WRMP 2019 Technical Document:

Supply Forecast

December 2019

Utility Week Awards 2018 Winner – Utility of the Year

The Queen's Awards for Enterprise: Sustainable Development 2015

This is a technical report that supports our WRMP submission.

This report provides an overview of our supply forecast. It explains the methodologies we have used to calculate deployable output and assess impacts from sustainability reductions, climate change and severe drought.

Contents

Executive Summary

We have developed our Supply Forecast in line with the relevant guidance and this document details the technical methodologies used.

Feedback from the Environment Agency following our WRMP 2015 and the 2011/12 drought, and our Problem Characterisation assessment, demonstrated that we needed to build our understanding of how system performance affects deployable output (DO).

We have addressed this by building a system model in Aquator to calculate system DO. This builds on the discrete source-based methodology previously used. Using Aquator, we have refined our understanding of issues relating to system connectivity and conjunctive use of resources.

Our Problem Characterisation assessment also showed we needed to develop our understanding of supply system performance in severe and extreme drought. We have carried out a systematic analysis of historical and stochastic droughts using extreme value analysis, hydrological modelling and system modelling using Aquator.

This work identified a DO impact of moving to a severe drought (approx 1 in 200 year return period) across all WRZs of 26.3 Ml/d. The analysis also concluded that some of our historical design droughts were of a severity equal to or greater than 1 in 200 years.

This is consistent with Risk Composition 2, providing a resilience tested plan considering a more challenging but plausible range of droughts.

We have also considered the risk to supply from an extreme 1 in 500 year drought event.

In addition we see significant impacts on DO from climate change and sustainability reductions in AMP7.

The sustainability reductions impact is 85.3 Ml/d. This includes impacts from both WINEP no deterioration recent actual licence caps in 2022 and sustainability reductions identified through the AMP6 National Environment Programme in 2024-5. The DO impact includes the benefit of associated mitigation options.

The total modelled climate change impact in the median scenario is 57.7 Ml/d in 2045, which we have calculated using the revised scaling equation. This has been applied from 2020 onwards, as following the consultation on our dWRMP we have chosen not to delay investment in climate change impacts. There remains uncertainty regarding impacts, and we have included this in headroom.

To avoid double counting of DO impacts at the same sources, we have applied an order of impact reflecting licence changes, changes to levels of service and then climate change.

1. Introduction

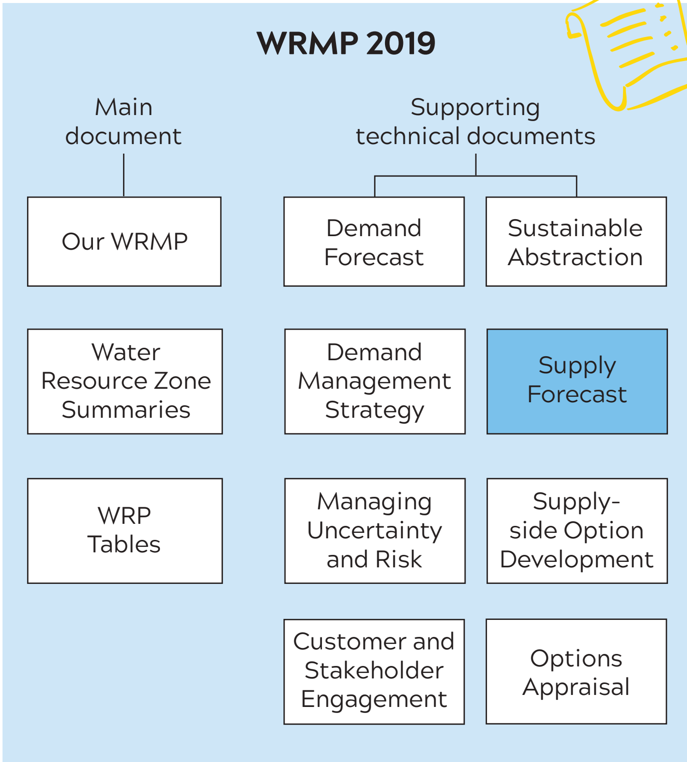
1.1 Overview

The purpose of the Water Resources Management Plan (WRMP) is to ensure a secure and sustainable supply of water, focusing on efficiently delivering the outcomes that customers want, while reflecting the value that society places on the environment. In our WRMP we have presented a reliable supply of water in the base year forecasted to 2045, in accordance with the Water Resources Planning Guideline (WRPG)[1]. This is how much water is reliably available to supply customers in each of our Water Resource Zones (WRZs) through the design drought.

Our WRMP 2019 submission is comprised of several reports, as set out in the diagram below. The main submission is supported by technical documents that explain our methodologies and provide the detailed results of our analysis.

This report describes the supply forecast process undertaken by Anglian Water in support of the WRMP 2019 to assess our sources' response to current constraints, climate change, sustainability reductions and droughts. We have cross-referenced to relevant points in the Environment Agency Checklist which are detailed in each section.

Figure 1.1 WRMP 2019 Submission



Reshaping the WRMP 2019

The constructive feedback we received from the consultation process has played a significant role in shaping our WRMP 2019.

The key changes we made to the modelling assumptions used in our WRMP 2019 are set out in the table below.

Table 1.1: Key changes between draft WRMP and WRMP 2019

	draft WRMP	WRMP 2019
Supply forecast	• Climate change impacts in AMP7 from 2024-25. • Sustainability reductions phased over AMP7 and AMP8. • Drought impacts in AMP7.	• **Climate change impacts in AMP7 from 2020-21.** • **Sustainability reductions take effect in AMP7.** • **Drought resilience enhanced by 2025.**
Neighbouring company trades	• Grafham reverse trade available from Affinity Central until 2029 (18 Ml/d). • Ardleigh agreement with Affinity Water East 70:30 in our favour for entire 25 year plan.	• **Grafham reverse trade not included.** • **Ardleigh agreement with Affinity Water East 50:50 from 2025.**

[1] *Environment Agency and Natural Resources Wales, April 2017, 'Water Resources Planning Guideline: Interim update'*

1.2 Developing our Supply Forecast

Table 1.2: WRMP 2019 - Water company checklist: 1.2 Developing Supply Forecast

Number	Action
87	Your approach to calculating your supply forecast is consistent with your risk composition choice, and the risk and uncertainty involved have been quantified using appropriate methods.
88	You have discussed your approach to calculating your supply forecast as early as possible with the Environment Agency or Natural Resources Wales.

The guidelines state that water companies should demonstrate they understand how their sources respond to droughts and the current constraints on and future changes to the water the sources can reliably supply.

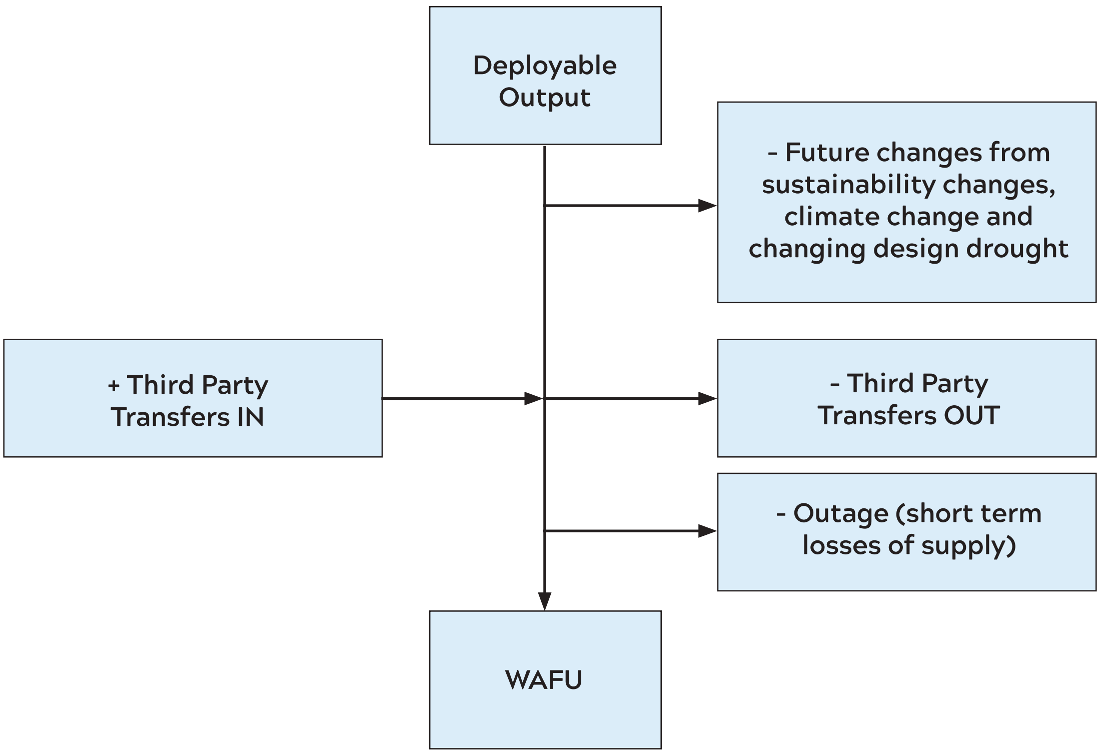
Our reliable supply of water is assessed as our Water Available For Use (WAFU), depicted in Figure 1.1. The WRPG states this needs to comprise:

- The deployable output (DO)
- Future changes to deployable output from sustainability changes, climate change and any other changes you may be aware of
- Transfers and any future inputs from a third parties
- Short term losses of supply and source vulnerability known as outage
- Any operational use of water or loss of water through the abstraction - treatment process.

The report is structured to detail the approach we have taken to quantify each of these elements. In line with the guidance, we have considered all individual components making up the supply forecast, and taken account of pressures on future supplies. We consider each element in turn:

- Supply forecast approach and DO assessment (section 2)
- Selection of design drought (section 3)
- Changing design drought (section 4)
- Climate change (section 5)
- Abstraction licence changes due to abstraction reform or sustainability improvements (section 6)
- Pollution or contamination implication for sources (section 7)
- Changes in contractual arrangements relating to transfers (section 8)

Figure 1.1: Deployable Output to WAFU process



1.2.1 Future changes to DO

The future changes to DO (sustainability reductions, drought and climate change) have been assessed in a fixed order to avoid double counting of impacts at the same sources:

1. sustainability changes,

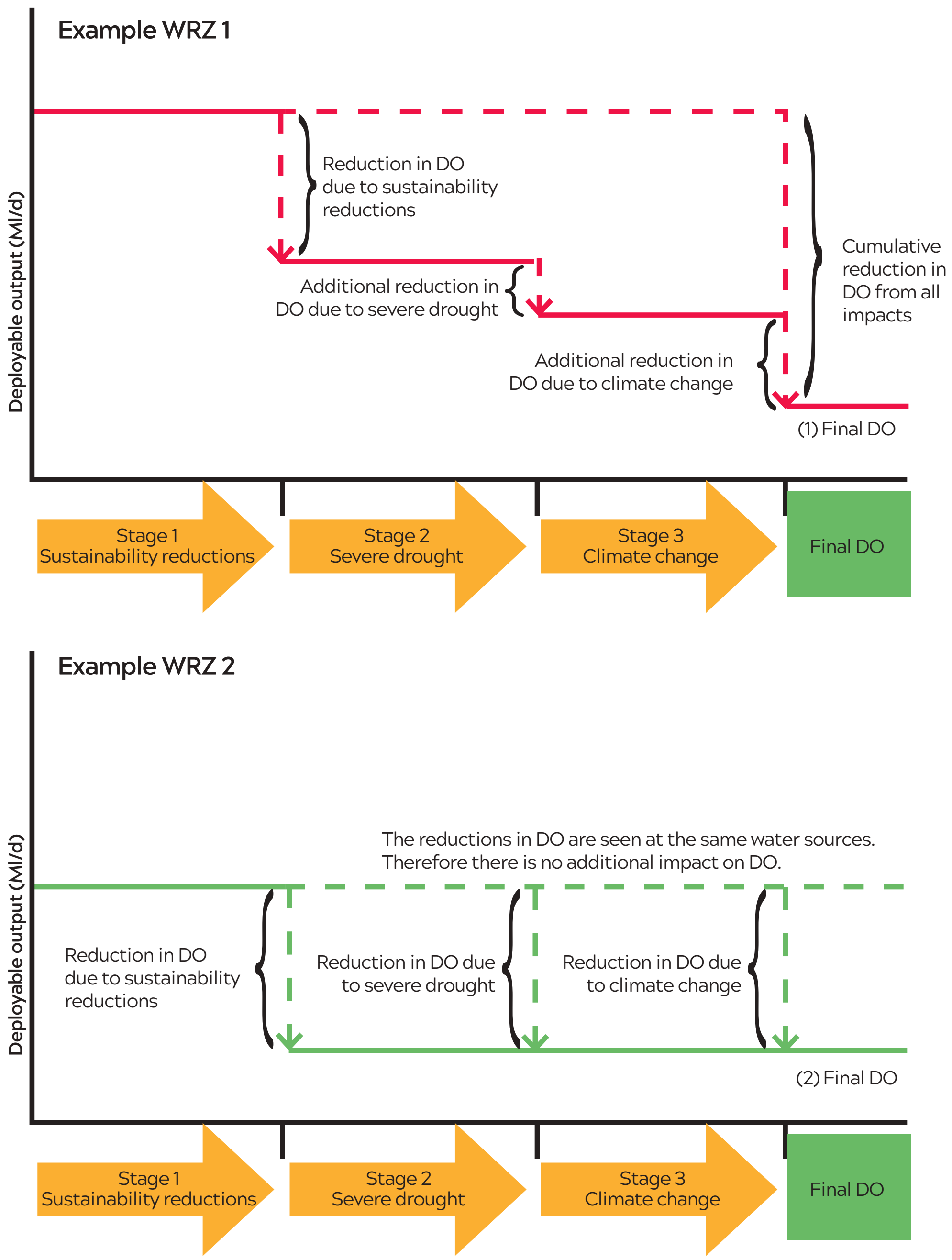
2. drought; and

3. climate change.

The order of impact reflects changes to licences first, then Levels of Service, followed by other changes in deployable output.

Modelling in this way allows each impact to be quantified and avoids double counting of impacts at sources vulnerable to more than one impact. Detail on how we have quantified and applied the impact of each change is detailed in the following sections. In summary, sustainability reduction impacts are seen from 2021 and have been entered into the baseline model as licence changes. Drought inputs are subsequently run through this new model, to identify additional drought impacts. This version of the model is then run again with climate change inputs. Climate change impact is calculated for the 2080s, and scaled back so that the impact can be determined for each year of the planning period.

Figure 1.2: The effects of our adopted order of impact on deployable output (DO) on two representative theoretical WRZs with multiple supply impacts



In both examples, sustainability changes are applied to the deployable output model, resulting in a deployable output reduction. Drought inputs are subsequently run through the revised model, to identify additional drought impacts. This version of the model is then run again with climate change inputs. Modelling in this way allows each impact to be quantified and avoids double counting.

In example WRZ (1), there is both additional drought and then climate change deployable output reductions realised in the modelling, resulting in a cumulative total impact on the final deployable output.
In example WRZ (2), no additional impact from either drought or climate change has been realised, and therefore there is only a sustainability reduction on the final deployable output.

Sustainability changes

Through the AMP6 National Environment Programme (NEP) we have worked with the Environment Agency and Natural England to understand where our current abstractions were causing, or had the potential to cause, environmental harm, and agree sustainability changes and associated mitigation measures required in AMP7. These are set out in the AMP7 Water Industry National Environment Programme (WINEP). In line with our WINEP obligations, we will be implementing a significant number of sustainability reduction schemes in AMP7 including schemes for the River Lark, River Nar, Catfield Fen, River Idle, River Poulter, and Bumpstead Brook. We will deliver all of these obligations by March 2025. We are also committed to delivering two schemes in the Happisburgh WRZ to mitigate any impacts that our groundwater abstraction may be having at Catfield Fen and the wider Ant Broads and Marshes.

Sustainability changes are also being driven by the need to prevent any potential deterioration through the Water Framework Directive (WFD). As such, we have committed to maintaining all of our groundwater abstractions below recent historical abstraction rates, where reasonably practicable, in order to eliminate the risk of deterioration. This is ahead of formal licence changes which are expected from 2022 onwards for many time-limited licences and in AMP8 for many permanent licences. In order to address this change and take account of the uncertainties surrounding future abstraction licence volumes, we have assessed the impact of sustainability changes on all groundwater sources in 2022 in our supply forecast. The impacts of the sustainability changes on DO is discussed further in Section 3. Further detail is provided in the Sustainable Abstraction supporting technical document.

Design drought

We have thought carefully about what Levels of Service are appropriate for our customers and our region. We believe that our Levels of Service for Temporary Use Bans and Non-Essential Use Bans are appropriate and we do not propose to make any changes to them in our WRMP.

However, we do not believe that our Level of Service for severe restrictions is appropriate or acceptable. In line with guidance, we also need to plan for future droughts that may be worse than we have historically seen, and therefore our objective is to ensure that no customers are exposed to the risk of standpipes and rota-cuts in a severe drought event by the end of AMP7. For modelling purposes, we have applied this impact on DO in 2025. This is discussed further in Section 4 and Appendix 2.

Climate change

Following the consultation on our dWRMP we have chosen not to delay investments in climate change impacts. Our dWRMP supply forecast modelled climate change impacts from 2024-25 onwards. For our final WRMP we have included climate change impacts from the start of the WRMP planning period (2020-21). Adopting the new methodology and factoring in the consultation feedback in this way has resulted in a large climate change impact in 2020, which increases year on year throughout the planning period to 2045.

1.2.2 Risk Composition and Guidance

Our method for deployable output determination is consistent with Risk Composition 2 (“resilience tested plan - consider a more challenging but plausible range of droughts”) which is discussed in more detail in the Supporting Technical Report: Managing Risk and Uncertainty. We have referred to WRMP 2019 Methods - Risk Based Planning: Guidance (UKWIR, 2016) or the Handbook of Source Yield Methodologies (UKWIR, 2014) as required.

1.2.3 Engagement with EA

We have engaged with the Environment Agency in the development of our Supply Forecast approach through a number of Methods Discussion meetings. All the Methods Discussion meetings have been minuted and we have maintained an action log.

Table 1.3: Supply Forecast Method Discussion meetings

Meeting date	Agenda items
20.09.2016	Deployable output assessment, Climate change projections and alignment with tiers, NEP mitigation options in options appraisal, Severe drought impact assessment, Table 10
10.01.2017	Aquator model build and Water Resource Zone Integrity Assessment
17.01.2017	Climate change impact assessment, Severe drought selection, Severe drought impact assessment
24.02.2017	Approach to ‘WFD no deterioration’, Incorporating WFD into the DO assessment
30.03.2017	Overview of WRMP DO assessment methodology for the supply forecast
07.09.2017	Drought permits

2. WRMP 2019 Supply Forecast Approach

Table 2.1: WRMP 2019 - Water company checklist: 2 WRMP 2019 Supply Forecast approach

Number	Action
72	You have explained the assumptions made when assessing baseline figures for your supply forecast. You have demonstrated that the baseline case represents the supplies that can be maintained through a design drought as appropriate for your company area.
89	You have considered all individual components making up the supply forecast, and taken account of pressures on future supplies including (but not limited to): • Climate change • Abstraction licence changes due to abstraction reform or sustainability improvements • Pollution or contamination implication for sources • Development and new infrastructure • Changes in contractual arrangements relating to transfers. You have clearly documented all assumptions made.
105	Your method for deployable output determination is consistent with your risk composition and the methods outlined in Handbook of source yield methodologies (UKWIR, 2014) or WRMP 2019 Methods - Risk Based Planning: Guidance (UKWIR, 2016); you have fully explained and documented your choice of method and supporting techniques.
137	You have recorded how you have calculated treatment works losses and operational use for each WRZ.
143	You have applied your approach consistently across all WRZs.

We define our DO for the WRMP 2019 as the annual average output that can be reliably supplied from a commissioned source or group of sources for a WRZ, during the design drought, with current investment.

To assess baseline DO and demonstrate supplies can be maintained through the design drought, we have built an Aquator water resource systems model to represent our system. This builds on the discrete source-based approach we used in WRMP 2015, and our existing strategic systems model in MISER. We have also calculated the critical period DO where applicable, and describe this further in Section 9.1.

We have assessed DO in accordance with the processes set out in the Handbook of Source Yield Methodologies (UKWIR, 2014). The overall assessment process presents four key stages which relate to data collation, analysis and interpretation, assessment of yields and constraints and finally DO evaluation.

2.1 Hydrological yield updates

The first step in assessing DO is to understand the hydrological yield of the source. The UKWIR Handbook defines hydrological yield as the daily volume from a source that can be sustained by the catchment or aquifer feeding that source. It is unconstrained by any physical or regulatory constraints. For water resources planning purposes we assume the hydrological yield represents the volume that can be taken in the worst drought at that source.

2.1.1 Surface water yield updates

Historically, we have assessed direct intake yields directly from simulated flows, and reservoir yields are assessed using OSAY (Operating Strategy for Assessing Yield), an in-house reservoir assessment model. In the WRMP 2019, we have continued to use these established methods to assess the hydrological yield of our surface water reservoirs and intakes respectively to allow comparison with WRMP 2015 figures.

River flow data has been simulated using our rainfall-runoff models as follows:

- HYSIM, used to provide flows for the direct river intakes: Stoke Ferry, Marham, Heigham, Clapham and Hall*. The model uses rainfall and PET data to generate surface runoff, percolation to groundwater and river flow.
- SIMFLOW, which is based on the Stanford Watershed Model, is used for the catchments contributing to the following reservoirs: Alton, Ardleigh, Grafham, Rutland, Pitsford, Ravensthorpe and Hollowell. The model is used for reproducing river flows at the reservoir intake points. The Stanford Watershed Model is a lumped parameter model that considers the catchment as a single unit upstream of a defined outflow point (e.g. a gauging station). The model outputs include daily streamflow, groundwater recharge, evapotranspiration and soil moisture storage. For these existing models, major catchments have been subdivided into smaller, reasonably homogeneous sub-catchments, in which surface geology, topography and land-use were assumed consistent.

The models were updated in 2016. Rainfall and potential evapotranspiration (PET) input data sets were extended to the end of 2015 (from 1920) in line with available data. Special consideration was given to the Grafham SIMFLOW model to account for a change in the Environment Agency's method of deriving flows at Offord, the abstraction point for Grafham reservoir on the River Great Ouse.

Revised bathymetric surveys were undertaken for all reservoirs to update the reservoir volume. In some cases the improved survey accuracy has resulted in an increase to reported reservoir capacity and therefore yield. A summary of the yield updates is provided in Tables 2.2 and 2.3 below. Full details of the rainfall-runoff update and yield assessment processes are in a separate yield assessment report by Mott MacDonald, 2016 .

The exception is for the Cadney intake, for which the flows and yield are calculated as part of the Environment Agency's Trent-Witham-Ancholme scheme assessment, as it is a supported source.

Table 2.2: 2017 direct intake yields updates for baseline supply forecast approach

WRZ	Direct Intakes	WRMP 2015 yield (Ml/d)[3]	WRMP 2019 yield (Ml/d)[2]	Explanation for change
Norwich and the Broads	River Wensum at Heigham	N/A	69	Not previously assessed (Costessey)
South Fenland	River Nar at Marham	14	13	Change to PET data
North Fenland	River Wissey at Stoke Ferry	12	11	Change to PET data
RHF South	River Great Ouse at Clapham	43	38	Change to PET data
East Lincs	River Ancholme at Cadney	72	75.3	Reviewed in 2017 EA-AWS assessment (Atkins, 2017[4])
Central Lincs	River Trent at Newton (Hall)	N/A	20*	Not previously operational.

**Hall is a direct intake on the River Trent and is a new source of supply for this WRMP. It is modelled using a rainfall-runoff model built in HYSIM by Mott MacDonald. We are reporting Hall intake with a 20 Ml/d yield under a 1 in 100 year return period. This is based on a review of historic drought return periods. For drought events more severe, we will seek to apply for a drought permit, which would involve increasing the permissible abstraction by lowering the Hands off Flow. Following WRMP investment, by the end of AMP7 we are investing in the Central Lincolnshire WRZ to ensure it is secure to a 1 in 200 year drought event. The Hall yield assessment and return period analysis is discussed further in Appendix 1.*

[2] *Mott MacDonald (2016) Surface Water Yield Assessment Update 2016*
[3] *Mott MacDonald (2012) Surface Water Yield Assessment Update 2012*
[4] *Atkins (2017) Trent Witham Ancholme Assessment Memo*

Table 2.3: 2017 OSAY reservoir yield updates for baseline supply forecast

WRZ	Reservoir	WRMP 2015 yield[5] (Ml/d)	WRMP 2019 yield[6] (Ml/d)	Comment
East Suffolk	Alton	34.0	35.0	This increase reflects a number of small changes to the reservoir and treatment works
South Essex	Ardleigh*	27.7	28.3	Increase in reservoir capacity
East Lincs	Covenham	59.5	59.0	Slight decrease reflects a number of small changes to the system
RHF South	Grafham	249	236	Change to the determination of Offord flows. This change led to reduced low flows and hence a reduction in reservoir yield
RHF North	Pitsford	40.5	39.0	Change in PET which led to decreased inflows and hence yield, offset by increase in reservoir capacity
RHF North	Ravensthorpe and Hollowell	7.0	6.5	Change in PET which led to decreased inflows and hence yield
RHF North	Rutland	324	337	This increase reflects an increased reservoir capacity

* Includes Balkerne river support. Total yield before Affinity Water take

Aquator does not use the calculated yield figures, but instead uses river flows directly to model dynamic reservoir and direct intake yields. Flows required denaturalisation to account for wider catchment abstractions and discharges not specifically included in Aquator. The updated PET series has also been used directly in the model, to represent reservoir evaporation.

2.1.2 Groundwater yield assessments

Groundwater source potential yields (PY) for a selection of sources were updated following the procedures outlined in the UKWIR Handbook, using UKWIR summary diagrams.

Of our 200 groundwater sources, 47 were considered to require a PY update, based on a weighted prioritisation process covering the following criteria:

- Average PY close to licence
- Peak PY close to licence
- DO constrained by PY
- Drought Risk Status
- PY recently reviewed
- Significant change to source
- Growth Forecast for the WRZ

The updates resulted in a total yield reduction of over 50 Ml/d, due to various factors including new/decommissioned boreholes, updated test pumping data, operational regime and more accurate deepest pumping water level assumptions.

Average groundwater yields are entered directly into Aquator as fixed average PY. This is calculated as the monthly average daily abstraction during a drought year. Peak PY is calculated as the maximum seven day rolling daily average abstraction in a drought year[7]. Full details of the methodology and yield updates are presented in ‘Source Reliable Output Update, Groundwater’ (Mott MacDonald, 2017).

2.2 DO constraint review

Constraints on a water resource system limit the hydrological yield available for supply. In accordance with the guidance, we have reviewed and updated the constraining components where required, as summarised below. We identify which components constrain DO in Section 2.6.

2.2.1 Licences and environmental constraints

Daily and annual abstraction limits are provided for each source/group of sources. The majority of our source licences sit within constraining group licences. It is assumed for the baseline scenario all licences up

[5] *Mott MacDonald (2012) Surface Water Yield Assessment Update 2012*
[6] *Mott MacDonald (2016) Surface Water Yield Assessment Update 2016*
[7] *Mott MacDonald (2017) Source Reliable Output Update, Groundwater*

for renewal will be renewed at their current volumes unless changes have been upfront permitted. Licence conditions such as Hands Off Flow (HOF) and Minimum Residual Flow (MRF) conditions or other environmental constraints have also been included.

2.2.2 Volumetric constraints

To estimate accurate reservoir volumes and account for storage losses due to sedimentation, bathymetric surveys have been updated for all reservoirs. These have been used to inform reservoir capacities used in the yield assessments and reservoir representation in the Aquator model.

2.2.3 Infrastructure constraints

Infrastructure constraints and assumptions - primarily pump capacities, Water Treatment Works (WTW) capacities, and WTW losses - were reviewed through a DO component review in summer 2016.

- **Pump Capacity**
  Capacities used in the previous WRMP were compared against telemetry data, pump databases, known operational issues and maintenance plans, to ensure that the most accurate values are used for planning. Any discrepancies were discussed with technical and operational staff and only changed where appropriate.

- **WTW losses**
  This was previously referred to as wash water losses but has now been changed to WTW losses, to include other losses in the process such as instrument waste. To establish accurate values for this component, the last 5 years of telemetry data for incoming and outgoing WTW flow was analysed, combined with discussions with operational colleagues. All surface water sources and groundwater sources with a previously defined loss of 5% or higher were reviewed, and amended if appropriate.

- **WTW Capacity**
  WTW capacity was reviewed through discussion with operational staff for sources where it was the constraining DO factor. Capacities were only changed where there was sufficiently credible supporting evidence; otherwise they remained at the WRMP 2015 figures.

- **Non-continuous running ratio (NCR)**
  The NCR is a reduction to WTW output to reflect that on average pumping hours are not continuous. It was previously included as 75% of peak DO, but for the WRMP 2019 this assumption has been revised to 87.5% WTW output, to provide consistency with the assumption of 21/24 hours pumping used in option costings to better reflect actual practice.

- **Network constraints and operating rules**
  Pipe capacities, network schematisation and operating rules required for system representation in the Aquator model were taken from our existing MISER systems model. Where Aquator required new operating rules, to capture system processes or assumptions not previously modelled, these were developed with operating staff to ensure they are realistic.

2.2.4 Water quality constraints

Water quality constraints such as blending ratios or treatment restrictions have also been reviewed and are included where possible. The capture of blending ratios in Aquator is still being refined. Short-term water quality risk such as pollution is captured in outage and long-term water quality deterioration (for groundwater only) is captured in headroom.

2.3 DO assessment approach

Our approach to calculating DO for the WRMP 2015 supply forecast was to individually define a maximum output for each source in an WRZ, with the total output for a WRZ being the aggregate output of all the individual sources within it. Whilst this approach is robust and consistent with WRP Guidance, it does not fully account for effects linked to connectivity and supply-system operation.

Regulatory feedback from our WRMP 2015 and response to the 2011/12 drought, was that we lacked a strategic model able to simulate the wider supply system under a range of both historic and future scenarios.

To support the WRMP 2019, we have built a water resources system model in Aquator, which allows an assessment of system rather than individual source DO. We currently have an existing strategic system model in MISER, but this does not have the capacity for DO assessment. Aquator was considered better on aspects including upstream hydrology modelling performance, model flexibility (VBA coding), industry standard for DO assessments and planned future developments.

We have continued to use the spreadsheet based assessment for comparison and to allow clearer WTW level understanding of DO, but the WRZ DO reported in the dWRMP supply forecast is modelled in Aquator. The DO spreadsheet was updated with current licences, updated yields and updated DO constraints gathered through the 2016 review. A detailed comparison exercise of input data for both Aquator and the updated spreadsheet was carried out to ensure they used the same input data.

2.4 Moving to a system model

2.4.1 Benefits of a system model

Moving to a system model allows the wider system to be considered conjunctively to better demonstrate how resources can interact. This is of particular benefit to our Ruthamford and Lincolnshire systems which are partially integrated. It provides a better representation of critical infrastructure constraints on DO, providing an understanding of how network connectivity influences DO. This cannot be captured through the individual source-based assessment which assumes all DO is available to supply the WRZ demand. Representing the region in one model also allows testing of spatial coherence and combined impacts of climate change, sustainability changes and drought.

2.4.2 Aquator pilot project

An initial investigation was undertaken to trial Aquator and assess the vulnerability of our Ruthamford system to a severe drought and development of options to increase the system's resilience. The project objectives were to:

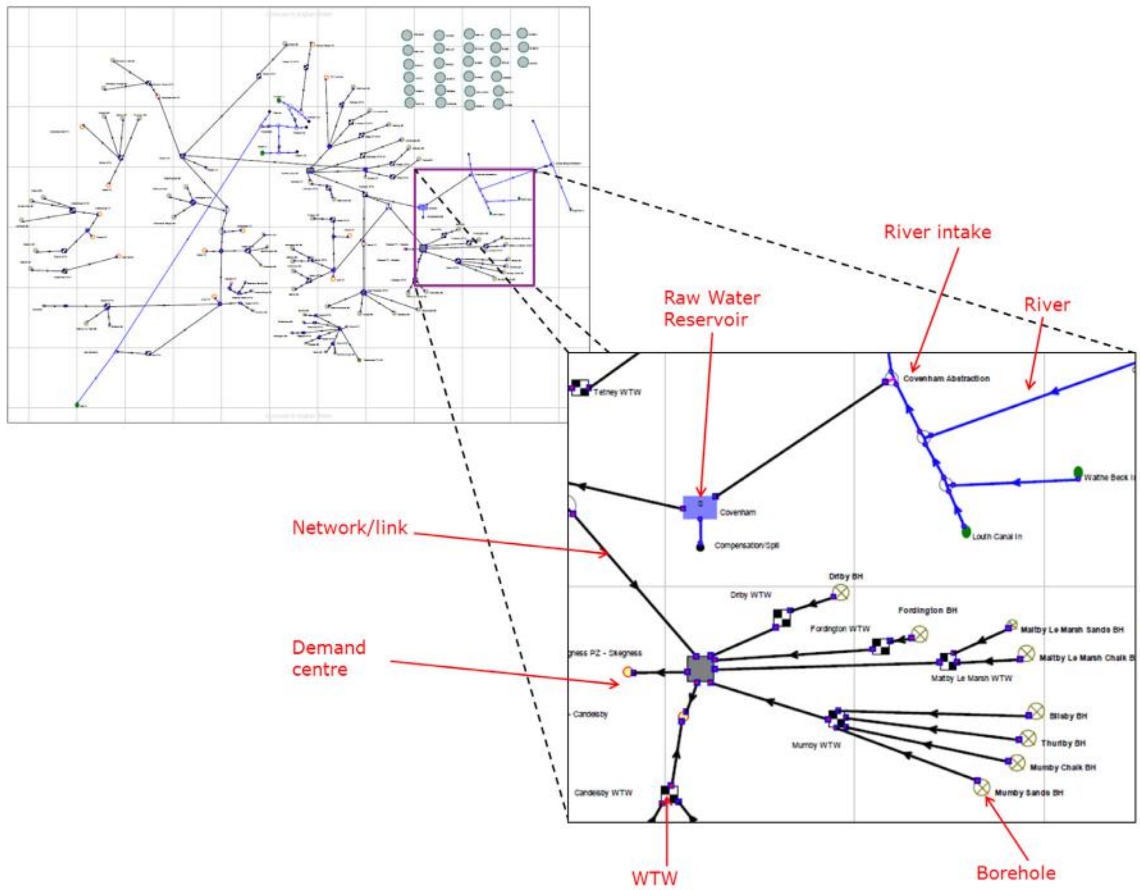
- Build a system model for Ruthamford and establish current DO
- Confirm the impact of a third dry year drought on DO
- Develop feasible options if required.

An Aquator model was built for the Ruthamford system and used for baseline and severe drought assessments. This provided a valuable platform to test the functionally and fit of Aquator to the most conjunctive part of our region. The Ruthamford model build was also subject to a peer review by a panel of experts, and their comments and lessons learned have been used to inform the development of the WRMP 2019 model.

2.5 Model build

Aquator allows a schematised representation of sources (reservoirs, direct intakes, boreholes), assets (WTWs, pipelines) and how they link with various demand centres (DCs). It should be noted that the model can only ever be a representation of what is in practice a complex network, but must include the key constraints on water movement (capacities, network constraints) and resource availability (river flows, licence conditions) to adequately assess the DO at a WRZ level. This simplification is necessary to ensure models are manageable, have a reasonable file size, and have a run time that is not excessive. An example of the system representation in Aquator is included below in Figure 2.1.

Figure 2.1: Example Aquator model and key features



The Aquator model schematisation and network capacities have been based on our existing strategic MISER system model. This was updated in 2016 as part of the MISER model update, which informed the WRZ Integrity Assessment. The sub- system components, such as yields, WTW and pump capacities, were also reviewed and updated in 2016 as detailed in Section 2.1 and 2.2.

Three sub-regional models representing the Lincolnshire, Norfolk, and Essex and Suffolk water resource systems were built. The existing Ruthamford model was updated to include lessons learned from the pilot project and improvements to the modelled representation, including a fixed import to South Lincolnshire. These sub-regional models allowed parallel working and quicker run times.

The verification process underwent a specific expert peer review during the model build process to ensure the methodology was appropriate and comments addressed as necessary. In addition the peer review panel have been re- engaged to carry out a current wider review of the overall approach of the model build and assumptions used to provide an opinion on if the model is ‘fit for purpose’ and recommendations for improvements.

Full details of the model build and verification are provided in separate Aquator reports (Mott MacDonald, 2017)[8,9].

2.6 Baseline DO assessment methodology

2.6.1 Approaches to assessing Deployable Output within Aquator

Aquator has two inbuilt methods for Deployable Output analysis. These are known as the English and Welsh method and the Scottish method.

- **English and Welsh method**
  The English and Welsh method takes the first failure of a DO run as being the DO. In addition, the user can specify whether or not Levels of Service (LOS) form part of a failure condition, with the user able to specify the maximum number of crossings of LOS curves (the number of crossings is equivalent to a return period when compared against a time series of known length).

- **Scottish method**
  The Scottish method steps through demand at set intervals and records the number of failures. The DO is then stated as a function of the number of failures using an extreme value distribution. For example, the 1 in 40 DO could be calculated as a run which has no more than two failures in an 80 year simulation.

For the WRMP 2019, we consider the English and Welsh method to the most appropriate for DO assessment. This is because demand failure, and thus DO, is defined by a single drought. In addition, the Scottish method does not take into account Levels of Service failures at this stage, and the English and Welsh method is consistent with other water companies.

2.6.2 Application of DO assessment method

Aquator is run at a starting base demand[10], with this demand being distributed across selected demand centres based on their relative contribution to overall demand. This base demand is tested by stepping through increasing demand values to find the maximum demand that can be satisfied from a source/system. The point demand can no longer be met is then considered to be the DO of the WRZ. It should be noted the demand in this context becomes theoretical as it is ramped up.

For Ruthamford, zones were considered conjunctively in a joint model to capture the existing inter-zone connections and drought resilience benefits. This required adaptation of the above approach. Following testing of various approaches, a resource zone scaling method was selected as the preferred approach. This allowed the DO of connected zones to be considered in relation to the WRZ in question.

For the WRMP we also considered Lincolnshire conjunctively in a combined RHF-Lincolnshire model. However due to changes in operational network configuration, we have revised this modelled arrangement and are now modelling RHF and Lincolnshire separately, but with a fixed transfer between South Lincolnshire and Ruthamford North to represent an existing transfer. We have also now modelled the Lincolnshire zones in isolation, as metaldehyde water quality constraints limit the zones from being fully conjunctive. This arrangement has been considered in detail through a number of model iterations, it was felt this arrangement provided better representation of the present Ruthamford-Lincolnshire connectivity. Modelling in this way also allows more accurate representation of impacts in the individual WRZs. We have undertaken a further system review and removed a number of intra-zone constraints in Aquator for both Central and East Lincolnshire that were affecting modelled DO, but are not considered to be constraints in reality. These model refinements have informed development of supply side options in the WRMP.

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[8] *Mott MacDonald (2017) Anglian Water Aquator Model Build and DO Assessment: Data Collation, Review and Model Build*
[9] *Mott MacDonald (2017) Anglian Water Aquator Model Build and DO Assessment: Model Verification*
[10] *from 2016, as reported in our annual company yearbook*

The English and Welsh DO method within Aquator records the first failure to supply and the resulting DO therefore represents the water supplied to a set of specified DCs one demand step below the first failure recorded by Aquator. This distinction is important at WRZ level, as within Aquator the DO represents the demand supplied to a set of DCs rather than the source output. In discrete zones, this is irrelevant as the demand supplied will be the same as the source output. However, in more complex zones with connections between WRZs this may not be true and the demand supplied may not be representative of the source output within a zone.

Full details of the DO assessment development and approach are included in a separate Aquator report (Mott MacDonald, 2018)[11].

2.6.3 Failure criteria

Within the models, failure criteria are routinely set as a failure to supply a DC or a reservoir entering Emergency Storage/LoS 3.

2.6.4 Baseline runs

The criteria for all baseline runs are as follows:

- Historic simulated flows from January 1920-December 2014;
- Current licence conditions;
- All network constraints in place.

2.7 WTW DO and constraining factors

The guidance defines DO as the output of a commissioned source or group of sources for the chosen design drought as constrained by:

- Hydrological yield
- Licensed quantities
- Environment (represented through licence constraints)
- Pumping plant and/or well/aquifer properties
- Raw water mains and/or aqueducts
- Transfer and/or output main
- Treatment
- Water quality
- WTW losses

To calculate individual WTW level DO and constraints, the DO spreadsheet has been used, as per WRMP 2015 methodology. As this method does not consider network connectivity and constraints which are included in the Aquator WRZ DO, an additional calculation has been applied to reflect this, so source DO is consistent with WRZ DO. This is summarised below in Table 2.4.

[11] *Mott MacDonald (2018) Anglian Water Aquator Model Build and DO Assessment: DO Assessment*

Table 2.4. Baseline DO and associated constraints

WRZ	Source-works	Source DO (Ml/d)	DO constraint (at source level)
Bourne	Wilsthorpe	18.55	Allocation of group licences
	Bourne	21.70	Allocation of group licences
	Etton	7.01	Allocation of group licences
	Tallington	7.01	Allocation of group licences
	Pilsgate	1.74	Allocation of group licences
	Total	**56.00**	
Bury Haverhill	Barrow Heath	7.35	Allocation of group licences
	Rushbrooke	8.74	Allocation of group licences
	Risby	2.42	Allocation of group licences
	Great Wratting	N/A	Allocation of group licences
	Kedington	6.06	Allocation of group licences
	Total	**28.00**	
Central Essex	Castle Hedingham	5.18	Allocation of group licences
	Halstead (Parsonage St)	1.33	Allocation of group licences
	Earls Colne	3.22	Allocation of group licences
	Total	**9.60**	
Central Lincs	Elsham (Potable)	24.24	Non-continuous running ratio
	Newton	40.18	Allocation of group licences
	Branston Booths	4.86	Allocation of group licences
	Dunston	2.15	Allocation of group licences
	Waddingham	4.02	Allocation of group licences
	Welton	5.17	Allocation of group licences
	Winterton	6.32	Allocation of group licences
	Barrow	30.07	Allocation of group licences
	Hall	20.00	Average yield
	Total	**137.00**	
Cheveley	Lower Links	1.70	Annual Average licence
	Total	**1.70**	

WRZ	Source-works	Source DO (Ml/d)	DO constraint (at source level)
East Lincs	West Pinchbeck	19.41	Allocation of group licences
	Maltby Le Marsh	1.95	Allocation of group licences
	Driby	3.01	Allocation of group licences
	Fordington	1.97	Allocation of group licences
	Candlesby	2.86	Allocation of group licences
	Mumby	5.02	Allocation of group licences
	Manby	3.74	Allocation of group licences
	Raithby	6.04	Allocation of group licences
	Barnoldby	2.85	Allocation of group licences
	Habrough	6.93	Allocation of group licences
	Little London	6.93	Allocation of group licences
	Healing	6.93	Allocation of group licences
	Little Coates	10.07	Allocation of group licences
	Weelsby	8.69	Allocation of group licences
	Tetney	0.00	Environmental constraint
	Covenham	44.01	Allocation of group licences
	Fulstow	3.56	Allocation of group licences
	Total	**134.00**	
East Suffolk	Alton	29.35	Alton licence limit
	Raydon	4.97	Annual Average licence
	Semer	3.59	Annual Average licence
	Tuddenham	3.38	Allocation of group licences
	Pettistree	5.65	Allocation of group licences
	Winston	1.38	Allocation of group licences
	Belstead	5.28	Average yield
	Whitton	10.25	Allocation of group licences
	Baylham	4.25	Allocation of group licences
	Bramford	10.15	Allocation of group licences
	Total	**78.25**	

WRZ	Source-works	Source DO (Ml/d)	DO constraint (at source level)
Ely	Beck Row	2.15	Allocation of group licences
	St Helena	4.04	Allocation of group licences
	Eriswell 1	3.13	Allocation of group licences
	Eriswell 2	6.65	Allocation of group licences
	Mildenhall (Twelve Acre Wood)	3.91	Allocation of group licences
	Isleham	4.11	Allocation of group licences
	Total	**24.00**	
Happisburgh	Royston Bridge	1.83	Allocation of group licences
	Ludham - Catfield	1.34	Allocation of group licences
	East Ruston	2.03	Allocation of group licences
	Total	**5.20**	
Ixworth	Ixworth/Stanton	6.20	Turbidity
	Total	**6.20**	
Newmarket	Warren Hill	3.57	Allocation of group licences
	Long Hill	1.98	Allocation of group licences
	Gazeley	1.59	Allocation of group licences
	Moulton	1.64	Allocation of group licences
	Newmarket (Southfields)	2.98	Allocation of group licences
	Ashley Road	4.24	Allocation of group licences
	Total	**16.00**	
North Fenland	Stoke Ferry	12.06	Allocation of group licences
	Hillington	19.70	Allocation of group licences
	Ringstead	2.21	Annual Average licence
	Fring	3.04	Allocation of group licences
	Total	**37.00**	

WRZ	Source-works	Source DO (Ml/d)	DO constraint (at source level)
North Norfolk Coast	Mundesley	0.80	Annual Average licence
	Glandford	4.09	Annual Average licence
	Sheringham	4.29	Annual Average licence
	Houghton St Giles	5.52	Allocation of group licences
	Wighton	1.37	Allocation of group licences
	Aylsham (Coldham Hall)	1.75	Allocation of group licences
	Aylsham	1.90	Allocation of group licences
	Metton	3.93	Allocation of group licences
	North Walsham	0.57	Allocation of group licences
	Foulsham	0.99	Allocation of group licences
	Salle Bridge	0.79	Allocation of group licences
	Total	**26.00**	
Norfolk Rural North	Carbrooke	1.78	Non-continuous running ratio
	Didlington (High Ash)	1.74	Annual Average licence
	East Watton	1.88	Environmental constraint
	Watton	2.71	Non-continuous running ratio
	East Dereham	2.94	Allocation of group licences
	Wicklewood (High Oak)	5.15	Average yield
	Old Buckenham	1.26	Allocation of group licences
	Beetley	2.01	Allocation of group licences
	West Bradenham	3.75	Allocation of group licences
	North Pickenham	3.77	Allocation of group licences
	Total	**27.00**	

WRZ	Source-works	Source DO (Ml/d)	DO constraint (at source level)
Norwich and Broads	Kirby Cane	2.15	Annual average licence
	Heigham	45.56	Allocation of group licences
	Little Melton	6.93	Allocation of group licences
	Thorpe (Mousehold)	7.30	Allocation of group licences
	Caistor	10.86	Allocation of group licences
	Lyng Forge	2.76	Allocation of group licences
	Mattishall	1.26	Allocation of group licences
	Postwick	5.18	Annual Average licence
	Total	**82.00**	
Nottinghamshire	Retford	8.71	Allocation of group licences
	Everton	8.71	Allocation of group licences
	Gainsborough	4.58	Allocation of group licences
	Total	**22.00**	
RHF North	Pitsford	33.83	Allocation of group licences
	Ravensthorpe	6.33	Average yield
	Wing	197.89	Allocation of group licences
	Morcott	69.94	Allocation of group licences
	Total	**308.00**	
RHF South	Grafham	215.62	Average yield
	Bedford	18.36	Non-continuous running ratio
	Dunton	4.02	Allocation of group licences
	Meppershall	5.22	Non-continuous running ratio
	Newspring	4.01	Allocation of group licences
	Pulloxhill	4.33	Annual Average licence
	Sandhouse	5.21	Allocation of group licences
	Birchmoor	6.23	Annual Average licence
	Total	**263.00**	

South Essex	Ardleigh	26.69	Ardleigh "into supply" 5 yr licence
	Petches Bridge	10.83	Allocation of group licences
	Codham Mill	3.50	Allocation of group licences
	Bocking	3.17	Allocation of group licences
	Great Horkesley	20.00	Allocation of group licences
	Bures	2.91	Allocation of group licences
	Lexden	2.91	Allocation of group licences
	Total	**70.00**	
South Fenland	Ryston	9.79	Allocation of group licences
	Marham	17.73	Allocation of group licences
	Denton Lodge	5.48	Allocation of group licences
	Total	**33.00**	
South Lincs	Saltersford	19.95	Allocation of group licences
	Aswarby	5.21	Allocation of group licences
	Billingborough	0.80	Allocation of group licences
	Clay Hill	8.04	Allocation of group licences
	Total	**34.00**	
Norfolk Rural South	Riddlesworth	4.47	Allocation of group licences
	Quidenham	1.51	Annual Average licence
	Rushall	7.59	Allocation of group licences
	Bunwell	1.42	Non-continuous running ratio
	Total	**15.00**	
Sudbury	Sudbury	4.22	Annual Average licence
	Conard	6.28	Non-continuous running ratio
	Total	**10.50**	
Thetford	Brandon	2.01	Annual Average licence
	Thetford (2 Mile Bottom)	4.89	Allocation of group licences
	Thetford (Nunnery Lodge)	3.19	Allocation of group licences
	Thetford (Barnham Cross)	2.42	Allocation of group licences
	Total	**12.50**	

2.8 Baseline DO changes since WRMP 2015

There have been a number of changes to DO since the last Plan, as a result of updates to WTW and pump capacities, yields and two new sources: Postwick groundwater source and Hall surface water abstraction on the River Trent.

In providing a representation of our wider system, Aquator includes additional intra- and inter- zone network constraints that in some cases have lowered the reported DO when compared to WRMP 2015. The spreadsheet method does not capture these downstream constraints and assumes all water from the WTW is available for supply. Aquator also introduces a number of other changes, notably allocating group licences more dynamically rather than a fixed split.

Table 2.5: Comparison of WRMP 2015 and 2019 baseline DO numbers

Plan	Reported total baseline DO (Ml/d)*
WRMP 2015	1492
WRMP 2019	1473

** These totals do not include non-potable supply*

3. Sustainability Changes Impact Assessment

Table 3.1: WRMP 2019 - Water company checklist: 3.1 Sustainability Changes

Number	Action
49	You have included confirmed or likely sustainability changes that you have been informed about.
117	You have determined the impact of any sustainability reductions on your deployable output and included these in your plan appropriately.
103	You have identified where deployable output is constrained by licences that are time limited and due to expire in the period covered by the plan, and evaluated the risks of non- renewal.
202	You have explained where there are any uncertainties related to non-replacement of time-limited licences (TLLs).

This section discusses the DO implications of applying sustainability reductions driven by both no deterioration and the AMP6 NEP - full details of the impacted sources, quantification of licence impacts and WINEP mitigation options is detailed in the Supporting Technical Documents: Sustainable Abstraction document.

3.1 WFD no deterioration

The Water Framework Directive (WFD) requires us to 'prevent deterioration of the status of all bodies of surface water and groundwater'. We recognise that we have a duty to ensure that deterioration of the environment does not occur as a result of our abstractions for public water supply.

In order to address this, and through collaboration with the Environment Agency, we assessed our abstractions and the risk they pose to water-bodies based on future forecast growth. As such, we have committed to maintaining all of our groundwater abstractions below recent historical abstraction rates, where reasonably practicable, in order to eliminate the risk of deterioration. This is ahead of formal licence changes which are expected from 2022 onwards for many time-limited licences and in AMP8 for many permanent licences.

In order to address this change and take account of the uncertainties surrounding future abstraction licence volumes, we have assessed the impact of sustainability changes on all groundwater sources in 2022 in our supply forecast.

Surface water abstractions do not pose a significant deterioration risk due to existing licence constraints such as Hands Off Flow and Minimum Residual Flow conditions, and hence no sustainability changes related to WFD no deterioration are expected.

3.2 Sustainability reductions

The AMP6 NEP programme specified 28 water-bodies and designated sites where the Environment Agency suspected that our current abstractions were causing, or had the potential to cause, environmental harm. An extensive investigation and options appraisal process resulted in the development of solutions that will deliver environmental benefits and provide the best value for our customers. We have agreed the mitigation measures and sustainability changes that we need to deliver in collaboration with the Environment Agency and Natural England. These are set out in the AMP7 Water Industry National Environment Programme (WINEP).

The AMP7 sustainability reductions have an agreed implementation date. For the majority of sources, this is in 2024, with the exception of a significant licence change at Marham surface water source in 2025. We are also committed to delivering a scheme in the Happisburgh WRZ by March 2021 to mitigate any impacts that our groundwater abstraction may be having at Catfield Fen. Furthermore we are committed to delivering a scheme in the Happisburgh WRZ to mitigate impact that two of our groundwater abstractions may be having in the Ant Broads and Marshes.

In some cases, we have agreed with the Environment Agency to implement mitigation schemes alongside smaller sustainability changes, rather than accept full sustainability changes. We call these the 'WINEP mitigation options', and they include options such as river restoration, river support, and adaptive management. These are detailed in the Sustainable Abstraction Supporting Technical Report.

The DO impact listed below assumes the benefit of these associated mitigation options as agreed with the Environment Agency. In a number of WRZs, this mitigation is sufficient to limit further DO impact after licences have been capped in 2022 to recent actual quantities for no deterioration. These can be identified in Table 3.2 as having an associated NEP water-body but no 2024 DO impact. However it should be noted if the mitigation options were not delivered, these WRZs would see additional sustainability reductions. There are a small number of zones where we are required to have a licence cap greater than recent actual and or mitigation is not sufficient to offset the DO impact, as can be seen in Table 3.2.

3.3 Modelling approach

In order to assess the impact of these sustainability changes on DO, a version of the Aquator baseline model was built to include the licence reductions associated with the sustainability changes.

The timing of the sustainability changes in the supply forecast has been applied based on chronological order.

Table 3.2: WRZ DO impact per year of WINEP no deterioration and AMP7 sustainability reductions, with associated NEP water-body

Water Resource Zone	2021		2022		2024		2025		Associated NEP water-body(s)
	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	
Bourne	-		11.0	Bourne Etton Pilsgate	-		-		West and East Glen, River Slea
Bury Haverhill	-		-		3.0	Wixoe Rushbrooke			Bumpstead Brook, Cavenham Stream, River Lark, River Linnet, Tuddenham Stream
Central Essex	-		-		-		-		
Central Lincolnshire	-		12.0	Newton Waddingham	1.0	Elkesley	-		Barlings Eau, Northern Chalk, River Idle, River Poulter, Witham Limestone
Cheveley	-		0.1	Lower Links	-		-		
East Lincolnshire	-		3.0	Driby Fulstow Mumby Habrough Healing Weelsby	-		-		Northern Chalk, River Slea
East Suffolk	-		-		5.0	Raydon Semer	-		River Brett
Ely	-		1.0	Isleham	2.0	Isleham			Cavenham Stream, Lee Brook, River Kennett-Lee, Tuddenham Stream
Happisburgh	1.3	Ludham	-		1.8*	East Ruston Witton	-		Catfield Fen, Ant Broads and Marshes
Hartlepool	-		-		-		-		
Ixworth	-		-		3.0	Stanton	-		River Sapiston, Stowlangtoft Stream
Newmarket	-		1.0	Ashley Rd	-		-		Cavenham Stream, Lee Brook, River Kennett-Lee, Tuddenham Stream
Norfolk Rural North	-		2.0	Carbrooke Didlington (High Ash) East Dereham North Pickenham W. Bradenham East Watton Old Buckenham	2.0	High Oak			

** Timing to be confirmed*

Water Resource Zone	2021		2022		2024		2025		Associated NEP water-body(s)
	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	DO impact (Ml/d)	Impacted source	
Norfolk Rural South	-		1.0		-		-		
North Fenland	-		3.0	Hillington Ringstead Stoke Ferry	-		-		River Gaywood, River Heacham
North Norfolk Coast	-		4.0	Foulsham Sheringham Wighton	-		-		West Runton Common
Norwich and the Broads	-		5.0	Kirby Cane Caistor Postwick	-		-		
Nottinghamshire	-		2.0	Everton Gainsborough Retford	-		-		River Idle, River Poulter
Ruthamford Central	-		-		-		-		
Ruthamford North	-		-		-		-		
Ruthamford South	-		2.0	Birchmoor Meppershall Newspring Sandhouse	1.0	Birchmoor	-		Broughton Brook
Ruthamford West	-		-		-		-		
South Essex	-		-		-		-		
South Fenland	-		-		-		13.0	Marham (GW)	River Nar, Old Carr Stream, River Gadder, Stringside Stream
South Humber Bank	-		-		-		-		
South Lincolnshire	--		2.0	Billingborough Clay Hill	-		-		River Slea
Sudbury	-		1.1	Conard (Blackhouse Lane) Sudbury (Woodhall Rd)	-		-		
Thetford	-		2.0	Brandon Thetford - Barnham Cross Thetford - Nunnery Lodge					
Hartlepool	-		-		-		-		
TOTAL	**1.3**		**52.2**		**17.0**		**13.0**		

3.4 Eel and Fish passage

We do not expect there to be an impact on DO from eel or fish passage works over the planning period.

3.5 Future exports

Of our neighbouring water companies, Affinity Water (Central and East), are facing potential sustainability reductions in AMP8. Given the limited options for them to develop new resources, they may need to compensate for this reduction by seeking a transfer from within our region. In agreement with Affinity we have modelled an export scenario of 50 Ml/d and 100 Ml/d.

4. Design drought impact assessment

Table 4.1: WRMP 2019 - Water company checklist: 4 Selecting the design drought

Number	Action
50	You have demonstrated a system that can cope with droughts of a magnitude and duration that you reasonably expect to occur in your area over your chosen planning period and have considered contingencies for challenging but plausible droughts beyond the capabilities of your supply system (with relevant links to your Drought Plan) including whether they require options to provide additional resilience.
63	You have explained how you have followed the processes outlined in WRMP 2019 Methods - Risk Based Planning: Guidance (UKWIR, 2016) to identify an appropriate design drought.
64	You have clearly set out and justified the risk composition you have selected for each WRZ and the reasons that lead you to select that option, including the availability of data where more complex risk compositions have been used.
65	Where different risk compositions are used in different parts of your supply system, you have explained this clearly and justified your reasoning. Also, where a more complex risk composition has been adopted but later abandoned to a simpler approach, this has been noted but your WRMP reflects the final risk composition adopted.
66	You have included a drought resilience statement in your plan which is consistent with your chosen risk composition, and have explained how this reflects the hydrological risks that drought may impose on your supply system.
68	You have reiterated the design drought you are basing your plan on for supply, and have based this on the drought risk assessment activities carried out under Section 3.4.
85	For water companies in England, you have set out a reference level of service that would mean resilience to an event of approximately 0.5% risk of annual occurrence (1:200 year drought event). You have presented this as a scenario and explained how you have modelled the drought event used.
91	As part of your supply assessment, you have determined and explained how your supply system behaves during the design drought.
100	You have demonstrated that your supplier will be able to maintain supply during your design drought and that levels of service can be achieved. You have demonstrated that your supplier has assessed that their statutory and policy obligations can be met.

4.1 Increasing resilience to severe drought

The Water Resources Planning Guideline (WRPG)[12] requires the definition and application of a ‘design drought’ for each WRZ. As a minimum, this should be the worst drought on record, but for a resilience tested plan (Risk Composition 2), a “more challenging but plausible range of droughts” should be considered. This is achieved through ‘event analysis’ using a range of meteorological and hydrological data[13]. The WRPG[14] specifies that the reference level of service should be set such that it provides resilience to a drought with an approximate 0.5% chance of annual occurrence (a ‘severe’ or 1 in 200 year drought event). This was reiterated in Ofwat’s draft methodology for PR19[15], which included a potential common resilience performance commitment that “measures the percentage of the population the company serves that would experience severe supply restrictions (e.g. standpipes or rota cuts) in a 1 in 200 year drought”. The risk composition of our plan is discussed further in the Supporting Technical Report: Managing Uncertainty and Risk.

[12] *EA. 2017. Water Resources Planning Guideline: Interim update. Environment Agency, April 2017.*
[13] *UKWIR. 2016. WRMP 2019 Methods - Risk Based Planning. Report Ref. No. 16/WR/02/11. UK Water Industry Research, London.*
[14] *As updated in 2017*
[15] *Ofwat. 2017. Delivering Water 2020: Consulting on our methodology for the 2019 price review. July 2017. The Water Services Regulation Authority, Birmingham*

In general our supply system is relatively insensitive to short-duration droughts like 1976, except in a few locations where river abstractions go directly into treatment. Groundwater and our reservoir systems (especially in Ruthamford) buffer short-term variations in weather and are sensitive to successive dry winters, as recorded in the early 1930s, 1940s and between 1989 and 1992.

We commissioned the Met Office to produce estimates of rainfall and a measure of aridity called the Standardised Precipitation-Evapotranspiration Index (SPEI), for different return periods and locations. We have compared this with observed historical data to estimate the return period of seven historical droughts back to 1920. We have concluded that the 1930s drought in Ruthamford was of the order of a 1 in 200 year event and the 1989-92 drought was more severe than 1 in 200 year for Lincolnshire, whilst also affecting parts of Norfolk and Suffolk. We have also considered more extreme drought events, up to 1 in 500 year severity, to which nearly the entire region shows some degree of vulnerability. However the nature of these droughts makes them both extremely unlikely and uncertain and therefore we will continue to develop our understanding of our system to such events, and are not at present proposing to invest against this level of risk.

We have already made significant investment in Lincolnshire and Ruthamford following the 1988-92 and 2010-12 droughts respectively. Following the 1988-92 groundwater drought and the 2011-12 drought, we have invested £37 million and £47 million respectively in new assets designed to improve resilience. We estimate the benefit of this investment to be approximately 100 Ml/d in Lincolnshire and 44 Ml/d in Ruthamford (compared to the historic baseline DO).

However, much of the eastern part of our region has not experienced a severe drought that is reflected in current design events for planning purposes. Therefore, we have tested stochastically generated severe droughts, as explained in the following section.

4.2 Severe drought development and selection

We used output from the monthly, spatially coherent rainfall generator used in the Water Resources East project. The rainfall generator produces a very large number of statistically plausible sequences of monthly rainfall which are spatially coherent over a defined geographical area. Post-processing produces daily rainfall and PET, for input into hydrological models.

There is no single definition of drought, and therefore we have used both rainfall accumulation (and deficit) and SPEI, over a range of magnitudes, and for 6, 12, 18, 24, 30, 36 and 60 month durations.

We used the following criteria to guide the drought selection process, and to ensure the selected design drought is consistent with ensuring system resilience and the WRPG:

- Droughts of greater severity than those observed in the historic record, as measured by rainfall deficit and SPEI and system performance metrics (e.g. reliability, resilience);
- Droughts with a range of durations;
- Droughts with different characteristics (e.g. combination of magnitude and duration; preceding conditions);
- Droughts which are significant for particular parts of the region; and
- Droughts which vary in geographical occurrence across the region.

We reviewed the 200, 91-year sequences from the Water Resources East (WRE) project to produce a short-list of droughts. This was based on ranking of sequences using meteorological and water resource system metrics (based on a run of the WRE simulator), followed by simple frequency-based return period analysis of droughts.

We subsequently used the rainfall and SPEI of the short-listed droughts, in combination with the Met Office extreme value analysis, to more accurately estimate the return period of these stochastic droughts. We modelled several short-listed droughts in Aquator to select a preferred 1 in 200 year drought for WRZs in Norfolk and Suffolk and Essex (including parts of Cambridgeshire). For Ruthamford we selected a slightly more severe drought as a sensitivity test, whilst in Lincolnshire we explored a shorter-duration 1 in 200 year event. We extended this analysis to identify an indicative 1 in 500 year drought for all WRZs. Further details on the stochastic drought analysis and selection are discussed in the Appendix (Section 10).

4.3 Severe drought impact assessment

4.3.1 Yield assessments

- **Surface water yield assessment**
  Stochastic river flow series were developed in the WRE project, where the all 200 generated weather data sets were run through the existing rainfall-runoff models described in Section 2.1.1.

The relevant flow series for the selected droughts were denaturalised for Aquator as per the baseline approach. Artificial influences were kept consistent with the baseline model. Whilst artificial influences are likely to vary in a severe drought, due to the other uncertainties within this impact assessment this was not considered to be significant.

- **Groundwater yield severe drought assessment** The 200 generated weather data sets were run through a lumped parameter model (LPM) for each regional aquifer to output time series of LPM groundwater storage which could then be used to estimate stochastic drought groundwater yields.

To determine the relevant drought yields, the first stage was to identify "severe drought" storage values from the stochastic series. Historical modelled LPM storage v observed groundwater level was plotted for key observation boreholes across the region in aquifers potentially vulnerable to drought, and used these to identify severe drought groundwater level responses, taking account of uncertainties in the level - storage relationship. A workshop involving experienced members of Anglian Water's Water Resource Management Team was held to determine severe drought yield at every groundwater source, following the baseline UKWIR source reliable output summary diagram approach. Possible water quality effects were also accounted for, through expert judgement, which could limit yield unless significant additional investment in treatment infrastructure was undertaken. This approach was subject to an independent peer review.

A total of 64 sources were determined as being at some risk of loss of yield under droughts more severe than historically seen, either directly due to dewatering of key flow horizons, or indirectly through severe water quality failures, requiring reduction in output to maintain functional treatment. The total potential loss of groundwater yield was calculated to be in excess of 150 Ml/d, but the realised DO impact is significantly less as the yields have only been used in WRZs in which we have adopted a more severe reference drought.

4.3.2 DO assessment

New versions of the Aquator model were created for the severe drought assessments. Stochastic rainfall, PET, river flows and yields were included for each of the selected droughts, and run through the Aquator model to produce alternative severe drought baseline WRZ DO. Sustainability and climate change amendments were then applied to the model, to identify these impacts during a more severe drought whilst avoiding double counting of impact from sources already affected by severe drought.

4.3.3 DO impact for 1 in 200 year events

For Norfolk, Suffolk and Essex sub-regions, in most WRZs the stochastic 1 in 200 year event did not reduce the baseline DO. This is primarily because yield impacts were limited by other factors such as licence, or the conjunctive nature of some WRZs meant that resources could be shared. Therefore the historic reference drought was maintained, as it is modelled based on actual experience and can be considered more reliable. However, in South Fenland, Newmarket, Cheveley and Bury Haverhill WRZs, there were impacts on groundwater that led to DO impacts at the WRZ level. As such, we have selected the stochastic 1 in 200 year drought as the reference drought in these WRZs. These impacts have been modelled as a reduction to the baseline DO in 2025-6 to allow selection of options during AMP7.

In Ruthamford and Lincolnshire the stochastic droughts of 1 in 200 year return period did not reduce DO because the events were not sufficiently more extreme than the historical reference drought. The exception is Central Lincolnshire, which sees a drought impact as a result of the loss of the surface abstraction on the River Trent in a severe drought. Moving to a 1 in 200 year Level of Service means this DO is no longer available. This is further discussed in Appendix 1. The drought impact is less than the full Hall licence, because the WRZ already sees a reduction in DO from sustainability reductions.

The additional DO impacts from severe drought are listed in Table 4.2, along with details of design drought and estimated return period for all WRZs. For both the 1 in 200 and 1 in 500 year drought events, we have modelled the additional drought impacts with the expectation that they would occur at the same time across the region.

Table 4.2: Summary of up to 1 in 200 year drought DO impact, reference design drought and estimated return period

WRZ	Severe drought DO impact (Ml/d	Vulnerable sources	Drought type	Reported worst drought year	Estimated return period
Bourne	0		Historical	1989-92	> 1 in 200 year
Bury-Haverhill	-3.0	Risby	Stochastic	Nominal Year 1949	> 1 in 200 year
Central Essex	0		Historical	1989-92	1 in 50 to 1 in 150 year
Central Lincs	-11.0	Trent intake	Historical	1976	> 1 in 200 year
Cheveley	-0.3	Lower Links	Stochastic	Nominal Year 1949	1 in 200 year
East Lincs	0		Historical	1989-92	> 1 in 200 year
East Suffolk	0		Historical	1997	1 in 200 year
Ely	0.0		Historical	1991-3	1 in 50 to 1 in 150 year
Happisburgh	0		Historical	1990-92	1 in 50 to 1 in 100 year
Ixworth	0		Historical	1996-98	1 in 50 to 1 in 150 year
Newmarket	-3.0	Ashley Rd, Long Hill, Southfields, Moulton	Stochastic	Nominal Year 1949	1 in 200 year
Norfolk Rural North	0		Historical	1991-2	1 in 50 to 1 in 100 year
Norfolk Rural South	0		Historical	1991-2	1 in 50 to 1 in 100 year
North Fenland	0		Stochastic	Nominal Year 1923	1 in 200 year
North Norfolk Coast	0		Historical	1990-92	1 in 50 to 1 in 100 year
Norwich and the Broads	0		Stochastic	1992	1 in 50 to 1 in 100 year
Nottinghamshire	0		Historical	1975-6	~ 1 in 200 year
RHF Central	0		Historical	1934	~ 1 in 200 year
RHF North	0		Historical	1934	~ 1 in 200 year
RHF South	0		Historical	1934	~ 1 in 200 year
RHF West	0		Historical	1934	~ 1 in 200 year
South Essex	0		Historical	1934	~ 1 in 200 year

WRZ	Severe drought DO impact (Ml/d	Vulnerable sources	Drought type	Reported worst drought year	Estimated return period
South Fenland	-9.0	Marham (GW)	Stochastic	Nominal Year 1923	1 in 200 year
South Lincs	0		Historical	1989-92	> 1 in 200 year
Sudbury	0		Historical	1989-92	1 in 50 to 1 in 150 year
Thetford	0		Historical	1996-98	1 in 50 to 1 in 150 year
Total	-26.3				

4.3.4 DO impact for 1 in 500 year events (extreme drought)

The severity of a 1 in 500 year type drought event poses further risk across the region compared to the baseline (both DO scenarios include sustainability reductions). Both Ruthamford North and South see a large additional drought impact, because river flows are considerably lower during this event. It should be noted however that we have not yet tested this impact in combination with climate change, and it may be that the resulting impact is lower due to some double counting of impacts.

Additional impacts are seen in South, East and Central Lincolnshire due to reduction in groundwater yields - these were not affected in a 1 in 200 year event as we have already invested against historically severe events. There is also the same impact at the Hall intake on the River Trent as described in the 1 in 200 scenario.

There are numerous smaller impacts across the eastern WRZs as a result of additional groundwater yield impact.

Table 4.3: Summary of approximately 1 in 500 year drought total DO impact and additional drought impact beyond 1 in 200 year events

Water Resource Zone	Total 1 in 500 yr drought impact (Ml/d) (compared to baseline DO)	Additional drought DO impact beyond 1 in 200 year drought impact (Ml/d)	Drought vulnerable source(s)
Bourne	-4.0	-4.0	Bourne, Pilsgate, Tallington, Wilsthorpe
Bury Haverhill	-3.0	0.0	Risby
Central Essex	-	-	
Central Lincolnshire	-15.0	-4.0	Trent intake, Barrow, Barton, Ulceby, Branston Booths, Glentham, Hibaldstow Bridge, Redbourne, Spridlington, Waddingham, Welton, Winterton
Cheveley	-0.3	0.0	Lower Links
East Lincolnshire	-	-	
East Suffolk	-3.0	-3.0	
Ely	-	-	
Happisburgh	-	-	
Ixworth	-	-	
Newmarket	-3.0	0.0	Ashely Road, Long Hill, Southfields, Moulton
North Fenland	-	-	
North Norfolk Coast	-	-	
Norfolk Rural North	-	-	
Norfolk Rural South	-	-	
Norwich and the Broads	-	-	
Nottinghamshire	-	-	
Ruthamford Central	-	-	
Ruthamford North	-41.7	-41.7	Pistford, Ravensthorpe and Hollowell, Rutland reservoirs
Ruthamford South	-35.3	-35.3	Grafham reservoir, Clapham intake, Battlesden, Birchmoor, Pulloxhill
Ruthamford West	-	-	
South Essex	-2.0	-2.0	Ardleigh reservoir
South Fenland	-9.0	0.0	Marham (GW)
South Lincolnshire	-2.0	-2.0	Aswarby, Billingborough, Drove Lane, Kirkby La Thorpe, Swaton
Sudbury	-	-	
Thetford	-	-	
TOTAL	-118.3		

5. Climate Change Impact Assessment

Table 5.1: WRMP 2019 - Water company checklist: 5 Climate Change Impact Assessment

Number	Action
39	You have included a robust forecast of the water you have available to supply customers with for each year within the planning period, accounting for climate change, and demonstrating that supply is both efficient and sustainable. You have achieved this by following the steps in Section 4 of this checklist.
123	You have determined the impact of climate change on river flows and groundwater recharge using one of the three methods set out in the guideline.
124	You have assessed and clearly demonstrated the vulnerability and risks your sources and supplies face for each of your WRZs.
125	You have set out and justified your assessment methods, outlined any assumptions made and clearly presented your results, explaining any differences in methodology between your resource zones.
126	You have clearly explained whether and how climate change has been accounted for in your headroom assessment and have reported this separately.
127	You have set out if/how you have used scaling methods to account for climate change that has already happened, and how this has affected your supplies.

5.1 Assessment methodology overview

We have followed the Environment Agency guidance to quantify the impact of climate change on our supply forecast, as provided in 'Climate change approaches in water resources planning - Overview of new methods' (2013) and 'Estimating impacts of climate change on water supply' (2017).

5.2 Stage 1: Climate Change Vulnerability Assessment

A vulnerability assessment for all WRZs has been be carried out to identify the extent to which each WRZ is susceptible to adverse effects of climate change, updating the assessment carried out in WRMP 2015 and using UK Climate Projections 2009 (UKCP09) data. The vulnerability assessment has been conducted following the methodology set out in the Water Resources Planning Guideline (WRPG): technical methods and instructions (Environment Agency, 2012)[16].

The vulnerability classification of each WRZ has been determined by its position on a magnitude versus sensitivity plot as shown in Figure 5.2. The plot shows the change in deployable output (DO) for the 'mid' climate change scenario against the uncertainty range (calculated as the difference between the 'wet' and 'dry' scenarios) for each WRZ[17].

[16] *Environment Agency (2017) WRMP19 supplementary information (revised April 2017) - Estimating the impacts of climate change on water supply*
[17] *Atkins (2017) Water Resource Zone Climate Change Vulnerability Assessment*

Figure 5.1: Magnitude versus sensitivity plot: all zones*

** RHF West and RHF Central WRZs not included in graph as WRZs receive DO from donor WRZs.*
Note, no data was available for the Hartlepool WRZ

Table 5.2: Summary of WRZs by vulnerability classification

Low Vulnerability	Medium Vulnerability	High Vulnerability
Central Lincolnshire East Lincolnshire Nottinghamshire South Lincolnshire Bourne Norfolk Rural North Norfolk Rural South North Norfolk Coast Happisburgh Ely Cheveley Sudbury Bury Haverhill Ixworth Thetford Central Essex South Essex	NONE	Ruthamford North * Ruthamford West * Ruthamford Central Ruthamford South North Fenland South Fenland Norwich and the Broads Newmarket East Suffolk

** WRZs classified based on their donor WRZ(s). Note, no data was available for the Hartlepool WRZ*

5.2.1 Selection of climate change projections

In line with the guidance, the vulnerability classification was used to determine the appropriate level of climate change analysis for WRZs based on the following tiers:

1. Tier 1: If the WRZ vulnerability is low and there are no rainfall-runoff models, use future flows hydrology monthly change factors
2. Tier 2: If the WRZ vulnerability is medium or there are available rainfall-runoff models for low vulnerability zones, use UKCP09 Spatially Coherent Projections (SCPs)
3. Tier 3: If the WRZ vulnerability is high or a water company has developed their own approach, then the UKCP09 probabilistic projections should be used.

Using the findings from our Climate Change Pilot Study and discussions with the EA in September 2016, we have selected to use SCPs throughout the assessment. Whilst the majority of our surface water sources have high vulnerability to climate change and the guidance indicates UKCP09 probabilistic projections should be used (Tier 3), they are not spatially coherent. To complement the move from individual source DO assessments to system DO assessments, we believe that climate change impacts on supply should be examined in a spatially coherent way. The Climate Change Pilot Study uses a test catchment, Grafham, to compare the use of UKCP09 probabilistic projections and SCP change factors on river flow generation. Grafham was considered to be a representative catchment because it is predominantly our surface water sources that show high vulnerability to climate change. The pilot study found that spatially coherent projections add important local detail not captured by the UKCP09 probabilistic projections. The guidance proposes future flows change factors for lower vulnerability zones but we consider the SCPs to be preferable and it also allows a more conjunctive and consistent approach across the region. As such, we have used the SCPs for all our WRZs, regardless of their vulnerability. This is also consistent with our approach in the Water Resources East (WRE) project[18].

We acknowledge that the UKCP09 projections proposed for Tier 3 include a greater range of uncertainty than the SCPs, and therefore have carried out a comparison of SCPs with UKCP09 probabilistic projections in the Climate Change Pilot Study17 as well as WRE[18], to understand and capture uncertainty. We feel that our proposed approach captures the benefits of including spatial coherence whilst exploring the greater range of uncertainty that the UKCP09 probabilistic projections offer, combining the benefit of Tier 2 and Tier 3 proposed methods. This method was agreed with the Environment Agency during our Methods Discussion meetings detailed in Table 2.

The following table describes the different sources of climate data referenced in the EA proposed three-tiered approach, UKCP09 climate projections and SCPs.

Table 5.3: UKCP09 climate projection descriptions

Climate projection	Description
UKCP09 climate projections	10,000 probabilistic sets of temperature/rainfall perturbation factors, 25km spatial resolution. These are not spatially coherent. One set of perturbation factors per decade. Gridded or large catchment scale change factors (n = 10,000) that are freely available, easy to access and use. Used for hydrological modelling, typically following sub-sampling to reduce n to 100 or 20 for practical purposes. Large number of scenarios can be problematic without sub-sampling.
UKCP09 SCPs	Based on the HadRM3-PPE (Hadleigh Centre Regional Climate Model). Eleven variants providing spatially coherent data - useful for considering large regional problems, such as major water transfers. Available for low, medium and high emissions scenarios providing 3 x 11 scenarios in total. Cover a wider range of uncertainty than the HadRM3-PPE, but less than UKCP09.

[18] *Atkins (2016) Climate Change Pilot Study: Comparison of methods to assess the impact of climate change on source yields*
[19] *Atkins (2018) WRE Lot 1 CC and Hydrology Final Report_v1.0 Section 9.7*

5.2.2 Selection of climate change scenario

In line with best practice, and taking into account the time period (2080s) when emissions scenarios will have diverged, we have considered the impact of all three emissions scenarios. There are 11 SCP projections for each high, medium and low scenario. In order to assess these in the most efficient manner, all 33 (11 scenarios x 3 SCP projections) were run through our rainfall-runoff models and groundwater models to assess impact on surface water and groundwater yields respectively. This allowed a representative selection of scenarios to be identified for use in the Aquator DO impact assessment.

We have selected the median SCP of the medium emissions scenario to calculate the reduction in DO used in the Preferred Plan. This median SCP was selected by ranking average climate change yields for surface water direct intakes, reservoirs and groundwater sources. SCP- 8 was identified as the most consistent median scenario across all yield assessments[19].

We have used representative high and low scenarios to inform the assessment of headroom and represent uncertainty. Selection of the scenarios and result of this scenario testing are presented in the Supporting Technical Report: Managing Uncertainty and Risk.

5.3 Stage 2: Yield assessments

5.3.1 Surface water yield assessment

To assess the impact of climate change on our surface water sources, SCP climate change factors (CFs) were obtained from the Met Office, on a 25km x 25km grid basis. These have been used to perturb rainfall and PET, which were then run through rainfall-runoff models to obtain perturbed river flows.

The application of change factors depends on the type of rainfall-runoff model. For direct intakes using HYSIM, CFs were derived for each scenario for each catchment, using the most suitable SCP grid square or squares (with averaging), and applied to the historic rainfall and PET series to produce new climate change series for simulating flows.

Reservoir catchments flows were created using factoring options contained within the SIMFLOW model. CFs were derived for each reservoir system, as follows:

- Alton catchments
- Ardleigh catchments
- Covenham catchments
- Grafham catchments (including Foxcote)
- Rutland catchments (including Pitsford, Ravensthorpe and Hollowell)

Reservoirs in Ruthamford are sub-grouped into either Grafham or Rutland based on shared catchments. Each sub-group shares the same CF, as we do not consider it appropriate to have different CFs for the same catchment in two different reservoir yield assessments. It would be possible to use different CFs for individual sub-catchments, but we consider that this would run the risk of introducing a spurious level of precision to the analysis.

Artificial influences were assumed to be as per the baseline model and applied to the naturalised series retrospectively, to maintain consistency with the baseline.

The yields were inputted into Aquator to obtain DO and also our reservoir simulation model (OSAY) to obtain yields, as a comparison.

5.3.2 Groundwater yield climate change assessment

Aquator also requires climate change perturbed groundwater yields to complete the DO assessment for non-surface water resource zones. This follows a similar approach as the previous WRMP 2015 groundwater yield climate change assessment, but using the Met Office SCPs for rainfall and temperature, rather than the spatially averaged probabilistic UKCP09 projections assessed previously, and to extend the analysis from the 2040s to a 2080s time horizon. The approach consists of:

As for the surface water assessments, SCP CFs were used to perturb rainfall/PET. This was run through the relevant WRE recharge model.

Results are outputted as time series of recharge at locations of previously assessed drought vulnerable boreholes, ranked in order of recharge impacts at each location.

A comparison of the recharge ranking with the results from the previous UKCP09 probabilistic scenarios in the WRMP 2015 was carried out. Where SCP recharge losses are greater than UKCP09, the following option was followed:

- Use the SCP recharge results to produce recharge series for the custom-designed lumped groundwater models, based on the Environment Agency's regional models, and as built for WRE. Model output to include time series of groundwater volume in storage, and baseflow, for each climate scenario.

[19] *Mott MacDonald (2017) Climate Change Surface Water Yield Assessment*

- Use the climate scenario groundwater lumped storage results to produce [potential yield (PY) v groundwater volume in storage] regression functions, which enable groundwater storage to be used directly as a proxy for groundwater yield.
- Determine historic drought climate change yield impacts from the lumped model groundwater storage volumes under each SCP climate scenario, for each vulnerable source.
- Running selected SCP scenarios through the relevant regional groundwater model (with recharge modelling in 4R as needed) was not considered necessary.

5.4 Stage 3: DO calculation and scaling

5.4.1 DO calculation in Aquator

These climate change perturbed river flows and yields were run through Aquator in place of baseline inputs, to calculate deployable output for the 2080s.

5.4.2 Scaling equation

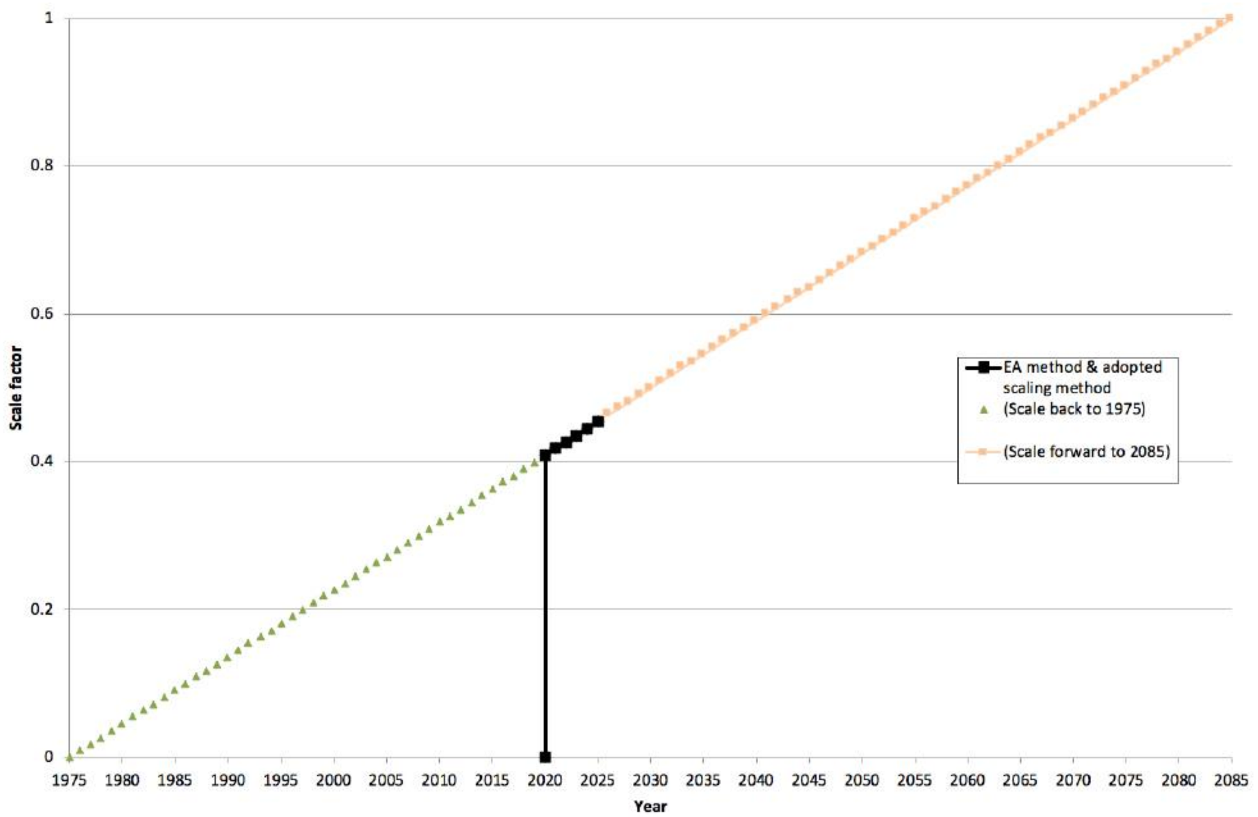
We have followed the Environment Agency's 2017 climate change assessment methodology[20], which is designed to better account for climate change impacts on current DO. This allows scaling back of the 2080s impact to the planning period using the EA's scaling equation:

$$\text{Scale factor} = \frac{\text{Year} - 1975}{2085 - 1975}$$

This requires a linear reduction year on year back to 1975, resulting in a large climate change impact at the beginning of the planning period.

Following the consultation on our dWRMP we have chosen not to delay investments in climate change impacts. Our dWRMP supply forecast modelled climate change impacts from 2024-25 onwards. For our revised dWRMP we have included climate change impacts from the start of the WRMP planning period (2020-21). Application of the revised scaling equation in this way results in a large climate change impact in the first year of the planning period. This is a change from the previous application of impact in WRMP 2015 which saw scaling from a zero impact at the start of the planning period.

Graphical representation of the 2017 climate change scaling equation and our adopted approach



[20] *Environment Agency (2017) Estimating impacts of climate change on water supply*

5.4.3 Climate Change DO results

Table 5.4 on the following page summarises the impact of climate change on DO at WRZ level. Where individual sources are vulnerable to climate change, these do not always result in a reduction to DO, as the impact may be buffered by other resources in the zone, or the source may already have seen a DO reduction from a sustainability reduction or drought impact applied.

Where zones have a more severe 1 in 200 year drought selected as the design drought, climate change impacts were rerun under the stochastic baseline to ensure there was no double counting of sources affected by both severe drought and climate change impacts.

5.5 Stage 4: headroom assessments

The impact of both higher and lower emissions scenarios on DO have been considered in headroom. This is discussed in the Supporting Technical Report: Managing Risk and Uncertainty.

Table 5.4: Summary of Climate Change impacts on DO

Water Resource Zone	Climate change impacts (Ml/d)		Climate vulnerable source(s)
	Impact in 2020	Total impact by 2045	
Bourne	-	-	
Bury Haverhill	-	-	
Central Essex	-	-	
Central Lincolnshire	-	-	
Cheveley	-	-	
East Lincolnshire	-	-	
East Suffolk	0.8	1.3	Alton Water reservoir
Ely	-	-	
Happisburgh	-	-	
Ixworth	-	-	
Newmarket	-	-	
North Fenland	-	-	
North Norfolk Coast	-	-	
Norfolk Rural North	-	-	
Norfolk Rural South	-	-	
Norwich and the Broads	-	-	
Nottinghamshire	-	-	
Ruthamford Central	-	-	
Ruthamford North	18.1	27.8	Pistford, Ravensthorpe and Hollowell, Rutland reservoirs
Ruthamford South	15.4	23.7	Sandhouse, Grafham reservoir, Clapham intake
Ruthamford West	-	-	
South Essex	2.0	3.1	Ardleigh reservoir
South Fenland	-	-	
South Lincolnshire	1.2	1.9	Aswarby
Sudbury	-	-	
Thetford	-	-	
TOTAL	**37.6**	**57.7**	

6. WRMP links to Drought Plan

Table 6.1: WRMP 2019 - Water company checklist: 3 WRMP links to Drought Plan

Number	Action
51	You have documented the impact of drought interventions on supply and demand and links with your Drought Plan.
92	You have explained links between your WRMP and your drought plan, including the likelihood of achieving planned levels of service and their impact on available supply.
93	You have explained how drought interventions (drought permits and orders) that are contained within the drought plan have been dealt with in the WRMP in accordance with levels of service, and outlined any contingencies for extreme droughts that exceed the capability of your system to meet.
94	For water companies in England you have not included benefits drawn from supply drought measures (e.g. drought permits and orders) in your baseline supply forecast.
106	You have described how deployable output will be affected by demand side drought restrictions according to the level of service you have planned for.

6.1 Levels of Service

Our Drought Plan 2014 sets out our operational response to how we will protect public water supplies during a drought. This includes both demand and supply-side interventions to maintain our committed Level of Service provided to our customers.

Levels of Service as described in our Drought Plan 2014 are summarised below, along with our revised Levels of Service for the dWRMP 2019.

Table 6.2: Anglian Water Levels of Service as set out in our Drought Plan 2014, including LOS demand savings as a percentage of demand

LOS Level	Action	Frequency (years)	Annual average risk	Demand saving for planning purposes
LoS 1	Publicity, temporary use ban	1:10	10%	5%
LoS 2	Publicity, non-essential use ban	1:40	2.5%	10%
LoS 3	Standpipes and rota cuts	1:100	1%	40%

Table 6.3: Anglian Water revised levels of service for the dWRMP 2019 from the end of AMP7

LOS Level	Action	Frequency (years)	Annual average risk	Demand saving for planning purposes
LoS 1	Publicity, temporary use ban	1:10 (no change)	10%	5%
LoS 2	Publicity, non-essential use ban	1:40 (no change)	2.5%	10%
LoS 3	Standpipes and rota cuts	1:200 and below	0%	N/A
		>1:200	<0.5%	40%

6.1.1 Changes to Level of Service

Through customer engagement in the dWRMP process, we believe that our Levels of Service for Temporary Use Bans and Non-Essential Use Bans are appropriate and the frequency of restrictions remains the same.

However we do not believe that our Level of Service for severe (LOS 3) restrictions is appropriate or acceptable. In our dWRMP,our objective is to ensure that no customers are exposed to the risk of standpipes and rota-cuts in a severe drought event, equivalent to a return period of approximately 1 in 200 years, by the end of AMP7.

As discussed in Section 4, we have undertaken extensive drought vulnerability analysis to improve our understating of drought resilience across our region. This identified severe drought vulnerabilities in Central Lincs, Cheveley, Bury Haverhill, Newmarket and South Fenland. Therefore for 2020-2025, we are maintaining our current levels of service as stated in Table 9, which allows a 1% annual risk of severe restrictions a 1 in 100 year severity drought event. From AMP8, following additional drought investment, we have committed to ensuring our customers in these WRZs are protected against up to a 1 in 200 year event without the risk of any severe restrictions (standpipes and rota cuts) (0% risk). Our other WRZs have been assessed as already being resilient against up to a 1 in 200 year event without the risk of severe restrictions. For a drought event of severity greater than a 1 in 200 year event, there is a 0.5% annual risk of standpipes and rota cuts.

6.2 Impact of drought interventions on demand

As with our water resources management planning, we follow a twin-track approach to managing our supplies during a drought. In the first instance we will seek to manage demand, before instigating any of the available supply-side measures. Demand savings are applied as a percentage of demand, as detailed above in Table 9.

6.2.1 Modelling demand savings

These are included in our baseline yield and DO assessments under the following scenarios:

- No Restrictions (NR): The constant rate of supply that can be maintained by a resource zone throughout the entire period of assessment, with no customer restrictions or other drought actions applied.
- Water Company planned levels of service: The rate of supply that can be maintained by a source or resource zone when the system is operated to meet current Levels of Service. LOS curves are included in the model for each reservoir, and the assessment will include the application of demand restrictions to the demand profile once a LOS curve is crossed.

6.2.2 Testing removal of LOS 3

We have removed LOS 3 demand savings from our modelling, as we have not experienced these in our historic record. This is in line with our commitment to ensure no standpipes or rota cuts during a severe drought event, as based on our drought analysis, we consider we have historically experienced up to a 1 in 200 year event. We have carried out a review of removing this curve in the 2016 OSAY yield update but results showed that there was insignificant influence on the shape of the LOS 1 and 2 curves and therefore on yield, and as a result we consider the existing LOS 1 and 2 curves to be suitable for use without LOS 3. More detail is in the Surface Water Yield Assessment Update 2016 (Mott MacDonald, 2016).

6.3 Impact of drought interventions on supply

During a drought, a water company can apply for drought permits and orders to secure additional water resources or to restrict the use of water. Drought permits are granted by the Environment Agency and modify or suspend conditions on an abstraction licence in order to increase water supply during a drought. Drought Orders are granted by the Secretary of State and can be used to further modify licence conditions or impose more stringent demand savings.

- **Drought Plan drought permits and orders**
  Our draft Drought Plan 2019 identifies the possible drought permits and orders we may apply for in a drought to secure additional resources.

Table 6.4: Drought Plan drought permits with associated yield and DO benefits

WRZ	Source	Drought permit application	Maximum Potential Yield (Ml/d) from draft Drought Plan 2019	Potential DO benefit (Ml/d)
East Suffolk	Alton Water	50% MRF reduction at intake on River Gipping	4.5	0
South Essex	Ardleigh	Increase the groundwater abstraction licence for the augmentation boreholes	6	0
Norwich and the Broads	River Wensum intake	Increase the annual abstraction quantity for the Costessey boreholes. Subject to ongoing investigations.	24	0
Ruthamford South	Grafham Water	50% MRF reduction at Offord intake on River Great Ouse	68	0
Ruthamford North	Pitsford	50% MRF reduction at Duston intake on River Nene	17	0
	Rutland Water	50% MRF reduction at Wansford intake on River Nene	62	
North Fenland	River Wissey intake	Increased abstraction licence for the supporting Wellington Wellfield groundwater source	10	0
Central Lincs	River Trent intake	Reduction in Hands off Flow	20*	20

** Since publishing the Drought Plan 2014, we have commissioned Hall WTW and have identified the need for a drought permit option for our River Trent intake, to maintain its reliability during a severe drought (1 in 200 year) event. The proposed permit option is a reduction to the Hands off Flow and is discussed further in our Drought Plan 2019 as well as Appendix 1 below.*

The WRP Guidance states that where there is a deficit driven by severe drought the potential solutions could include use of drought permits and orders. The supplementary guidance note 'Drought options' states that drought permits and orders should be considered alongside other options as part of the decision making process.

We have assessed the drought permits and orders listed in our draft Drought Plan 2019. For planning purposes, we do not consider that any drought permit can be guaranteed year round, or during a more severe drought, and in accordance with the guidelines we have not included drought permits or orders in our options appraisal process or baseline DO. The benefit of such interventions has therefore been included in Table 10 under the Drought Plan sections.

We have modelled the potential drought permit DO benefit in Aquator. This showed that, with the exception of the Trent permit, at a WRZ level, there was no overall DO benefit. Whilst the Drought Plan 2014 refers to a yield benefit, this allows DO to be maintained at a drought specific and local resource level.

6.4 WRP Table 10

The new Water Resources Planning (WRP) Table 10 requires information describing drought impacts, and on the links with the Drought Plan. In some cases assessments are required specifically for the purposes of filling in the table, rather than for defining the Supply-Demand Balance. Therefore, for clarity, in Table 6.5 below we provide further information on how we have assessed WRP Table 10 requirements.

The table presents our historic reference drought alongside a stochastic 1 in 200 year event. In some cases, the stochastic 1 in 200 year event did not cause further DO impact on the WRZ, and therefore we have kept the historic reference drought as this is modelled using recorded data rather than synthetic data. For the revised dWRMP we have also included an indicative 1 in 500 year drought event and tested the benefit of the drought permits against an extreme event. Note this does not include consideration of the actual feasibility or likely environmental effects during such a drought.

Table 6.5: Description of Table 10 entries

Section	Columns	Description
Planning scenarios	B, C, D, E, F	• We describe key historical droughts and identify which is the reference drought for the WRMP. This has been calculated from either OSAY reservoir yields or the lowest water level seen at localised EA observation boreholes. • We also include details of the relevant stochastic drought and indicate whether this has been used to re-define DO for the WRMP. • We include an estimate of the return period of the historical and stochastic droughts.
Water resources management plan	G, N	• WRMP DO is the annual average output that can be reliably supplied from the zone during a critical year. This has been calculated through the Aquator system model. • For reservoir zones, WRMP DO has been modelled with LOS demand restrictions included, and the DO is reported in the 'WRMP DO Levels of Service' column N. • For groundwater zones without an associated reservoir and LOS, the DO has been calculated without these and therefore is reported 'WRMP DO of Sources (not including drought measures)' column G. The exceptions to this are the groundwater zones in Lincolnshire, which have been run through Aquator in combination with Ruthamford zones and share the reservoir LOS.
		• Drought permit DOs have not been included in WRMP DO as they are not considered sufficiently reliable or relevant to offset severe drought DO.
		• Demand savings for reservoir zones have been calculated as the difference between baseline DO (LOS included) and a 'no restrictions' Aquator run. • For groundwater-only zones without LOS, the reported baseline DO is already considered without demand savings. Savings have been calculated as the relative benefit from an Aquator scenario applying LOS savings from the worst drought at Grafham reservoir applied to the zone as a proxy.
Drought plan	N/A	• Our current Drought Plan does not include the stochastic droughts we have identified in the WRMP. These will be reviewed during the Drought Plan update in 2018.
	O, P, Q	• Where drought permits are included in the Drought Plan, we have included their benefit to yield and DO for information. These have not been included as options in the WRMP and therefore are included in the Drought Plan section of the Table only. These have only been included for historic droughts as we are uncertain of the benefit in a more severe drought.
	R, S, T	• LOS 3 demand savings are not included in the WRMP DO assessment. However they have been considered in the Drought Plan, and as such have been included in a separate line under the historic drought. • As the LOS3 curve is not included in the WRMP DO, the benefit of LOS3 saving on the zone is the relative benefit should the curves be crossed.
Demand	U, V	• Unrestricted demand is inputted as baseline Distribution Input • Restricted demand is the unrestricted demand minus demand savings

7. Other impacts

7.1 Abstraction reform

Table 7.1: WRMP 2019 - Water company checklist: 7.1 Abstraction Reform

Number	Action
120	For catchments managed by the Environment Agency, you have not included any changes to DO from abstraction reform. You have identified sources having unused licence volumes that are required for emergency purposes and have explained how you define these (e.g. drought source or other purposes).

We have not included any changes to DO from abstraction reform, and do not have any unused licence volumes that are required for emergency purposes to consider.

7.2 Deteriorating raw water quality and catchment management

Table 7.2: WRMP 2019 - Water company checklist: 7.2 Deteriorating raw water quality and catchment management

Number	Action
133	You have supported objectives for drinking water in protected areas.
134	You have checked that the drinking water arising from the water treatment regime applied meets the Standards of the Drinking Water Directive plus any other legislation.
135	You have abided by Section 68(1) of the Water Industry Act 1991 in terms of quality of supplied water, and applied this to water from your own sources as well as transfers.
136	You have considered appropriate measures to prevent deterioration of water quality in a protected area.
140	You have considered measures to protect supplies against long term risks of pollution.
141	You have considered measures to reduce the treatment process whilst still complying with the requirements of the drinking water regulations.
142	You have demonstrated that all sources you may rely on have been correctly identified and measures taken to provide protection where necessary, e.g. SPZs around groundwater abstractions.
259	You have considered and prioritised solutions that promote the requirements of Article 7 of the WFD and are consistent with RBMP objectives and solutions, highlighting how you will or are working with others to achieve this.

The quality of our public water supply is regulated by the Drinking Water Inspectorate (DWI). Our performance is reported on by the DWI in the form of the annual Chief Inspector's Report. Since July 2016 additional quarterly reporting has been introduced. The published reports detail our drinking water quality data results and the findings of audits and other checks that the DWI has carried out. Like all water companies we closely monitor our water before, during and after the treatment process to ensure that it meets the stringent water quality standards specified by law. To do this, we undertake annual reviews of all our water supply systems, make monthly and annual returns to the DWI, internally monitor the compliance of our assets using sampling, risk assessments and audits. This process ensures that we comply with Section 68(1) of the Water Industry Act 1991 in terms of quality of supplied water.

Drinking Water Protected Areas (DrWPAs) are designated under Article 7 of the Water Framework Directive (WFD). The WFD objectives for DrWPAs are to ensure that, under the water treatment regime applied, the drinking water produced meets the requirements of the Drinking Water Directive 98/83/EC and ensure necessary protection in the DrWPA with the aim of avoiding deterioration in water quality in order to reduce the level of purification treatment required in producing drinking water.

We support the Environment Agency in meeting these objectives through the implementation of catchment management, the assessment of pollution risk for all our groundwater and surface water sources, a comprehensive monitoring programme, the acquisition of relevant datasets and catchment modelling. Our catchment risk assessment procedures align fully with the DWI's requirement to implement a Drinking Water Safety Planning approach. We have developed and successfully implemented a Catchment Management Strategy, including the Slug It Out initiative, to subsidise farmers to use alternative products in priority catchments. We continue to work with the Environment Agency on Safeguard Zone Action Plans and the development of Source Protection Zones.

Measures to prevent deterioration of water quality and reduce the need for treatment are considered through our extensive catchment management programme. In AMP6 we have introduced catchment advisors, working to reduce use of metaldehyde and clopyralid in surface water catchments, alongside an operational catchment surveillance process to highlight and escalate catchment water quality risks around our abstractions. Catchment surveillance feeds into our groundwater and surface water source risk assessments (CRAGS and SWRAs), allowing identification of source vulnerability through a risk assessment based on assessment of hazards and pathways in the catchment. All sources are risk assessed but measures and monitoring is implemented according to risk; specified high risk sites receive enhanced monitoring.

8. Water transfers

Table 8.1: WRMP 2019 - Water company checklist: 8. Water Transfers

Number	Action
99	Where you receive a raw or treated water import from a third party, your supply forecast reflects the contractual arrangements with this third party supplier.
129	You have quantified all water transfers including all raw and potable imports/exports and entered this in the water resources planning tables. You have noted the direction of transfers along with the potential to change the direction if needed.
130	You have documented agreed limits between supplier and recipient companies for all transfers, including any contractual variations that might apply (e.g. in times of drought).
131	You have documented the total volume available to you via transfer for each year of your plan (accounting for operational or infrastructure constraints that may reduce quantities).
132	You have assessed and documented the quality of transferred water and any impact of the transfer on the quality of receiving waters.

The baseline supply forecast includes all bulk imports and exports as per WRMP 2015, as summarised in Table 25. The Elsham non-potable bulk export has been extracted from Central Lincs and made into a standalone WRZ, South Humber Bank, so it is not considered as surplus water in the WRZ.

Table 8.2: Baseline Supply Forecast bulk transfers

Transfer type	Associated WRZ	Company	Volume (Ml/d) in 2020		Comment
			Average	Peak	
Bulk export	Ruthamford North (Rutland - Wing)	Severn Trent Water	18	18	
Bulk export	Ruthamford South (Grafham)	Affinity Water	84.6	109	Reduces to 81.3 Ml/d in 2045. Peak is fixed throughout planning period.
Bulk import	South Essex (Tiptree)	Essex and Suffolk Water	3	4.5	
Bulk import	Thetford (Barnham Cross)	Cambridge Water	0.25	0.25	

The bulk export to Affinity Water from Grafham Water has been reviewed to account for the change in Grafham yield and climate change impact, and sees a reduction from the WRMP 2015 export volume. This was calculated based on a 2085 15 Ml/d climate change yield impact scaled over the planning period. It is based on the scaling methodology referred to in Section 5.4.2.

Inter-zone transfers are identified through the Economics of Balancing Supply and Demand (EBSD) model, which optimises the transfers within their constraints to determine the WAFU in each WRZ. These are detailed in the WRP tables.

All existing supplier-recipient and water quality agreements remain in place and are considered to remain valid.

9. 2019 Supply Forecast

Table 9.1: WRMP 2019 - Water company checklist: 9 2019 Supply Forecast

Number	Action
97	You have explained your decision to include a critical period, if relevant, and have provided a supply forecast for it.
101	You have expressed the supply forecast as the Water Available for Use (WAFU).
143	You have applied your approach consistently across all WRZs.
147	You have clearly set out the total WAFU, and demonstrated how changes in deployable output, transfers, operational use and outage impact on the calculated total.

9.1 Planning scenario - DYAA and Critical Period

The WRMP 2019 supply forecast is based on a Dry Year Annual Average (DYAA) scenario, representing an 'average' dry year output during the design drought.

The guidelines state the supply forecast should also be presented as a Critical Period (CP) scenario for each WRZ where applicable. CP is defined as the peak daily output on any given day during the design drought. The CP DO has been calculated for all WRZs, but has only been reported in the WRP tables for those with a CP deficit as identified through EBSD modelling. These are:

- Bury-Haverhill WRZ
- Central Lincolnshire WRZ
- Cheveley WRZ
- Happisburgh WRZ
- Ruthamford Central WRZ
- South Fenland WRZ

CP DO has been calculated using the spreadsheet based method, as Aquator cannot calculate DO in this way. The CP assessment assumes peak licences, peak yields and 24 hour continuous pumping. There are no climate change impacts applied to the critical period. The only sustainability changes that affect CP DO are where the sources experience a full loss of licence. Drought impacts on source yields have also been applied.

9.2 Outage

We have included outage in the supply forecast to calculate WAFU from DO. Outage describes an allowance of water which represents the risk of short-term (less than 3 months) supply-side failure. The development of the outage figures are discussed in the Supporting Technical Document: Managing Uncertainty and Risk.

9.3 WAFU

Table 9.2 on the following page summarises the DYAA baseline DO for the design drought over the planning profile, for our Preferred Plan. Total impacts on DO (climate change, sustainability reductions) and outage are also included. Baseline WAFU includes bulk imports, exports and inter-zone transfers that have been identified through supply-demand modelling. We have identified residual supply-demand deficit in South Essex and Ruthamford South and we have sought to manage this through short term solutions. This is discussed in the 'Forward Look' chapter of the revised dWRMP and the Managing Uncertainty and Risk technical report.

South Humber Bank is captured as an output from Elsham WTW in a separate non-potable WRZ and is not modelled in Aquator. Hartlepool is also not modelled in Aquator as it is a discrete WRZ outside of the Anglian Water system.

Table 9.2: Summary of WRZ baseline DO, impacts, outage and WAFU

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Bourne BRN	Baseline Deployable Output	56.00	56.00	56.00	56.00	56.00	56.00
	Sustainability change impact	0.00	-11.00	-11.00	-11.00	-11.00	-11.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.92	0.74	0.74	0.74	0.74	0.74
	Transfers In*	0.00	0.00	0.00	0.00	0.02	0.00
	Transfers Out*	6.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**49.08**	**44.26**	**44.26**	**44.26**	**44.26**	**44.26**
Bury-Haverhill BHV	Baseline Deployable Output	28.00	28.00	28.00	28.00	28.00	28.00
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	-3.00	-3.00	-3.00	-3.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.63	0.50	0.50	0.50	0.50	0.50
	Transfers In*	2.84	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**30.21**	**24.50**	**21.50**	**21.50**	**21.50**	**21.50**
Central Essex CEX	Baseline Deployable Output	9.60	9.60	9.60	9.60	9.60	9.60
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.16	0.16	0.16	0.16	0.16	0.16
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**9.44**	**9.44**	**9.44**	**9.44**	**9.44**	**9.44**
Central Lincs CLN	Baseline Deployable Output	137.00	137.00	137.00	137.00	137.00	137.00
	Sustainability change impact	0.00	-13.00	-13.00	-13.00	-13.00	-13.00
	Drought impact	0.00	0.00	-11.00	-11.00	-11.00	-11.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	2.49	2.49	2.49	2.49	2.49	2.49
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**134.51**	**121.51**	**110.51**	**110.51**	**110.51**	**110.51**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Cheveley CVY	Baseline Deployable Output	1.70	1.70	1.70	1.70	1.70	1.70
	Sustainability change impact	0.00	-0.10	-0.10	-0.10	-0.10	-0.10
	Drought impact	0.00	0.00	-0.30	-0.30	-0.30	-0.30
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.06	0.05	0.05	0.05	0.05	0.05
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**1.64**	**1.55**	**1.25**	**1.25**	**1.25**	**1.25**
East Lincs ELN	Baseline Deployable Output	134.00	134.00	134.00	134.00	134.00	134.00
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	2.12	2.07	2.07	2.07	2.07	2.07
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**131.88**	**128.93**	**128.93**	**128.93**	**128.93**	**128.93**
East Suffolk ESU	Baseline Deployable Output	78.30	78.30	78.30	78.30	78.30	78.30
	Sustainability change impact	0.00	-5.00	-5.00	-5.00	-5.00	-5.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	-0.82	-0.89	-0.98	-1.07	-1.16	-1.25
	Outage Allowance‡	1.34	1.26	1.25	1.25	1.25	1.25
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**76.14**	**71.15**	**71.07**	**70.98**	**70.89**	**70.80**
Ely ELY	Baseline Deployable Output	24.00	24.00	24.00	24.00	24.00	24.00
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.33	0.29	0.29	0.29	0.29	0.29
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**23.67**	**20.71**	**20.71**	**20.71**	**20.71**	**20.71**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Happisburgh HPB	Baseline Deployable Output	5.20	5.20	5.20	5.20	5.20	5.20
	Sustainability change impact	0.00	-3.10	-3.10	-3.10	-3.10	-3.10
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.10	0.08	0.08	0.08	0.08	0.08
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.30	0.30	0.30	0.30	0.30	0.30
	Total WAFU	**4.80**	**1.72**	**1.72**	**1.72**	**1.72**	**1.72**
Hartlepool HPL	Baseline Deployable Output	36.84	36.84	36.84	36.84	36.84	36.84
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**36.84**	**36.84**	**36.84**	**36.84**	**36.84**	**36.84**
Ixworth IXW	Baseline Deployable Output	6.20	6.20	6.20	6.20	6.20	6.20
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.11	0.06	0.06	0.06	0.06	0.06
	Transfers In*	1.53	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	2.84	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**4.78**	**3.12**	**3.12**	**3.12**	**3.12**	**3.12**
Newmarket NWM	Baseline Deployable Output	16.00	16.00	16.00	16.00	16.00	16.00
	Sustainability change impact	0.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Drought impact	0.00	0.00	-3.00	-3.00	-3.00	-3.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.22	0.16	0.16	0.16	0.16	0.16
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**15.84**	**14.84**	**11.84**	**11.84**	**11.84**	**11.84**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Norfolk Rural North NNR	Baseline Deployable Output	27.00	27.00	27.00	27.00	27.00	27.00
	Sustainability change impact	0.00	-4.00	-4.00	-4.00	-4.00	-4.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.56	0.47	0.47	0.47	0.47	0.47
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**26.44**	**22.53**	**22.53**	**22.53**	**22.53**	**22.53**
Norfolk Rural South SNR	Baseline Deployable Output	15.00	15.00	15.00	15.00	15.00	15.00
	Sustainability change impact	0.00	-1.00	-1.00	-1.00	-1.00	-1.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.28	0.26	0.26	0.26	0.26	0.26
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**14.72**	**13.74**	**13.74**	**13.74**	**13.74**	**13.74**
North Fenland NFN	Baseline Deployable Output	37.00	37.00	37.00	37.00	37.00	37.00
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.66	0.61	0.61	0.61	0.61	0.61
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	3.30	3.30	3.30	3.30	3.30	3.30
	Total WAFU	**33.04**	**30.09**	**30.09**	**30.09**	**30.09**	**30.09**
North Norfolk Coast NNC	Baseline Deployable Output	26.00	26.00	26.00	26.00	26.00	26.00
	Sustainability change impact	0.00	-4.00	-4.00	-4.00	-4.00	-4.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.35	0.30	0.30	0.30	0.30	0.30
	Transfers In*	0.30	0.30	0.30	0.30	0.30	0.30
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**25.95**	**22.00**	**22.00**	**22.00**	**22.00**	**22.00**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Norwich and the Broads NTB	Baseline Deployable Output	82.00	82.00	82.00	82.00	82.00	82.00
	Sustainability change impact	0.00	-5.00	-5.00	-5.00	-5.00	-5.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	1.35	1.27	1.27	1.27	1.27	1.27
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**80.65**	**75.73**	**75.73**	**75.73**	**75.73**	**75.73**
Nottinghamshire NTM	Baseline Deployable Output	22.00	22.00	22.00	22.00	22.00	22.00
	Sustainability change impact	0.00	-2.00	-2.00	-2.00	-2.00	-2.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.54	0.49	0.49	0.49	0.49	0.49
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**21.46**	**19.51**	**19.51**	**19.51**	**19.51**	**19.51**
Ruthamford Central RTC	Baseline Deployable Output	0.00	0.00	0.00	0.00	0.00	0.00
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers In*	70.39	73.54	75.24	77.14	78.68	80.54
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**70.39**	**73.54**	**75.24**	**77.14**	**78.68**	**80.54**
Ruthamford North RTN	Baseline Deployable Output	308.00	308.00	308.00	308.00	308.00	308.00
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	-18.11	-19.72	-21.74	-23.75	-25.76	-27.78
	Outage Allowance‡	4.48	4.45	4.42	4.39	4.36	4.32
	Transfers In*	46.00	40.00	40.00	40.00	40.00	40.00
	Transfers Out*	85.60	86.34	87.16	87.74	88.30	88.86
	Total WAFU	**245.80**	**237.48**	**234.68**	**232.12**	**229.58**	**227.04**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
Ruthamford South RTS	Baseline Deployable Output	263.00	263.00	263.00	263.00	263.00	263.00
	Sustainability change impact	0.00	-3.00	-3.00	-3.00	-3.00	-3.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	-15.43	-16.80	-18.52	-20.23	-21.95	-23.66
	Outage Allowance‡	4.25	4.32	4.29	4.26	4.24	4.21
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	151.05	153.63	154.63	155.82	156.65	157.81
	Total WAFU	**92.27**	**85.24**	**82.56**	**79.68**	**77.16**	**74.32**
Ruthamford West RTW	Baseline Deployable Output	0.00	0.00	0.00	0.00	0.00	0.00
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers In*	67.60	68.34	69.16	69.74	70.30	70.86
	Transfers Out*	44.00	44.00	44.00	44.00	44.00	44.00
	Total WAFU	**23.60**	**24.34**	**25.16**	**25.74**	**26.30**	**26.86**
South Essex SEX	Baseline Deployable Output	70.00	70.00	70.00	70.00	70.00	70.00
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	-2.05	-2.23	-2.45	-2.68	-2.91	-3.14
	Outage Allowance‡	1.16	1.16	1.06	1.06	1.06	1.06
	Transfers In*	3.00	3.00	3.00	3.00	3.00	3.00
	Transfers Out*	7.80	7.80	13.10	13.10	13.10	13.10
	Total WAFU	**61.99**	**61.81**	**56.39**	**56.16**	**55.93**	**55.71**
South Fenland SFN	Baseline Deployable Output	33.00	33.00	33.00	33.00	33.00	33.00
	Sustainability change impact	0.00	0.00	-13.00	-13.00	-13.00	-13.00
	Drought impact	0.00	0.00	-9.00	-9.00	-9.00	-9.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.62	0.45	0.21	0.21	0.21	0.21
	Transfers In*	3.30	3.30	3.30	3.30	3.30	3.30
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**35.68**	**35.85**	**14.09**	**14.09**	**14.09**	**14.09**

Water Resource Zone	Water Balance Components (Ml/d)	Base year 2020-21	End of AMP7 2024-25	End of AMP8 2029-30	End of AMP9 2034-35	End of AMP10 2039-40	End of AMP11 2044-45
South Lincs SLN	Baseline Deployable Output	34.00	34.00	34.00	34.00	34.00	34.00
	Sustainability change impact	0.00	-2.00	-2.00	-2.00	-2.00	-2.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	-1.23	-1.34	-1.47	-1.61	-1.75	-1.88
	Outage Allowance‡	0.44	0.41	0.41	0.41	0.41	0.41
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**32.33**	**30.25**	**30.12**	**29.98**	**29.84**	**29.71**
Sudbury SUD	Baseline Deployable Output	10.50	10.50	10.50	10.50	10.50	10.50
	Sustainability change impact	0.00	-1.10	-1.10	-1.10	-1.10	-1.10
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.16	0.14	0.14	0.14	0.14	0.14
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**10.34**	**9.26**	**9.26**	**9.26**	**9.26**	**9.26**
Thetford THT	Baseline Deployable Output	12.50	12.50	12.50	12.50	12.50	12.50
	Sustainability change impact	0.00	-2.00	-2.00	-2.00	-2.00	-2.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.18	0.15	0.15	0.15	0.15	0.15
	Transfers In*	0.25	0.25	0.25	0.25	0.25	0.25
	Transfers Out*	1.53	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**11.04**	**10.60**	**10.60**	**10.60**	**10.60**	**10.60**
South Humber Bank SHB	Baseline Deployable Output	57.00	57.00	57.00	57.00	57.00	57.00
	Sustainability change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Drought impact	0.00	0.00	0.00	0.00	0.00	0.00
	Climate change impact	0.00	0.00	0.00	0.00	0.00	0.00
	Outage Allowance‡	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers In*	0.00	0.00	0.00	0.00	0.00	0.00
	Transfers Out*	0.00	0.00	0.00	0.00	0.00	0.00
	Total WAFU	**57.00**	**57.00**	**57.00**	**57.00**	**57.00**	**57.00**

**bulk imports, exports and inter-zone transfers identified through EBSD modelling (baseline scenario)*
‡ this is represented as a positive but taken off DO in the WAFU calculation

10. Appendix 1: Hall intake River Trent

10.1 Introduction

Our Hall intake on the River Trent at Newton is a new source of supply for dWRMP 2019.

10.2 Current security of supply (1 in 100 years)

We are reporting Hall intake with a 20 Ml/d yield under a 1 in 100 year return period in line with our current Level of Service. This was based on a review of historic drought return periods: rainfall analysis by the Met Office and Atkins indicates that the 2010-12 drought event was approximately a 1 in 100 year event for the Trent catchment. Whilst flows in the Trent became low during this period we did not experience any instances where we could not abstract water and are therefore using this as our 1 in 100 year reference drought.

10.3 Future security of supply (1 in 200 years and above)

In line with guidance, we are moving to a 1 in 200 year Level of Service by the end of AMP7, to protect customers from more severe droughts. We have undertaken extensive drought vulnerability analysis and modelling to understand the impacts of this change on our supply forecast. Please see Section 3 for further details. This work identified Central Lincolnshire WRZ as drought vulnerable as during the summer of 1976, the worst drought on record for the Trent, flows were below the licenced Hands off Flow (HoF) for an extended period. Rainfall analysis for this event places it in the region of a 1 in 200 year event.

We have included WRMP investment to ensure the WRZ is secure to a 1 in 200 year drought event by the end of AMP7. In the interim, for drought events up to 1 in 200 year event, we will seek to apply for a drought permit to allow us to continue to use Hall in such an event. This is a new permit which involves a lowering of the Hands of Flow licence condition. It has been developed through discussion with the relevant Environment Agency and Natural England stakeholders, before being formally consulted on in the 2019 Drought Plan update. Following the completion of the AMP7 investment, Hall would continue to be used as a lower yielding source of supply. The yield assessment (Mott MacDonald 2018) identified that during 1976, there is a reliable yield of 6.8 Ml/d.

10.4 Modelled flow series

The Hall intake is modelled using a rainfall-runoff model built in HYSIM by Mott MacDonald. It uses National River Flow Archive (NRFA) data as the reference series, which identified 1976 as the worst historic drought. We now understand the Environment Agency have lower spot flow records which suggest it was even more severe. However, for the yield assessment, both series indicate yields of 6.8 Ml/d, as the length of time the flows are below the HoF are very similar. The magnitude of flow below the HoF does not influence the yield. Therefore for the purposes of our WRMP, we have used our modelled 1976 event as the reference 1 in 200 year event, as this is consistent with previous yield assessment and licence application and other Trent flow projects.

There is inherent sensitivity in projecting yields from modelled flows, especially when in reference to HoF thresholds, because there is a high dependency on the minimum flow which can vary markedly. We have commissioned a review of the Trent flows and yield assessment, and have issued a revised Hall yield report incorporating the issues discussed above (Mott MacDonald 2018).

11. Appendix 2: Stochastic drought analysis and selection

11.1 Introduction

Droughts vary in their timing, duration and magnitude (e.g. the extent of the rainfall deficit). These factors combine to produce a wide range of impacts on water resources. In our previous WRMPs we have used extended meteorological records to simulate the corresponding hydrology and thus evaluate the impacts of longer-term historical droughts. For example, this has captured the long duration drought of the early 1920s. However, more extreme droughts beyond those experienced over the last 100 years or so are plausible and may be of a different character. As such for this WRMP we have explored the droughts present in a large set of stochastically generated weather and associated hydrology produced for the Water Resources East project. We have also quantified the return period of historical and stochastic droughts to facilitate drought selection.

Our drought selection has been informed by a number of wider studies as well as specifically commissioned projects for the WRMP 2019:

- Water UK Water resources long-term planning framework[24]
- Water Resources East (WRE)[25]
- AWS AMP6 Third Dry Winter study
- AWS WRMP19 customer engagement work
- AWS WRMP19 drought selection project, with Atkins, Mott MacDonald and the Met Office
- AWS WRMP19 assessment of plausible reference droughts, with University of East Anglia
- AWS WRMP19 drought selection peer review, with Loughborough University

11.2 Regulator requirements for WRMP19 / PR19

The Water Resources Planning Guideline (WRPG)[26] requires the definition and application of a 'design drought' to inform assessments of deployable output (DO). As a minimum, this should be the worst drought on record, but for a resilience tested plan (Risk Composition 2)[27], a "more challenging but plausible range of droughts" should be considered. Plausible droughts are broadly defined as "periods of lower than usual rainfall that a company might reasonably be expected to prepare for"[28]. The selection of plausible droughts should[29]:

- Demonstrate how a company's supply system will respond to events that are both more challenging than the existing DO design event and of different character (e.g. different combinations of rainfall deficit and duration);
- Be broadly representative of the full range of drought stresses that a company plans to be resilient against; and
- Analysis modelling on the hind-cast record, or from other design droughts (e.g. drought scenarios from drought plan or stochastic modelling).

Selected droughts are to be presented in a new Water Resource Plan (WRP) Table 10. Droughts presented in WRP Table 10 require an estimate of drought severity, with a return period preferred, although ranking of droughts is acceptable[30]. The WRPG[31] specifies that the reference level of service should be set such that it provides resilience to a drought with an approximate 0.5% chance of annual occurrence (a 1 in 200 year drought event). This was reiterated in Ofwat's draft methodology for PR19[32], which included a potential common resilience performance commitment that "measures the percentage of the population the company serves that would experience severe supply restrictions standpipes or rota cuts) in a 1 in 200 year drought".

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[24] *https://www.water.org.uk/water-resources-long-term-planning-framework*
[25] *www.waterresourceseast.com*
[26] *EA. 2017. Water Resources Planning Guideline: Interim update. Environment Agency, April 2017*
[27] *For further details see our Problem Characterisation Report*
[28] *EA. 2016. Drought plan and WRMP links: A supporting document for the WRPG. Environment Agency, June 2016*
[29] *Ibid.*
[30] *Ibid.*
[31] *As updated in 2017*
[32] *Ofwat. 2017. Delivering Water 2020: Consulting on our methodology for the 2019 price review. July 2017. The Water Services Regulation Authority, Birmingham*

11.3 Approach

For the WRMP, plausible droughts need to be selected for each Water Resource Zone (WRZ). However, it is important that spatial coherence is maintained for areas which are linked or share similar characteristics in terms of meteorology, hydrology and the water resource system. Furthermore it is necessary to constrain the analysis to a workable number of areas (e.g. there are at least 39 rainfall gauges with good records in the WRE region of analysis). Therefore, five sub-regions have been developed. These are largely homogeneous in terms of climate, whilst recognising hydrological and water resource system boundaries (notwithstanding some transfers between them). The sub-regions are:

- The Trent (to North Muskham);
- Lincolnshire (including part of Nottinghamshire);
- Ruthamford;
- Norfolk (including Cambridgeshire Fens); and
- Essex and Suffolk (including parts of Cambridgeshire).

There is no single definition of drought, and therefore we have used both rainfall accumulation (and deficit) and a measure of aridity called the Standardised Precipitation-Evapotranspiration Index (SPEI)[33], over a range of magnitudes, and for 6, 12, 18, 24, 30, 36 and 60 month durations.

Furthermore there a variety of methods to calculated return periods. We have explored a several techniques, including frequency-based methods and extreme value analysis.

We used the following criteria to guide the drought selection process, and to ensure the selected design drought is consistent with ensuring system resilience and the WRPG:

- Droughts of greater severity than those observed in the historic record, as measured by rainfall deficit and SPEI and system performance metrics (e.g. reliability, resilience);
- Droughts with a range of durations;
- Droughts with different characteristics (e.g. combination of magnitude and duration; preceding conditions);
- Droughts which are significant within the target sub-region combined with different droughts elsewhere; and
- Droughts which vary in geographical occurrence across the region.

We have undertaken the following steps:

- Review of historical droughts, back to 1920.
- Identification of alternative droughts from stochastically generated weather sequences.
- Extreme value analysis of historical and stochastic droughts to estimate return periods.
- Hydrological and water resource system modelling of droughts.
- Selection of new reference droughts where required.

11.4 Historical droughts in our supply area (plus Trent basin)

There have been at least seven notable droughts in our supply area since 1920. Tables 11.1 and 11.2 provide an assessment of these droughts in terms of rainfall deficits and SPEI respectively. Figures 11.1 and 11.2 geographically illustrate the rainfall deficit for 12 and 36 month periods respectively. The droughts have varied in location, duration and magnitude. There is some coherence in droughts across our supply area, particularly in the east.

In general our supply system is relatively insensitive to short-duration droughts like 1976, except in a few locations where river abstractions go directly or quickly into treatment. Groundwater and our reservoir systems (especially in Ruthamford) buffer short-term variations in weather and are sensitive to successive dry winters, as recorded in the early 1930s, 1940s and between 1989 and 1992.

[33] *Vicente-Serrano, S.M., Beguería, S. and López-Moreno, J.I. 2010. A multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index - SPEI, Journal of Climate, 23, 1696-1718.*

Table 11.1: Sub-regional maximum rainfall deficits (mm) for post-1920 droughts

Drought	Duration	Sub-region				
		Ruthamford	Lincolnshire	Norfolk	Essex and Suffolk	Trent
Early 1920s	36 month	-330	-294	-241	-451	-246
	24 month	-318	-339	-318	-313	-298
	12 month	-269	-273	-274	-265	-305
Early 1930s	36 month	-391	-360	-335	-366	-471
	24 month	-403	-313	-308	-307	-432
	12 month	-260	-223	-183	-198	-297
Mid 1940s	36 month	-379	-294	-431	-355	-407
	24 month	-297	-287	-351	-258	-313
	12 month	-207	-215	-258	-201	-177
1975-76	36 month	-353	-396	-454	-349	-459
	24 month	-269	-296	-380	-318	-366
	12 month	-281	-278	-254	-215	-314
1988-92	36 month	-326	-495	-417	-382	-390
	24 month	-337	-391	-337	-309	-376
	12 month	-215	-211	-184	-176	-207
1995-96	36 month	-337	-374	-394	-374	-505
	24 month	-337	-380	-375	-365	-503
	12 month	-192	-220	-267	-221	-301
2010-12	36 month	-338	-270	-238	-203	-444
	24 month	-339	-292	-253	-207	-421
	12 month	-233	-218	-224	-189	-295

Table 11.2: Sub-regional minimum SPEI for post-1920 droughts

Drought	Duration	Sub-region				
		Ruthamford	Lincolnshire	Norfolk	Essex and Suffolk	Trent
Early 1920s	36 month	-1.90	-1.78	-1.59	-2.28	-1.20
	24 month	-2.05	-2.20	-1.88	-2.11	-1.72
	12 month	-2.48	-2.43	-2.41	-2.54	-2.09
Early 1930s	36 month	-2.17	-2.04	-1.85	-1.89	-2.17
	24 month	-2.13	-1.96	-1.78	-1.89	-2.24
	12 month	-2.16	-1.79	-1.81	-2.01	-2.21
Mid 1940s	36 month	-2.01	-1.59	-1.58	-1.69	-1.89
	24 month	-1.96	-1.58	-1.64	-1.59	-1.83
	12 month	-2.07	-1.80	-1.96	-2.01	-1.72
1975-76	36 month	-2.28	-2.36	-2.21	-1.99	-2.34
	24 month	-1.94	-2.11	-1.95	-1.97	-2.19
	12 month	-2.55	-2.49	-2.53	-2.33	-2.45
1988-92	36 month	-1.94	-2.38	-2.21	-2.19	-1.82
	24 month	-2.12	-2.36	-2.15	-2.24	-1.97
	12 month	-2.34	-2.21	-2.00	-2.21	-1.80
1995-96	36 month	-1.90	-1.98	-1.98	-1.96	-2.22
	24 month	-2.17	-2.24	-2.21	-2.21	-2.38
	12 month	-1.93	-2.25	-2.68	-2.46	-2.22
2010-12	36 month	-1.66	-1.38	-1.25	-1.15	-1.84
	24 month	-1.92	-1.73	-1.55	-1.35	-1.99
	12 month	-2.14	-2.07	-2.15	-1.94	-2.22

Figure 11.1: 12-month rainfall deficits (% of 1910-2016 average) for post-1920 droughts

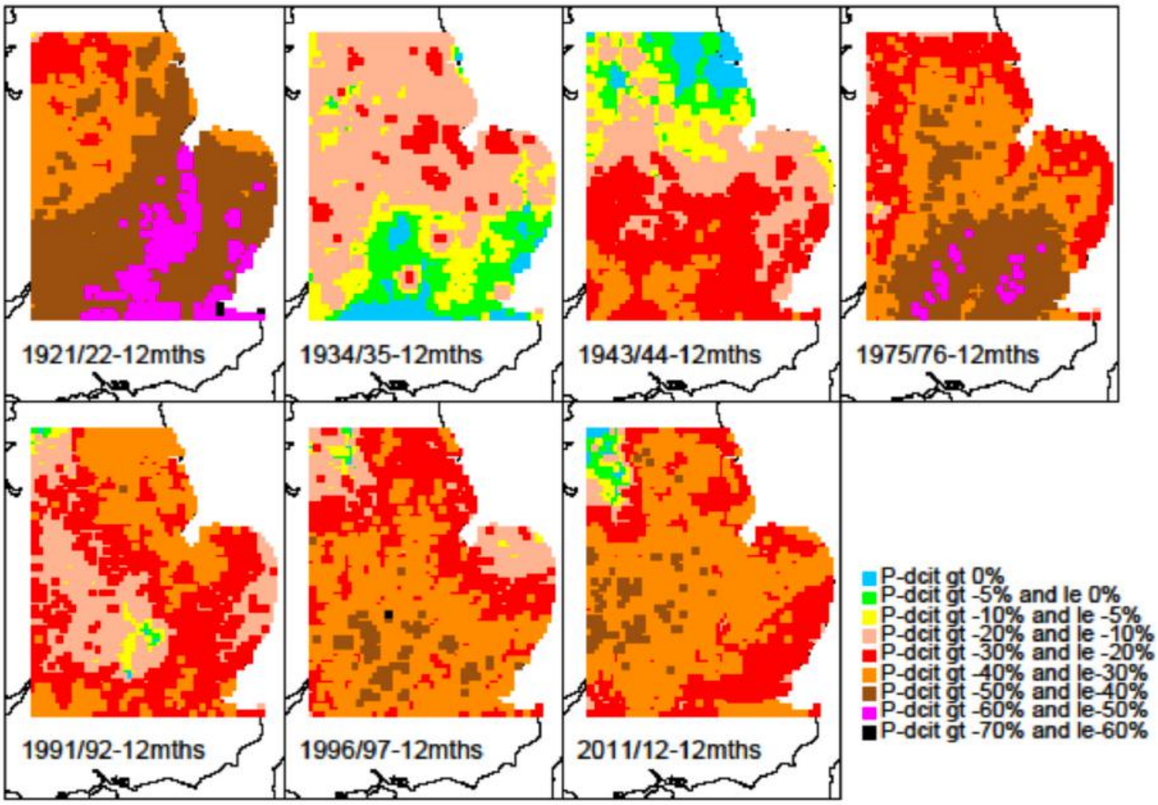
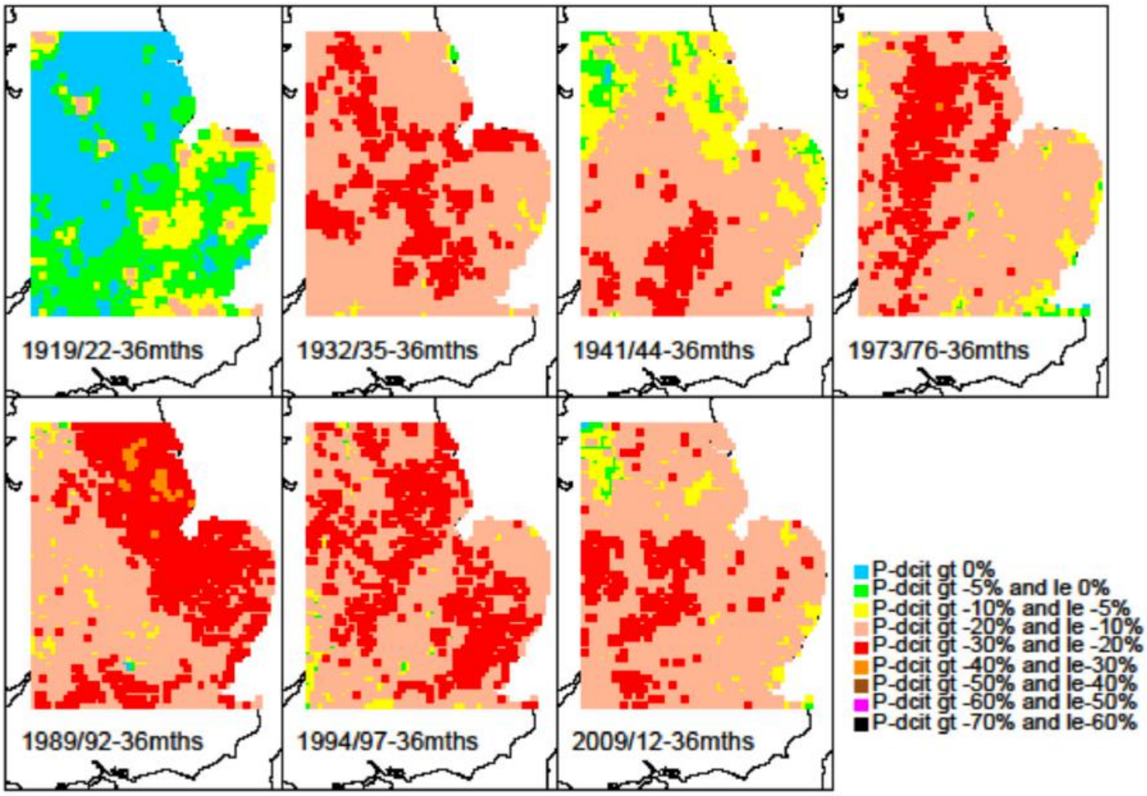


Figure 11.2: 36-month rainfall deficits (% of 1910-2016 average) for post-1920 droughts



We commissioned the Met Office to produce estimates of rainfall and SPEI for different return periods and locations. Return periods can be calculated using simple frequency-based analysis (e.g. inverse-ranking or plotting position methods), or extreme value analysis based on the statistical properties of events combined with theoretical models of extremes (for which there are alternative distributions). The Met Office undertook exploratory analysis using Generalised Extreme Value (GEV) and Generalised Pareto Distribution (GPD) approaches. However, although the observed data was de-clustered to remove dependency[34], either indirectly (GEV) or as part of the method (GPD), for accumulation periods of more than 18 months, the data is relatively smooth. This means that there are effectively very few data points left to robustly fit either a GEV or GPD model.

For the main analysis the Met Office applied a Bayesian[35] methodology[36]. The Bayesian method is less dependent on the number of sample points and has been extended to analyse longer duration accumulation periods by considering the average cluster width of events above a given threshold. The Bayesian extended GPD method has been compared to GEV and GPD approaches using 12-month accumulation data and performs well.

We have compared the Met Office output with the observed historical data to estimate the return period of the historical droughts. We have concluded that the 1930s drought in Ruthamford was of the order of a 1 in 200 year event and the drought was more severe than 1 in 200 year for Lincolnshire, whilst also affecting parts of Norfolk and Suffolk. Estimated return periods for the worst historical droughts on record are given in Table 11.3.

Table 11.3: Estimated return period of sub-regional worst historical droughts

Sub-region	Worst historical drought	Return period	Exceptions
Lincolnshire	1989-92	>1 in 200 year	Nottinghamshire WRZ (1976) ~ 1 in 200 year
Ruthamford	Early 1930s	~ 1 in 200 year	
Suffolk and Essex	1989-92 or 1995-7	1 in 50 to 1 in 150 year	East Suffolk WRZ (1997) ~ 1 in 200 year; South Essex WRZ (1934) ~ 1 in 50 year
Norfolk (including Cambridgeshire Fens)	1990-92	1 in 50 to 1 in 100 year	

Based on the preceding analysis the following gaps were identified in terms of defining plausible droughts, in particular with respect to the reference level of service:

- Severe short-term drought in Lincolnshire (in particular to test surface water sources)
- A more severe drought in Ruthamford, to test sensitivity
- Severe long-term droughts for the eastern part of the region

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[34] *Autocorrelation that exists in the data, plus that induced by using overlapping periods.*
[35] *Bayesian statistics is a mathematical process that applies probabilities to statistical inference. The original statistical assumption or understanding (described in the prior distribution) is updated to a final position (posterior distribution) based on new evidence e.g. from observations or simulation.*
[36] *Specifically, a Bayesian estimation of the shape and scale parameters of the GPD was applied to the data above a threshold.*

11.5 Stochastic droughts

A new monthly, spatially coherent rainfall generator was developed by Newcastle University, with input from the University of East Anglia and Atkins, for use in Southern Water's WRMP 2015[37]. This has been subsequently improved and added to by Atkins, and further updated with the Met Office in 2016 for use in the WRE project. The rainfall generator produces a very large number of statistically plausible sequences of monthly rainfall which are spatially coherent over a defined geographical area. This spatial coherence allows us to evaluate and compare stochastic datasets across our supply area. The rainfall generator is based on underlying drivers of UK weather, namely the North Atlantic Oscillation (NAO), Sea Surface Temperature (SST) and the East Atlantic Index (EAI). The EAI was added in 2016. Post processing routines correct the wet bias at the dry end of the distribution when compared to observations[38] and produces daily rainfall and PET for use in hydrological modelling.

We reviewed the 200, 91-year sequences from the WRE project to produce a shortlist of droughts. This was based on ranking of sequences using meteorological and water resource system metrics (based on a run of the WRE simulator), followed by simple frequency-based return period analysis of droughts. Spatial categories of droughts were identified based on the correlations in the stochastic data and expert judgement of how sub-regions have responded in the past to historical droughts:

- Norfolk, Suffolk and Essex;
- Norfolk, Suffolk and Essex with some impact in Lincolnshire;
- Ruthamford only
- Lincolnshire only; and
- Ruthamford with some impact in Lincolnshire and Trent.

Droughts to satisfy each of these spatial configurations were selected by considering the sub-regions as 'target' and specifying that they should satisfy an approximate 1 in 200 year event whilst giving secondary consideration to 'non-target' sub-regions. Three durations were considered (12, 14 and 36 months) with a focus on critical periods of relevance to the hydrological and water resource system performance of the sub-region, as well as durations for which there has not historically been a severe drought.

We subsequently used the rainfall and SPEI of the short-listed droughts, in combination with the Met Office extreme value analysis, to more accurately estimate the return period of these stochastic droughts. We tested 1 in 200 year droughts for WRZs in Norfolk and Suffolk and Essex (including parts of Cambridgeshire). For Ruthamford we tested a slightly more extreme drought, whilst in Lincolnshire we explored a shorter-duration 1 in 200 year event. This was based on using trace 41 for the whole region, except for the Norfolk sub-region where trace 39 was adopted (see Tables 4 and 5 for rainfall deficits and SPEI relating to the selected droughts). Trace 39 and 41 produce an identical drought impact in the Norfolk sub-region except for Norwich and The Broads WRZ, where a wetter preceding winter lowered drought risk in trace 41. In all WRZs we tested an indicative 1 in 500 year drought.

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[37] *For background see Serinaldi, F. and Kilsby, C.G. 2012. A modular class of multi-site monthly rainfall generators for water resource management and impact studies, Journal of Hydrology, 464-465, 528-540*

[38] *This exists due to unexplained driving factors, such as atmospheric blocking behaviour; the correction adjusts the stochastic output based on the difference between the stochastic mean and historical value for the same rank of event.*

Table 11.4: Sub-regional minimum SPEI for post-1920 droughts

Drought	Duration	Sub-region				
		Ruthamford	Lincolnshire	Norfolk	Essex and Suffolk	Trent
Stochastic Trace 41, Nominal Year 1949	36 month	*-420*	-293		*-514*	-283
	24 month	*-420*	-346		*-279*	-303
	12 month	*-310*	*-291*		*-279*	-303
Stochastic Trace 39, Nominal Year 1923	36 month			*-495*		
	24 month			-371		
	12 month			-371		

Values in italics are at least as severe as in the seven historical droughts (Table 1)

Table 11.5: Sub-regional minimum SPEI for selected stochastic droughts

Drought	Duration	Sub-region				
		Ruthamford	Lincolnshire	Norfolk	Essex and Suffolk	Trent
Stochastic Trace 41, Nominal Year 1949	36 month	-1.83	-1.62		*-2.41*	-1.20
	24 month	*-2.43*	-2.20		*-2.58*	-2.18
	12 month	*-2.59*	*-2.49*		*-2.63*	-2.35
Stochastic Trace 39, Nominal Year 1923	36 month			*-2.31*		
	24 month			-2.07		
	12 month			-1.51		

Values in italics are at least as severe as in the seven historical droughts (Table 2)

We used the modelled hydrological impact of the stochastic droughts from the Water Resources East project, supplemented by a new groundwater yield assessment using source summary diagrams. Drought flows and yields were then run through our Aquator model to produce estimates of impacts on DO.

For Norfolk and Suffolk and Essex, in several cases the stochastic 1 in 200 year event did not reduce the baseline DO. For some sources, yield impacts were limited by other factors (e.g. licence), whilst the conjunctive nature of some WRZs meant that resources could be shared. However, in South and North Fenland WRZs, Newmarket WRZ and Cheveley WRZ, there were impacts on groundwater that led to DO impacts at the WRZ level. These are listed in Table 6, along with details of the new reference drought. We would expect these impacts to occur at the same time in a severe drought. The stochastic drought does not reduce the DO for Norwich and The Broads WRZ, but does in combination with climate change.

In Ruthamford and Lincolnshire the stochastic droughts of around 1 in 200 year return period did not reduce DO because the events were not sufficiently more extreme than the historical reference drought. The drought impact in the Central Lincolnshire WRZ (Table 6) is a result of an assumption that a drought permit on the Trent would not be reliable in a 1 in 200 year event.

Table 11.6: Additional severe drought impacts on DO

Sub-region	WRZ	Severe drought impact (Ml/d)	Reference drought
Lincolnshire	Central Lincolnshire	-30.0	Historical 1976
Suffolk and Essex (including parts of Cambridgeshire)	Cheveley	-0.3	Stochastic Trace 41, Nominal Year 1949
	Newmarket	-3.0	Stochastic Trace 41, Nominal Year 1949
	Bury Haverhill	-3.0	Stochastic Trace 41, Nominal Year 1949
Norfolk (including Cambridgeshire Fens)	South Fenland	-9.0	Stochastic Trace 39, Nominal Year 1923

11.6 Extreme droughts

For the revised dWRMP we have undertaken some further analysis of extreme droughts, using the same stochastic dataset described above. We focussed on events likely to affect our major surface sources and groundwater and therefore used 36-month rainfall durations.

We short-listed a number of extreme droughts by searching for droughts in the extreme return period range (as modified to adjust for unusually narrow ranges). In particular we looked for droughts that extended across the region, as we expect such rare events to be spatially extensive and we wanted to apply a sensitivity test.

We analysed the short-listed droughts in terms of rainfall and hydrological response before refining the selection and modelling in Aquator.

We will be furthering the analysis of extreme drought as part of our adaptive planning process. This includes a review of multiple techniques for estimating extreme droughts and research into the combination of extreme drought and climate change.

11.7 Wider considerations

Our selection of droughts has been based on stochastic baseline meteorology applied to the 'baseline' water resource situation as used in the WRMP 2019 baseline supply demand balance. It is important to note that this assumes that the selection of droughts would remain robust for potential future changes to our water resource system, considering licence changes due to sustainability reductions and the impacts of climate change. We have mitigated this risk (e.g. of double-counting impacts) by checking for overlap on a WRZ by WRZ basis, and removing any duplicate impacts for relevant sources (e.g. where a drought or climate change vulnerable source is to be removed through a sustainability reduction). We have also considered the potential combined impact of drought and climate change in locations where we have needed to explore a severe drought (e.g. climate change is only relevant to Norwich and The Broads WRZ when combined with the stochastic drought).

Cover photo shows Rutland Water

Rutland Water is a reservoir in Rutland, England, east of the county town, Oakham. It is filled by pumping from the River Nene and River Welland and provides water to the East Midlands. It is one of the largest artificial lakes in Europe.

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