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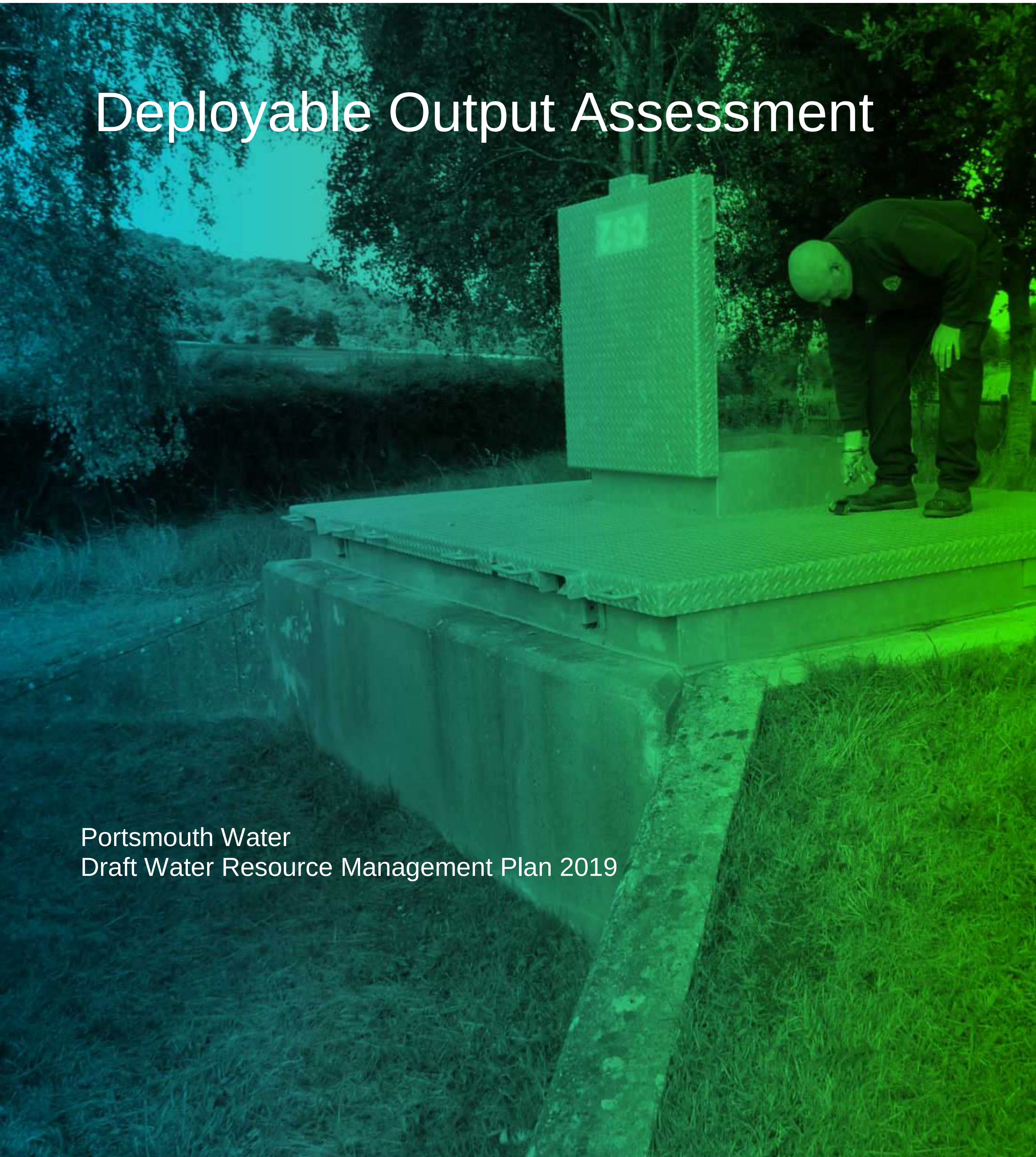
Deployable Output Assessment



Portsmouth Water
Draft Water Resource Management Plan 2019

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Contents

List of Tables

List of Drawings

List of Appendices

List of Figures

Abbreviations and glossary

DO	Deployable Output
ADO	Average Deployable Output. The reliable output / abstraction of water that can be achieved on average throughout the year, expressed as mega litres per day.
DAPWL	Deepest Advisable Pumping Water Level
EBSD	Economics of Balancing Supply and Demand
EHCC	East Hampshire & Chichester Chalk
HOF	Hands Off Flow
LoS	Levels of Service
MDO	Minimum Deployable Output. A reliable output / abstraction of water that can be achieved when groundwater levels and / or river flows are low, expressed as mega litres per day.
NEUBs	Non-Essential Use Bans (also referred to as Ordinary Drought Orders). Used to restrict demand in a drought.
Ofwat	The economic regulator of the water sector in England and Wales
PDO	Peak Deployable Output. A reliable output / abstraction of water that can be achieved during the peak summer demand period, expressed as mega litres per day.
PET	Potential Evapo-Transpiration
TUBs	Temporary Use Bans. Used to restrict demand in a drought.
UKWIR	UKWIR was set up by the UK water industry in 1993 to provide a framework for the procurement of a common research programme for UK water operators on 'one voice' issues. UKWIR's members comprise 20 water and sewerage undertakers in England, Wales, Scotland, Northern Ireland and the Republic of Ireland.
WRMP	Water Resources Management Plan
WRMP14	Water Resources Management Plan, 2014
dWRMP19	Draft Water Resources Management Plan, 2019
WRPG	Water Resources Planning Guideline
WRSE	Water Resources in the South East group
WRZ	Water Resource Zone
WWTW	Wastewater Treatment Plant

Executive Summary

Background

Portsmouth Water operates nineteen groundwater sources that take water directly from the local Chalk aquifer via boreholes and wells; groundwater is also captured as it emerges from the Chalk aquifer via springs in the Source B area. Therefore the majority of water supplied by Portsmouth Water to customers in South East Hampshire and West Sussex is derived from the local Chalk aquifer. The exception is a surface water abstraction on the River Itchen, a little to the west of the supply area.

As part of Portsmouth Water's 2019 draft Water Resources Management Plan (dWRMP19) submission, Portsmouth Water must calculate the total amount of water it can reliably supply to customers over the course of a 'design drought', expressed as an average daily rate of supply in the drought year. It may also draw attention to the amount it can supply during specific parts of the design drought, known as 'critical periods'. In the Portsmouth Water supply area the key critical period is during the summer, when the customer demand for water is significantly higher than during other parts of the year. There are numerous factors that can affect the amount of water that can reliably be supplied to customers. In wells and boreholes, fissures (natural cracks in the Chalk rock) and adits (tunnels dug into the Chalk rock) are important because they allow more groundwater to be taken from the aquifer. During a drought a lack of rainfall can reduce recharge so that aquifer storage reduces and groundwater levels fall to unusual levels. The fissures and adits may become less effective, or the quality of the water may deteriorate so that the raw water is not suitable for conventional treatment, such that the amount that can be supplied to customers is reduced; flows from groundwater springs will also reduce and the springs may appear at a lower point in the valley (because groundwater levels are lower).

The reliable supply may also be impacted in a drought owing to groundwater levels reaching the depth of pumps in boreholes and wells; or there may be a need to lessen the amount of water abstracted from the aquifer (or cease abstraction at specific boreholes and wells altogether), so that river flows and the ecology they support are protected.

Purpose of this report

AECOM has undertaken the supply calculations described above on behalf of Portsmouth Water, referred to as a Deployable Output (DO) assessment; the reliable supply over the course of a year is known as Average DO (ADO) and the reliable supply during the summer is known as Peak DO (PDO). Both ADO and PDO are presented in the units of 'millions of litres per day' (or 'Ml/d').

The purpose of this report is to present the methodology and results of the DO assessment, in compliance with the Environment Agency's *Water Resource Planning Guideline* (WRPG) (April 2017). The outputs will be considered within Portsmouth Water's decision making tool for the dWRMP19. The methodology and results of the impact of climate change on DO are reported separately in AECOM's *Climate Change Impact Assessment* (November 2017).

Deployable output assessment

Data and models

In order to reassess the Portsmouth Water DO, records of groundwater levels and abstractions have been analysed by AECOM. These, along with a review of constraints information (e.g. adit and fissure levels), have been used to predict the reliable supply that can be achieved when groundwater levels in the wider Chalk aquifer are high, average or low. Models have been developed in order to predict the groundwater levels and reliable supplies that might be available in plausible droughts that are more severe than those experienced in the past (i.e. more severe than those experienced in the 1970s and 1990s). An existing Environment Agency groundwater model for the supply area has also been used by AECOM to check that DO values are realistic; this has led to the recommendation of a cap on ADO in order to protect the magnitude of reliable supplies when droughts occur.

Links with the drought plan

When drought conditions begin, Portsmouth Water will implement its drought plan. This results in a steady escalation of restrictions on the demand for water, from Temporary Use Bans (TUBs) such as bans on the use of hosepipes / sprinklers, to Non-Essential Use Bans (NEUBs, also referred to as ordinary drought orders) that may start to impact businesses in the local area; as a last resort, water companies may also ask for emergency drought orders (e.g. use of standpipes and rota cuts to reduce the demand for water), although these are part of the emergency plan and not the drought plan. Portsmouth Water has agreed with its customers the frequency at which demand restrictions might need to be implemented (e.g. once every 20 years for TUBs), known as 'Levels of Service' (LoS).

A range of DOs for different drought return periods have been presented in this report. These can be used within Portsmouth Water's decision making tool for the dWRMP19 in order to understand the impact of drought and the investment costs with or without drought plan measures (permits and orders). It follows that the existing LoS can be reviewed and revised as necessary (following consultation with customers).

Results of the deployable output assessment

The Environment Agency has requested that water companies test a 'reference' drought within the dWRMP19 that might occur once every 200 years (i.e. a severe drought) in addition to the 'design drought' selected by the water company. The selection of a design drought will be finalised by Portsmouth Water through testing of the supply demand balance in its decision making tool. Therefore DO values for a range of return periods (a range of drought severities) have been calculated to support this testing, including the 'worst historic' and reference droughts (see table below).

Return period of DO (related to drought severity)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)
1 in 20 year	227	280	252
1 in 40 year	217	270	237
Worst Historic	215	267	242
1 in 83 year	212	263	233
1 in 125 year	203	252	235
1 in 200 year	191	236	222
1 in 500 year	185	238	217

Conclusions

The methodology and results of the DO assessment are presented within this report. The outputs will be considered within Portsmouth Water's decision making tool for the dWRMP19. The methods comply with the requirements of the WRPG and related guidance.

1 Introduction

1.1 The Portsmouth Water resource zone

The Portsmouth Water Resource Zone (RZ) includes parts of South East Hampshire and West Sussex. The company operates nineteen Chalk groundwater sources, the Source B Springs and the Source A (River Itchen) surface water source. Further details are provided in Table 1-1.

Table 1-1 Portsmouth Water sources

Source Name	Source Type	Licence		Aquifer/ River
Source T	Groundwater		QRST Group Licence	Chalk aquifer
Source Q	Groundwater			
Source S	Groundwater			
Source R	Groundwater			
Source M	Groundwater		LMNOP Group Licence	
Source L	Groundwater			
Source P	Groundwater			
Source O	Groundwater			
Source N	Groundwater			
Source U	Groundwater			
Source D	Groundwater		Source C & Source D Group Licence	
Source C	Groundwater			
Source G	Groundwater		Source G & Source F Group Licence	
Source F	Groundwater			
Source K	Groundwater			
Source I	Groundwater			
Source E	Groundwater			
Source H	Groundwater			
Source J	Groundwater			
Source B Springs	Spring			
Source A	Run-of-River			River Itchen

1.2 Deployable output and historic assessments

Portsmouth Water is required to submit deployable output (DO) values to the Environment Agency (EA) and the Office of Water Services (OFWAT) every five years as part of its Water Resources Management Plan (WRMP) submission. DO is defined by UKWIR's *Handbook of source yield methodologies* (2014) as:

"the output of a commissioned source or group of sources or of bulk supply as constrained by licence (if applicable), pumping plant and/or well/aquifer properties, raw water mains and/or aqueducts, transfer and/or output main, treatment and water quality, for specified conditions and appropriate demand profiles to capture variations in demand over the year".

Historic assessments of DO were undertaken by the former Southern Water Authority in 1984. Portsmouth Water subsequently undertook a review of DO in 1997 and for the majority of sources DO assessment diagrams were produced. These incorporated operational data from the 1970's or 1990's droughts, which were used to define operational drought lines. The diagrams are only available in a PDF format; the supporting Excel files and accompanying report are no longer available.

Arup undertook a reassessment of Portsmouth Water's DO for the WRMP09 submission, which largely comprised of an update of DO constraints data (Arup, 2009). However, new DO assessments were also derived for groundwater sources developed since the 1997 assessment; Source T, Source D and Source G.

AECOM (incorporating URS) undertook the most recent reassessment of Portsmouth Water's DO for the WRMP14 submission (URS, 2013). This was completed in accordance with the regulators' *Water Resources Planning Guideline* (WRPG) (October 2012) and the supporting guidance in the UKWIR's *WR27 DO Report* (2012) and *A Unified Methodology for the Determination of Deployable Output from Water Sources* (2000).

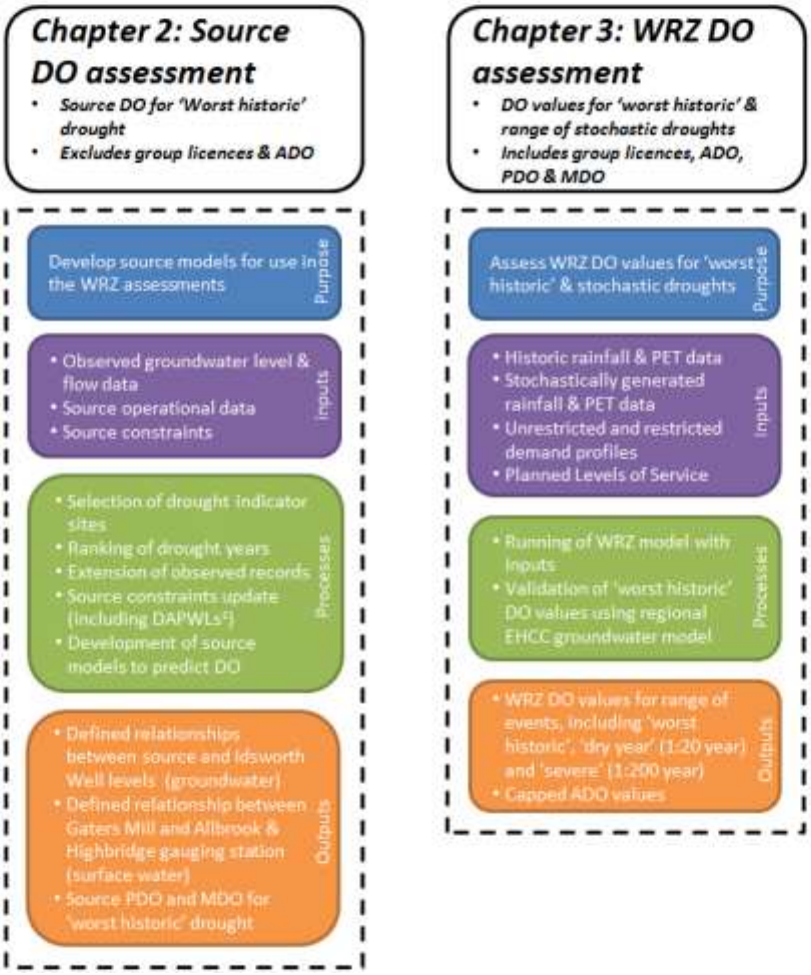
1.3 The current report

AECOM has been commissioned to undertake the reassessment of Portsmouth Water's DO for the dWRMP19 submission. This reassessment has been completed taking into account the Environment Agency's *Water Resources Planning Guideline* (WRPG) (April 2017), the supporting *Drought Plan and WRMP Links* (June 2016), and the following UKWIR guidance:

- *A Unified Methodology for the Determination of Deployable Output (2000).*
- *WR27 (DO report) Water Resources Planning Tools (2012);*
- *Handbook of source yield methodologies (2014);*
- *WRMP 2019 Methods - decision making process guidance (2016a); and*
- *WRMP 2019 Methods – risk based planning (2016b).*

This report outlines the procedures followed for the reassessment of DO for dWRMP19 and summarises the results. Each step of the DO assessment process is outlined in Drawing 1-1, detailing the purpose, inputs, process and outputs. The impact of climate change on DO is reported separately in AECOM's *Climate Change Impact Assessment* (2017).

Drawing 1-1 Report outline



1.4 Planning scenarios, levels of service and deployable output assessment

1.4.1 Problem characterisation and risk composition

The dWRMP19 development process involves a ‘problem characterisation’ to evaluate strategic needs and complexity (see step 3 within UKWIR 2016a). Portsmouth Water developed a problem characterisation for its supply area (Portsmouth Water, July 2016) and this indicated ‘None’ with respect to the ‘Strategic Needs Score’, and ‘Low’ with respect to the ‘Complexity Factors Score’; this placed the Portsmouth Water WRZ in the green zone of the problem characterisation matrix.

The result of the problem characterisation suggests that the supply side might be assessed in-line with ‘Risk Composition 1’ within UKWIR (2016b); ‘*conventional DO or historically based time series*’. However Portsmouth Water decided to explore ‘*conventional plus event based DO or timeseries*’ in line with ‘Risk Composition 2’, in order to explore the implications of alternative/more severe droughts such as a 1 in 200 year event.

1.4.2 Selection of planning scenarios and the design drought

The Environment Agency’s *WRPG* (April 2017) indicates that the data in the WRMP should be based on the ‘*dry year annual average’* (for demand) and a ‘*design drought’* (for supply). The *WRPG* also states that the *‘design drought’* can be the worst on record or a more challenging but plausible drought. The current deployable output assessment explores the impact of severe (but plausible) droughts through consideration of stochastic data, in addition to the ‘worst historic’ drought. The selection of the ‘design drought’ will be informed by the outputs of Portsmouth Water’s decision making tool.

The Environment Agency’s *WRPG* (April 2017) also indicates that the water company may choose to explain how it will deal with a period of peak strain, known as the ‘*critical period*’ scenario. Portsmouth Water’s WRMP14 demonstrated that it has a critical period associated with peak summer demand. For this reason a critical period (peak summer demand) scenario is addressed within the current deployable output assessment, in addition to the dry year annual average scenario.

A critical period (minimum groundwater level and river flow) scenario is also addressed, although the previous deployable output assessment (URS, 2013) demonstrated that in most drought years this condition is not the critical constraint.

1.4.3 Levels of service and drought plan links

When drought conditions begin, Portsmouth Water will implement its drought plan. This results in a steady escalation of restrictions on the demand for water, from Temporary Use Bans (TUBs) such as bans on the use of hosepipes / sprinklers, to Non-Essential Use Bans (NEUBs, also referred to as ordinary drought orders) that may start to impact businesses in the local area; as a last resort, water companies may also ask for emergency drought orders (e.g. use of standpipes and rota cuts to reduce the demand for water), although these are part of the emergency plan and not the drought plan. Portsmouth Water has agreed with its customers the frequency at which demand restrictions might need to be implemented (e.g. once every 20 years for TUBs), known as ‘Levels of Service’ (LoS).

A range of DOs for different DO return periods (linked to drought severity) have been presented, as derived from Water Resources South East (WRSE) group stochastic climate data (WRSE, 2017). These can be used within Portsmouth Water’s decision making tool to understand the impact of the drought condition on the supply and demand balance and the investment costs with or without demand restrictions and drought permits. It follows that existing LoS can be reviewed and revised as necessary (following consultation with customers). A recommendation is that the Drought Plan and drought triggers are reviewed and revised as necessary to ensure consistency with the resources assessment in this report and any proposed changes to LoS.

1.4.4 Planning scenarios and calculation of average, minimum and peak deployable output

The links between planning scenarios and DO are as follows:

- The assessment of Average demand Deployable Output (ADO) is linked to the dry year annual average planning scenario. The UKWIR WR27 DO report (2012) defines the ADO as *‘the deployable output of a source for the average annual period’* and goes on to state that *‘the average demand is literally the average over the year computed as average over a normal year or average over a dry year’*. In the current assessment the ADO is assessed for various return periods in a Water Resource Zone (WRZ) model that includes demand profiles.
- The Peak demand Deployable Output (PDO) is linked to the critical period (peak summer demand) planning scenario. The UKWIR WR27 DO report (2012) defines PDO as *‘the deployable output of a source during the peak demand period’*.

- The assessment of Minimum Deployable Output (MDO) can be linked to a critical period (minimum groundwater level and river flow) planning scenario. Under the UKWIR unified methodology guidance published in 2000, groundwater source 'ADO' assessments (improved methodology) were based on monthly operational data for those months when groundwater levels were at or near their annual minima for the worst drought to have affected the area of the source. However, the use of data associated with minimum groundwater levels means that the assessments now fall under the category of Minimum Deployable Output (MDO). The UKWIR WR27 DO report (2012) defines MDO as '*the deployable output of a source during the minimum resource period and for groundwater sources – this is the minimum water level period'*.

1.5 Acknowledgements

Members of staff at Portsmouth Water and the Environment Agency have assisted with the provision of data and the investigation of queries on various source issues. They have been mentioned where appropriate in the assessment audit trails. The Consultant gratefully acknowledges this assistance.

2 Source deployable output assessment

2.1 Introduction

The key purpose of undertaking individual source DO assessments within this study is to prepare source models for use in the WRZ DO assessment (see Section 3). The process of source DO assessment also provides an opportunity to:

- Select appropriate 'critical period' observation borehole and gauging station records (i.e. good drought indicators);
- Identify and rank drought years using the historic groundwater level and flow records;
- Extend the historic observed record ('hindcasting');
- Refine the source constraints information;
- Review the source operational data; and
- Estimate individual source DO values for the worst drought in the historic record (excluding group licence constraints).

Further information on the methodology followed is outlined in the sections below.

2.2 Selection of drought indicator sites

2.2.1 Introduction

Appropriate drought indicator sites are required for DO assessment to identify key drought years and periods of minimum levels / flows. These can be referred to as minimum level / flow 'critical period' observation boreholes and gauging stations. They typically have long and continuous records, preferably extending back to pre-1920, with a good resolution of data and minimal influence from local groundwater abstraction (i.e. good drought indicators).

The locations of the Portsmouth Water public water supply sources are provided in Figures 1 and 2. The sources are distributed across the 50 km by 25 km resource zone within different groundwater and surface water catchments. Consequently, more than one critical period (drought) indicator has been examined for the Portsmouth Water area. This is further discussed in Section 2.2.2 for observation boreholes and in Section 2.2.3 for gauging stations.

2.2.2 Observation boreholes

An analysis of the Environment Agency observation borehole network was undertaken as part of the previous study (URS, 2013) to identify potential critical period observation boreholes. Two observation boreholes were identified; Well 'Z' (EA station no. 245221014) and Well 'Y' Owslebury (EA station no. 142209228). In addition, an analysis of the Portsmouth Water long term groundwater level and spring flow monitoring records for Well 'X' and Source B springs, respectively, was undertaken. Well 'X' is located in a central position within the Portsmouth Water resource zone (Figure 1) up-gradient of the Source B Springs, and the period of record extends from 1932 with water levels monitored on a weekly basis.

The previous deployable output assessment (URS, 2013) used Well 'X' as the critical period and drought year indicator for all Portsmouth Water groundwater sources (it is also the key drought indicator in the Portsmouth Water drought plan). For the current study the use of Well 'Z' and Well 'Y' observation boreholes was explored again (including development of lumped parameter models), although it is considered there is no significant improvement in the modelling of source DOs relative to the use of Well 'X' (see Section 2.4.3). Therefore Well 'X' is maintained as the critical period observation borehole for the current study.

2.2.3 Gauging stations

Portsmouth Water abstracts water from the River Itchen at Source A (see Figure 2). Observed flow records are available for Allbrook and Highbridge gauging station (152208001) from 1958 and Riverside Park (152210001) from 1982. The flows in the River Itchen are influenced by Southern Water abstractions upstream of these gauging stations and also by Southern Water's Chickenhall Waste Water Treatment Works (WWTW) discharge (see Figure 2). Therefore, the historic flows are not suitable for critical period analysis.

A naturalised flow record for Riverside Park gauging station on the River Itchen was provided by Southern Water for the previous study (URS, 2013). It included the period 1918 to 2010 and was developed within the Environment Agency's Test and Itchen regional groundwater model. The period 1918 to 1969 was based on Run 88 (PENSE at West Stoke Farm and rainfall based on 3 rain gauges) and the period 1970 to 2011 was based on Run 86 (MOSES v2.0.1 and rainfall based on 69 rain gauges).

For the previous study a naturalised flow record for the Allbrook and Highbridge gauging station was also generated by HR Wallingford using CatchMOD for the period 1880 to 2005. A naturalised flow record for the Riverside Park gauging station was then developed using a regression relationship with the record for the Allbrook and Highbridge gauging station.

For the current study, the River Itchen at the Riverside Park gauging station is retained as the critical period gauging station. It is the CatchMOD flows that are used for the current DO assessment (largely owing to modelling efficiency with respect to use of stochastic data) (see Section 2.4.4).

2.3 Ranking of drought years

For the previous assessment (URS, 2013), frequency analysis was carried out on the observed record of groundwater levels at the critical period boreholes, observed flows at Source B Springs and naturalised flow records for Riverside Park, to identify drought years and to provide a ranking of drought events within the historic record. The groundwater level and spring flow records indicated that autumn 1973 into winter 1974 was the most severe drought within the period of record (1880 to 2011). The modelled River Itchen datasets indicated that 1944 and 1976 were the most severe droughts for surface water flow.

The frequency analysis has not been updated for the current study, as no pertinent droughts have occurred since that analysis. The analysis is also not reproduced within this report, as it is the return period of the WRZ DO that is pertinent to the current assessment (see Section 3.2.3).

2.4 Extension of observed groundwater level and flow records

2.4.1 Introduction

Previous Environment Agency and UKWIR guidance has recommended the use of observation borehole and gauging station records that extend back to pre-1920, such that droughts of the 1920s and 1930s are captured; where observed records were of insufficient length it was recommended that records were extended (hindcast) using rainfall data and modelling. The extension or hindcasting of records to assist with deployable output assessment is discussed in this section.

2.4.2 Lumped parameter model for Well 'X'

For the previous DO assessment (URS, 2013) the observed groundwater level record for Well 'X' was extended from 80 years (1932 to 2011) to 98 years (1908 to 2005) using a good correlation with flows at the Source B Springs. This was subsequently used in the resource zone model to calculate WRZ DO.

For the current study the observed groundwater level record at Well 'X' has been extended to 132 years (1880 to 2011) using a lumped parameter model. The input data were daily rainfall and Potential Evapo-Transpiration (PET) for the Wallington Catchment. The data for the period 1880 to 2005 was derived from the Environment Agency's Reliability of Public Water Supplies Project undertaken by URS (July 2011). The climate dataset was subsequently extended from 2005 to 2011 by HR Wallingford, using GEAR daily rainfall and the temperature based Oudin method for PET.

The calibration of the Well 'X' model is provided in Figure 3 and involved adjustment of parameters that dictate the rate of rise and fall of hydrograph 'limbs' and the nature of the seasonal peaks and troughs. The modelled groundwater levels have been used within the assessment of WRZ DO (see Section 3).

2.4.3 Lumped parameter models for Well 'Z' and Well 'Y'

A recommendation of the previous DO assessment (URS, 2013) included further consideration of Well 'Z' and Well 'Y' observation boreholes for the modelling of source outputs in the WRZ model (i.e. instead of Well 'X'). This was completed for the current study as described below.

The testing of the Well 'Z' and Well 'Y' observation boreholes involved the development of a lumped parameter groundwater level model (similar to that developed for Well 'X'). Daily rainfall and PET data for the Chichester and Lower Itchen catchments (1880 to 2011) were used as the basis of the Well 'Z' and Well 'Y' lumped parameter models, respectively. The models were then calibrated by varying the aquifer properties that affect the groundwater level i.e. the rate of rise and fall of hydrograph 'limbs' and the nature of the seasonal peaks and troughs.

The Well 'Y' lumped parameter model was successfully calibrated to the overall hydrograph pattern and the annual maxima and minima (see Appendix A). The Well 'Z' lumped parameter model was successfully calibrated to minimum levels, but not to maximum levels (see Appendix A).

In order to assess the drought behaviour of the observation boreholes, annual minima of the observed groundwater levels were plotted for each borehole and compared (Appendix A). There is a very strong correlation between annual minima groundwater levels at Well ‘X’ and Well ‘Z’ (R^2 value of 0.91), suggesting that groundwater levels in these boreholes are very similar in terms of drought behaviour. While the correlation between annual minima groundwater levels at Idsworth and Well ‘Y’ is also strong, the R^2 value of 0.8 suggests that there is some variation in drought behaviour (with respect to groundwater levels) between these boreholes.

Following testing it was considered there was no significant improvement in the modelling of source DOs using these models compared with the lumped parameter model developed for Well ‘X’. The Well ‘X’ is used in the Portsmouth Water drought plan; therefore the Well ‘Y’ and Well ‘Z’ records and models are not considered further within this report.

2.4.4 CatchMOD modelling of the River Itchen

For the previous DO assessment (URS, 2013) a CatchMOD model was developed by HR Wallingford to allow for the hindcasting of observed river flow records using historic rainfall and PET data. The observed flow record for the Allbrook and Highbridge gauging station was extended from 54 years (1958 to 2011) to 126 years (1880 to 2005).

For the current study, the existing CatchMOD model was used to extend the observed (historic) flow record at Allbrook and Highbridge gauging station by a similar process to 132 years (1880 to 2011) and to simulate flows for the worst drought on historic record. The input data were daily rainfall and PET for the Upper Itchen catchment. The data for the period 1880 to 2005 was derived from the Environment Agency’s Reliability of Public Water Supplies Project undertaken by URS (July 2011). The climate dataset was subsequently extended from 2005 to 2011 by HR Wallingford, using GEAR daily rainfall and the temperature based Oudin method for PET.

Naturalised flows at the Riverside Park gauging station (downstream of Allbrook and Highbridge) have been generated using a regression relationship with flows at Allbrook and Highbridge. The naturalised flows from CatchMOD have subsequently been used within the assessment of residual flows and DO for Source A.

2.5 Approach to assessing peak deployable output for individual sources

2.5.1 Groundwater sources

In this study the assessment of source PDO provides a value of the reliable output (prior to the application of group licence constraints) that can be obtained during the worst drought year on record during the peak summer demand period.

The yield assessment method requires that a ‘peak week’ is defined using daily abstraction data on the basis of a 7 day running mean. Data for the peak week, and the 2 weeks either side should be considered (i.e. a 5 week period) for the worst drought year experienced by the source (UKWIR, 2000). As Portsmouth Water holds a combination of individual and group groundwater abstraction licences for its resource zone (see Table 1-1), peak weeks for individual sources have usually been allocated on the basis of source abstraction, and peak weeks for group licence sources have been allocated on the basis of resource zone abstraction, in line with the UKWIR groundwater methodologies.

On the PDO assessment diagrams (see Appendix B), the abstraction data have been plotted as the 7 day running mean outputs ending on the day of the water level measurement. The drought period analysis (observed record) has indicated that the most severe drought (for groundwater) occurred in the period autumn 1973 into winter 1974. However, in this study operational water level data are not available prior to 2005. Therefore operational data have only been plotted for recent drought years.

In order to estimate the PDO for the worst drought year on record, curve shifting of the operational drought curve to the water level condition in the peak period of 1973 has been undertaken; the peak week is taken as mid-August based on the updated demand profile from Portsmouth Water (when groundwater levels in Well ‘X’ were 14.17 mAOD). The degree of shift in groundwater source rest water level is calculated from analysis of the Well ‘X’ critical period record and the application of scaling factors to describe the relationship between water level fluctuations at the critical period observation borehole and those at the source borehole (see Table 2-1).

Each groundwater source has also been assigned a ‘signature’ observation borehole (see Table 2-1); this is an observation borehole that is relatively close to the source, where the water level fluctuations are expected to be similar. Where there is uncertainty with regard to the source rest water levels, the signature observation borehole record has been examined to verify or discount these source water levels. The signature observation boreholes were not used directly in the estimation of DO.

Table 2-1 Sources, signature observation boreholes and Well 'X' scaling factors

Source name	Signature observation borehole	Scaling factor and derivation (Well 'X' to source borehole)
Source C	Whitebeams	0.35 or 0.24 depending on water level condition
Source D	Whitebeams	1.68 or 0.34 depending on water level condition
Source E	Source E Hut	0.50 or 0.41 depending on water level condition
Source F	Rookwood Farm	0.81 or 0.17 depending on water level condition
Source G	Rookwood Farm	1.58 or 0.58 depending on water level condition
Source H	Driftway	0.62 or 0.25 depending on water level condition
Source I	Standard Way	0.06 or 0.20 depending on water level condition
Source J	Source J OBH	2.78 or 0.12 depending on water level condition
Source K	Catherington	1.42 or 0.84 depending on water level condition
Source L	Source L Langford Farm	1.71 or 0.11 depending on water level condition
Source M	West Marden Farm	2.47 or 1.28 depending on water level condition
Source N	West Marden Farm	1.89 or 0.22 depending on water level condition
Source O	West Marden Farm	1.51 or 0.39 depending on water level condition
Source P	Source P Deeside	0.11 or 0.07 depending on water level condition
Source Q	Norton Grange	1.34 or 0.76 depending on water level condition
Source R	Norton Grange	1.46 or 0.91 depending on water level condition
Source S	Norton Grange	0.63 or 1.0 depending on water level condition
Source T	Norton Grange	1.70 or 0.21 depending on water level condition.

2.5.2 Source B Springs

Weekly flows are available for the Source B Springs for the period 1908 to 2015. Since 2015, daily flows are available, with records of spring overflow plus abstraction collected by telemetry.

The method for selecting peak weeks and calculating PDO is similar to that used for the groundwater sources, although weekly flows are used in the absence of daily data. The potential yield has been calculated based on total spring flow, as measured by Portsmouth Water.

2.5.3 Source A run-of-river source

An updated historic naturalised flow record for the Allbrook and Highbridge gauging station on the River Itchen was developed by HR Wallingford using CatchMOD for the period 1880 to 2011 (see Appendix C). A naturalised flow record for the Riverside Park gauging station has then been generated using a regression relationship with the naturalised flow record for Allbrook and Highbridge gauging station, for use in the surface water DO model. The DO model denaturalises the record and calculates DO assuming the following:

- Hands-Off-Flow (HOF) constraint of 198 Ml/d applied at the Allbrook & Highbridge gauging station.
- Restriction on Southern Water summer time abstraction rates. It is assumed that the Otterbourne sources (groundwater, surface water and Twyford) are restricted to 137.0 Ml/d (June), 127.1 Ml/d (July), 111.1 Ml/d (Aug), 76.0 Ml/d (Sept) and 136.6 Ml/d (Oct to May). Therefore, the total upstream abstraction (including the Easton and Totford sources) is assumed to be 168.9 Ml/d (June), 159.0 Ml/d (July), 143.0 Ml/d (Aug), 107.9 Ml/d (Sept) and 159.3 Ml/d (Oct to May).
- Dry weather flow of 32 Ml/d from Chickenhall WWTW.
- HOF constraint of 194 Ml/d at Riverside Park gauging station.
- Average annual licensed abstraction rate of 45.5 Ml/d for Portsmouth Water's Source A, with a summer licence profile of 44.3 Ml/d (June), 41.1 Ml/d (July), 40.6 Ml/d (Aug), 39.2 Ml/d (Sept).

Southern Water in its dWRMP19 DO assessment for the Otterbourne sources has used the same assumptions for (i) HOF at Allbrook & Highbridge and (i) restrictions on summer time abstractions rates (Pers. Comm. Simon Cook, Southern Water,10 August 2017). However Portsmouth Water has used a Catchmod model to derive river flows, whereas Southern Water has used the regional groundwater model (Test and Itchen); sensitivity analysis at WRMP14 demonstrated the two models produced similar results with respect to WRZ DO assessment (despite a different ranking of drought years).

The residual flows and Source A licence profile are shown on Figure 4. The PDO has been assessed for the peak period (mid-August) of the worst drought year in the available naturalised flow record.

2.6 Approach to assessing minimum deployable output for individual sources

2.6.1 Groundwater sources

The assessment of source MDO provides a value of the reliable output (prior to the application of group licence constraints) that could be obtained during the worst drought year on record when water levels and river flows were at their lowest.

On the source MDO assessment diagrams (see Appendix B), the abstraction data have been plotted as the 30 day running mean outputs, in Ml/d, ending on the day of the water level measurement. The analysis of records as described in Section 2.3 has indicated that the minimum groundwater level and spring flow condition occurred during autumn 1973 into winter 1974. However, operational water level data are not available prior to 2005. Therefore data have been plotted on the assessment diagrams for recent years only and the curve shifting method has been used for estimating deployable output in the 1973 drought (as per the peak deployable output method, see Section 2.5.1).

2.6.2 Source B Springs

Weekly flows are available for the Source B Springs for the period 1908 to 2015. The method for calculating MDO is similar to that used for the groundwater sources, although four-week running mean flows are used in the absence of daily data. Portsmouth Water measures total spring flow and therefore it has been possible to calculate the potential yield.

2.6.3 Source A run-of-river source

As described by the UKWIR *WR27 (DO Report) Water Resources Planning Tools* (2012), for a stand-alone surface water source, *'DO is the daily abstraction rate in the specified dry year or critical period conditions within the licence, physical and ecological need constraints without demand restrictions'*. Therefore the source MDO has been calculated for the minimum available flow within the most severe drought year (according to the CatchMOD based output).

It is noted that for the WRZ DO modelling (see Section 3) the Source A surface water source output is considered alongside the groundwater abstractions. This means that the worst drought year is defined by the lowest WRZ DO, which is based on access to the combined groundwater and surface water resource.

2.7 Time series data for deployable output assessment

2.7.1 Introduction

Groundwater source water level and abstraction time series data are a key component of the DO assessment process. Good availability and quality of data is required to reduce uncertainty in the curve shifting process and the derived DO values. Further information on Portsmouth Water data is provided in this section.

2.7.2 Abstraction and distribution data

The historic and recent abstraction and distribution input data were provided by Portsmouth Water as a series of spreadsheets, as follows:

- Weekly distribution input data for the period January 1999 to March 2016 (with and without the bulk supply to Southern Water) in the 'Water Supply Information.xls' spreadsheet;
- Daily source abstraction data for the period January 1989 to January 2016 were provided in the 'Annual Abstraction 2005 to Jan 2016.xls' spreadsheet; and
- Fifteen minute abstraction data for each source for the period January 2012 to December 2015 in a series of source-specific spreadsheets.

Groundwater level data were also supplied by Portsmouth Water as outlined in the next section.

2.7.3 Source groundwater level telemetry data and manual dips

The historic and recent source water level data were provided by Portsmouth Water as a series of spreadsheets, as follows:

- Minimum and maximum water level telemetry data by groundwater source for the period June 2005 to April 2016; and
- Fifteen-minute water level data for individual boreholes and wells for the period January 2012 to April 2016.

Prior to the previous DO assessment (URS, 2013) there were no historic manual dip data for the groundwater sources. In order to determine the degree of telemetry calibration, AECOM (incorporating URS) undertook site visits for key sources in September and October 2012 to obtain manual dips. These were compared against the on-site telemetry displays and also the Portsmouth Water centralised telemetry system. The calibration results generally indicated less than a 2 metre difference between the telemetry values and the manual dips, providing a higher degree of confidence in the 2012 water level data. No further manual dip data has been made available to the current study, although the quality of the telemetry data can generally be determined by comparing levels and fluctuations with the 2012 validated data.

For the *Potential Yield Scoping Report* (AECOM, 2017), the latest datum levels from topographical surveys and additional source borehole drawings were made available. This enabled the further correction of numerous water level jumps and data inversions in the telemetry data. Where time series data appears to be incorrect, it has been marked as invalid and has not been used in the reassessment of DO.

2.7.4 Source abstraction vs water level data

The source DO assessment diagrams are provided in Appendix B and these plot extracts from the time series data described above. It is noted that certain diagrams (Source C, Source F and Source H, in particular) show operational data plotting below the constructed drought curves. This indicates that the source may have been operated differently in the past or tested at higher abstraction rates.

2.8 Source constraints

2.8.1 Introduction

Good water level and abstraction data allows for the construction of operational drought curves (for curve shifting), although for reliable DO assessment the most up to date constraints information (such as pump capacity) is also required; this is because the DO is defined by the intercept between the operational drought curve and critical constraints.

A review of DO constraints has been undertaken as part of the current re-assessment. The starting point was the constraints information contained within the DO assessment spreadsheets for the previous assessment undertaken by AECOM (incorporating URS). The constraints on DO and key updates are discussed within the report sections below.

2.8.2 Licence constraints

For the Portsmouth Water groundwater sources the individual source daily licence quantity has been used to constrain the source PDO, while the individual source average annual licence quantity has been used to constrain the source MDO. The use of the annual licence to constrain MDO is perhaps a conservative approach, but is considered appropriate given the published methodologies.

The Environment Agency has issued a number of licence variations since the previous DO assessment (URS, 2013). Details of the environmental flow conditions under these variations are provided in Section 2.8.3, while details of the variations to daily and annual licence quantities are identified below:

- Source I: As of May 2015, the daily and annual licence quantities have been reduced from 8 to 7 Ml/d and from 2,491 to 2,040 Ml/ year, respectively.
- Source U: As of April 2016, the daily and annual licence quantities have been reduced from 4.55 and 3.74 Ml/d, respectively, to 3.03 Ml/d.

The groundwater sources are also subject to a number of group licences. These are not incorporated within the source DO assessment; instead they are applied within the WRZ DO assessment. Group licence details are as follows:

- Source C and Source D are together licensed to abstract 20.5 Ml/d at the annual average rate and 31.5 Ml/d at the peak rate.
- Source F and Source G are together licensed to abstract 9.02 Ml/d at the annual average rate and 15.0 Ml/d at the peak rate.
- Source L and Source M are together licensed to abstract 27.26 Ml/d at the average annual rate and 32 Ml/d at the peak rate.
- The QRST Group Licence (Source Q, Source R, Source S and Source T) has an annual average licence rate of 28.38 Ml/d and peak licence rate of 41.0 Ml/d. The peak is also constrained by a condition which limits abstraction over a 60 day period to no more than 2,100 Ml, i.e. average of 35 Ml/d.
- The LMNOP Group Licence (Source N, Source U, Source O, Source P, Source M and Source L) has an annual average licence rate of 65.04 Ml/d. Source N licence is further constrained by a condition which limits abstraction over a 28 day period to no more than 891,016 m^3, i.e. average of 31.8 Ml/d. Source P is also limited by a maximum abstraction of 70 Ml/week during the period August to November inclusive.

For Portsmouth Water's spring and surface water sources, the following licence restrictions apply:

- The Source B Springs have an average licence rate of 98.0 Ml/d and a peak licence rate of 137.0 Ml/d. There is also a licence condition to maintain flows in the Brockhampton Mill Lake (70 l/s) and the Langstone Mill Stream (15 l/s). Portsmouth Water does not believe the former is a constraint in a drought, although the latter is thought to represent a 0.5 Ml/d reduction in available abstraction (Portsmouth Water, 2011). The use of this reduction is a conservative approach and is considered appropriate. The reduction is small relative to the overall size of the source.
- The Source A surface water abstraction is subject to a HOF constraint of 194 Ml/d for the River Itchen at Riverside Park gauging station, downstream of the abstraction intake (see Figure 2). Annual average abstractions are limited to 45.5 Ml/d and summer peak abstractions are limited to 44.3 Ml/d in June, 41.1 Ml/d in July, 40.6 Ml/d in August and 39.2 Ml/d in September.

Additionally, the licence conditions at Source H allow for an increase in daily abstraction from 9.12 Ml/d to 13.6 Ml/d for 15 days maximum when flow in the River Meon, at Mislingford, is greater than 29.4Ml/d at the start of such abstraction. Appendix G provides a plot of predicted source non-pumping water levels at Source H and river flows at Mislingford. This plot illustrates how river flows are often higher than the constraint, allowing the abstraction rate to be uplifted; however the constraint can be active for significant periods of time in drought years.

The environmental conditions that further constrain abstraction are described below.

2.8.3 Environmental constraints

There are a number of environmental conditions incorporated within the abstraction licences, including those brought about by licence variations since the previous DO assessment (URS, 2013),as follows:

- Source I: As of May 2015, abstraction is limited to 1.5 Ml/d when gauged flow in the River Wallington at North Fareham is 21 l/s or less. Appendix G provides a plot of predicted source non-pumping water levels at Source I and river flows at North Fareham. The DO for the source is difficult to define owing to a relatively poor calibration between groundwater levels and river flows; however there is a risk that at source non-pumping water levels of less than 3.3maOD, the flow condition will be triggered. Further detail is provided on the source DO assessment diagram for Source I in Appendix B.
- Source F: As of April 2016, the continuous release of compensation water from Source F to the River Meon of 2 Ml/d is required when gauged river flow at Mislingford is equal to or less than 0.1 m^3/s. Appendix G provides a plot of predicted source non-pumping water levels at Source F and river flows at Mislingford. River flows do not drop below the trigger levels of 0.1 m^3/s during the period of record (2005-2016).
- Source U: As of April 2016, the source is required to discharge 25 l/s of augmentation water to the River Ems when gauged river flow at Westbourne falls below 31 l/s, continuing until natural flow in the River Ems exceeds 38 l/s.
- Source N: As of April 2016, if the augmented river flow in the River Ems (augmented by Source U) falls below the rate of 25 l/s at Hampshire Farm, Westbourne, for more than 30 consecutive days, or if it falls below 15 l/s, Source N is required to discharge a minimum of 13 l/s of augmentation water to the River Ems (and augmentation shall cease from Source U). Augmentation shall continue until the river flow exceeds 38 l/s.

Regression analysis has been undertaken on the predicted non-pumping water levels (NPWLs) for the Source I and Source F sources and gauged river flows, so that the DO can sensibly reflect the environmental flow or augmentation condition (Appendix G). The historic river flow records were obtained from the Environment Agency in a series of spreadsheets. The available periods of flow data vary depending on the record, but typically extend to July or August 2016.

2.8.4 Pump constraints

The pump capacities provided for DO assessment are often nominal pump capacities (design capacity for a given head of water), and may not accurately reflect the operational capability of the pump installed in the borehole. As part of the previous DO assessment, 15-minute abstraction data was plotted against 15-minute water level for each source to determine the operational pump capacity. This analysis has been updated for the DO assessment using 2015 and 2016 data where possible. The operational pump capacity line is not always vertical on the DO assessment diagram, providing an indication of how pump capacity changes with water level.

Pump depth and pump cut-out levels are shown as horizontal lines on the DO assessment diagram. Pump cut-out levels are currently estimated by Portsmouth Water to be 3 m above the pump depth. This assumption is considered appropriate as a reduction of this 3m buffer could put the pump and operational regime at risk. The only sources constrained by pump cut-out levels are Source D and Source G; reducing cut-out levels here would only result in up to 0.4 Ml/d combined increase in DO values.

2.8.5 Treatment and water quality constraints

Updated information has been obtained from Portsmouth Water regarding treatment works constraints. The previous assessment (URS, 2013) noted Source C to be constrained by treatment works capacity; however it is now understood that this source is in fact constrained by throttled pumps to avoid water quality issues (Pers. Comm. Paul Sansby, 12th July 2016). Only the DO for the Source B Springs is believed to be constrained by treatment works capacity.

Source U suffers from turbidity issues and has not been used for supply over a number of years. While the output from Source U is not being put into supply, the source is being used to augment flows in the River Ems, in accordance with a new environmental flow condition on the licence. There is no reliable DO from this source owing to a combination of water quality issues and augmentation requirements, and a reduction of DO to zero is considered appropriate. Portsmouth Water has identified that it is not currently economic to install further treatment at the source.

2.8.6 Distribution / demand constraints

The current study assumes that booster pump capacities and the distribution network are adequate to allow abstractions to be redistributed around the resource zone as required. A high level assessment was undertaken for a previous WRMP (Arup, October 2007) to confirm the single resource zone assumption and it is understood from Portsmouth Water that there have been no significant changes to the resource zone since that assessment.

2.8.7 Deepest advisable pumping water level and potential yield

The potential yield of a source is reached when groundwater levels are drawn down to a Deepest Advisable Pumping Water Level (DAPWL). The DAPWL is defined by UKWIR's *A Unified Methodology for the Determination of Deployable Output from Water Sources* (2000) as follows: '*The DAPWL for each well at a source should be selected so as to prevent undesirable effects occurring were the pumping water level to reduce further…in some cases the DAPWL will be controlled by features of the well construction, such as the location of the base of solid casing or the top of an adit, or by features of the aquifer system, such as the base of a confining layer. If these are not a constraint, the DAPWL should be set at a depth so as to prevent a significant reduction in flow were the level to reduce further. This depth is best identified by downhole geophysical/CCTV surveys, but in the absence of these, the driller's descriptions and/or an examination of the lithological logs may be help. If this information is not available, then the user should carry out investigations on their source to obtain this information'.*

The DAPWL constraints have been identified for each groundwater source following the compilation and assessment of borehole logs, CCTV and geophysical logs (where available). This work is reported separately in a *Potential Yield Scoping Report* (AECOM, October 2017) and the results have been incorporated into the DO assessments (see Appendix B).

2.9 Assessment grades and values obtained

Previous UKWIR guidance has suggested a grading system for groundwater and spring yield assessments based on matrices of data quality versus 'option'. Grades were provided for each source in the previous assessment (URS, 2013) and the two key limitations on DO assessment quality were a lack of (i) manual dips to validate telemetry data and (ii) deepest advisable pumping water levels to understand potential yield. On the latter point there has been a substantial effort to define DAPWLs, such that these are now available for all Portsmouth Water groundwater sources; this means that the assessment grades would improve from 'Option B' to 'Option C' (the most sophisticated option).

The results of the individual source DO assessment (based on the worst drought on record) are summarised in Table 2-2. Note that MDO can be used as a proxy for ADO in the case of individual source assessments.

Table 2-2 Source deployable outputs and potential yields for the worst drought on record (1973)

Source name	Peak demand critical period			Minimum groundwater level critical period		
	PDO** (Ml/d)	PDO critical constraint	PY* (Ml/d)	MDO** (Ml/d)	MDO critical constraint	PY* (Ml/d)
Source A (CatchMOD)	40.65	Licence	45.3	39.17	Licence	44.6
Source B	71	Spring flow	71	52.5	Spring flow & compensation flow	53
Source C	22.5	Water quality (turbidity)	> 28	20.5	Licence	> 20.5
Source D	2.7	Pump cut-out level / pump depth	> 3.5	0.7	Pump cut-out level / pump depth	> 1.75
Source E	0.46	Licence	< 0.6	0.46	Licence	< 0.6
Source F	12.4	Fissure horizon DAPWL	12.4	9.02	Licence	9.5
Source G	3.8	Pump cut-out level / pump depth / licence	> 4	1.9	Licence	> 4

Source name	Peak demand critical period			Minimum groundwater level critical period		
	PDO** (Ml/d)	PDO critical constraint	PY* (Ml/d)	MDO** (Ml/d)	MDO critical constraint	PY* (Ml/d)
Source H	9.12	Licence	> 13.6	9.0	Operational pump capacity / licence	> 10
Source I	2.2	Environmental flow condition (licence)	> 7	1.5	Environmental flow condition (licence)	> 5.59
Source J	10.2	Fissure horizon DAPWL	> 10.2	10.2	Fissure horizon DAPWL	> 10.2
Source K	12.3	Operational pump capacity	> 13.5	11.37	Licence	> 11.37
Source U	0	Water quality / environmental flow condition (licence)	> 4	0	Water quality / environmental flow condition (licence)	> 3
Source L	16	Operational pump capacity	> 25	16	Operational pump capacity	> 21
Source M	6.3	Operational pump capacity	7	4	Cavity DAPWL	4
Source N	35.23	Environmental flow condition (licence)	> 35.23	26.14	Environmental flow condition (licence)	> 27.28
Source O	5.4	Adit DAPWL	5.4	1.8	Adit DAPWL	1.8
Source P	10.0	Operational pump capacity	> 10	10.0	Operational pump capacity	> 10
Source Q	13.0	Operational pump capacity	> 22	12.0	Operational pump capacity	> 22
Source R	14.0	Operational pump capacity	> 20	12.5	Operational pump capacity	> 20
Source S	2.5	Licence	> 2.5	2.5	Licence	> 2.5
Source T	8.8	Operational pump capacity	> 10	8.1	Operational pump capacity	> 10

*where Potential Yield is uncertain owing to extrapolation of drought curves a '>' symbol is used.

**excludes the impact of group licences. This is considered within the WRZ assessment (see Section 3).

The key assumptions that have been taken as part of the source DO assessment are as follows:

- Curve shifting of the operational drought curve, through the application of scaling factors and based on the analysis of critical period observation borehole water levels for Well 'X', provides a useful approximation of the water level condition at the groundwater source and the deployable output of the source.
- The identification of new water quality DAPWLs assumes that water quality may deteriorate if pumping water levels are drawn down below the top of the Chalk where confined, or below known adits or cavities associated with the source, where pumping water levels have not been drawn below this level to date.
- The identification of new flow DAPWLs assumes that a break-away in water levels may occur if pumping water levels are drawn down below critical flow horizons associated with the source, where pumping water levels have not been drawn below this level to date.
- The degree of telemetry calibration available to this study is sufficient to provide a useful estimate of DO values; and
- Booster pump capacities and the distribution network are adequate to allow abstractions to be redistributed around the resource zone.

Differences between the previous and current source DO assessment are described below.

2.10 Comparison with previous yield assessments

Figures 5 and 6 provide a graphical comparison of the previous (URS, 2013) and current 2017 assessment with respect to calculated source PDO and MDO values. The key reasons for changes are described below:

- The Source K PDO and MDO have both increased following the use of 15 minute data to define an operational pump capacity (the source was not in use at the time of the previous assessment).
- The Source M, Source L and Source A PDOs have decreased owing to a shift of the peak period from July to August.
- The Source M MDO has decreased owing to the identification of a large cavity DAPWL.
- The Source O PDO and MDO have decreased, MDO significantly, owing to the identification of an adit DAPWL.

- The Source J PDO and MDO have both reduced owing to a shift of the peak period from July to August and to the identification of major fissure flow DAPWLs.
- The Source I PDO and MDO have reduced significantly owing to a new environmental river flow condition on the abstraction licence.
- The Source H PDO has also reduced following a reassessment of the licence's environmental river flow condition and the impact on DO through analysis of river flow data.
- The Source D MDO has increased owing to a datum correction following the potential yield study (AECOM, October 2016).
- The Source C PDO has decreased owing to throttling of the pump to overcome turbidity issues.
- The Source U PDO and MDO have lowered to zero owing to ongoing cryptosporidium, turbidity, and land use water quality related issues. The source is also to be used for river augmentation following a new licence variation.

Following revision of the source models (through the process of calculating source DOs) they were subsequently used to inform the WRZ DO assessment, which is described in Section 3.

3 Resource zone deployable output assessment results

3.1 Introduction

The WRZ DO assessment builds on the source DO assessment work by:

- Including the impact of group licences on DO;
- Introducing restricted and non-restricted demand profiles to allow calculation of ADO (in addition to MDO and PDO);
- Identifying the relationship between WRZ DO and WRZ DO return period; and
- Demonstrating how ADO can be impacted by the shape of demand profiles.

To some degree the approach is similar to that in the previous assessment (URS, 2013), with the following key differences:

- The previous assessment only considered an unrestricted demand profile.
- The assessment of DO against DO return period has been calculated using stochastic climate data (1,000 year time series) in addition to the conventional use of historic climate data (132 years). The stochastic climate data should provide a more reliable estimate of DO return period.
- Whilst the relationship between DO and DO return period was demonstrated, the previous assessment focussed on assessing deployable output for the 1 in 20 year DO in line with the company's level of service for TUBs (at the interface between WRMP and Drought Plan). The latest guidelines (Environment Agency, April 2017) state that water companies should test their plans against a range of challenging but plausible droughts. Therefore the revised WRZ DO assessment also focuses on estimating DOs for more severe droughts.
- The Environment Agency also requires companies to demonstrate a reference LoS, which is resilience to a drought with a 1 in 200 year return period, where no emergency drought measures are required (standpipe and rota cuts). Therefore the DO for the 1 in 200 year DO return period is calculated.

The report sections below outline the resource zone model and describe the assessment of WRZ DO assessment based on historic and stochastic climate records.

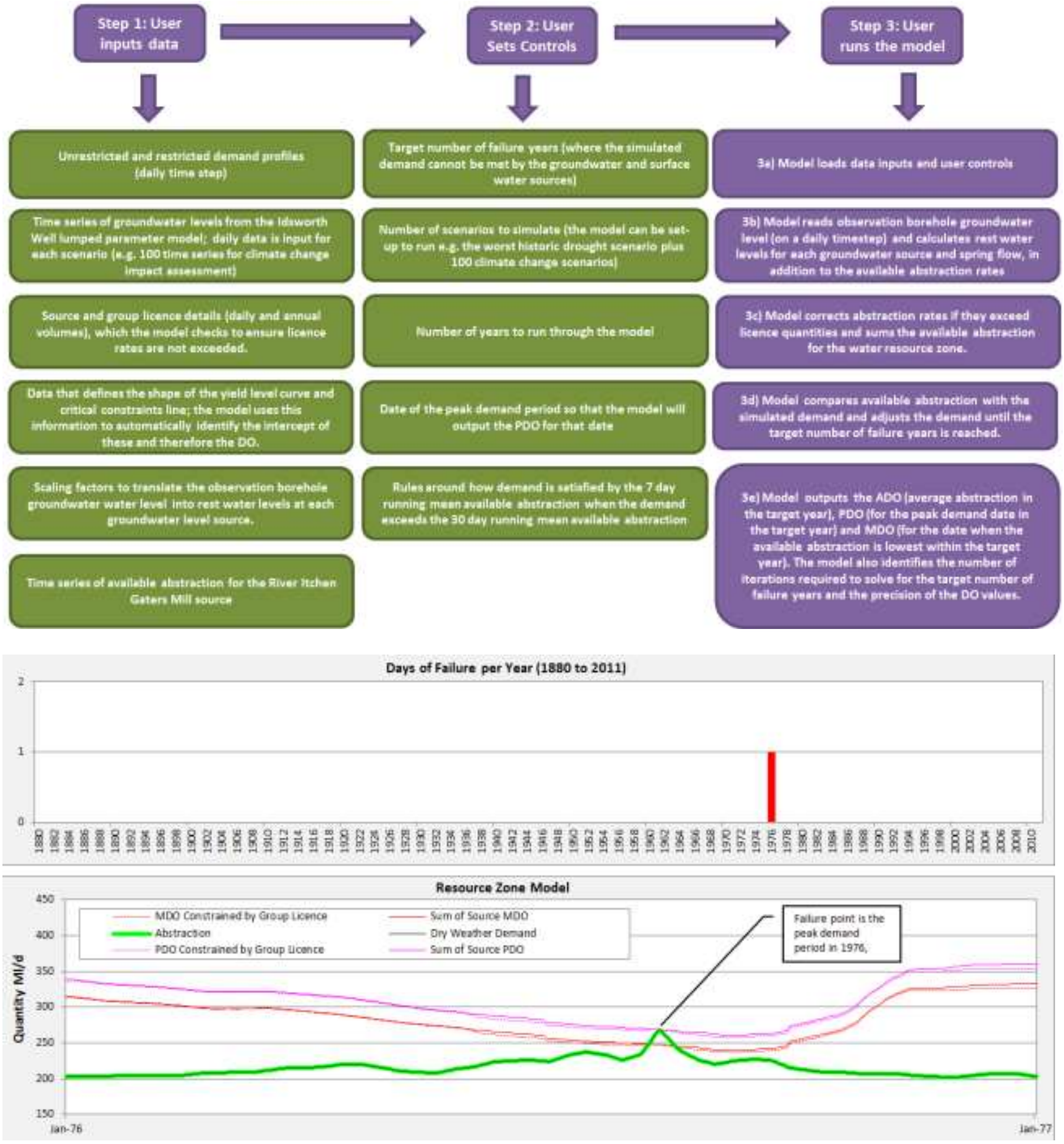
3.2 The resource zone model

3.2.1 Overview

The Portsmouth Water WRZ model was developed for WRMP14 and has been refined and updated for the dWRMP19. It is an Excel based model which uses individual source constraints, group licence constraints, resource availability (based on Well 'X' groundwater levels) and various profiles of demand to estimate ADO, PDO and MDO on a daily time step for Portsmouth Water's WRZ. An outline of the modelling steps is provided in Drawing 3-1.

The model reads the observation borehole groundwater level on a daily time step and calculates rest water levels for each of the groundwater sources and the available abstraction rates. The model then corrects the abstraction rates if these exceed licence quantities and sums the available abstraction for the WRZ. The model runs the selected groundwater level record (extended historic record or baseline stochastic dataset) and increases simulated demand until the available resource fails to meet the demand for a target number of years in order to provide an estimate of DO (e.g. fifty failures within the 1,000 year stochastic sequence to represent the 1 in 20 year drought DO).

Drawing 3-1 Water resource zone modelling steps



3.2.2 Demand profiles

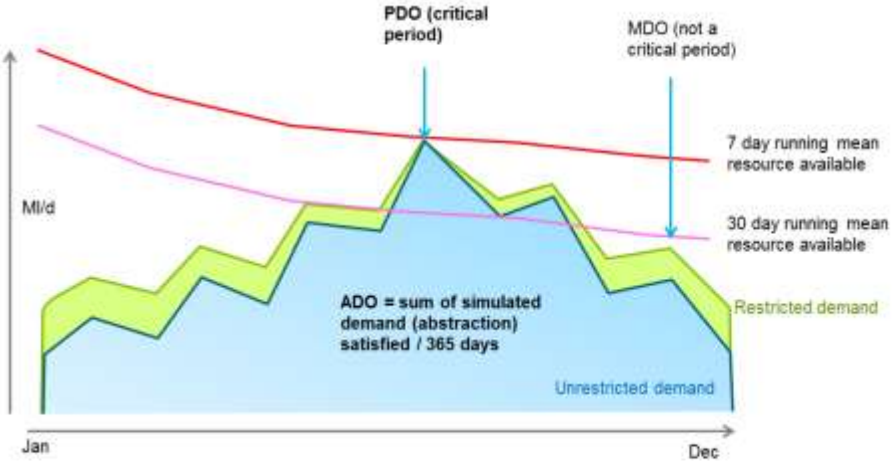
Portsmouth Water provided a range of demand profiles for use in this study (see Figure 7). The unrestricted demand profile was derived using weather demand modelling to rebase past years as at 2015/16. The profile was then smoothed to reflect the typical company demand profile whilst maintaining the Dry Year Annual Average (DYAA) and Dry Year Critical Period (DYCP) demands established from the weather demand model.

The new demand profile is less smooth (relative to the WRMP14 profile) and undulates throughout the year, such that it is more realistic (including recognising a minor peak around Easter). Portsmouth Water will be providing further information on the demand profile in other parts of the dWRMP19 reporting.

A key difference between the unrestricted demand profiles used in the current and previous assessment (URS, 2013) is that the peak week is now week 33 (13th August), as opposed to week 28 (9th July). The adjustment follows new analysis of demand data by Portsmouth Water. However the timing of the peak week within actual distribution input data from 1999 to 2015 has been reviewed by AECOM; according to this data, the date of the peak abstraction ranged between 27th April and 13th August (the latter occurring in 2003). The use of the 13th August as the peak week is therefore plausible; it is also a more conservative approach as the available resources will typically be lower in August than in July. The sensitivity of DO to peak week timing was examined by comparing WRZ PDO values on the identified range of dates for the 1 in 20 year event (using the stochastic climate data). The WRZ PDO value for this event is 280 Ml/d (using 13th August) and the alternative values range between 280 Ml/d and 313 Ml/d; therefore the impact on moving the peak week is up to 12% for the 1 in 20 year event.

The current study has also applied a range of restricted demand profiles within the WRZ model; they demonstrate the potential impact of TUBs and non-essential use (ordinary) drought orders on the shape of the unrestricted demand profile, and consequently on the magnitude of ADO. The impact percentages are in line with those used by the WRSE models. The restricted demand savings are cumulative and they flatten the summer peak demand relative to the average demand. This means that where WRZ DO is constrained by the peak summer demand critical period, the ADO may increase as a result of using the restricted demand profiles as per Drawing 3-2.

Drawing 3-2 The influence of demand profiles on calculated ADO



It is important to recognise that the demand profiles described above do not impact modelled groundwater levels within the WRZ models. It is possible that implementation of demand restrictions will help to conserve aquifer storage to some degree, although the effect is believed to be relatively minor when compared with the impact of demand restrictions on reservoirs. In part this is probably owing to (i) the leaky nature of aquifers (i.e. they contribute baseflow to rivers), (ii) the inability to access groundwater in some boreholes and wells owing to low groundwater levels, (iii) the importance of antecedent conditions. Further work is recommended to investigate and understand the impact of differing levels of normal and dry year abstraction on regional groundwater levels and consequently on drought DO (including links with the Drought Plan and impacts of supressed demand); this would be undertaken using available regional groundwater models. In the meantime it is recommended that the impact of demand restrictions is explored on the demand side of Portsmouth Water's decision making tool.

The use of emergency drought orders is considered to be emergency planning territory; the impact of these restrictions on the demand profile is not considered within this report. Additionally, supply side drought permits are excluded from the DO assessment as per the Environment Agency guidance.

3.2.3 Levels of Service and DO return periods

The restricted and unrestricted demand profiles have been applied to a range of drought conditions in order to understand the impact of their shape on ADO. However to demonstrate the current link between the WRMP and the drought plan, the results of the WRZ DO assessment are mapped to show the DO relative to the company's planned LoS (see the arrows and text boxes on Figure 10). In its WRMP14, Portsmouth Water outlined its planned levels of service and drought scenarios as follows:

- Temporary use bans, 1 year in 20 return period;
- Ordinary Drought Orders, 1 year in 80 return period; and
- Emergency Drought Orders, 1 year in 300 return period.

In any given model run the WRZ DO is calculated by increasing the simulated demand (distributed throughout the year according to the demand profile factors on Figure 7) in the resource zone model to generate supply failures. For example, to determine the reliable DO for a 1 in 20 year event (linked to drought severity), the simulated demand is increased until the model is on the verge of seven failure years within the 132 year historic modelled time period (or on the verge of fifty failures within the 1,000 year stochastic sequence). Therefore the return periods are return period of WRZ DO, rather than rainfall or groundwater levels.

3.2.4 Groundwater source deployable output time series

The resource zone model includes time series of available 7 day and 30 day running mean abstraction rates for each Portsmouth Water source. The resource zone model sums these time series, applies group licence restrictions, and gives an available 7 day and 30 day running mean abstraction rate for the resource zone at any time step within the model. The modelled historic period is 1880 to 2011, equating to a 132 year time period (and for the stochastic runs the modelled period is 1,000 years).

The available abstraction rates for each source have been calculated using the same curve shifting method as described in Section 2 (that was used for calculating the 1973 source PDOs and MDOs). The resulting outputs are time series of available 7-day running mean output (derived from the PDO source models) and 30-day running mean output (derived from the MDO source models), which reflect the regional water level condition in the aquifer and the critical source constraints.

When groundwater sources are constrained by the same rigid output constraint (e.g. licence rate) across the full range of dry year to severe drought conditions, the available 7-day running mean output (PDO source models) or 30-day running mean output (MDO source models) remains constant. However, if groundwater sources are constrained by operational pump capacity (for example), the output of the source may vary according to the performance of the pumps under different water level conditions. Under drought water level conditions there is also a risk that the output of a groundwater source will become significantly constrained by the level of a DAPWL, environmental flow constraint or pump cut-out level. This can lead to a more rapid lowering of the available DO for that source.

For much of the year, the groundwater sources abstract at a rate less than the total available 30-day running mean output (MDO source models). However, when demand rises above this value (e.g. during the peak summer demand period), the additional volume / rate that can be taken is controlled as follows:

- At the point the available 30-day running mean abstraction line is exceeded, the additional volume that can be abstracted is calculated from: (available 7-day running mean abstraction – available 30-day running mean abstraction) * 7 days; a volume is used because otherwise even a slight increase in demand above the available 30-day running mean abstraction would trigger a 7-day countdown.
- Once the additional volume is used up, the resource zone 7-day running mean abstraction rate linearly decays back to the 30-day running mean abstraction rate over a 23 day period.

In addition to the Portsmouth Water groundwater sources, the Source A surface water source and Source B spring sources are also included in the WRZ model as described below.

3.2.5 Source A run-of river and Source B Springs DO time series

The available daily flow for abstraction at the Source B Springs is the modelled flow based on a pre-defined relationship with groundwater levels at the up-gradient Well 'X' observation borehole (unless this is capped by the licence or treatment work constraint). This relationship is demonstrated on Figure 8.

The available daily flow for abstraction at the Source A run-of-river source is the modelled residual flow, unless this is capped by the licence profile (see Figure 4).

3.2.6 Bulk transfers

The resource zone model does not take account of Portsmouth Water's bulk transfer arrangement with Southern Water. The inclusion of bulk supplies in DO is not a standard approach (instead it is a separate input into the dWRMP19 tables).

3.3 Results for the historic sequence of climate (including worst drought on historic record)

3.3.1 Water resource zone DO assessment (historic climate data)

The first set of WRZ model runs calculated DO based on a 132 year time series of groundwater and river flow (the historic climate). The ADO was calculated by increasing the unrestricted demand profile in the WRZ model to generate failures and the outputs (DO versus DO return period) are shown in Figure 8.

The WRZ ADO from the previous assessment (URS, 2013) is also provided on Figure 8. The WRZ ADOs for various drought conditions have lowered for a number of reasons:

- The individual source PDOs and MDOs have lowered since the previous assessment owing to the identification of new constraints, including DAPWLs (as outlined in Section 2). This is subsequently reflected within the WRZ DO assessment and it is the key reason why DOs have lowered.

- The demand profile used in the current assessment has a mid-August peak instead of the mid-July peak of the previous assessment. The ADO is largely driven by the PDO because the peak summer demand is the critical period; the demand profile 'hits a roof' when the peak demand reaches the available PDO rate, causing failures in the model. This can be seen in Drawing 3-2. By using a profile with a peak in mid-August, the peak is more likely to be closer to the MDO period (the time of minimum groundwater levels), such that PDO is more likely to be constrained e.g. by environmental flow conditions or DAPWLs.
- A lumped parameter model was used to generate the Well 'X' time series data for the current assessment; the previous assessment used observed data. This means that the 1976 water levels, and therefore predicted DO, are different.
- Note that both the current and previous WRZs assessments indicate that 1976 was the worst historic drought with respect to DO, and not 1973 as selected for the individual groundwater source assessment; although groundwater levels reached their lowest point in the winter of 1973/74, the water levels during the August peak summer demand period of 1976 were lower than those in August 1973.

The 'worst historic' drought ADO is 215 Ml/d (see Figure 8), the PDO is 267 Ml/d and the MDO is 242 Ml/d (see Figure 11); this is based on the use of an unrestricted demand profile. With a restricted demand profile, where the shape of the demand profile is influenced ('flattened') by TUBs and NEUBs, the ADO is 225 Ml/d.

A recommendation of the previous DO assessment (URS, 2013) involved testing the WRZ DOs within the regional groundwater model for the Portsmouth Water area. This work has been undertaken for the current assessment and is described below.

3.3.2 Validation of WRZ DO values using the regional EHCC groundwater model

The WRZ DO assessment described above works on the basis that increased annual abstraction does not have a significant impact on regional groundwater levels and therefore WRZ DO. The ADOs generated by the WRZ model for the 1 in 20 year condition (around 240Ml/d) have been tested within the Environment Agency's East Hampshire and Chichester Chalk (EHCC) regional groundwater model in order to check this assumption; note that only the groundwater source ADOs were needed for input to the EHCC model (around 131Ml/d), with the remainder of the 240Ml/d representing spring flows and river flows.

The EHCC model is a regional groundwater flow model developed in MODFLOW with one layer representing chalk, and one layer representing drift and tertiary deposits in the Chichester syncline. The model is on a 250m grid giving a predicted groundwater level at this scale. The model is generally well calibrated to the trend and timing of the seasonal cycles, while actual level is variably high and low compared to the observed across the model area. The modelled time period is 1965 to 2011.

The EHCC model pre-processing for abstraction profiles was undertaken in the Environment Agency's National Groundwater Modelling System (NGMS) platform, and groundwater levels were extracted for the different scenarios from NGMS. The process was as follows:

- **Conventional 'historic' EHCC run:** The 'historic' scenario in the EHCC model was used to derive the historic simulated groundwater level for Well 'X', based on historic abstraction data from returns provided to the Environment Agency and the historic climate.
- **Prepare the first 'what if' scenario abstraction data:** The calculated daily abstraction rates for the 1 in 20 year historic event with unrestricted demand were extracted from the WRZ DO model. These rates were then converted to fit the EHCC regional model 10 day stress period set up.
- **First 'what if' EHCC run:** The converted abstraction rates for each of the nineteen groundwater sources were then inserted into the 'historic' scenario of the EHCC model and run as a 'what-if' scenario (the climate data is the same as the 'historic ' scenario but the abstractions are elevated). The simulated groundwater level for Well 'X' was then extracted.
- **Compare 'historic' and first 'what if' EHCC runs:** The simulated 'what-if' groundwater levels for Well 'X' were compared to the simulated 'historic' scenario groundwater levels. The differences in groundwater levels (according to the EHCC model) were then applied to the Well 'X' groundwater levels within the WRZ DO model.
- **Re-run the WRZ model:** The WRZ model was re-run for the 40 year time period (the same as the EHCC model). The lower Well 'X' groundwater levels (associated with elevated abstraction) resulted in lower resource availability.
- **Repeat the above process:** The above process was repeated for a second 'what-if' scenario based on the revised WRZ model abstractions. However the results were very similar to the first iteration.

The results with respect to ADO are presented on Figure 8 where return periods can be compared (note the EHCC testing work is based on a 40 year time series compared with a 132 year time series in the initial WRZ model run). The output of the EHCC testing with respect to Well 'X' groundwater levels is shown on Figure 9 and further exports from the model (groundwater levels, spring flows, environmental flows and abstraction rates) are included within Appendix E.

Historic levels of groundwater abstraction between 1989 and 2015 have averaged around 107 Ml/d (see Table 3-1). Therefore the EHCC test at 131 Ml/d Portsmouth Water groundwater abstraction is a significant (>20%) increase on historic levels. The impact on regional groundwater levels is demonstrated by up to a 3m lowering of levels at Well 'X' (relative to the historic groundwater levels), which consequently reduced the 1 in 10 year WRZ ADO from 243 Ml/d to 217 Ml/d (see Figure 8); whilst part of this reduction in ADO is associated with reduced outputs from groundwater sources, the Source B Springs output was modelled to reduce significantly from 70 Ml/d to 52 Ml/d (in response to lower regional groundwater levels). The reduction is such that the predicted WRZ ADO in the worst drought on record (1976 in the WRZ model), based on the historic groundwater level record, may become a 1 in 10 year event when including the impact of increased abstraction on regional groundwater levels.

Table 3-1 Historic abstraction and Portsmouth Water abstraction rates tested in the EHCC regional model

	Portsmouth Water average abstraction in the WRZ model for the 1 in 10 year event based on historic Well 'X' levels (Ml/d)	Portsmouth Water actual average historic abstraction (1989 to 2015) (Ml/d)	Portsmouth Water average abstraction used in the EHCC regional model test (M/d)	Resulting Portsmouth Water abstraction in the WRZ model for the 1 in 10 year event following adjustment of Well 'X' levels (Ml/d)
Groundwater sources	138	106.9	131	130
Source B Springs	70	57.9	Not applicable	52
Source A (River Itchen)	35	23.9	Not applicable	35
Total	243	188.7	131	217

Based on the outputs of the EHCC model testing, it is recommended that the predicted maximum ADO is capped as a precautionary measure. This assumes it would not be acceptable from a drought resilience perspective to increase normal year groundwater abstraction significantly above the long term historic rate; at least until further modelling work is undertaken to better understand (and optimise) the trade-off between higher groundwater abstraction and reduced spring flows, with respect to WRZ ADO across the range of drought severities.

The precautionary ADO cap of 238 Ml/d is selected because it approximates the historic long term groundwater abstraction rate of 107 Ml/d plus the potential (maximised) average annual output of the Source B Springs and the River Itchen abstraction (87.5 Ml/d and 44Ml/d, respectively); the spring and River Itchen outputs are based on the modelled historic flows and assume that all available abstraction is taken i.e. there is a preference for taking spring and river flow in normal (non-drought) years as opposed to groundwater, in order to maintain higher outputs in a drought year.

Following completion of the above modelling associated with the historic climate, the next step of the assessment methodology involved testing stochastic data sequences. This work is described below.

3.4 Results for the stochastic sequence of climate

3.4.1 Preparation of time series data

The assessment of DO through WRZ modelling of historic climate and groundwater levels (as described above) is limited by the length of the records (even when extended to 132 years through hindcasting). In order to provide more certainty in the relationship between WRZ DO and WRZ DO return period, testing of a longer stochastic time series within the WRZ model has been undertaken. This assists in complying with the Environment Agency WRPG (April 2017) with respect to exploring a reference level of service that would mean resilience to a drought with a 1 in 200 year return period.

HR Wallingford undertook a process of 'translating' 15,600 years of stochastic rainfall and potential evapotranspiration data (available through the WRSE project), before generating naturalised river flows for the River Itchen within CatchMOD (see Appendix F); input climate data were for the Upper Itchen catchment. The translated stochastic climate data has also been used to generate groundwater levels for Well 'X' within AECOM's lumped parameter model for this location; input climate data were for the Wallington catchment.

3.4.2 Water resource zone DO assessment (stochastic climate data)

From the available 15,600 years of synthetic groundwater level and flow data, the first block of 1,000 years has been used within the WRZ model; this was a manageable length of record with respect to modelling efficiency that still allows improved characterisation of a 1 in 200 year drought event. As the return period of DO relates to the return period of supply-demand failures, this 1,000 year block of data will contain, for example, five 1 in 200 year events and provides more certainty with regards to DO at this return period. A comparison of Figures 8 and 10 demonstrates that the 1,000 years of data includes challenging but plausible droughts that are more severe than the worst historic drought (the ADO is significantly lower at 1 in 200 and 1 in 500 year events compared with the ADO for the worst drought in the historic record).

The ADO was calculated by increasing the unrestricted demand profile in the WRZ model to generate failures and the outputs (DO versus DO return period) are shown in Figure 10; the corresponding PDO and MDO are shown on Figure 11, and summarised in the table below. The source by source apportionments are provided in Section 3.4.3 and Appendix D.

Table 3-2 WRZ DO values for selected return periods (based on stochastic climate data and unrestricted demand profiles)

Return period	Demand profile (shape)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)
1 in 20 year	Unrestricted	280	252	227
1 in 40 year	Unrestricted	270	237	217
1 in 83 year	Unrestricted	263	233	212
1 in 125 year	Unrestricted	252	235	203
1 in 200 year	Unrestricted	236	222	191
1 in 500 year	Unrestricted	238	217	185

It was proposed that the ADO cap established via the regional EHCC model testing is applied to the WRZ DO assessment results. However the upper plot on Figure 10 demonstrates that the cap does not impact the stochastic ADOs for the selected return periods; the cap would mostly impact normal year (non-drought) abstractions. The stochastic results on the upper plot of Figure 10 also suggest that the ADO derived for the worst historic drought on Figure 8 (around 215 Ml/d) is perhaps representative of a 1 in 50 year event.

The lower plot on Figure 10 provides an indication of how restricted demand profiles can impact ADO across a range of return periods; Table 3-3 summarises the WRZ DO values and the source by source apportionments are provided in Appendix D.

Table 3-3 WRZ ADO values for selected return periods (based on stochastic climate data and restricted demand profiles)

Return period	Demand profile or 'shape'	ADO (Ml/d)
1 in 20 year	Restricted (TUBs)	233
1 in 40 year	Restricted (TUBs)	224
1 in 83 year	Restricted (TUBs & NEUBs)	220
1 in 125 year	Restricted (TUBs & NEUBs)	211
1 in 200 year	Restricted (TUBs & NEUBs)	197
1 in 500 year	Restricted (TUBs & NEUBs)	193

As previously indicated, the PDO drives the ADO because peak summer demand is the critical period for Portsmouth Water (as per the scenario in Drawing 3-2). The MDO is associated with the minimum groundwater level condition (which can be another type of critical period), although it is a secondary constraint in the Portsmouth Water WRZ. The PDO and MDO values for the historic and stochastic WRZ assessments are provided on Figure 11. Similar to ADO, the stochastic results suggest that the PDO derived for the worst historic drought (around 267 Ml/d) is perhaps representative of a 1 in 50 year event.

3.4.3 Apportioned water resource zone DO assessment (stochastic climate data)

The WRZ DO output from the WRZ model has been apportioned to sources based on simulated rates of abstraction. The apportionment for selected return periods is provided in Table 3-4 based on the stochastic climate data and unrestricted demand profile. Further detail is provided in Appendix D.

Table 3-4 Apportioned WRZ DO values for selected return periods (based on stochastic climate data and unrestricted demand profiles)

Source	1:20 year return period			1:40 year return period			1:83 year return period			1:125 year return period			1:200 year return period			1:500 year return period		
	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	ADO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)
Source E	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.4
Source D	1.1	2.4	0.9	0.8	2.1	0.5	0.8	1.9	0.5	0.6	1.7	0.5	0.8	2.3	0.9	0.5	0.5	1.2
Source F	7.2	11.7	8.9	7.3	11.9	9.2	7.1	12.1	9.1	7.2	11.9	9.2	6.9	11.8	9.1	6.9	9.3	6.4
Source H	7.7	9.1	9.3	7.6	9.1	9.1	7.3	9.1	9.1	7.3	9.1	9.2	7.2	9.1	9.5	7.0	9.3	7.0
Source G	1.5	3.3	1.9	1.6	3.1	1.9	1.5	2.9	1.9	1.5	2.6	1.9	1.5	3.2	1.9	1.5	2.0	1.3
Source J	9.1	10.2	10.5	8.5	10.2	7.5	8.5	10.2	7.1	7.8	7.9	8.4	8.3	10.2	10.6	6.7	7.4	8.9
Source I	1.5	2.1	1.6	1.4	2.0	1.5	1.4	1.9	1.5	1.3	1.9	1.5	1.4	2.0	1.6	1.2	1.6	1.5
Source K	9.6	12.3	11.6	9.5	12.2	11.6	9.2	12.2	11.5	9.1	12.2	11.6	9.0	12.3	11.8	8.8	11.8	8.7
Source U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Source N	22.2	35.2	26.8	22.1	35.2	26.6	21.3	35.2	26.5	21.1	33.9	26.6	20.9	35.2	27.2	20.2	27.1	20.0
Source O	4.1	4.2	2.8	2.9	2.7	0.4	2.8	1.7	0.3	1.6	1.3	0.7	2.8	3.7	2.6	0.9	0.3	5.1
Source M	4.5	6.0	4.6	3.7	4.8	1.9	3.5	3.9	1.7	2.8	2.8	2.4	3.8	5.7	4.5	2.2	1.8	4.4
Source L	13.7	15.5	16.1	13.3	15.0	15.1	12.9	14.7	14.9	12.5	14.3	15.2	12.6	15.3	16.3	11.7	15.3	12.9
Source P	8.4	10.0	10.3	8.4	10.0	10.2	8.1	10.0	10.2	8.0	10.0	10.2	7.9	10.0	10.4	7.7	10.4	7.7
Source T	6.4	8.5	6.6	6.5	8.4	7.4	6.5	8.0	7.2	6.4	8.2	7.3	6.4	8.4	8.5	6.2	8.2	6.5
Source R	10.3	13.5	10.4	10.2	13.1	11.3	10.2	12.5	11.0	10.1	12.6	11.1	10.1	13.3	13.3	9.5	12.4	10.6
Source Q	9.7	12.4	9.9	9.7	12.1	10.9	9.7	11.6	10.6	9.6	11.7	10.7	9.6	12.3	12.7	9.1	12.0	10.0
Source S	1.9	2.5	2.0	2.0	2.5	2.4	1.9	2.4	2.3	2.0	2.5	2.3	1.9	2.5	2.6	1.9	2.6	1.9
Source C	17.3	22.5	21.0	17.2	22.5	20.9	16.6	22.5	20.8	16.5	22.5	20.9	16.3	22.5	21.3	15.8	21.2	15.7
Source B	53.0	57.8	56.4	47.6	52.1	42.6	46.6	48.7	41.3	42.4	43.9	45.1	46.5	55.5	56.4	36.1	42.5	52.8
Source A	36.9	40.6	40.1	36.6	40.6	45.0	35.3	40.6	45.0	35.2	40.6	39.9	16.4	0.0	0.0	30.7	42.1	34.2
Total	***227***	***280***	***252***	***217***	***270***	***237***	***212***	***263***	***233***	***203***	***252***	***235***	***191***	***236***	***222***	***185***	***238***	***217***

4 Conclusions and recommendations

4.1 Conclusions

A reassessment of DO has been completed to support Portsmouth Water's next WRMP. This involved updating source models (operational data and constraints), followed by the reassessment of DO in a WRZ model using (i) unrestricted and restricted demand profiles and (ii) both historic and stochastic climate sequences.

The individual source DOs have decreased across a range of drought conditions owing to the identification of new constraints, including environmental flow constraints and DAPWLs. The WRZ DO derived from historic climate sequences was tested in the EHCC regional groundwater model to check its validity; the results suggest that ADO should be capped to prevent significant loss of ADO, PDO and MDO in a drought. In addition, PDO and ADO have further reduced through adjustment of the peak demand period from July to August.

The potential impact of restricted demand profiles on WRZ ADO across a range of drought conditions has been demonstrated. Portsmouth Water's planned customer LoS has been mapped onto the WRZ DO results. A range of WRZ DOs for different drought return periods have been presented in this report. These can be used within Portsmouth Water's decision making tool for the dWRMP19 in order to understand the impact of drought and the investment costs with or without drought plan measures (permits and orders). It follows that the existing LoS can be reviewed and revised as necessary (following consultation with customers).

4.2 Recommendations

The new WRZ DO values for the 'worst historic' drought and 1 in 200 year drought are significantly lower than in previous assessments of DO. Despite this, it is recommended that any development of the average annual abstraction within the Chalk aquifer is progressed in a slow and phased manner, such that potential impacts on drought WRZ ADO, PDO and MDO (and LoS) can be understood and addressed. Continued testing of DOs and different abstraction patterns (spatial and temporal) within the EHCC model may also be beneficial to future WRMPs and Drought Plans. It is also recommended that drought trigger levels in Portsmouth Water's drought plan are reviewed to ensure they are consistent with this WRZ DO assessment and any proposed change in LoS within the dWRMP19.

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Appendix A. Lumped parameter models for Well ‘Z’ and Well ‘Y’

Appendix B. Source PDO and MDO assessment diagrams

Appendix C.Surface water modelling

Appendix D. Apportionment of WRZ DOs by source

Appendix E. Exports from the EHCC model

Appendix F.Translation of stochastic climate data

Appendix G. River flow licence conditions

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