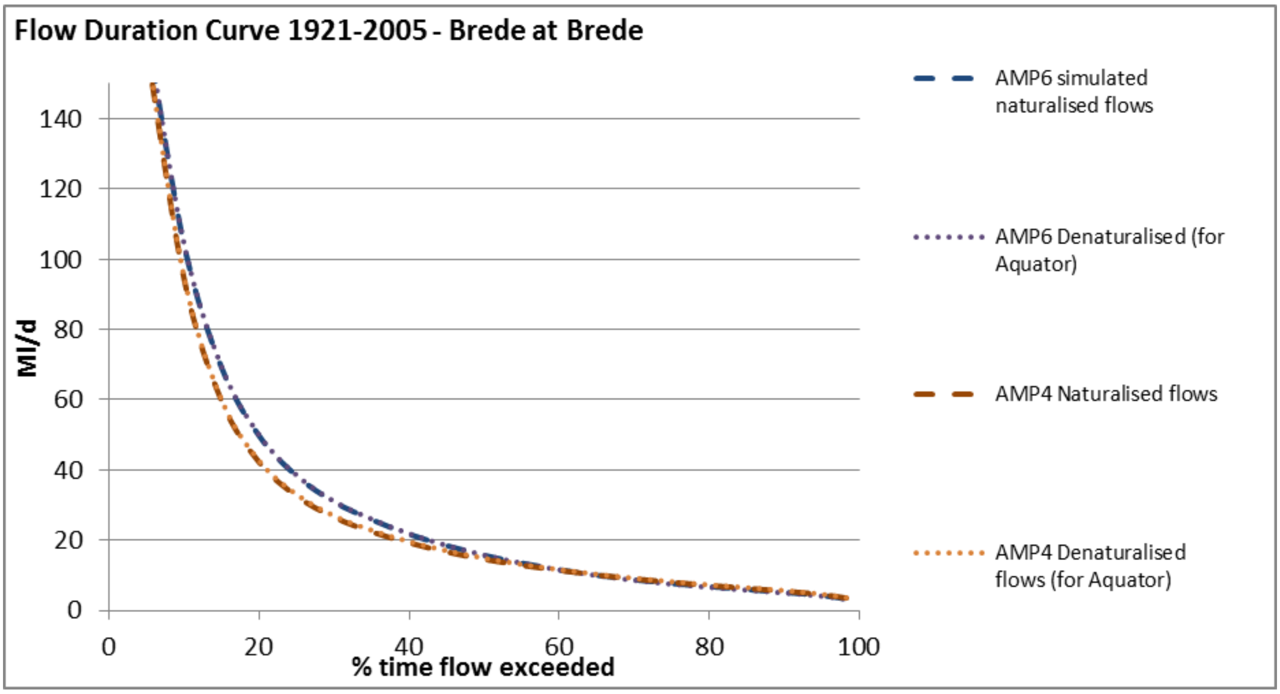


Figure 72 Brede at Brede: AMP6 simulated naturalised flows vs AMP4 simulated naturalised flows and AMP6 denaturalised flows vs AMP4 denaturalised flows



E Rother at Udiam

Figure 73 E Rother at Udiam: Observed gauged flows vs simulated fully denaturalised and Naturalised flows by decomposition vs Simulated naturalised flows

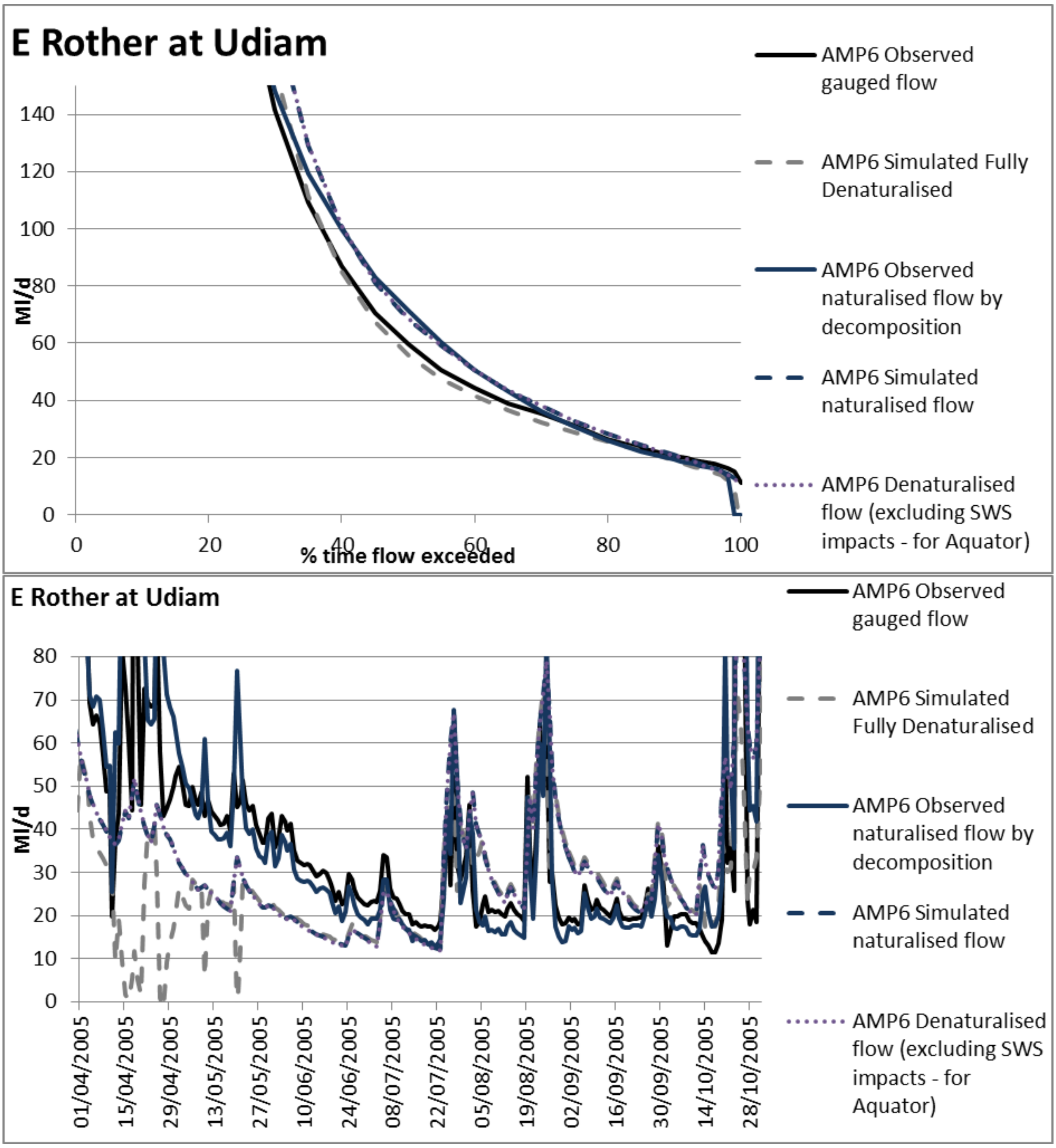
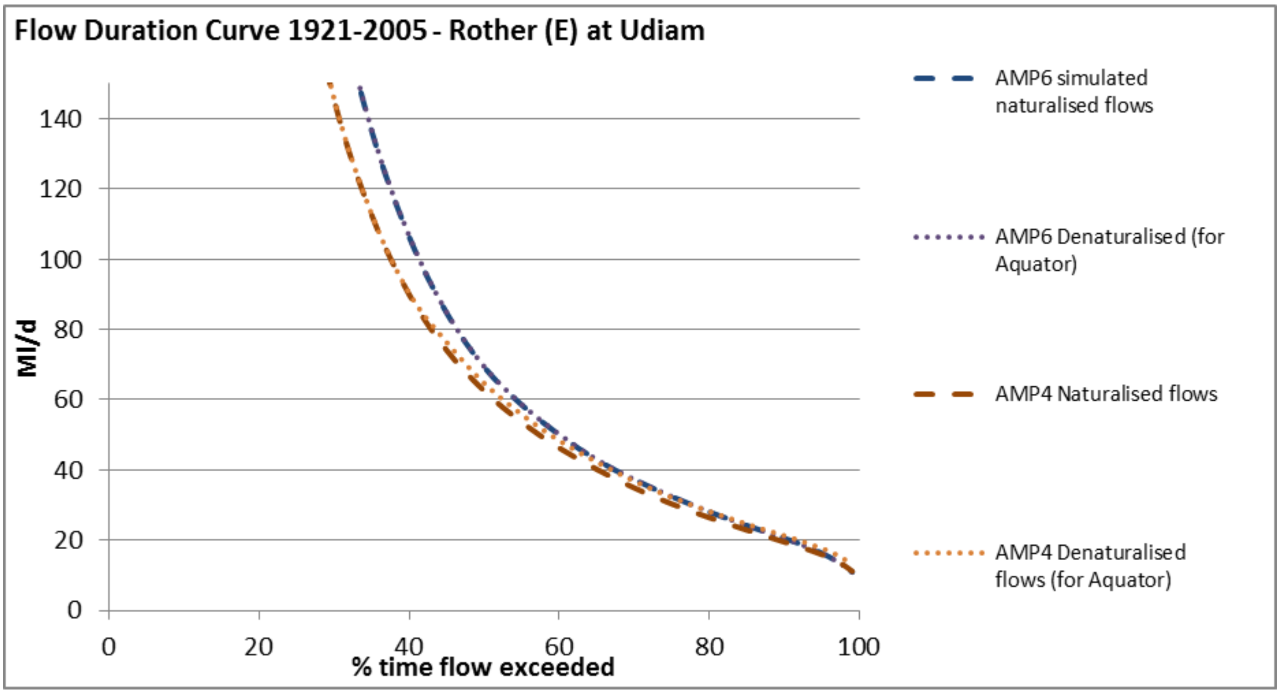


Figure 74 E Rother at Udiam: AMP6 simulated naturalised flows vs AMP4 simulated naturalised flows and AMP6 denaturalised flows vs AMP4 denaturalised flows



Western Rother at Hardham

Figure 75 Western Rother at Hardham: Observed gauged flows vs simulated fully denaturalised and Naturalised flows by decomposition vs Simulated naturalised flows

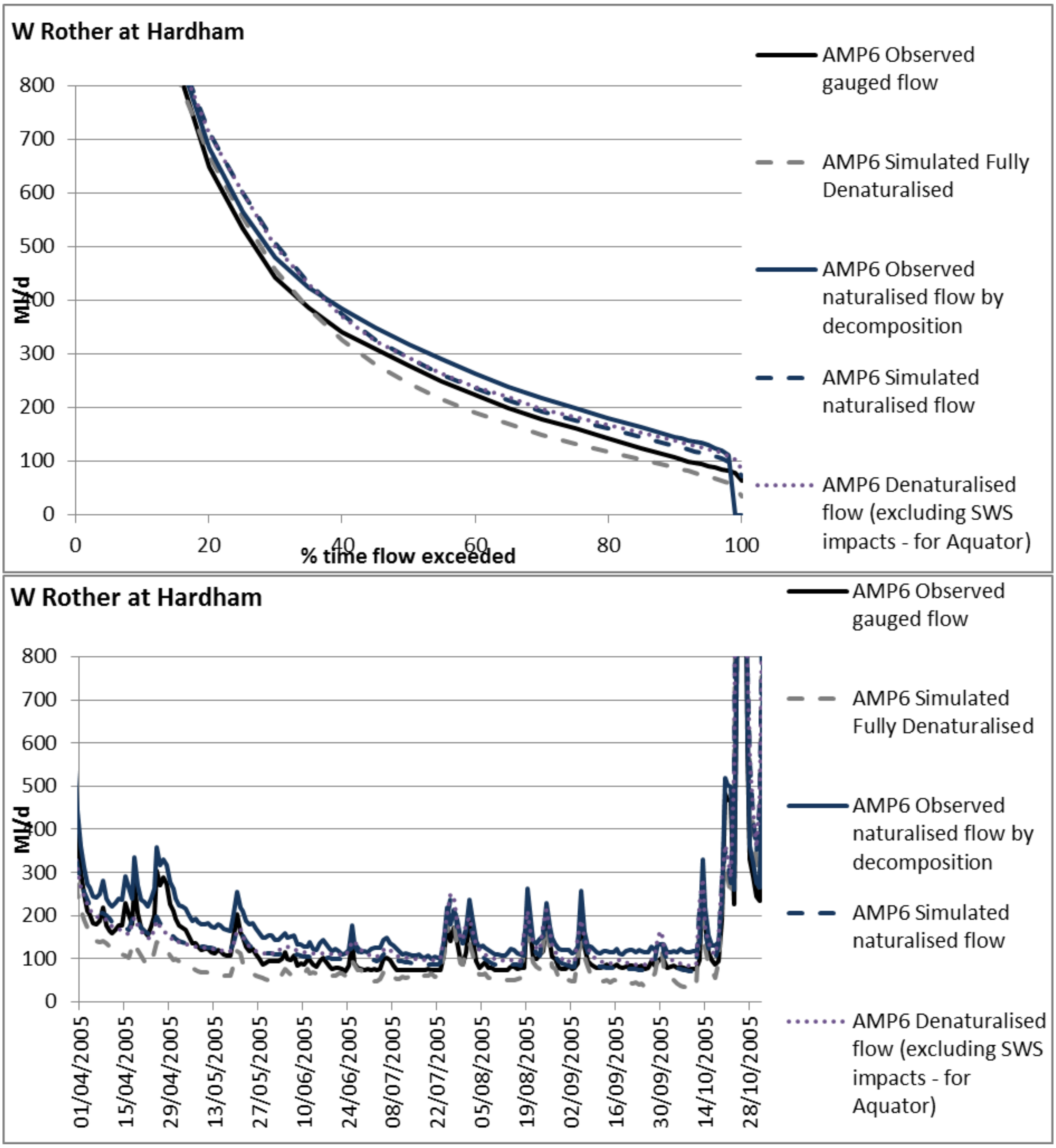
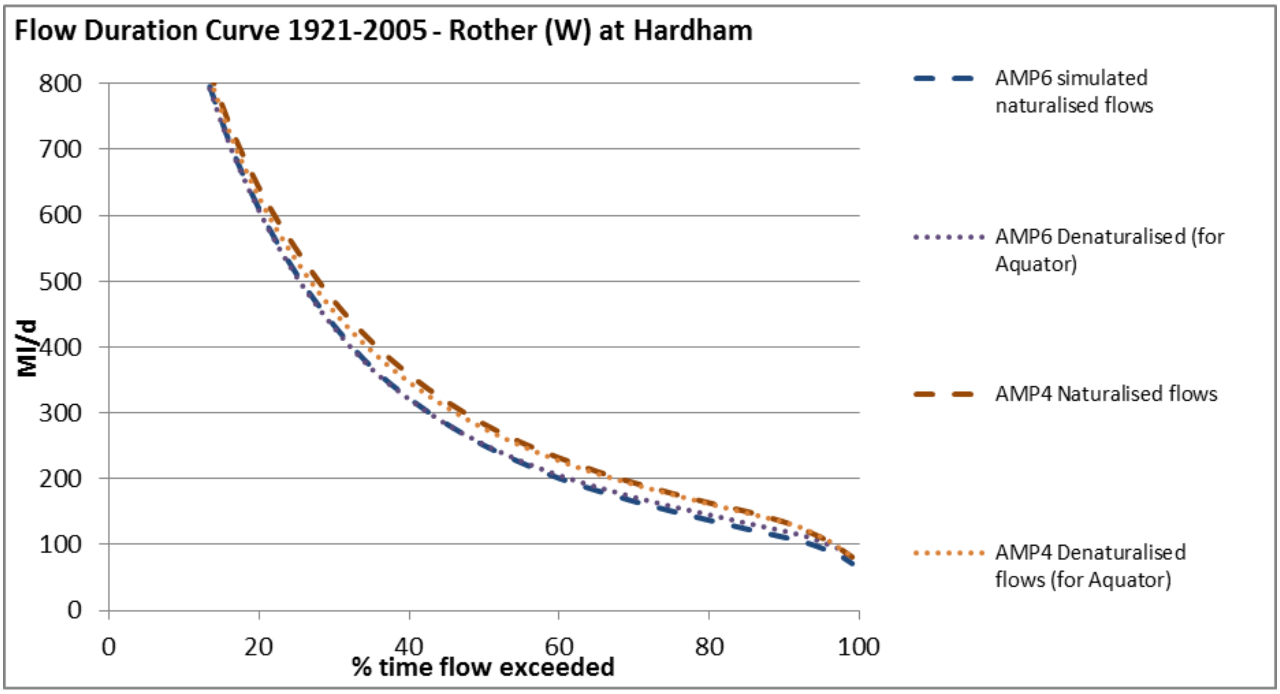


Figure 76 Western Rother at Hardham: AMP6 simulated naturalised flows vs AMP4 simulated naturalised flows and AMP6 denaturalised flows vs AMP4 denaturalised flows



Water Resources Management Plan 2019

Annex 3: Supply Forecast

Appendix D: Aquator modelling control rules

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RESTRICTED INFORMATION IN SEPARATE PDF, AVAILABLE UPON REQUEST

Water Resources Management Plan 2019

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Appendix E: Benefits of drought restrictions

December 2019

Version 1

Technical Note prepared by Atkins, 13 February 2017

Introduction

This technical note provides an empirically based analysis of the impacts of the demand restrictions that were applied by Southern Water during the 2005-06 drought. The analysis is based on an empirical model of household demand that accounts for both weather influences and the effect of metering on demand. The 2012 event was not considered due to the exceptionally high rainfall that occurred almost immediately after the temporary use ban (TUB) was introduced.

Data used

The following data sources were used in the analysis:

1. Daily Distribution Input (DI) data from 2001 to 2015 inclusive, aggregated according to Area*
2. Monthly leakage calculations from 2001 to 2015 inclusive
3. Annual average non-household demand based on regulatory return data (‘Table 10’) from 2001 to 2015 inclusive
4. Daily rainfall for the Otterbourne, Ditchling Road, and Canterbury rain gauges from 2001 to 2015 inclusive
5. Daily mean air temperature for the Wiggonholt site from 2001 to 2015 inclusive

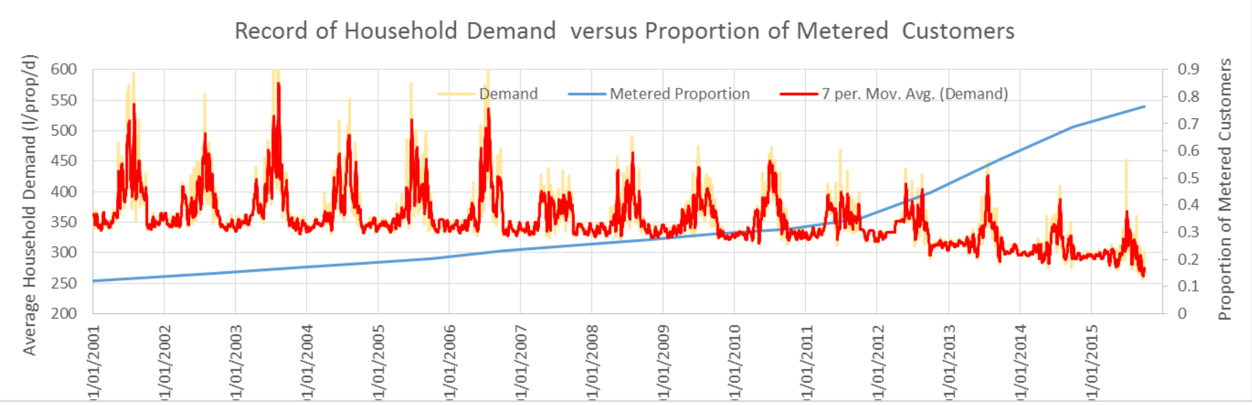
**The analysis was originally going to be carried out at a Water Resource Zone level, however there are some clear data issues that meant the inter-zonal transfers are not reliably represented at this level, particularly post 2010. The aggregated Area data (Western, Central and Eastern) are reliable so this has been used in preference. The one exception to this is the Isle of Wight, where the separation in DI from the rest of Hampshire in the Western Area was reliable. This allowed the Isle of Wight to be used as a ‘control’ data set, representing a WRZ where there have been very high levels of metering for some considerable time.*

Methodology

The methodology that was used was broadly in line with the Environment Agency Drought Demand Modelling Guidance (i.e. additive multiple linear regression models based on temperature and household demand), although it contained two key enhancements that made the resultant models suitable for Southern Water's purposes:

1. Rather than use sunshine hours, which generally act as a proxy for the time of the year and have a large degree of auto-correlation with temperature, three sub-models were set up to represent the October to March (winter), April to July (spring/early summer) and August to September (late summer) conditions. This was found to generate much better models as it accounted for the inherently smaller response to weather that occurs within most of Southern Water's region during the August and September periods (presumably due to summer holiday effects that continue into September), and accounted for the clear difference in demand response observed between the late winter/early spring period and the 'spring growing season' (April and May).
2. Because Southern Water has implemented a universal metering programme, the simple additive linear model proposed by the EA guidance was not able to reflect the demand response seen at high levels of metering. In particular it is evident at the higher levels of metering (i.e. beyond 40%) achieved by the universal metering programme that there is a large reduction in the summer peak usage that reduces the peak to average demand ratio. This can be clearly seen in the output for the Eastern Area, as shown in Figure 77 below. **This model therefore contained a non-linear response to metering that was accounted for in two ways; an additive component applied to the underlying demand and a multiplicative function that was applied to the weather response component of the model.**

Figure 77 Example Demand versus Metering Behaviour (Eastern Area)



Observed household demand was calculated for each day using the following equation:

$$HH\ Demand = DI - NHH\ Demand - Lekage$$

Where

NHH Demand = interpolated non-household demand figure based on mid-year to mid-year linear trend using the Table 10 data

Leakage = interpolated figure based on mid-month to mid-month operational leakage estimate

The regression analysis was carried out using standard good practice and a number of different model formats were tested. The preferred model format was derived based on graphical demand responses to individual explanatory factors followed by rapid testing in the miniTab statistical package. The following model format was found to represent both the best statistical fit and the most plausible explanation of the response to metering (which included the metering sensitivity response described later):

$$D = A + Meter^{B} + \left({}^{1}\!/_{Meter^{C}}\right) \times \left((D(Temp > 10)^{2} + E(dry\ day) + F(lograin7) + G(lograin30)\right)$$

Where:

D = household demand (l/prop/d)

A to H are regression constants

Meter = proportion of households that are metered

Temp>10 = number of degrees above 10 degC in each day (min = 0 at 10 degrees)

dry day = no rainfall on that day stated as a binary 1 (no rain) or zero (some rain)

log rain7, 14, 30 = logarithm of the total rainfall over the last 7, 14 or 30 days

For each model in each area all factors were tested and those that were not statistically significant were not included in the final model – for example the Central Area winter model did not have a statistically significant response to any of the weather related components. A summary of the model coefficients that were derived is provided in Table 1. **N.B. 2005 and 2006 were excluded from the data set used to construct the model, as the model was designed to provide estimates of household demand without demand restrictions in place.**

Table 76 Summary of Calculated Model Coefficients (*zero values indicate the explanatory factor was not statistically significant so not used)*

Area	Model (time of year)	A (underlying demand)	B (meter)	C (meter power)	D (meter weather response)	E (Temp)	F (dry day)	G (Log Rain7)	H (Log Rain30)
Isle of Wight	Summer	418.2	0.0	0.0	0.0	0.9	11.4	-11.6	-9.6
	Winter	385.4	0.0	0.0	0.0	0.0	0.0	-4.9	-9.6
Western	Spring/ Early Summer	422.5	-104.6	0.60	0.3	0.6	12.9	-15.0	-12.0
	Late Summer	387.6	-110.6	0.60	0.3	0.5	9.5	-12.0	-4.9
	Winter	390.0	-75.0	0.60	0.0	0.0	0.0	-2.1	-14.9
Central	Spring/ Early Summer	451.4	-116.3	0.40	0.2	0.62	2.7	-17.6	-17.3
	Late Summer	370.5	-77.3	0.40	0.2	0.42	7.7	-10.5	-0.2
	Winter	360.0	-55.0	0.40	0.2	0.42	0.0	0.0	0.0
Eastern	Spring/ Early Summer	473.0	-200.5	0.55	0.3	0.7	0.0	-23.2	0.0
	Late Summer	437.7	-180.4	0.55	0.3	0.7	0.0	-14.0	0.0
	Winter	405.0	-120.0	0.55	0.3	0.0	0.0	-9.1	0.0

The demand response in each area was then tested in two ways to derive the estimates of the effectiveness of demand restrictions:

1. The theoretical model outputs for 2005 and 2006 were compared against the actual recorded values. Any systematic bias in modelled versus actual by month was accounted for when making the comparison.
2. The model was re-set to estimate the equivalent size that the 2005 and 2006 summer peak would have been if the proportion of measured properties had been 80% during that drought. Because there is clear evidence that the size of the summer peak relative to underlying demand has reduced as a result of metering, then the benefits of demand restrictions will have reduced accordingly. This analysis was carried out based on a comparison of the peak to average ratio across the whole of the summer period with the metering at the time and with current levels of metering.

Results and analysis

A comparison of the modelled versus observed demand for each month is provided in Figure 78 to Figure 81 below. As shown the model provides an excellent weekly fit in all Areas and readily accounts for the impact of metering both on underlying demand and on the size of the peak. The impact of both the 2005/06 demand restrictions and the 2008-09 financial crisis are both evident in the mainland Areas. Data from the Isle of Wight indicate that there was no significant time based trend across this period, although it is notable that the Isle of Wight also demonstrated no response to either the 2005-06 drought publicity or the 2008-09 financial crisis. Although there may have been some shift in behaviour over time in the mainland Areas that was not reflected in the Isle of Wight, the evidence from this ‘control’ WRZ suggests that the trend based behaviour observed in the three mainland Areas is mostly associated with metering and specific events such as the demand restrictions during the droughts and the 2008/09 financial crisis, rather than a time based behavioural trend.

Figure 78 Observed versus Modelled Demand on the Isle of Wight

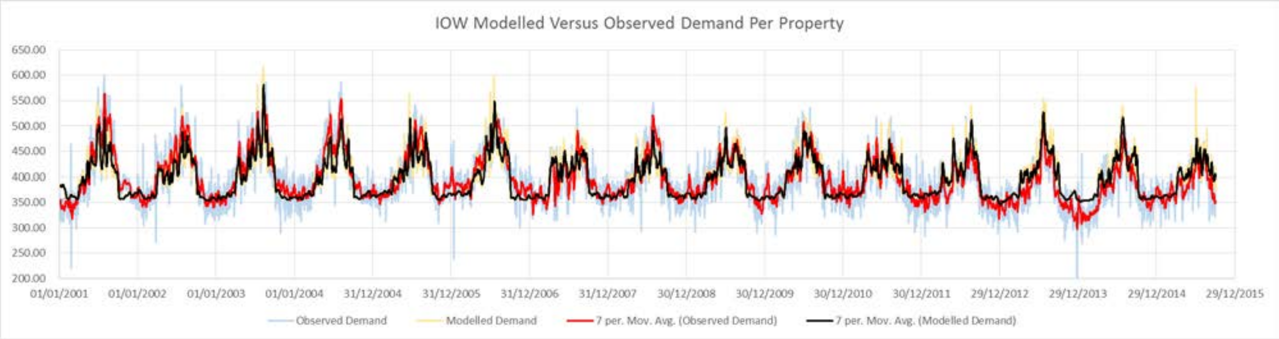


Figure 79 Observed versus Modelled Demand for Western Area (excl IOW)

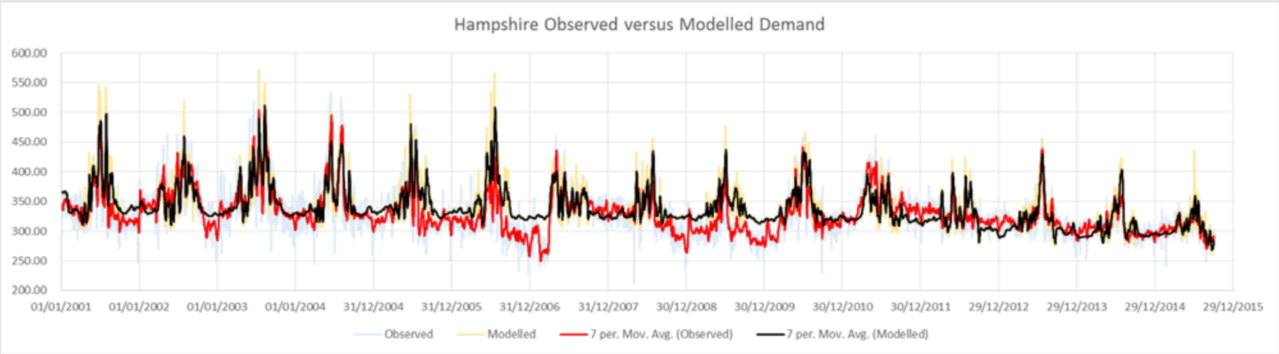


Figure 80 Observed versus Modelled Demand for Central Area

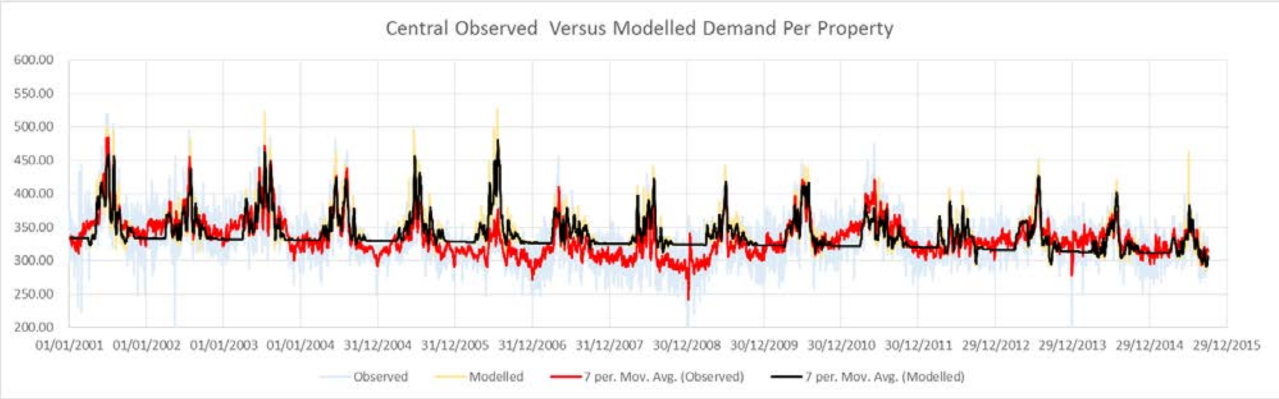
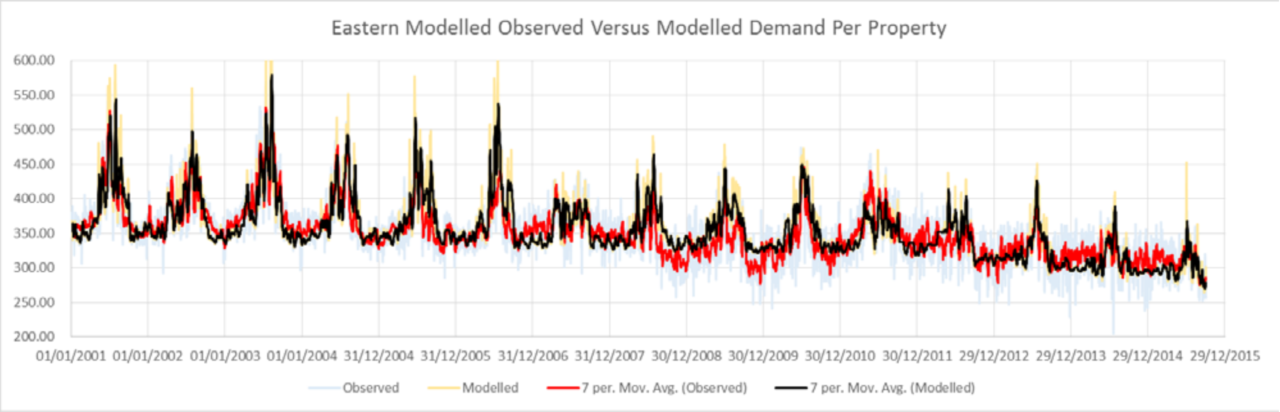


Figure 81 Observed versus Modelled Demand for Eastern Area



An analysis of the amount of monthly bias from the model (if 2005-06 and 2008-09 are excluded) is provided in Figure 82 to Figure 84 below (bias = observed/modelled average for each month). As shown the models are accurate to within +/-3% for almost all months.

Figure 82 Model Bias by Month – Western Area

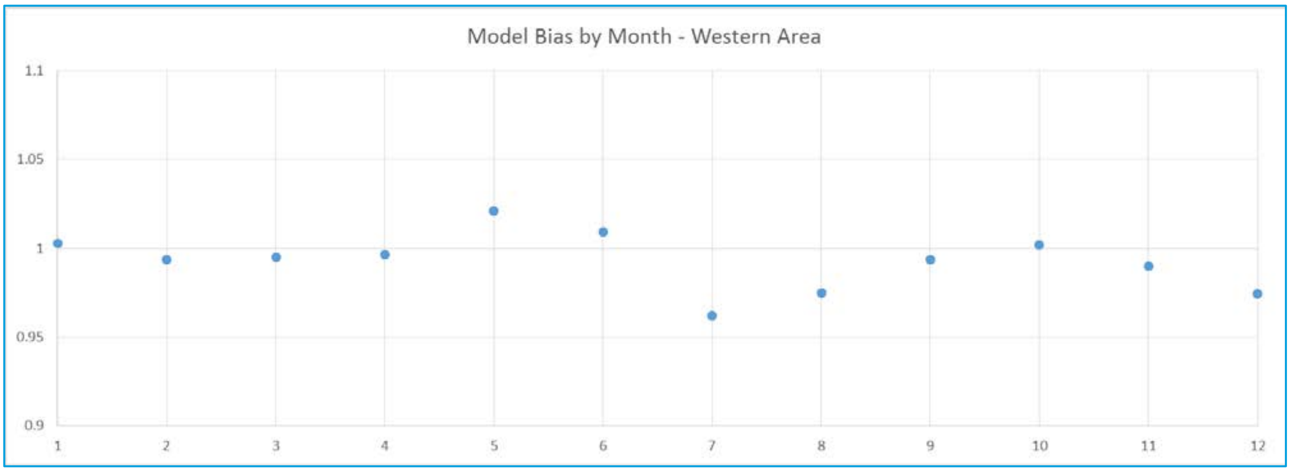


Figure 83 Model Bias by Month – Central Area

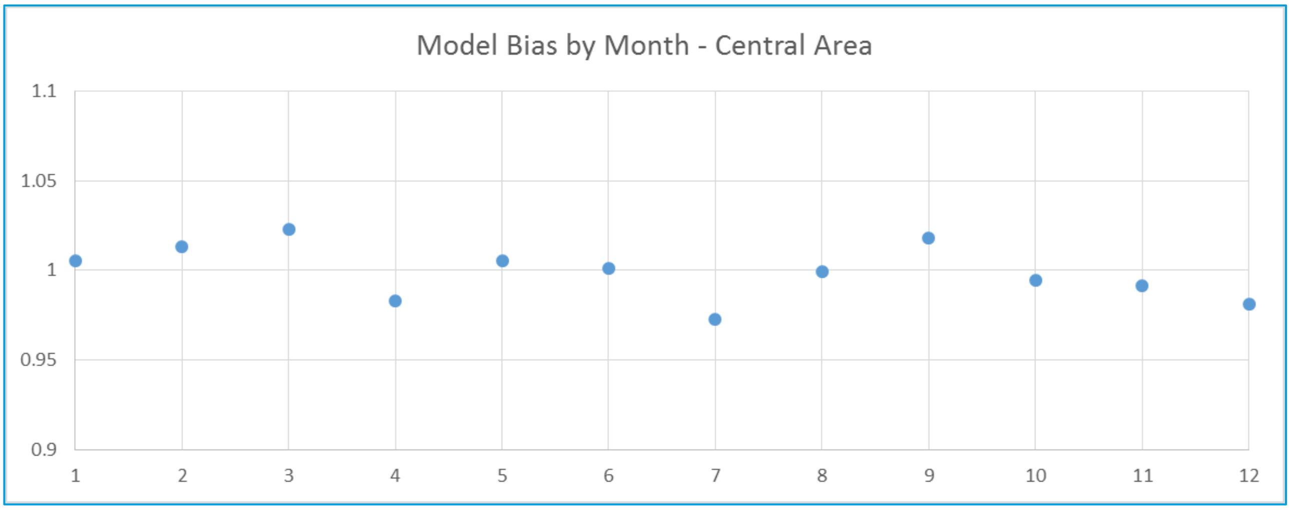
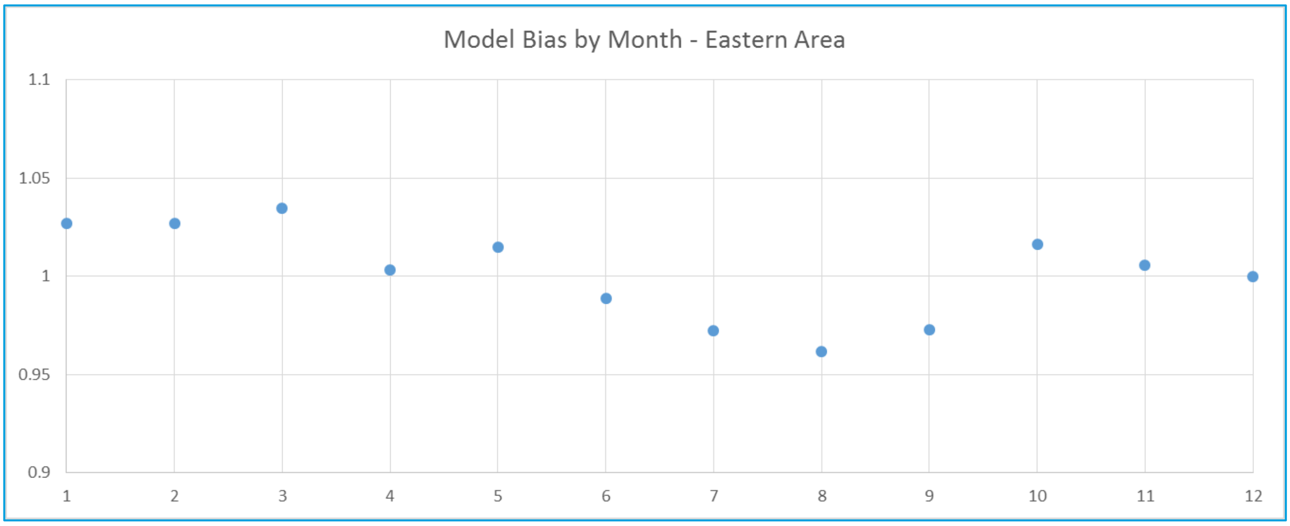


Figure 84 Model Bias by Month –Eastern Area



An analysis of the modelled demand if metering was a constant 80% for the whole period across the three Areas is provided in Figure 85 to Figure 87.

Figure 85 Estimate of Demand for a Constant 80% Metered Population Area – Western Area (excl IOW)

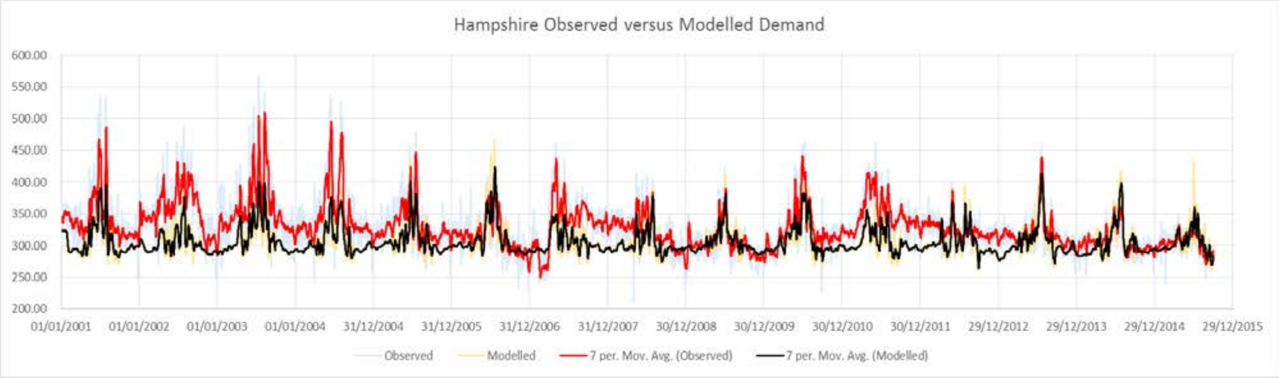


Figure 86 Estimate of Demand for a Constant 80% Metered Population Area – Central Area

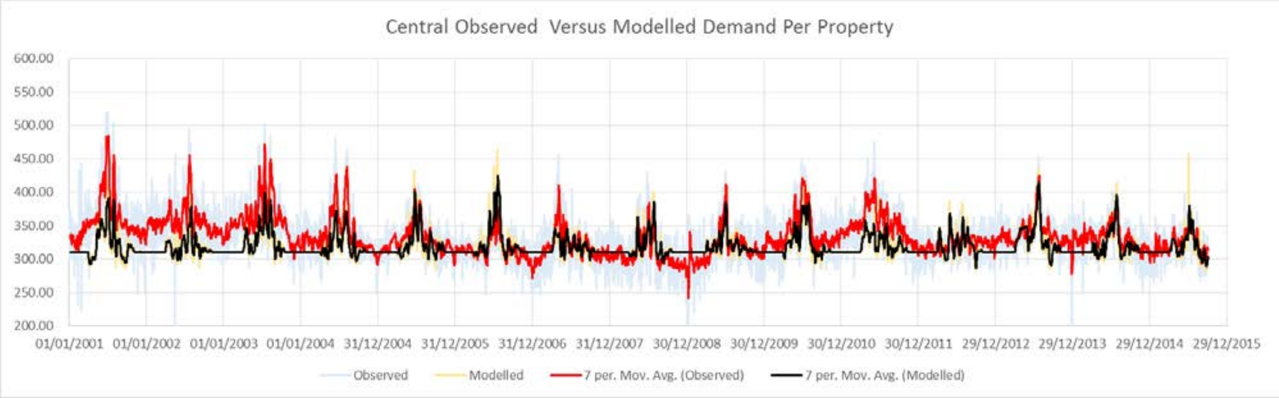
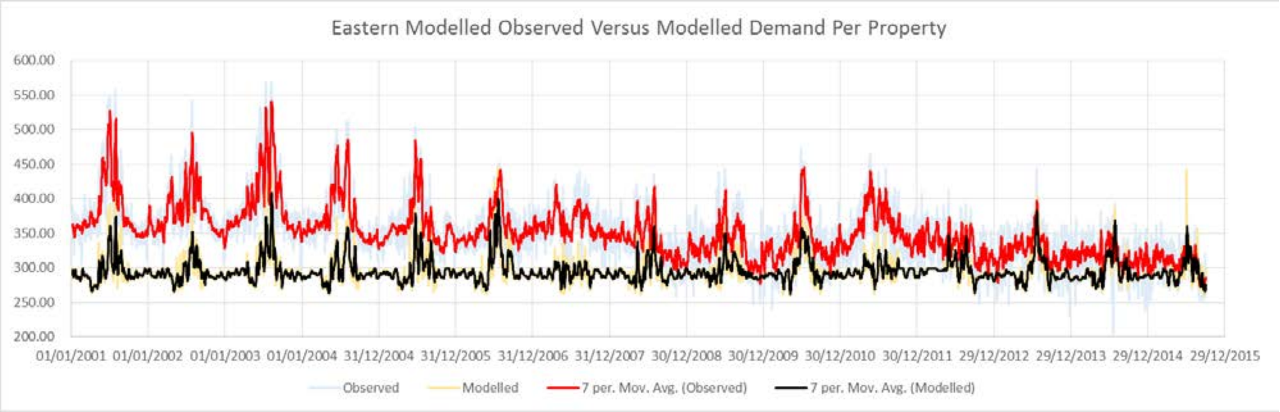


Figure 87 Estimate of Demand for a Constant 80% Metered Population Area – Eastern Area



Overall the above analyses show that:

1. Metering seems to have had a much larger effect on the Eastern Area that the other two Areas. As well as affecting the underlying demand more, the relative impact on the peak demand is also much higher when compared with the Central and Western Area. In the Eastern Area the overall summer peak for a 2005/06 style event (theoretical, without demand restrictions) has reduced by around 60%, compared with a 35% reduction in the Central and Western Areas. A small amount of this is due to a smaller actual measured population at the time (circa 23% versus 26% in Western and Central at the end of 2006), but the majority represents a different behavioural response.
2. The model format continues to provide logical results even when this high level of stress test is applied, even though there are non-linear and multiplicative terms within the model.

Figure 88 to Figure 90 show the expected versus modelled results with bias correction for the three Areas. The Isle of Wight is not shown as Figure 78 clearly demonstrates that there was no response to either the 2005 hosepipe ban or the publicity surrounding the 2006 non-essential use bans.

Figure 88 Estimate of Demand Restriction Impacts during the 2005-06 Event: Western Area (excl. IOW)

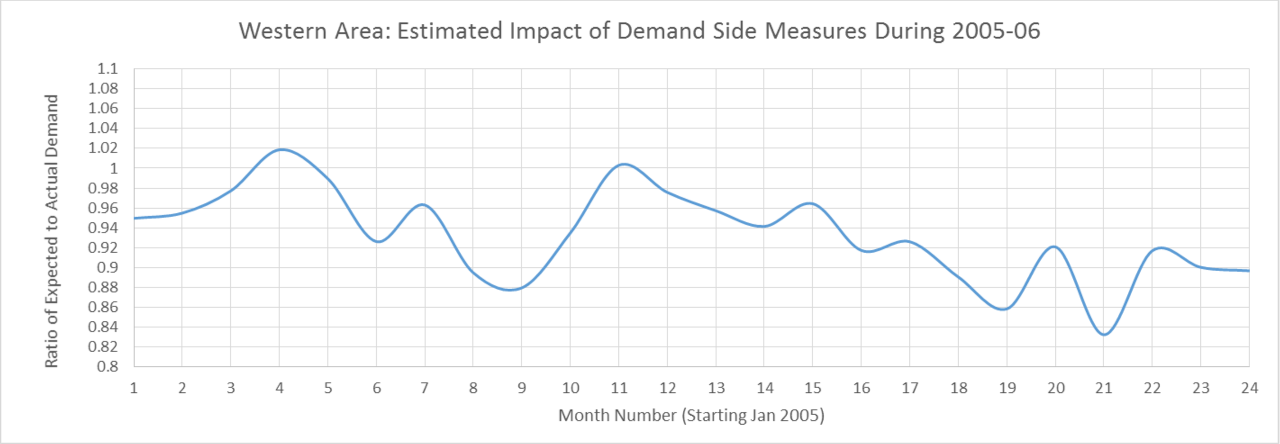


Figure 89 Estimate of Demand Restriction Impacts during the 2005-06 Event: Central Area

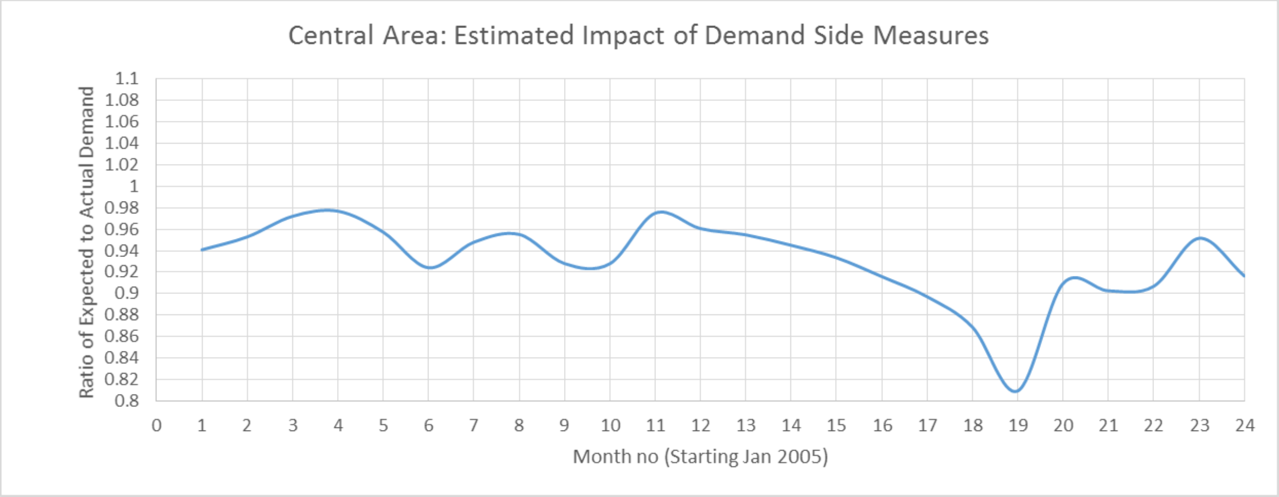
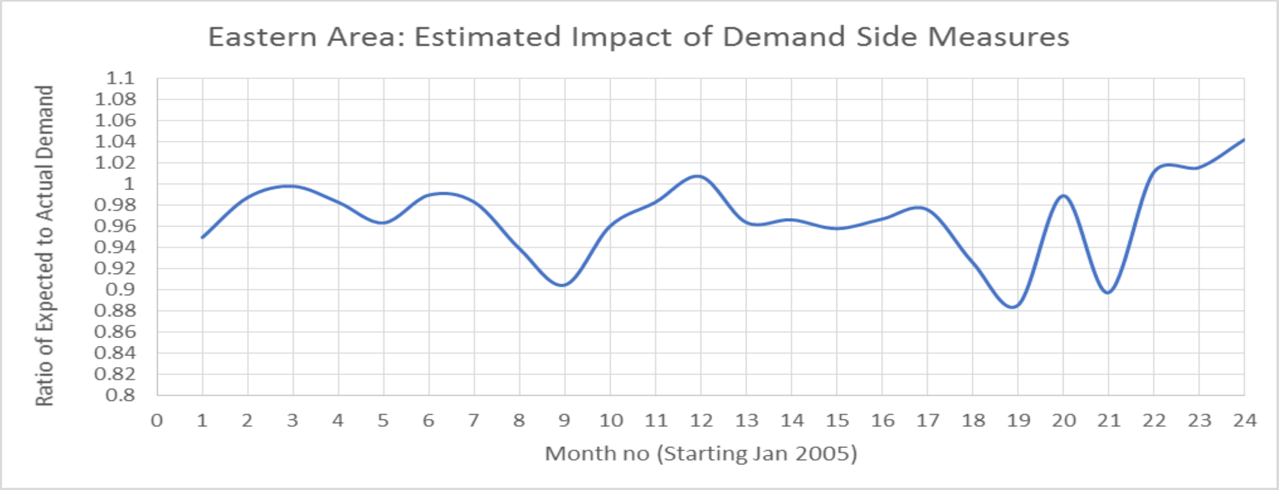


Figure 90 Estimate of Demand Restriction Impacts during the 2005-06 Event: Eastern Area



These effectiveness of restrictions figures show that:

1. The Western and Central Areas demonstrate a continuous time based trend that was similar in magnitude, even though a non-essential use ban wasn't actually put in place in Hampshire. The results for Nov-December 2006 in Western (Hampshire) and December 2006 in Central should be viewed with caution, as Figure 79 and Figure 80 indicate apparent demand measurement errors around that time (likely associated with leakage and/or non-household use fluctuations not accounted for in the simple trend based interpolations used in this analysis). However, even slowing for this it is apparent that the effects of the publicity surrounding the drought were cumulative over the two year period, without any notable stepped change as a result of the NEU ban. This makes an exact evaluation of the impact of NEU bans difficult, as it appears that a rapidly introduced ban might not have the same impact as the longer sequence of events and publicity generated during the 2005-06 drought.
2. The Eastern Area displayed similar levels of response to the Western and Central Areas to the 2005 hosepipe ban, but very little response to the Non-Essential Use ban. The reasons for this are not known, but are likely to be associated in some way with the different attitudes to water saving as demonstrated in the response to metering discussed previously.

Based on the demand responses observed at the time and the reduction in the summer peak volumes observed as a result of metering, a summary of the maximum, June-September and underlying demand ('MDO') that would be anticipated under current levels of metering is provided in Table 2**Error! Reference source not found.**Table, Table 3 and Table 4Table 79

Table 77 Estimated Impacts of Restrictions; Western Area

	At the time	Current Metering Levels
2005 (HPB)	10% max monthly	7% max monthly
	6%JJAS	4%JJAS
	2% MDO	1%MDO
2006 (HPB with NEU)	15% max monthly	10% max monthly
(NEU publicity only)	10% JJAS	7%JJAS
	4%MDO	3%MDO

Table 78 Estimated Impacts of Restrictions; Central Area

	At the time	Current Metering Levels
2005 (HPB)	8% max monthly	5% max monthly
	6%JJAS	4%JJAS
	3%MDO	2%MDO
2006 (HPB plus NEU)	18% max monthly	12% max monthly
	13% JJAS	8%JJAS
	5%MDO	3%MDO

Table 79 Estimated Impacts of Restrictions; Eastern Area

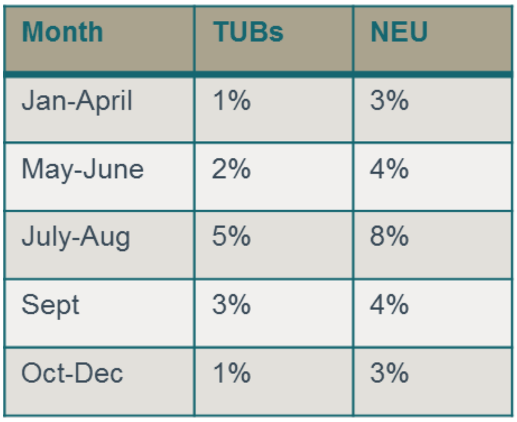
	At the time	Current Metering Levels
2005 (HPB)	10% max monthly	4% max monthly
	5%JJAS	2%JJAS
	1%MDO	Negligible MDO
2006 (HPB plus NEU)	11% max monthly	5% max monthly
	7% JJAS	3%JJAS
	2% MDO	1%MDO

For the Central and Western Areas the effects of hosepipe bans (HPBs) is similar, and the impact of NEUBs is seen to almost double the HPB effects. However, as noted previously a large proportion of this appears to be due to ongoing publicity that caused a time based trend over the course of the drought. Some caution is therefore advised in the Central Area, where major droughts only have a critical period of 12-18 months, and this time based effect would not therefore occur in time to benefit the drought supply/demand balance. The 18% maximum monthly saving in July 2006 also appears to be an outlier and possibly represents a model over-response to the record breaking temperatures encountered in that month. This has been accounted for within the recommended profiles of demand restriction benefits discussed below.

As shown in Table 79, the impacts of NEU bans appear to be much smaller in the Eastern Area than the other two. Because the loss of peak demand is also much larger this results in very small anticipated responses to both HPBs and NUEBs within the Eastern Area under current levels of metering.

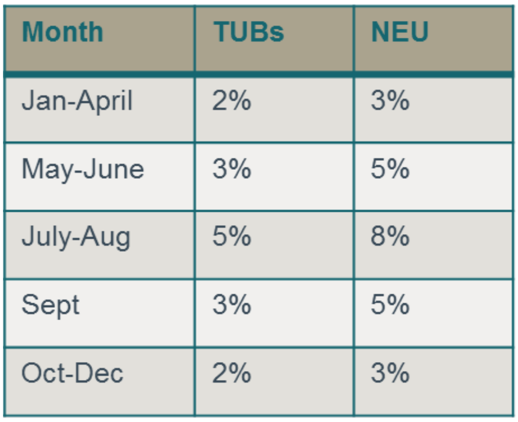
Based on the above analysis, Table 80 to Table 82 provide the recommended profiles for the effectiveness of demand restrictions (EODR) within each of the three Areas **under current levels of metering**:

Table 80 Recommended EODR profile Western Area (excl IOW)



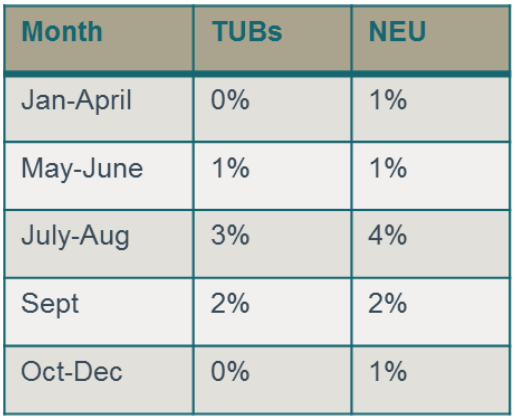
Month	TUBs	NEU
Jan-April	1%	3%
May-June	2%	4%
July-Aug	5%	8%
Sept	3%	4%
Oct-Dec	1%	3%

Table 81 Recommended EODR profile for Central Area



Month	TUBs	NEU
Jan-April	2%	3%
May-June	3%	5%
July-Aug	5%	8%
Sept	3%	5%
Oct-Dec	2%	3%

Table 82 Recommended EODR profile for Eastern Area



Month	TUBs	NEU
Jan-April	0%	1%
May-June	1%	1%
July-Aug	3%	4%
Sept	2%	2%
Oct-Dec	0%	1%

Conclusions

In broad terms the methodology described in this technical report followed the recommended methods contained within the EA Drought Demand Modelling study report, with a minor change surrounding the inclusion of time of year/sunshine hours as an explanatory factor. However, the models that were used contained a significant enhancement to allow a quantified analysis of the impact of metering on summer peak demand. This incorporation of a demonstrably stable and accurate, but non-linear and multiplicative form of regression model meant that the impacts of metering on both underling demand and demand response to weather could be modelled, allowing the response of the current, mostly metered, customer base to restrictions to be quantified.

This form of modelling demonstrated that the ratio of summer demand to underlying (winter) demand has decreased as a result of the universal metering, with the relative size of the summer peak (as calculated relative to winter ‘MDO’ demand) now approximately 35% smaller for the Western and Central Areas and 60% smaller for the Eastern Area than it was in the early to mid 2000s. This will affect the effectiveness of demand restrictions because discretionary use is clearly now smaller as a percentage of total demand (it is worth noting that there was no observable response to the 2005 hosepipe ban on the fully metered Isle of Wight).

The model used was therefore able to accurately estimate the impact of restrictions on demand during the 2005-06 drought event, and estimate how this is likely to have changed as a result of increased metering. The estimated profiles for the Western (excl Isle of Wight) and Central Areas are now in the order of 1% rising to 5% for Temporary Use Bans (TUBS - winter to summer profiles) and 3% rising to 8% for TUBs plus Non-Essential Use Bans (NEUBs). The Eastern Area is expected to have a much lower response, at 0% rising to 3% for TUBs and 1% rising to 4% for NEUBs.

Water Resources Management Plan 2019

Annex 3: Supply Forecast

Appendix F: Outage Allowance

December 2019

Version 1

Summary

Outage is the planning allowance included in the supply-demand balance to account for the temporary loss of deployable output (DO) from a source. The outage allowance accounts for both unplanned outage events (e.g. mechanical failure) and planned outage (e.g. to perform maintenance on assets). Different outage causes can have different effects on a water supply works. This can cause full outage or partial outage to the site. Full outage is where a site is completely offline and partial outage is where a site is unable to provide its full capacity, for example one of five borehole pumps is out and therefore the site cannot reach its full DO. The full and partial outage combined then make up the total outage of the site.

This technical appendix explains the analysis used to derive the outage allowance figures used in the Water Resources Management Plan 2019 (WRMP19). There are three methods that were considered. The first method uses Monte Carlo simulations on outage events from available data over the period 2015-2017. Further historic data at the required level of granularity was not available to allow analysis over a longer time period. This follows the 1995 UKWIR methodology. The second method, used within the draft WRMP19, is an update of the methodology used in the Water Resources Management Plan 2014 (WRMP14), extending the data range to ten plus years but at a lower level of detail. The third method, which has been adopted for the WRMP19, is based on latest actual outage data and follows an outage recovery profile for the remainder of AMP6 and AMP7. The three methods are detailed within this appendix.

Historically (from 1993 to 2010), our actual[2] outage levels were around 25 Ml/d or under as seen in Figure 91 by the blue bars. This is based on data comprising full outage events i.e. only taking account of sources whose full deployable output is unavailable. During AMP5 (2010 to 2015), Southern Water introduced a new system of ‘triple validation’ for water quality monitoring at its water supply works (WSW), which increased the frequency of site shutdowns. Consequently, reported outage increased to just under 60 Ml/d for full outage events. Another factor which has contributed to higher outage levels is the company’s successful customer metering programme which, in helping to reduce the average demand for water by 16%, has led to lower abstraction and source outputs. The lower utilisation of sources has led to more system failures when attempts to increase source outputs above these lower levels have been made. We are using the lessons from this to improve our asset management processes and preparedness for drought events.

In 2015-16 we improved our reporting methodology to provide a better picture of resource availability by including partial outage events, shown by the orange bars in Figure 91, which is when a site is operational but cannot achieve its full deployable output. The new methodology for reporting outage was shared with the Environment Agency (EA) in December 2015 and we reported provisional figures for partial outage in the 2016 Annual Review of our WRMP14. At this point the partial outage dataset was subject to further investigation to understand whether the causes were legitimate outage events. A further meeting was held with the EA in November 2016 to discuss outage definitions and reporting and since the 2017 Annual Review of our WRMP14 we have formally reported partial, full and total outage figures to the EA.

By including partial outage in our assessment of actual outage Southern Water has gone further than most other water companies in attempting to fully quantify our ability to achieve deployable outputs

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[2] Measured outage as reported to the Environment Agency. This is calculated in relation to the minimum deployable output (MDO) for groundwater and run-of-river surface water sources and average deployable output (ADO) for reservoir sources, and differs from the outage figure reported to Ofwat which is based on peak week production capacity (PWPC) of water supply works.

during design drought events to maintain supplies. Our total outage levels should not be compared to other companies who have not included partial outage in their assessment and only based their assessments on full outage events.

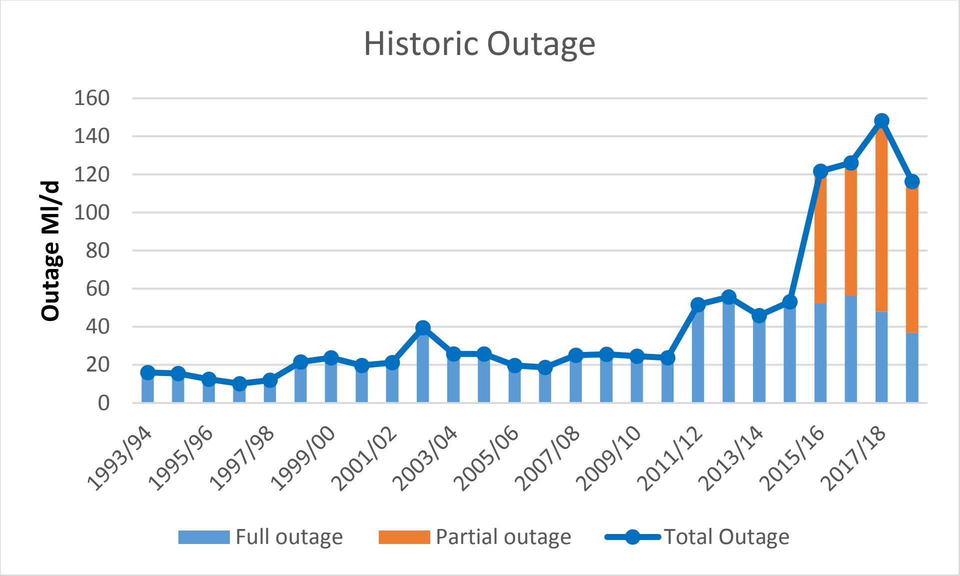

Figure 91: Historic outage

In line with best practice our initial outage allowance assessment for the WRMP19 followed the UKWIR 1995 outage methodology[3] and can be seen in section 2. The assessment was based on our full outage dataset recorded from 2015-17 when sufficiently robust outage data was available. Whilst we have historic outage data prior to 2015-16 which includes the timing and location of outage events we do not have data on the causes of all these outage events which is needed to apply the methodology.

Monte Carlo analysis was used to develop a company level distribution of full outage events for the period from 2015-17 based on the nine water resource zones (WRZs) with full outage events in that data range. Ten thousand simulations were run, across all the outage causes considered, to develop a distribution. This led to a full outage allowance of approximately 65 Ml/d, which is slightly higher than the May 2018 full actual outage figure of 58 Ml/d. The breakdown of the May 2018 outage can be seen in Table 83. The full actual outage figure of 58 Ml/d is made up of both greater than 90 days and less than 90 days full outage data. The partial outage data is not used in the Monte Carlo analysis for the reason stated above. The May 2018 outage figure was the most up to date full outage figure available at the time of the analysis.

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[3] UKWIR, 1995, WRP-0001/B Outage Allowances for Water Resource Planning

Table 83: Outage levels as of May 2018 by WRZ

Water Resource Zones	> 90 days full outage	< 90 days full outage	Partial outage	Total outage 2017/18
I.o.W.	5.64	0.00	0.00	5.64
Hants Andover	0.49	0.00	1.32	1.81
Hants Kings	0.00	0.00	0.00	0.00
Hampshire Rural	0.00	1.50	2.20	3.70
Hampshire Winchester	0.00	0.00	0.00	0.00
Hampshire Southampton East	0.00	0.00	16.76	16.76
Hampshire Southampton West	0.00	0.00	35.00	35.00
Sx Brighton	2.30	0.36	5.95	8.61
Sx North	10.12	0.14	0.00	10.26
Sx Worthing	0.00	0.15	3.26	3.41
Kent Medway East	1.30	18.53	10.42	30.25
Kent Medway West	1.02	0.43	27.53	28.98
Kent Thanet	15.00	0.40	5.27	20.67
Sx Hasts	0.62	0.00	0.00	0.62
Southern Water	36.49	21.51	107.71	165.71

We considered that the results of the Monte Carlo simulation, referred to above, which followed the UKWIR methodology were not representative of an appropriate outage allowance in the long term due to the short dataset used in the analysis and the high actual outage experienced during the period when data was available. The assessed full outage allowance figure of 65 Ml/d is an overestimate of the actual outage we expect to be able to maintain throughout the course of our WRMP19. In addition, we needed a methodology that could take account of the more accurate actual outage data we were reporting (including partial outage data). We considered that the results of the Monte Carlo simulation, referred to above, which followed the UKWIR methodology were not representative of an appropriate outage allowance in the long term due to the short dataset used in the analysis and the high actual outage experienced during the period when data was available. Furthermore we needed to account for the development and implementation of a focused outage reduction plan that was overseen by a new Operational Resilience group to manage water supply resilience risks.

Due to the need to base the outage allowance on a longer data set we then followed an adapted version of the Monte Carlo methodology that was previously adopted for Southern Water's WRMP14 and our draft WRMP19. This is presented in detail in section 3. This method used a minimum period of five years of full outage data. An assessment of partial outage based on recent actual data was also made and added to the full outage allowance calculated using the Monte Carlo method. A total outage allowance of 79.6 Ml/d was derived by this approach but it was also considered too high as a long term outage allowance when compared to other water companies and Southern Water's previous WRMP outage allowances.

The Environment Agency's July 2016 technical note 'WRMP19 methods: Outage allowance' highlights that water companies should, where possible, use the UKWIR 1995 outage methodology, but if they decide not to they should discuss their alternative approach with the Environment Agency and clearly explain within their WRMP why they have chosen a different approach and the risks and benefits of doing so. The guidance note also urges companies to consider how the outage allowance could vary over the planning period and consider ways to reduce outage to manage supply-demand problems. As such we have developed a hybrid approach in line with this guidance which takes account of our current data availability and recent high total outage levels. We discussed aspects of our new approach with the Environment Agency in June 2018 as we considered what changes were necessary to our WRMP following the consultation of the draft WRMP19. This included the concept of having a different level of outage allowance for different severities of drought which we have adopted in the WRMP19.

The outage allowance we have used in the WRMP19 has been calculated based on our outage recovery plan and the historic full outage levels experienced during the 2005-06 drought event and can be seen in detail in section 4. The outage allowance is based on total outage (full plus partial outage) and on how we have forecast total outage to reduce in line with the outage recovery plan though the end of AMP6 to the end of AMP7.

The outage allowance profile follows a glide path, starting at 76 Ml/d at the beginning of AMP7 and reducing to 35 Ml/d by the end of AMP7. The outage allowance for the rest of the planning period from AMP8 (2025-26) to 2070 is set at 35 Ml/d in the normal and drought (1 in 20 year severity) planning scenarios in our WRMP19. In the severe drought (1 in 200 year severity) and extreme drought (1 in 500 year severity) planning scenarios the allowance for total outage is lower (29.5 Ml/d) to reflect the levels of outage that we expect to maintain during more severe drought events. This is based upon full outage data from 2005-06 and includes an allowance for partial outage. Whilst the risk of some outage causes may increase in severe drought events (e.g. due to deteriorating raw water quality), we would do everything possible to fully utilise existing source of supply in order to maintain supplies to cutomers and avoid implementing drought permits and orders which have an environmental impact. The outage event of 2005-06 provides some evidence of the level of outage which could be maintained in such circumstances which is why we have used it as a best estimate of the outage allowance in severe and extreme droughts.

It is important to note that one of the key drivers to the approach we have followed in the WRMP19 is the fact that adopting higher outage allowances would result in larger supply-demand deficits, triggering a need for more or larger water resource schemes to manage the supply-demand balance. These would likely be more expensive than maintaining a lower outage level. However, there will be a point at which it becomes more expensive to maintain a low outage level than to implement a new demand management or supply scheme. We believe applying a similar concept as the economic level of leakage to outage could be explored further in future and in dialogue with regulators.

Monte Carlo Simulation

Monte Carlo assumptions

The Monte Carlo simulation method follows the UKWIR 1995 methodology where possible. The data set used spans the period from 2015-17. Outage cause data prior to this was not available at the time of analysis. The dataset contains the WRZ, the site, the outage duration and the cause for full outage events less than 90 days and greater than 90 days inclusive. The Minimum Deployable Output (MDO) and Peak Deployable Output (PDO) values for each site use the WRMP14 values.

A failure in this approach corresponds to when a site is unable to supply its deployable output. The impact of a failure is measured using duration of failure as a percentage of the year and size of failure. The duration of the failure is how long the deployable output is unavailable for as a percentage of the year. The size of a failure is how much deployable output is affected by the failure, a small works will have a smaller size of failure than a larger works. The magnitude of failure is then the duration of failure multiplied by the size of the failure. A large works that is offline for one day could have a smaller magnitude than a smaller works that is offline for a month.

The magnitude of failure is calculated for each outage cause by water supply works. Each cause tends to have multiple durations which can be converted into the minimum likely duration, the average duration and the maximum likely duration. This gives the range of magnitudes that a specific outage cause might be expected to give.

Triangular distributions were then applied to the range of outages. The triangular distribution assumes a distribution that is capped by minimum and maximum values, with a most likely peak at the mean. By using this distribution in a Monte Carlo simulation with 10,000 runs, a full outage distribution was created for each of the WRZs and the company. The benefit of a Monte Carlo simulation is that it models the range of possible outages and can be aggregated to a zonal level. The zonal level then gives an estimate of how much outage is most likely to occur and allows us to incorporate this into the WRMP to protect customers against this uncertainty. Several percentiles of the simulation results (linked to return periods) were then chosen for comparison; the fiftieth percentile (1 in 2 years), eightieth percentile (1 in 5 years) and ninetieth percentile (1 in 10 years).

Monte Carlo results

The Monte Carlo simulation was run for over 50 outage causes, split between 43 sites spanning nine of our water resource zones. Five of our 14 WRZs did not have any outages in the data range; Hampshire Southampton East and West, Hampshire Winchester, Hampshire Andover and Hampshire Kingsclere. The results of these zones are therefore zero. The distribution at the company level for outage under an MDO scenario can be seen in Figure 92. The figure shows an average outage of 63Ml/d and a range of +/-3Ml/d. This outage includes both greater than and less than 90 day events to reflect all full outage issues.

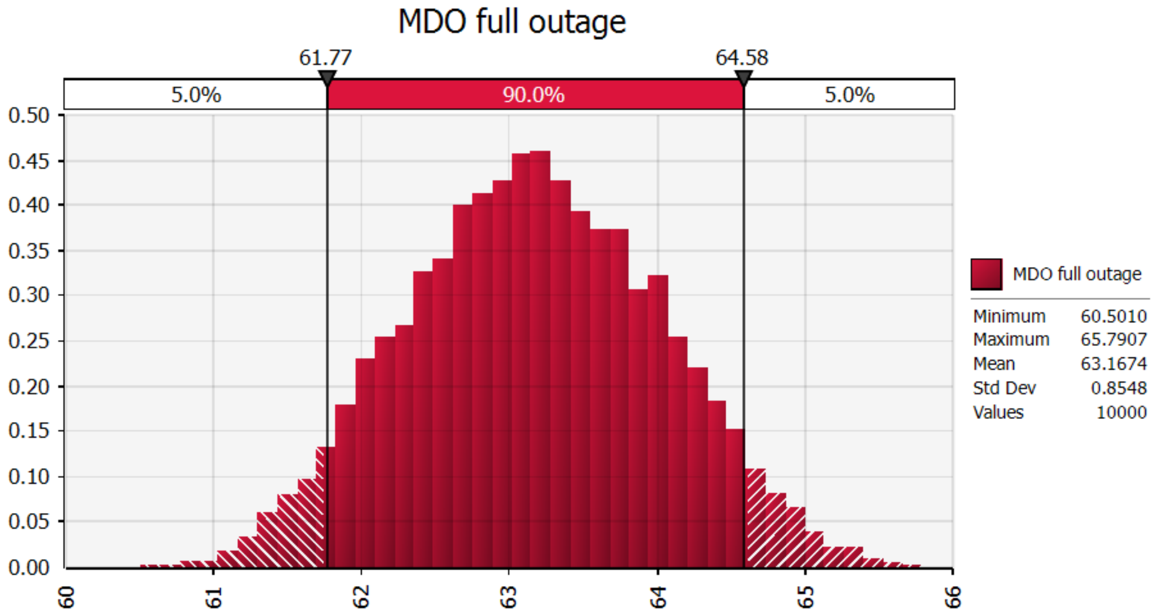


Figure 92: Company level full outage distribution for MDO scenario

Table 84 shows the MDO and PDO outage values for the three scenarios; 1 in 2 years, 1 in 5 years and 1 in 10 years. The short data set used and the high outage values seen in the years of the data set mean that the Monte Carlo outage figures are higher than those seen in the WRMP14 outage allowance.

Table 84: Monte Carlo simulation results

	50%ile (1 in 2 years)		80%ile (1 in 5 years)		90%ile (1 in 10 years)	
Water Resource Zone	**MDO**	**PDO**	**MDO**	**PDO**	**MDO**	**PDO**
I.o.W.	7.61	9.37	7.64	9.41	7.66	9.43
Hants Andover	0.49	0.49	0.49	0.49	0.49	0.49
Hants Kings	0.00	1.00	0.00	1.00	0.00	1.00
Hampshire Rural	0.46	0.46	0.47	0.47	0.48	0.48
Hampshire Winchester	0.00	0.00	0.00	0.00	0.00	0.00
Hampshire Southampton East	0.00	0.00	0.00	0.00	0.00	0.00
Hampshire Southampton West	0.00	0.00	0.00	0.00	0.00	0.00
Sx Brighton	7.17	9.67	7.35	9.87	7.45	9.98
Sx North	5.07	6.16	5.13	6.36	5.16	6.45
Sx Worthing	1.65	1.91	1.65	1.91	1.65	1.92
Kent Medway East	10.19	13.64	10.87	14.63	11.22	15.10
Kent Medway West	2.30	4.03	2.38	4.12	2.42	4.16
Kent Thanet	28.13	31.05	28.46	31.43	28.63	31.62
Sx Hasts	0.04	0.05	0.04	0.05	0.04	0.05
Total	63.11	77.83	64.49	79.74	65.20	80.67

The assessed full outage allowance figure of 65 Ml/d (ninetieth percentile MDO) is an overestimate of the actual outage we expect to be able to maintain throughout the course of our WRMP19. Since AMP5 and the beginning of AMP6 we have implemented a more accurate reporting of actual outage data (including partial outage data). We have developed and implemented a focused outage reduction plan, which is overseen by a new Operational Resilience group to manage water supply resilience risks.

WRMP09, WRMP14 and draft WRMP19 Methodology

Method

Due to the need to base the outage allowance on a longer data set we applied the adapted version of the Monte Carlo methodology that was previously adopted for Southern Water's WRMP14 and our draft WRMP19. To overcome the difficulties in applying the Monte Carlo method to less granular datasets, an adapted methodology was created for WRMP09, which was updated for WRMP14 and updated again for the draft WRMP19. This approach was to calculate the full outage in each WRZ on each day for which data was available. This was achieved using data which described whether a source was operating or not on any given day, together with the deployable output of the source.

On any given day it is possible to have more than one outage event in a WRZ. It is therefore considered to be prudent to make allowances for potential outages arising from combinations of simultaneous outage events in a WRZ – i.e. where more than one outage event occurred in each WRZ simultaneously on any given day.

The critical MDO period is generally considered to last for approximately two months (e.g. October to November), although it can last longer. Therefore, to assess outage affecting the MDO period (which was also assumed to apply to the annual average period), the rolling 60 day average of the daily total outage volumes in a given WRZ was derived. This effectively determined the average outage condition that might be expected during the two month MDO period. The approach assumes that outages are random events which can occur at any time during the year, and so are equally likely to occur during the MDO period as in the rest of the year. It is therefore considered applicable to use a rolling average for the whole date period to estimate the MDO outage.

A similar approach was used for assessing PDO outage. However, in this case the rolling seven day average of the daily outage volumes was used. Ideally, planned outage events should be excluded from the analysis. However, historic data did not always distinguish between planned and unplanned outages, so this approach was not possible. Outages are assumed to occur randomly, and therefore deemed to have the same probability of occurring during the peak period as in the whole year.

This assessment enabled a cumulative distribution function of outage events to be developed for the 60-day rolling average scenario and for the 7-day rolling average scenario. These cumulative distribution functions were subsequently used to derive percentiles of certainty for the outage allowances.

In order to derive an outage value for each WRZ, it is necessary to select an appropriate outage percentile. However, the number of sources varies significantly between WRZs. In WRZs with few sources an outage event at one source could result in a significant loss of supply within that zone – i.e. an outage event could present a high risk to the company's ability to meet demand in that zone. Therefore, it is prudent for the outage percentile to be relatively high for planning purposes. Conversely, in WRZs with a large number of sources, the supply risk from an outage at one source is likely to be low, and therefore it is considered reasonable to accept a lower outage percentile when determining the outage allowance.

A pragmatic approach was developed to aid percentile choice based on the number of sources in each zone. The assumed relationship between number of sources in the WRZ and the appropriate outage percentile is presented in Figure 93.

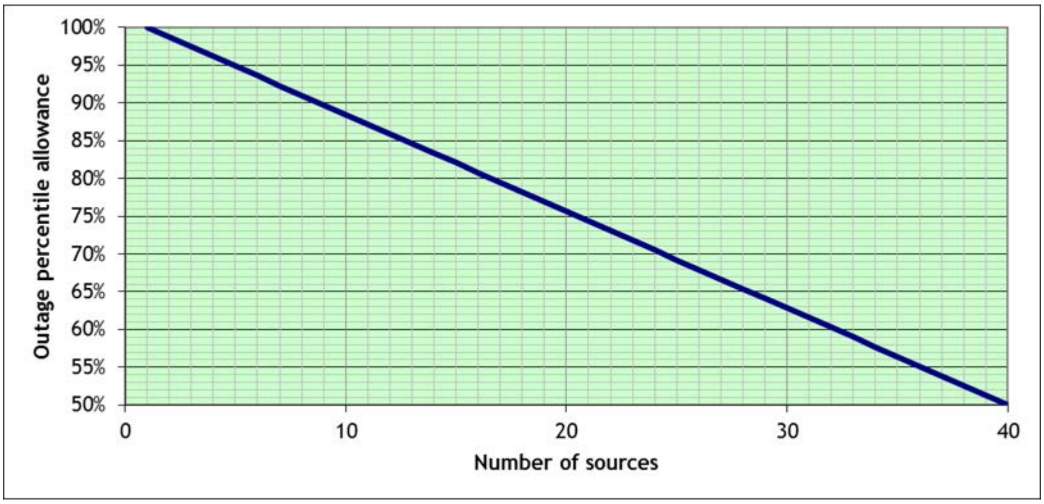


Figure 93: Outage percentile allowance

Full outage results

A risk based approach to the calculation of full outage has been adopted for this assessment. The outage allowance for each WRZ, based on the methodology outlined above, follows the same methodology that was used for the WRMP14.

Two assessments have been undertaken for different time periods. The first was up until 2017, and this was the time period used in the draft WRMP19. The second time frame extends the period up until 2018, incorporating the extra year of data that had been collected during this period. This second assessment is used as a sensitivity of the extra year of data on the results.

For the first assessment, periods of analysis for each WRZ have varied depending on the availability of complete historic data. The periods of analysis for each WRZ can be seen in Table 85.

Table 85: Data used in the draft WRMP19 outage analysis

Water resource zone	Outage dataset used
Sussex Hastings, Kent Thanet, Hampshire Kingsclere, Hampshire Andover	January 1995 – May 2017
Hampshire Southampton East, Hampshire Southampton West, Hampshire Rural, Hampshire Winchester	January 2002 – May 2017
Sussex Brighton, Sussex Worthing, Sussex North	January 2007 – May 2017
Isle of Wight	April 2007 – March 2017
Kent Medway	April 2013 – March 2017

Actual outage data was extracted for the selected periods from Southern Water’s master outage spreadsheet and then checked to ensure it only contained full outage events in line with the UKWIR methodology. Data for sources where we reduced the deployable output to zero in the baseline of the draft WRMP19 were removed as were events which last longer than 90 days. Table 86 shows the changes that we made to the dataset for these reasons.

Table 86: Outages excluded from the outage analysis in the draft WRMP19

WRZ	Source	Action	Dates	Source
IOW	Ventnor 3	DO written off for baseline		St Lawrence
	Newchurch (LGS)	Off for longer than 90 days	Written off for entire 2012-2017 period	Knighton LGS
	Ventnor 2	DO written off for baseline		Niton
	Lukely Brook	Off for longer than 90 days	19/12/12 - 04/06/13	Bowcombe
			28/03/14 - 16/04/14	
			25/07/14 - 11/01/16	
			27/04/16 - 20/07/16	
			08/03/17 - 31/03/17	
	Rookley	Off for longer than 90 days	21/03/13 - 30/10/13	Chillerton
			15/04/15 - 06/07/15	
			27/03/16 - 03/05/16	
	Shalcombe	Off for longer than 90 days	18/11/13 - 27/05/14	Shalcombe
			28/08/14 - 31/05/17	
Hampshire Rural	Kings Sombourne	Off for longer than 90 days	23/12/12 - 17/01/13	Horsebridge
			19/04/13 - 23/07/13	
			08/06/14 - 17/10/14	
			20/02/15 - 30/06/15	
Hampshire Andover	Chilbolton	DO written off for baseline		Chilbolton
Sussex North	West Chiltington	DO written off for baseline		Smock Alley
	Petworth	DO written off for baseline		Haslingbourne
	Petersfield	Off for longer than 90 days	Written off for entire 2012-2017 period	Rogate
Sussex Worthing	Long Furlong A	Off for longer than 90 days	03/02/14 - 19/03/14	Clapham
			26/06/14 - 24/08/15	
	North Arundel	Off for longer than 90 days	01/12/13-15/12/13	Madehurst
	East Worthing	Off for longer than 90 days	03/03/14 - 05/06/14	Northbrook
			24/01/15 - 01/04/17	
Sussex Brighton	Lewes Road	DO written off for baseline		Lewes Road
	North Falmer A	Off for longer than 90 days	04/01/17 - 31/03/17	Housedean
	North Shoreham	Off for longer than 90 days	02/03/13 - 12/06/13	Mossy Bottom
			09/11/13 - 02/12/13	
	Hove B	Off for longer than 90 days	28/04/17 - 29/05/17	Mile Oak
	Brighton B	Off for longer than 90 days	31/07/12 - 07/05/12	Surrenden
Sussex Hastings	Bulverhythe	DO written off for baseline		Filsham
Kent Medway	Gravesend	DO written off for baseline		Windmill Hill
	Capstone Chalk	Off for longer than 90 days	31/03/12 - 25/02/15	Capstone Chalk
	Capstone Greensand	Off for longer than 90 days	04/04/12 - 09/05/12	Capstone Greensand
			27/02/15 - 05/09/16	
	Hartlip Hill	Off for longer than 90 days	01/01/12 - 31/03/17	Gore
	Gravesend South	Off for longer than 90 days	23/04/13 - 10/05/13	Hazells
	Newington	Off for longer than 90 days	19/02/15 - 31/03/17	Keycol
	Luddesdown Greensand	DO written off for baseline		Luddesdown Greensand
	Rochester	Off for longer than 90 days	08/10/12 - 11/07/13	Three Crutches
			20/12/13 - 11/02/14	
Kent Thanet	Stourmouth	DO written off for baseline		Plucks Gutter
	Manston	Off for longer than 90 days	Written off for entire 2012-2017 period	Lord of the Manor
	North dover	Off for longer than 90 days	13/07/12 - 24/09/12	Martin Mill
	Ramsgate B	Off for longer than 90 days	14/02/14 - 16/04/14	Minster B
			14/06/15 - 31/05/17	
	North Deal	Off for longer than 90 days	31/03/12 - 17/06/12	Sutton
			17/09/12 - 27/11/12	

For the second assessment, a ten year period from 01/04/2008 to 31/03/2018 was taken for each WRZ except for Kent Medway East and West, where the data period goes from 01/04/2013 to 31/03/2018 due to no available data pre 2013.

Table 87 shows the results of both assessment periods. By including the extra year in the analysis the MDO full outage increases by 3 Ml/d and the PDO full outage increases by 14 Ml/d as can be seen from the ‘Assessment 2’ columns.

Table 87: Draft WRMP19 outage analysis results

			Assessment 1		Assessment 2	
Water Resource Zone	**2017 No. of Sources**	**Outage percentile level**	**MDO**	**PDO**	**MDO**	**PDO**
I.o.W.	8	91%	1.72	3.70	2.44	4.23
Hants Andover	4	96%	1.11	0.49	0.19	0.39
Hants Kings	2	99%	1.60	0.26	0.00	0.00
Hampshire Rural	2	99%	1.50	1.50	1.50	1.50
Hampshire Winchester	3	97%	0.00	0.00	0.02	0.00
Hampshire Southampton East	3	97%	0.00	0.00	0.00	0.00
Hampshire Southampton West	1	100%	0.00	0.00	0.00	0.00
Sx Brighton	13	85%	10.18	12.39	10.31	12.71
Sx North	6	94%	5.74	5.88	5.71	9.71
Sx Worthing	11	87%	2.51	1.93	8.46	11.81
Kent Medway East	17	79%	5.35	4.91	4.19	8.97
Kent Medway West	11	87%	4.98	6.43	4.81	6.59
Kent Thanet	18	78%	5.28	10.38	5.91	6.94
Sx Hasts	3	97%	1.33	3.29	1.23	2.00
Total			41.29	51.14	44.77	64.84

The Monte Carlo approach using just two years' worth of data yielded a higher full outage figure than the longer data sets used for the draft WRMP19 method above. Assessment 1 has a lower MDO full outage than the Monte Carlo approach, 41.29 Ml/d compared with 65.20 Ml/d and a lower PDO full outage, 51.14 Ml/d compared with 80.67 Ml/d. Assessment 2 has a lower MDO full outage value and lower PDO full outage value when compared with the Monte Carlo approach.

Assessment 1 shows the outage allowance values used within the draft WRMP19. These values were kept constant over the planning horizon. Assessment 2 was carried out as a sensitivity of the draft WRMP19 values using more up to date data. The extra year of data has a small effect on the MDO full outage value and a significant effect on the PDO full outage value. Assessment 1 is considered the better assessment in this case as it is not as skewed by recent data.

Total outage results

We considered that a more complete view of outage would be to look at total outage, not just full outage. In order to get a total outage figure an estimate of partial outage had to be calculated using three years of data. The partial outage data is monthly by site and goes back to July 2014. The critical MDO period is generally considered to last for approximately two months (e.g. October to November), therefore to assess outage affecting the MDO period, the rolling two month average of the monthly partial outage volumes in a given WRZ was derived. For PDO the monthly values were taken as there are no seven day periods in the data. The WRZ specific percentiles were then applied to the analysis to come up with the partial outage figures seen in Table 88 alongside the WRZ specific percentile full outage values and consequential total outage values.

Table 88: Total outage breakdown from draft WRMP19 method

Water Resource Zone	MDO full outage	PDO full outage	MDO partial outage	PDO partial outage	MDO total outage	PDO total outage
I.o.W.	1.72	3.70	0.00	5.22	1.72	8.92
Hants Andover	1.11	0.49	0.57	3.53	1.68	4.02
Hants Kings	1.60	0.26	0.00	0.00	1.60	0.26
Hampshire Rural	1.50	1.50	4.32	4.74	5.82	6.24
Hampshire Winchester	0.00	0.00	2.51	3.70	2.51	3.70
Hampshire Southampton East	0.00	0.00	5.84	17.42	5.84	17.42
Hampshire Southampton West	0.00	0.00	0.00	0.00	0.00	0.00
Sx Brighton	10.18	12.39	8.23	10.72	18.41	23.11
Sx North	5.74	5.88	0.00	9.71	5.74	15.59
Sx Worthing	2.51	1.93	5.92	13.87	8.43	15.80
Kent Medway East	5.35	4.91	7.10	9.97	12.45	14.87
Kent Medway West	4.98	6.43	0.46	2.16	5.44	8.59
Kent Thanet	5.28	10.38	3.34	4.06	8.62	14.44
Sx Hasts	1.33	3.29	0.00	0.00	1.33	3.29
Total	41.29	51.14	38.29	85.10	79.58	136.25

The total outage values from the draft WRMP19 method were higher than those used for WRMP14 and this was caused by the high outage levels seen in the beginning of AMP6. It is expected that the levels of outage will not be this high and that the outage allowance figures calculated using the draft WRMP19 and Monte Carlo approaches are overestimating the outage allowance. Therefore the approach taken for calculating the outage allowance values in the final WRMP19 is to use an outage recovery profile over the remainder of AMP 6 and AMP 7, bringing the total outage down to levels that are achievable during drought conditions.

Outage recovery plan

Outage recovery profile

Southern Water accepts that our actual outage levels in recent years have been too high, even when just considering full outage events. This poses a risk to customers' security of supply if droughts develop. The company is committed to delivering the outage recovery plan set out below to enable it to reduce outage to acceptable levels in order to minimise cutomers' security of supply risk.

When the outage allowance for the revised draft WRMP19 was derived, our total actual outage was 166 Ml/d (May 2018). By year end of 2018-19, total outage had reduced to 116 Ml/d because of outage recovery schemes delivered during the year. This reduction in total outage aligns with our outage recovery plan as seen in Figure 94.

There is a plan for the reduction of full and partial outage at specific sources through to the end of AMP6 (March 2020) and then through to the end of AMP7 (March 2025). The plan is designed to tackle recent high levels of outage and reduce the risk of not achieving our planned customer levels of service. The profile assumes and incorporates the risk of an additional 10 Ml/d of new outage at the beginning of AMP7. This is approximately equivalent to having two average groundwater sources out of service and we consider that incidence of new outage can be maintained at this level through the asset maintenance programme moving forward.

The outage allowance profile follows a glide path. The starting level of outage is assumed to be approximately 76 Ml/d at the beginning of AMP7. Through the outage recovery plan this reduces to 35 Ml/d by the end of AMP7 as seen in Figure 94. In 2019-20, an additional 10Ml/d of outage is added to the company total (split between WRZs) to allow for new outage that has a chance of arising. The outage allowance for the rest of the planning period from AMP8 (2025-26) to 2070 is set at 35 Ml/d in the normal and drought (1 in 20 year severity) planning scenarios in our WRMP19.

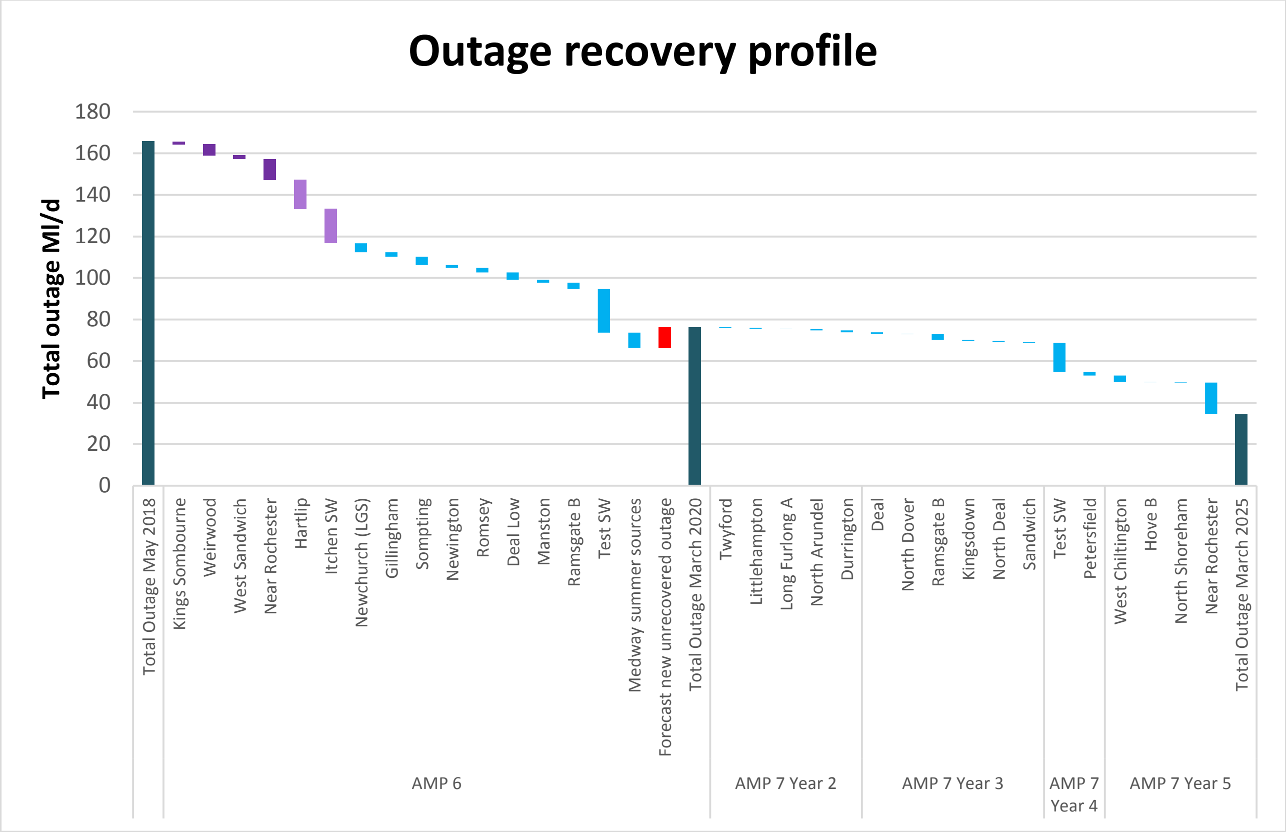


Figure 94: Outage recovery profile (Dark purple indicates sites fully recovered, light purple indicates sites partially recovered and blue indicates schemes yet to be completed. Red indicates assumed new outage which may occur in AMP7)

The most notable planned reductions in total outage in AMP6 are due to schemes at our Hartlip, Itchen surface water and Test surface water sources. At the end of 2018-19 the Hartlip outage had been recovered, with schemes due to be completed for Test surface water and Itchen surface water by March 2020. Progress on the outage recovery plan towards achieving the outage allowance profile in the WRMP19 undergoes internal review and assurance on a monthly basis and we have committed to provide quarterly updates on progress to the Environment Agency.

The outage recovery plan used to inform the outage allowance in the WRMP19 was based on the outage situation at the time the allowance was calculated for the revised draft plan (May 2018). For the purpose of developing the outage recovery plan, Average and Minimum Deployable Outputs (ADO / MDO) stated in the WRMP14 were compared against maximum available source outputs to calculate outage as a temporary loss of deployable output. For the purpose of the outage recovery plan, **total** outage is used, which consists of **full** and **partial** outage.

Prioritising sites for outage recovery is dependent upon a number of factors. For the outage recovery plan, analysis was undertaken to better understand outage and where attention should be focused. This analysis considered the following:

1. Current outage against ADO / MDO
2. Current outage against previous historic maximum outputs
3. WRZ supply-demand deficits (against target headroom)
4. Cost of contingency water resource
5. Ability to recover deployable output
6. Site criticality in the WRZ

From these considerations a priority assessment of potential outage recovery options was made which ultimately formed the outage recovery plan.

The Test surface water and Itchen surface water schemes are large capital investment projects which are due to be completed by March 2020. Following the recent (March 2019) abstraction licence changes on the Test and Itchen, we expect that the partial outage at Test surface water and Itchen surface water will be fully resolved via the work plan being completed in 2019-20. In assessing the new level of outage for the Test surface water and Itchen surface water sources we have taken account of the Section 20 Agreement between Southern Water and the Environment Agency which sets out a process for maintaining supplies to customers whilst a long term water resources solution is implemented. As such we will be measuring outage not against the new deployable output of these sources but against the maximum benefit that a drought permit or order will need to provide to maintain supplies until the long term solution is implemented.

The outage recovery plan was revised and extended in May 2018 due to the need to address rising levels of outage, as well as to produce an outage allowance profile for the WRMP19. This has led to a re-prioritisation of outage schemes and better governance around the delivery of the plan. Due to the nature of outage events, the recovery plan will be subject to continuous review and where necessary will be revised to address changing circumstances. We will continue to update the EA on a quarterly basis on any changes to the plan and on progress with its implementation.

The planned set of outage recovery schemes is set out in Table 89. By the start of AMP7 total outage is forecast to have reduced by 90Ml/d to 76Ml/d. By 2024-25 full outage will have reduced from 58Ml/d down to 24Ml/d. In the same period partial outage will have reduced from 108Ml/d down to 10Ml/d bringing total outage down to 35 Ml/d.

The causes of outage for each site in the recovery plan are shown in Table 89. The majority of these are system failures or turbidity issues where work plans have been developed towards preventing or reducing the risk of future issues which could cause outage events. System failures include faulty monitors, mechanical shutdowns, and valves in need of repair and pump failures. They are often quite complex and require an investigation to determine what remedial action is necessary. The actions to resolve these would be the necessary repairs and system improvements to reduce or remove the risk of future outages.

Table 89: Outage recovery plan WRMP19

AMP/Year	State/SEMD Site Name	Total Ml/d	Outage cause	Full/Partial
	Total Outage May 2018	165.7		
AMP 6	Newchurch (LGS)	4.4	System failure	Full
	Kings Sombourne	1.4	Turbidity	Full
	Gillingham	2.2	System failure	Partial
	Sompting	4.0	System failure	Partial
	Weirwood	5.4	System failure	Full
	Newington	1.3	Turbidity	Full
	Hartlip	14.0	System failure	Full
	Romsey	2.2	System failure	Partial
	Deal Low	3.5	System failure	Full
	Manston	1.5	System failure	Full
	Ramsgate B	3.0	System failure	Full
	West Sandwich	1.7	System failure	Partial
	Itchen SW	16.5	System failure	Partial
	Test SW	21.0	System failure	Partial
	Medway summer sources	7.4	System failure	Partial
	Near Rochester	10.0	System failure	Partial
	Forecast new unrecovered outage	-10.0		
	Total Outage March 2020	76.3		
AMP 7 Year 2	Twyford	0.3	System failure	Partial
	Littlehampton	0.5	System failure	Partial
	Long Furlong A	0.15	Turbidity	Full
	North Arundel	0.5	System failure	Partial
	Durrington	1	Turbidity	Partial
AMP 7 Year 3	Deal	0.7	System failure	Full
	North Dover	0.21	Turbidity	Full
	Ramsgate B	2.8	System failure	Partial
	Kingsdown	0.44	System failure	Partial
	North Deal	0.6	System failure	Partial
	Sandwich	0.4	System failure	Full
AMP 7 Year 4	Test SW	14	System failure	Partial
	Petersfield	1.6	System failure	Full
AMP 7 Year 5	West Chiltington	3.12	System failure	Full
	Hove B	0.23	System failure	Full
	North Shoreham	0.14	System failure	Full
	Near Rochester	15	System failure	Partial
	Total Outage March 2025	34.6		

In the severe drought (1 in 200 year severity) and extreme drought (1 in 500 year severity) planning scenarios the allowance for total outage is lower (29.5 Ml/d) to reflect the levels of outage that we expect to maintain during more severe drought events. This is based upon full outage data from 2005-06 and includes an allowance for partial outage as can be seen in Table 90. Whilst the risk of some outage causes may increase in severe drought events (e.g. due to deteriorating raw water quality), we would do everything possible to fully utilise existing source of supply in order to maintain supplies to customers and avoid implementing drought permits and orders which have an environmental impact. The outage event of 2005-06 provides evidence of the level of outage which could be maintained in such circumstances which is why we have used it as a best estimate of the outage allowance in severe and extreme droughts.

Table 90: 1:200 and 1:500 post 2025 outage figure

	MDO full outage	PDO full outage	Weighted full outage	Partial outage	Total outage
2006 drought year	18.68	31.69	19.62	9.83	29.45

It is important to note that one of the key drivers to the approach we have followed in the WRMP19 is the fact that adopting higher outage allowances would result in larger supply-demand deficits, triggering a need for more or larger water resource schemes to manage the supply-demand balance. These would likely be more expensive than maintaining a lower outage level. However, there will be a point at which it becomes more expensive to maintain a low outage level than to implement a new demand management or supply scheme. We believe applying a similar concept as the economic level of leakage to outage could be explored further in future and in dialogue with regulators.

Catchment management schemes

As well as the outage recovery profile, there are several catchment management schemes being implemented during the period covered by the WRMP19. While catchment management might reduce outage this is not the main driver for the catchment schemes, some of which are implemented alongside a treatment solution to negate the need for future treatment or renewal of treatment processes.

We are expecting that our Catchment First programme will deliver the benefit of reducing the frequency and magnitude of outage events caused by raw water quality issues such as high turbidity and pesticides. By working with farmers, landowners and other stakeholders, within catchments, we expect to see an improvement in raw water quality and consequential reduction in the frequency and magnitude of water quality outage incidents, hence reducing our outturn outage levels. Whilst we also have an outage recovery plan this does not currently include any catchment management schemes.

Catchment Management will help reduce outage by:

1. Protecting kast features to prevent fast pathway of nitrates/cryptosporidium/turbidity – we commonly have outages due to this in the Lewes Valley sources at North Falmer A, Lewes and North Falmer B in Brighton
2. Reducing the risk from runoff from agricultural land into rivers by advising/funding fencing/buffer strips/trees/hedges etc – we have a significant issue of sediment washing off fields into the Western River Rother in Sussex North WRZ
3. Offering advice/funding mitigation on pesticide storage and application – we have seen recent pesticide pollution incidents within the River Beult catchment (a sub-catchment of the River Medway in Kent) which have the potential to impact on the refilling of Bewl reservoir and the abstraction from the Medway near Rochester.
4. Metaldehyde removal – the farmers in the Western Rother Valley (Pulborough WSW catchment) have pledged to be metaldehyde free by 2021 – there is no effective treatment at Pulborough to remove metaldehyde, and blending options are used as mitigation currently.

5. We are running a campaign to match fund the upgrade of oil storage/septic tanks/cess pits. We have had recent incidents of oil tank spills (North Dover in Thanet) and groundwater contamination from inappropriate sewerage discharges (Faversham 3 in Kent)
6. We have sources that are showing deteriorating nitrate trends which will either be switched off or require a treatment solution from AMP9 onwards We are investing in catchment schemes within these catchments to try to slowdown or ultimately reverse these trends (e.g. Romsey in Hampshire).

Outage recovery profile results

The outage recovery profile starts with a high level of total outage which reduces by the end of AMP6, reflecting the position in 2017-18. This level of outage decreases through AMP7 corresponding to planned outage recovery schemes, resulting in an outage figure of 34.6Ml/d by 2024-25 as seen in Table 91. This profile will be used for normal and dry year annual average and MDO scenarios.

Post 2024-25, a revised outage allowance for 1:200 and 1:500 drought scenarios is used as it is expected that a lower level of outage will be maintained during a drought event as seen historically. This figure is calculated to reduce to 29.45Ml/d. For drought scenarios with a severity of less than 1:200, the 34.61 Ml/d will be used for post 2024-25 outage allowance.

Table 91: Outage recovery profile

Water Resource Zone	Total outage 2017/18	Total outage 2018/19	Total outage 2019/20	Total outage 2020/21	Total outage 2021/22	Total outage 2022/23	Total outage 2023/24	Total outage 2024/25	Total outage 2025/26
I.o.W.	5.64	1.29	1.68	1.68	1.68	1.68	1.68	1.68	1.43
Hants Andover	1.81	1.81	2.14	2.14	2.14	2.14	2.14	2.14	1.82
Hants Kings	0.00	0.00	0.14	0.14	0.14	0.14	0.14	0.14	0.12
Hampshire Rural	3.70	0.10	0.29	0.29	0.29	0.29	0.29	0.29	0.24
Hampshire Winchester	0.00	0.00	0.36	0.36	0.36	0.36	0.36	0.36	0.31
Hampshire Southampton East	16.76	16.76	0.64	0.64	0.34	0.34	0.34	0.34	0.29
Hampshire Southampton West	35.00	35.00	15.59	15.59	15.59	15.59	1.59	1.59	1.35
Sx Brighton	8.61	4.61	6.01	6.01	6.01	6.01	6.01	5.64	4.80
Sx North	10.26	4.86	5.59	5.59	5.59	5.59	3.99	0.87	0.74
Sx Worthing	3.41	3.41	4.25	4.25	2.10	2.10	2.10	2.10	1.79
Kent Medway East	30.25	12.75	6.69	6.69	6.69	6.69	6.69	6.69	5.69
Kent Medway West	28.98	28.98	20.26	20.26	20.26	20.26	20.26	5.26	4.48
Kent Thanet	20.67	10.97	11.71	11.71	11.71	6.56	6.56	6.56	5.58
Sx Hasts	0.62	0.62	0.94	0.94	0.94	0.94	0.94	0.94	0.80
Southern Water	165.71	121.16	76.30	76.30	73.85	68.70	53.10	34.61	29.45

As would be expected, while some sites are repaired and outage is reovered, other sites may go offline due to new outage events. Owing to the uncertain nature of these incidents the outage recovery plan will further adapt to these problems, but we expect it will still follow the overall glide path that forms the outage allowance in the WRMP19. Furthermore, we are working to improve our asset management and maintenance processes to better understand and reduce the root cause of outage events.

Outage recovery profile scheme benefits

Figure 95, Figure 96 and Figure 97 show the final planning supply demand balances in the Western, Central and Eastern supply areas respectively for the Dry Year Annual Average planning scenario in the severe drought (1 in 200 year severity) state of the world. The figures show the final supply demand balances with the planned outage recovery schemes implemented and the impact on the supply demand balances if they are not. The outage recovery plan assumes the profile in Figure 94 and much of the outage should already have been resolved by 2020-21.

In the Western area there is an immediate supply demand deficit due to the Test and Itchen licence changes which cannot be solved in the short term without the reliance on drought permits and orders to maintain supply to customers. Figure 95 incorporates the maximum benefit of drought permits and orders that are required to recover the supply demand deficit. If the Test surface water and Itchen surface water outage schemes are not delivered then we would not be able to fully benefit from the Test and Itchen surface water sources with a drought permit or order in place. Although Figure 95 shows the supply-demand situation at the area level to be positive which assumes a full benefit from the drought permit and orders available, the situation is different at WRZ level. If the outage recovery plan is not delivered there would be a supply demand deficit in the Hampshire Southampton West (caused primarily by Test surface water) and Isle of Wight (caused primarily by Newchurch (LGS)) WRZs even with drought permits and orders in place. Furthermore, any delay or failure to recover outage in the Western area could increase the frequency of needing to apply for and implement drought permits and orders.

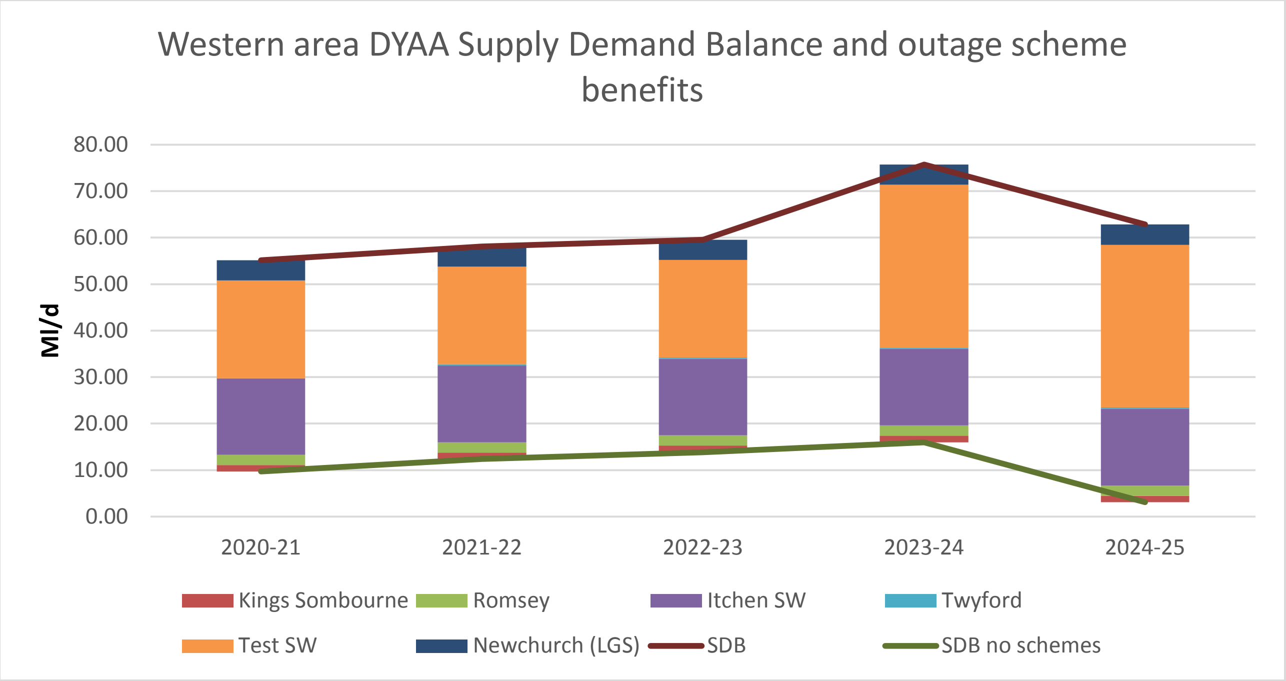


Figure 95: Western area supply demand balance (WAFU minus forecast demand) showing the benefits of the outage schemes in the outage recovery plan

In the Central area the supply demand balance is also positive at the area level with the outage recovery plan both implemented and not delivered. However, at the WRZ level, if outage schemes are not delivered, this would lead to a deficit in the Sussex Brighton (caused primarily by Sompting) and Sussex North (caused primarily by Weir Wood reservoir) WRZs.

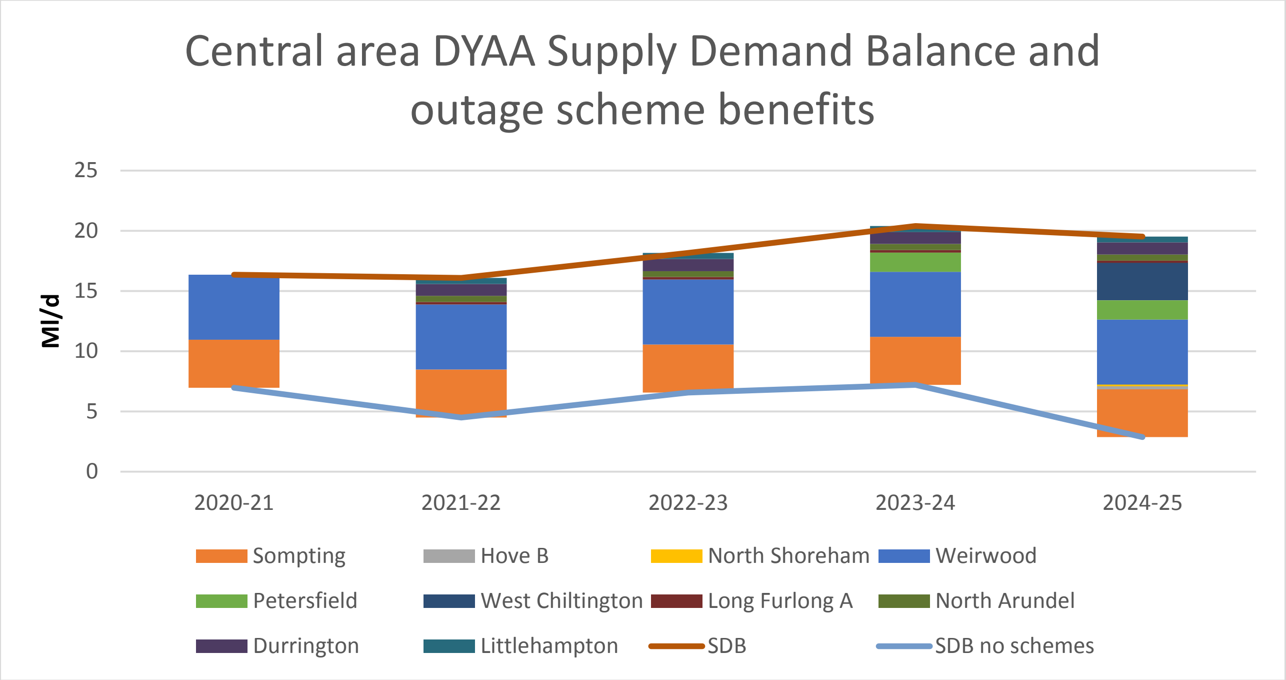


Figure 96: Central area supply demand balance (WAFU minus forecast demand) showing the benefits of the outage schemes in the outage recovery plan

In the Eastern area there is a surplus in the final planning supply demand balance, however, as can be seen in Figure 97, there would be a supply demand deficit at the area level if the outage recovery plan were not to be delivered. This highlights the importance of delivering the schemes in our outage recovery plan.

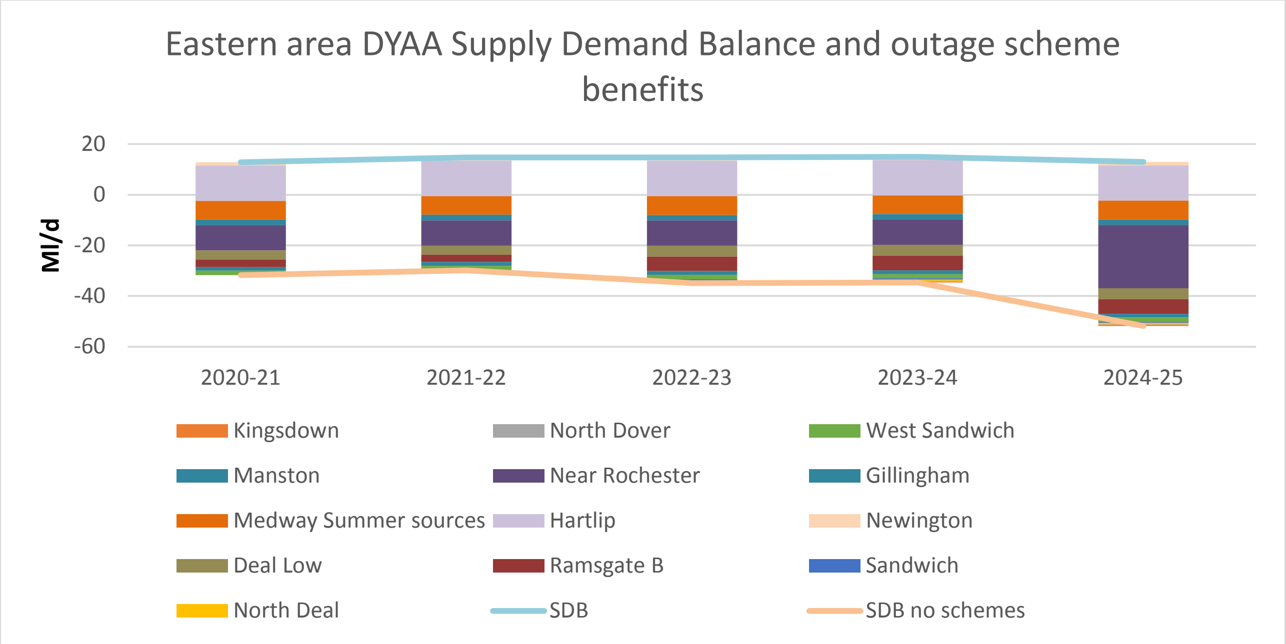


Figure 97: Eastern area supply demand balance (WAFU minus forecast demand) showing the benefits of the outage schemes in the outage recovery plan

Sensitivity testing

The WRMP19 incorporates an outage allowance profile based on the outage recovery plan. Compared to the draft WRMP19 the profile has a higher level of outage allowance in years one to four of AMP7 (2020-2024). From year five of AMP7 the outage allowance profile then becomes lower than the draft WRMP19 profile.

As a result of this change in outage allowance it was expected that there could be an effect on the preferred investment plan which now uses the revised outage allowance profile. To this end a sensitivity test was carried out using the draft WRMP19 outage allowance profile. The two outage scenarios were tested to see the effect on the cost of the plan and on scheme implementation.

For the Eastern area, the preferred plan has a cost of £283 million. The draft WRMP19 outage allowance scenario had a cost of £259 million. This is the only supply area where the draft WRMP19 outage allowance scenario has a lower cost. This is due to the high levels of outage currently seen in the Eastern area. The timing of several schemes change during the beginning of AMP7, these are mainly catchment management, Drought Permits and Orders and demand interventions. During the planning period, there are only three schemes with a benefit above 5 Ml/d which differ in timings and volume for the severe drought annual average state of the world, detailed in Appendix 1.

For the Central area, the preferred plan has a cost of £501 million against a cost of £565 million for the dWRMP19 outage allowance scenario. There are some slight timing differences for schemes during AMP7 and these are mainly on catchment management, Drought Permits and Orders and cessation of use of sites. There are five schemes above 5 Ml/d that differ between the scenarios for the severe annual average state of the world and six schemes above 5 Ml/d that differ between the scenarios for the severe critical period state of the world.

For the Western area the preferred plan had a cost of £1097 million compared to a cost of £1107 million for the dWRMP19 outage allowance scenario. There are only a small number of schemes which have different starting dates during AMP7 and these are mostly catchment management schemes. There are seven schemes above 5 Ml/d for both the severe annual average and severe critical period states of the world that differ between the scenarios across the planning period. The most notable of these being the third module of the proposed desalination option.

Companywide, the cost of the preferred plan is £50 million less than the plan using the dWRMP19 outage profile. This can be seen by Area in Table 92. The options above 5 Ml/d which differ between the preferred plan and the dWRMP19 outage allowance scenario can be seen in a table showing the results of the sensitivity test in section 8.

Table 92: Cost comparison by area of preferred plan versus draft WRMP19 outage allowance

Area	Scenario	Plan cost (NPV, £M)	Compare to preferred (£M)
Central	**PREFERRED PLAN**	501	-
	Outage scenario 1	565	🟢 64
Western	**PREFERRED PLAN (Test drought permit variations)**	1097	-
	Outage scenario 1	1107	🟢 10
Eastern	**PREFERRED PLAN**	283	-
	Outage scenario 1	259	🔴 -24
Company	**Preffered Plan**	1881	-
	Outage Scenario 1	1931	🟢 50

Further work

Risk based planning

The 2016 risk based planning guidance recommended using a risk based approach to outage. The approach was an improvement to the 1995 UKWIR methodology for calculating outage. There was insufficient data to carry out this approach for the WRMP19 and as such a more evidence based approach to calculating an outage allowance has been adopted.

In addition we tested a new approach to generating an outage allowance figure that considered economic factors. However, this approach was not ready to use for this plan and will be considered further for possible inclusion in the 2024 WRMP. This delay will allow a more robust approach and give time to discuss the methodology with regulators and incorporate the improvements to our reporting of actual outage.

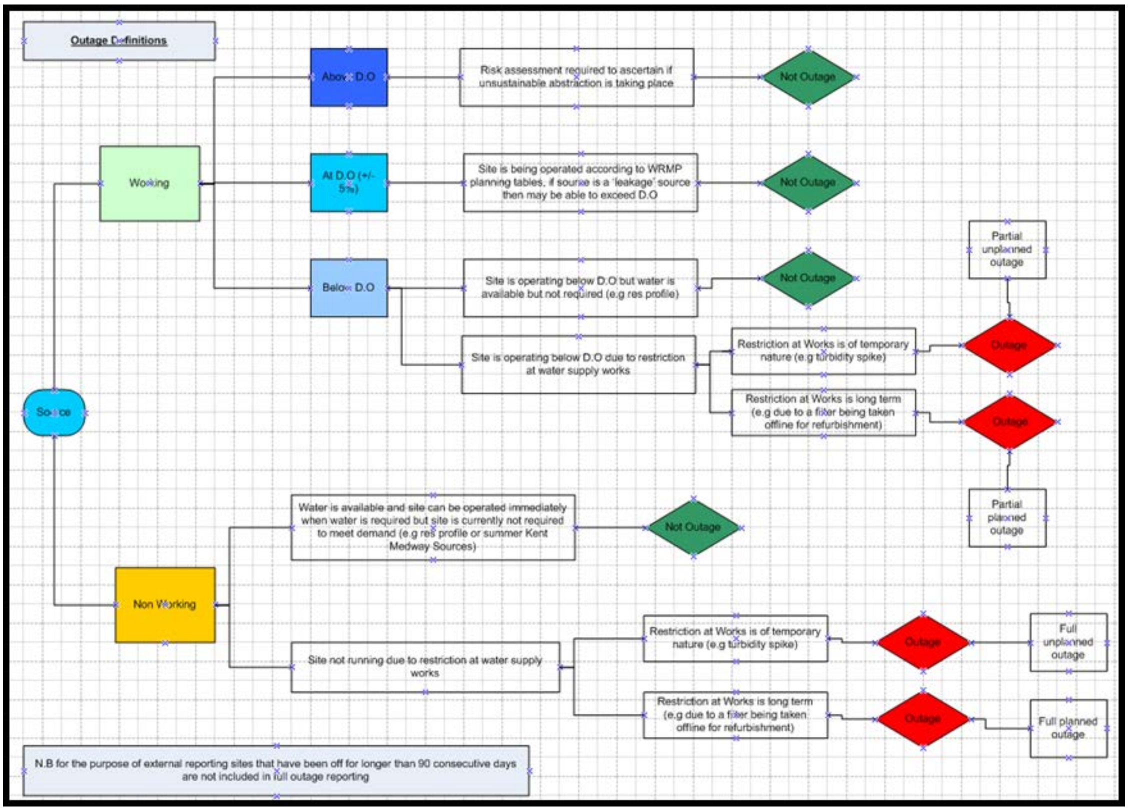
Data capture

Southern Water has in place a process for reporting outage. Figure 98 shows how outage is classified within the company. Outage can be either full, whereby a water supply works is out of service for a whole day or longer, or partial, where the maximum daily output from the WSW is constrained to be less than the DO of the source. Partial outage typically occurs due to plant shutting down for a period of time less than a whole day or replacement assets being installed which do not allow the full DO of the site to be achieved.

Both full and partial outage events are classified into planned and unplanned categories. The 1995 UKWIR methodology provides a definitive list of legitimate unplanned outage events. To address the current risk to operations Water Strategy have added additional criteria to this list (shown in red):

- Pollution of source
- Turbidity
- Nitrate
- Algae
- Power failure
- System failure (to include asset deterioration)
- Pesticides

Where the output from a WSW is less than the DO due to the level of demand rather than a constraint on the ability to achieve the DO this is not classified as outage i.e. the WSW must be able to deliver the DO if required.



N.B for the purpose of external reporting sites that have been off for longer than 90 consecutive days are not included in full outage reporting

Figure 98: Outage classification process

Southern Water has long records of full outage data going back to 1992 which has enabled it to understand the typical type and frequency of outage events experienced in different areas. This has informed our outage allowance assessments for this and previous WRMPs. The length of data available for each water resource zone can be seen in Table 93.

Table 93: Historical full outage available

Water resource zone	Historic full outage data available
I.o.W.	01/01/1992 to 31/12/2000, 01/04/2002 to present
Hants Andover	01/01/1995 to present
Hants Kings	01/01/1995 to present
Hants South	01/01/1992 to present
Sx Brighton	01/01/1992 to present
Sx North	01/01/1992 to present
Sx Worthing	01/01/1992 to present
Kent Medway	01/01/1992 to present
Kent Thanet	02/01/1995 to present
Sx Hasts	01/01/1992 to present

Whilst we believe that we should now include partial outage in our outage reporting and allowance assessments, we do not yet have a good enough set of data to do this. Distinguishing between genuine partial outages caused by a legitimate outage category and sources where the output is reduced due to demand is one of the biggest challenges to capturing partial outage data. This is being tackled with an improvement in outage reporting whereby, through a validation process, no outages are excluded in error and no instances of sources not being used due to low demand are incorrectly captured as outage. The introduction of the new reporting process will allow us to improve the accuracy of data available for the WRMP24 and will overcome the difficulties seen in previous plans in following the UKWIR 1995 methodology.

Since April 2019 our outage reporting has improved to ensure we are fully compliant with the Ofwat AMP7 outage methodology. This looks at the failure or deterioration of any asset in the water production process which impacts on the ability to achieve the peak week production capacity (PWPC). The PWPC is essentially the maximum sustained capacity output of a WSW and could be the constraint on deployable output. In other instances, it will be greater than the deployable output where there are other constraints such as, for example, the hydrological yield of a source in the design drought. The process of collecting data to report against the PWPC also allows us to compare failures against the ADO / MDO to provide data consistent with outage reporting to the EA. This provides fully assured data that is directly comparable across both methodologies.

We are concurrently running the old and new reporting methods until the new process is fully established as reliable and accurate. The Water Production Manager owns the process for reporting outage. Monthly updates to the outage recovery plan are reviewed by the Operational Resilience group and we are implementing a new outage reporting system which will be internally assured on a monthly basis.

Telemetry data is used to indicate asset faults or failures, with this being recorded at the start of the outage period. This telemetry data is then linked to SCADA (supervisory control and data acquisition) data, which provides flow volumes and work completion information. Once all required work is complete, the final completion date and time is used at the end of the outage period. This period of outage is then compared to internal records to separate planned outage. Flow data from the site is then used to determine the volume of water put into supply during the period of outage, ensuring that both full and partial outage are captured.

This flow data is compared against PWPC and MDO to produce comparable figures for both Ofwat and the EA. Further validation is also carried out against exclusion criteria, and to ensure that if there has been a failure of the telemetry system, any reduction in flow is still captured and investigated to ensure no outages are excluded in error and similarly to ensure that no instances of low demand are incorrectly captured as outage. The reports will be assured on a monthly basis in terms of data accuracy and then again on a yearly basis against reporting requirements.

Governance

Our governance has been revised and improved for outage reporting. Overall outage reporting is owned by the Head of Planning and Resilience, with the Water Production Manager owning the process behind the data analysis and reporting. Monthly updates to the outage recovery plan are reviewed by the Operational Resilience group and we are implementing a new outage reporting system which will be internally assured on a monthly basis. This is, in part, to collect data for Ofwat's shadow outage metric and so the new reporting system will be fully compliant with Ofwat's revised reporting requirements as well as being consistent with our processes for reporting to all regulators.

Methodology results comparison and conclusion

Historically our actual outage levels were low, based on data comprising full outage events only. During AMP5 (2010 to 2015), Southern Water introduced a new system of ‘triple validation’ for water quality monitoring at its water supply works (WSW) as well as implementing a very successful customer metering programme, both of which aided in increased outage due to increased frequency of site shutdowns and lower abstraction respectively (the lower utilisation of sources leading to more system failures). We are using the lessons from this to improve our asset management processes and preparedness for drought events.

A new methodology for reporting outage (including partial outage) was shared with the EA in December 2015 and we reported provisional figures for partial outage in the 2016 Annual Review of our WRMP. Since the 2017 Annual Review of our WRMP we have formally reported partial, full and total outage figures to the EA. By including partial outage in our assessment of actual outage Southern Water has gone further than most other water companies in attempting to fully quantify our ability to achieve deployable outputs during design drought events to maintain supplies. Our total outage levels should not be compared to other companies who have not included partial outage in their assessment and only based their assessments on full outage events.

In line with best practice our initial outage allowance assessment for the WRMP19 followed the UKWIR 1995 outage methodology. The assessment was based on our full outage dataset recorded from 2015-16 to 2017-18 when sufficiently robust outage data was available. Whilst we have historic outage data prior to 2015-16 which includes the timing and location of outage events we do not have data on the causes of all these outage events which is needed to apply the methodology. This led to a full outage allowance of approximately 65 Ml/d. We considered that the results were not representative of an appropriate outage allowance in the long term due to the short dataset used in the analysis and the high actual outage experienced during the period when data was available.

Due to the need to base the outage allowance on a longer data set we then followed an adapted version of the Monte Carlo methodology that was previously adopted for Southern Water’s WRMP14 and the draft WRMP19. A total outage allowance of 79.6 Ml/d was derived by this approach but it was also considered too high as a long term outage allowance when compared to other water companies and Southern Water’s previous WRMP outage allowances.

The outage allowance we have used in the WRMP19 has been calculated based on our outage recovery plan and the historic full outage levels experienced during the 2005-06 drought event. The outage allowance is based on total outage (full plus partial outage) and on how we have forecast total outage to reduce in line with the outage recovery plan though the end of AMP6 to the end of AMP7.

The outage allowance profile follows a glide path, starting at 76 Ml/d at the beginning of AMP7 and reducing to 35 Ml/d by the end of AMP7. The outage allowance for the rest of the planning period from AMP8 (2025-26) to 2070 is set at 35 Ml/d in the normal and drought (1 in 20 year severity) planning scenarios in our WRMP19. In the severe drought (1 in 200 year severity) and extreme drought (1 in 500 year severity) planning scenarios the allowance for total outage is lower (29.5 Ml/d) to reflect the levels of outage that we expect to maintain during more severe drought events. This is based upon full outage data from 2005-06 and includes an allowance for partial outage. Whilst the risk of some outage causes may increase in severe drought events (e.g. due to deteriorating raw water quality), we would do everything possible to fully utilise existing source of supply in order to maintain supplies to cutomers and avoid implementing drought permits and orders which have an environmental impact. The outage event of 2005-06 provides some evidence of the level of outage which could be maintained in such circumstances which is why we have used it as a best estimate of the outage allowance in severe and extreme droughts.

It is important to note that one of the key drivers to the approach we have followed in the WRMP19 is the fact that adopting higher outage allowances would result in larger supply-demand deficits, triggering a need for more or larger water resource schemes to manage the supply-demand balance. These would likely be more expensive than maintaining a lower outage level. However, there will be a point at which it becomes more expensive to maintain a low outage level than to implement a new demand management or supply scheme. We believe applying a similar concept as the economic level of leakage to outage could be explored further in future and in dialogue with regulators.

References

- UKWIR, 1995, WRP-0001/B Outage Allowances for Water Resource Planning
- UKWIR, 2016, 16/WR/02/11 WRMP 2019 METHODS – RISK BASED PLANNING

Results of investment model sensitivity test showing impact of using draft WRMP19 outage allowance

				AMP6				AMP7					AMP8		AMP8			AMP9	AMP10	AMP11	AMP12	AMP13	AMP14	AMP15	AMP16
Area	State of the world	Option reference	Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2064	2065-2069
Central	Severe AA	DO_SI_Har	Preferred	0.0	0.0	0.0	0.0	8.3	8.3	8.3	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	8.3	8.3	8.3	8.3	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		CM_NeM	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	5.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9	10.9
		CM_Phm	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	8.1	8.1	6.2	2.2	1.2	0.6	0.8	1.2	1.5	2.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	8.1	8.1	8.1	8.1	8.1	6.6	6.8	7.6	7.8	8.1
		DO_DI-SN	Preferred	0.0	0.0	0.0	0.0	5.3	5.3	5.3	5.3	5.3	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	5.3	5.3	5.3	5.3	5.3	5.3	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PWR_For20	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	4.0	1.9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		EXI_Hou	Preferred	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0
	Severe CP	DO_SI_Har	Preferred	0.0	0.0	0.0	0.0	16.8	16.8	16.8	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	16.8	16.8	16.8	16.8	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DO_SI_Wei	Preferred	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	5.4	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		CM_Hou	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	4.1	2.5	0.6	0.0	0.0	0.2	0.4	1.1
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.0	6.0	6.0	6.0	6.0	4.9	5.1	5.0	6.0	6.0
		CM_NeM	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	11.7	11.7	11.7	11.7	11.7	11.6	11.7	11.7	11.7	11.7
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
		CM_Phm	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	8.1	7.0	5.2	1.6	0.2	0.0	0.0	0.0	0.1	0.2

				AMP6				AMP7					AMP8		AMP8			AMP9	AMP10	AMP11	AMP12	AMP13	AMP14	AMP15	AMP16
Area	State of the world	Option reference	Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2064	2065-2069
Eastern	Severe AA	CM_Min	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.1	5.7	4.5	3.6	5.7	5.7	5.7	5.7	5.7	5.2	5.1	5.7	5.7	5.7	5.7
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	5.7	4.9	4.0	5.7	5.7	5.7	5.7	5.2	4.7	4.6	5.7	5.7	5.7	5.7
		DO_SI_Ket	Preferred	0.0	0.0	0.0	0.0	7.5	7.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		DO_SI_Bew	Preferred	0.0	0.0	0.0	0.0	16.2	16.2	16.2	16.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

				AMP6				AMP7					AMP8		AMP8			AMP9	AMP10	AMP11	AMP12	AMP13	AMP14	AMP15	AMP16
Area	State of the world	Option reference	Scenario	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2059	2060-2064	2065-2069
Western	Severe AA	CM_Tim	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.3	0.0	0.0	0.0	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	3.6	3.5	3.5	3.4	3.4	10.8	10.7	10.7	10.5	10.5	10.5	10.4	10.5	10.6	10.6	10.7
		BS_Kna	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	10.8	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	11.4	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
		DES_FawM50	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	25.0	23.7	21.4	18.4	17.7	17.5	19.1	21.8	23.2
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	25.0	21.1	18.8	17.2	16.0	17.2	18.7	20.0	21.5
		DES_FawM75	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	9.4	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PWR_SEY9	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		IWR_SCM9	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.3	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
		PWR_SEY5	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Severe CP	CM_Tim	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.7	0.0	0.0	0.0	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	3.0	2.9	2.9	2.8	2.8	10.1	10.1	10.0	9.8	9.7	9.7	9.6	9.7	9.8	9.8	9.9
		DES_FawM25	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	7.7	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	6.3	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
		DES_FawM50	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	25.0	20.7	18.2	9.0	13.8	6.5	7.2	16.0	16.6
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	24.8	19.1	16.5	14.7	13.2	13.2	14.0	15.4	16.1
		DES_FawM75	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.3	7.7	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		PWR_SEY9	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		IWR_SCM9	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
		PWR_SEY5	Preferred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			dWRMP Outage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0