Thames Water

Final Water Resources Management Plan 2019

Technical Appendices

Appendix U: Climate change

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Climate change

- This section of our Water Resources Management Plan 2019 (WRMP19) describes the potential impacts of climate change on the water supply demand balance. A methodology has been developed to enable use of the UKCP09 data to determine the uncertainty around the effects of climate change on water supply and a "best estimate" of the potential impact presented for each water resource zone (WRZ).
- A vulnerability analysis has been undertaken and the results described. The methodology for climate change assessments is presented and issues around the scaling of climate change impacts are discussed. The means by which climate change is included in Target Headroom is described and the results presented.

A. Report structure

U.1 This appendix is structured as follows:

- The background to the climate change assessment is presented along with the vulnerability assessment
- The methodology for assessing the climate change impact on DO is described for each WRZ
- The approach is described for groundwater sources, surface water sources and conjunctive use zones (CUZs)
- The supply side climate change impacts are presented together with the uncertainty around these estimates
- The demand side climate change impacts are presented together with the uncertainty around these estimates
- The impact of the changes to the scaling of the climate change impacts as specified in the Environment Agency's WRPG supplementary information (revised April 2017), 'Estimating impacts of climate change on water supply'[1], which clarified earlier guidance
- A comparison is made between the climate change impacts of Water Resources Management Plan 2014 (WRMP14) and those of the WRMP19 using the UKCP09 data

[1] Environment Agency, WRMP19 supplementary information, Estimating the impacts of climate change on water supply, Revised April 2017

B. Climate change impact assessment

Background to climate change assessment

U.2 The Environment Agency's WRPG details the requirement of how to assess the impacts of climate change on DO with particular reference to the Environment Agency/United Kingdom Water Industry Research (UKWIR) 2013 report 'Climate change approaches in water resources planning – Overview of new methods'[2]. The methods make particular reference to using the probabilistic climate data available from the UK Climate Projections 2009 (UKCP09). The UKCP09 projections provide a large amount of information on how the UK climate may change over the next 100 years in response to different levels of greenhouse gas emissions. To understand the impact of the new scenarios on our assessments of supply and demand, HR Wallingford was engaged to develop a methodology to make the most use of the UKCP09 output data as practically possible. Details of our climate change impact methodology are presented here, which follow the principles of the requirements in the Environment Agency and UKWIR (2013) report. This has been applied to each of our WRZs.

U.3 The updated climate change scenarios, UKCP09, were launched by UKCIP in June 2009 and provide 10,000 equally possible outcomes of future temperature and precipitation. The new projections are 'probabilistic' in the sense that they encapsulate a wide range of possible changes in climate, based on the strength of evidence derived from observations, climate models and expert opinion. There will only be one future climate and, therefore, the probability in UKCP09 means, for example, that there is currently a 10% certainty that the temperature rise will be less than 1.3^{o}C, but a 90% certainty that temperature rise will be less than 4.6^{o}C, and a central estimate of 2.7^{o}C . This example is for London and south east England in the 2050s[3]. Similar probabilistic statements can also be made about rainfall. The Environment Agency's 2012 WRPG[4] for WRMP14 was to consider a climate change impact to the 2030s time horizon. However, the 2018 WRPG that the Environment Agency has published for the WRMP19 recommend the use of the 2080s time horizon for assessing climate change impacts on rainfall, evaporation and river flows and is used in our assessments.

U.4 The Met Office published the next set of climate projections for the UK, UKCP18 in November 2018. Since publication of UKCP18, Thames Water has commissioned HR Wallingford to consider the potential implications on the London WRZ. The resultant March 2019 report 'UKCP18 Climate Projections: Thames Water Rapid Assessment' introduces the UKCP18 climate projections, summarises the key differences with UKCP09, and assesses the potential impacts for the London WRZ in terms of system Deployable Outputs (DO).

U.5 When assessing the projected impacts of climate change in the 2080s time horizon using the UKCP18 probabilistic projections for the London WRZ the assessment of climate change

[2] Environment Agency/UKWIR, Climate change approaches in water resources planning – Overview of new methods, 2013
[3] Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A. (2009), UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.
[4] Environment Agency and Natural Resources Wales and also produced in collaboration with Defra, the Welsh Government, and Ofwat, Water Resources Planning Guideline, 2012

impacts undertaken for the WRMP 2019 using UKCP09 Medium Emissions remains appropriate under the set of probabilistic projections available for different RCPs available within UKCP18.

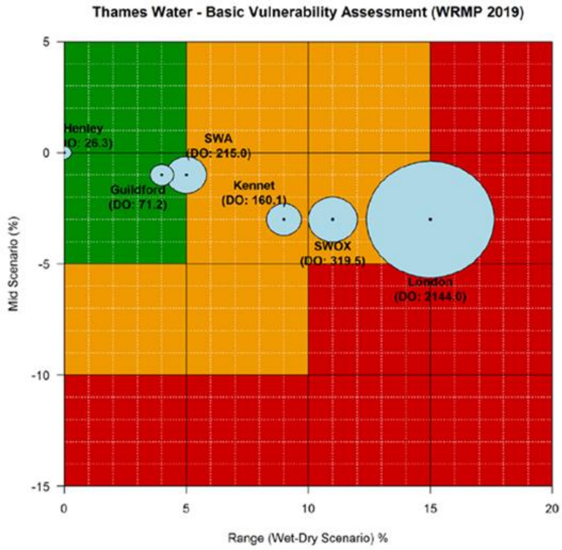
Basic vulnerability assessment

U.6 The first stage of the analysis by HR Wallingford was to undertake a basic vulnerability assessment (BVA) of all our WRZs (HR Wallingford, 2017)[5]. This is the first phase of analysis in a tiered approach to climate change analysis as outlined in the Environment Agency/UKWIR 2013[2] report. The basic vulnerability assessment was undertaken using data from WRMP14, specifically the climate change impact on DO in the 2030s. Figure U-1 taken from HR Wallingford's 2017 report shows green, orange and red areas that represent, low, medium and high vulnerability respectively. The WRZ circles are scaled with respect to their DO as at WRMP14.

U.7 For the WRMP19, the magnitude-sensitivity plot (Figure U-1) shows that the London WRZ is classified as high vulnerability and SWOX is classified as medium vulnerability. However, given the interactions between London and SWOX, and SWOX's vulnerability to short, intense droughts, its vulnerability has been upgraded to high vulnerability.

U.8 Thus Guildford and Henley WRZs have been identified as low vulnerability, Kennet and the Slough, Wycombe and Aylesbury (SWA) WRZs as medium vulnerability with the Swindon and Oxfordshire (SWOX) and London WRZs classified as high vulnerability, which required further "intermediate assessment".

Figure U-1: Basic vulnerability plot



Source: Figure 2.1: Climate change vulnerability matrix for WRMP19 showing for each WRZ the mid-climate change impact (% change) on the y-axis and the range from wet to dry climate change impact

[5] Thames Water climate change assessment, vulnerability assessment and impacts on supply (HR Wallingford, March 2017). Note also the HR Wallingford (April 2012) Thames Water climate change impacts on supply for the 2030s report produced for WRMP14

(% change) on the x-axis relative to the WRMP14 DO. Note that SWOX has been upgraded to high vulnerability. Thames Water Climate Change Assessment (HR Wallingford, March 2017, page 3).

Intermediate vulnerability assessment

U.9 The intermediate vulnerability assessment for the London and SWOX WRZs involves the identification of current system vulnerability through the analysis of the causes and mechanisms of historic droughts.

U.10 The WRMP14 approach to assessing climate change impacts was based around using climatological drought indicators to identify a sub-sample of 20 climate change scenarios from the 10,000 member UKCP09 ensemble. When a similar approach was applied for the 2080s, the detailed analysis presented in the HR Wallingford 2017 report indicated that the resulting sub-sample may not be as adequate for identifying an appropriate sub-sample of rainfall and evaporation scenarios to take forward to the DO assessment.

U.11 The 2080s climate change projections have a much larger range of projected changes in climate which means that the sub-sampling methods and techniques become more important because a larger range of possibilities need to be covered by the sub-sample. The suitability of latin hypercube sampling, used at WRMP14, for obtaining a representative sample of 100 UKCP09 scenarios was evaluated by repeating the sampling procedure which is additional to the method set out in the WRMP guidance. Without this check of the sampling it is possible that a given latin hypercube sampling sample may not best represent the full UKCP09 10,000 alternative climate scenarios.

U.12 In order to identify a more robust sample of climate change scenarios, simplified London and SWOX water supply system models were used to simulate the full 10,000 member UKCP09 ensemble for the 2080s medium emission scenario. This allowed the impacts of each climate change scenario on water supply system performance to be calculated using a system-based metric, as opposed to relying on the drought indicator methods, which were shown to be less reliable for the 2080s. The climate change impacts simulated using the simplified water supply system model are considered to much better reflect their relative impacts when used in Water Resources Management System (WARMS2) and therefore provide a better basis for identifying a sub-sample to take forward into the WRMP19.

U.13 WARMS2 currently applies the Teddington flow factors to the Teddington and Days Weir natural inflows. It also uses a number of rainfall run-off models to simulate flows in various sub-catchments of the Thames. Thus when climate change factors of rainfall, evaporation and flows are input to the model, perturbed flows are generated and then used to calculate the flows of the various gauged and ungauged catchments throughout the model. It should be noted that in WARMS2, the greater proportion of flows are generated by rainfall-runoff models for gauged locations, where climate change impacts are simulated with the use of climate factors, and not through the use of flow factors. The simplified water supply system model however demonstrates that by using only a single set of flow factors, as opposed to location specific hydrometric factors, the impacts of climate change on DO may be under-estimated by ~50 Ml/day for London. This is because WARMS2 is more detailed and generates and accumulates flows from multiple points throughout the Thames catchment rather than from a limited number of locations.

U.14 The output from the HR Wallingford 2017 study however is a sub-sample of 20 UKCP09 climate change scenarios that are considered to provide the most appropriate representation as to the range and likelihood of the projected climate change impacts in the London WRZ. The sub-sample has also been shown to be valid for the SWOX WRZ and is therefore considered to represent the most robust sample of scenarios to use.

U.15 The percentiles of the sample extracted for use in the DO impact analysis are shown in Table U-1. The probability weighting (an indicative rank weighting to reflect the relative position of each of the 20 scenarios in the full distribution of the 100 scenarios as stated in the HR Wallingford 2017 report) is also shown in Table U-1. This is used as input to the discrete distributions to determine the uncertainty around climate change impacts on DO in the Target Headroom analysis.

Table U-1: Sample data used for climate change impact analysis

Scenario	Percentile	Probability weighting
No CC	N/A	N/A
1	99	0.01
2	98	0.01
3	97	0.01
4	96	0.01
5	95	0.01
6	94	0.01
7	93	0.01
8	92	0.01
9	91	0.01
10	90	0.01
11	89	0.05
12	80	0.095
13	70	0.1
14	60	0.1
15	50	0.1
16	40	0.1
17	30	0.1
18	20	0.1
19	10	0.095
20	1	0.06

Note: Scenarios: 1 – Very Dry; 5 – Dry; 10 – Med-Dry; 15 – Medium; 19 Med-Wet

Choice of emissions scenario

U.16 The UKCP09 projections are available for three emissions scenarios; Low, medium and high. For WRMP14 we used the medium emissions scenario to quantify the impact of climate change on our water resources. The WRPG states that, when using the spatially coherent projections a medium emission scenario should be adopted as a minimum. This is also relevant when using the UKCP09 probabilistic scenarios that we used for the WRMP19, therefore being consistent with previous analysis at WRMP14 and to be compliant with the guidance, the medium emission scenario has been used to assess climate change impacts for the 2080s.[6]

U.17 We have investigated the climate change impacts of a High Emissions UKCP09 scenario for the 2080s within the London WRZ. On average, there is little change in the impact of a High Emissions 2080s scenario compared to a Medium Emissions 2080s scenario. Within the sample of 20 climate change scenarios from the High Emissions 10,000 member ensemble, the weighted average climate change impact is about 12 Ml/d lower (i.e. less severe) with the impact of the very dry end of the sample quite significantly more severe and the impact of the very wet end of the sample significantly less severe.

U.18 The Met Office published the next set of climate projections for the UK, UKCP18 in November 2018.

U.19 The UKCP18 climate projections include the Medium (SRES A1B) emission scenario for direct comparison with UKCP09 but not the High emission scenario. A new feature of the UKCP18 data, relative to UKCP09, is the inclusion of the latest emissions scenarios used in the Fifth Assessment Report from the IPCC (ie. the Representative Concentration Pathways, RCPs).

U.20 Headline results suggest that when considering a 2080s time-horizon, the assessment of climate change impacts undertaken for the London WRZ for the WRMP19 (using UKCP09 Medium Emissions) remains appropriate under the set of probabilistic projections available for different RCPs available within UKCP18.

C. Climate change impact on Deployable Output

Climate change impact on groundwater sources

U.21 We have undertaken analysis of climate change impact on its groundwater sources based on the UKCP09 data for the 2080s. Five scenarios from the 20 were selected to assess the groundwater system sensitivity to each of the potential futures. The scenarios were selected,

[6] HR Wallingford report (November 2017) 'Trajectory of climate change impacts and scaling' states that 'The range of uncertainty related to system performance [on the London WRZ] within a UKCP09 climate ensemble is significantly larger than that between climate ensembles for different time horizons or emissions scenarios' and the full range of uncertainty within the medium emissions scenario has been captured within headroom (Appendix V: Risk and uncertainty). Furthermore, HR Wallingford report (March 2019) 'UKCP18 Climate Projections: Thames Water Rapid Assessment' shows that 'the range of uncertainty related to system performance within a UKCP09 and UKCP18 climate ensemble is significantly larger than that between UKCP09 and UKCP18 and the different climate ensembles for different time-horizons or emission scenarios'.

based on their percentiles, to focus on drier potential futures, but also to consider wetter scenarios. The percentiles used are 99, 95, 90, 50 and 10 as indicated in grey in Table U-1. The rainfall and temperature climate change factors for each of the five scenarios were used to generate recharge scenarios for input into Environment Agency regional groundwater models covering the major aquifers of London and the Thames Valley. These models were then used to undertake hydrogeological analysis of the climate change impacts on the aquifers, specifically the impact on groundwater levels.

U.22 The groundwater level changes derived from this regional analysis of five scenarios for each of the groundwater sources were then used to assess the impact on groundwater source DOs (SDOs). The SDOs for the remainder of the twenty climate change scenarios were derived by interpolation. This interpolation used a relationship between SDO and modelled baseflow change in the River Thames at Teddington for each of the five successive pairs of discretely defined SDOs. This data based on the UKCP09 data for the 2080s is used to assess the central impact (mid-way between wet and dry) of climate change on DO.

Impact on London Deployable Output

U.23 The London CUZ consists of three interconnected sub-zones; Thames Valley (London), Lee Valley and south east London. The resources of each of the sub-zones have different characteristics and therefore each has had to be assessed individually for each scenario of climate change. The selected sub-sample of 20 scenarios has been evaluated in a broadly three step process:

- **Step 1:** Five scenarios (Table U-1 grey lines equivalent for the 2080s) from the 20 were selected to assess the groundwater system sensitivity to each of the "wet" to "dry" potential futures. The scenarios were selected, based on their percentiles, to focus on drier potential futures, but also to consider wetter scenarios. The rainfall and temperature climate change factors for each of the five scenarios were used to generate recharge scenarios for input into three Environment Agency regional groundwater models covering the London WRZ. These models were used to undertake hydrogeological analysis of the climate change impacts on the unconfined and confined chalk aquifers. The groundwater level changes derived from this analysis were then used to assess the impact on Annual Review 2017(AR17) groundwater SDOs. The SDOs for the remainder of the 20 climate change scenarios were derived by interpolation. Initially a linear interpolation method was used based on the percentage change in baseflow in the River Thames at Teddington; however this produced some unexpected results, including negative SDOs as well as SDOs for some dry scenarios being far greater than for wetter scenarios. Consequently, other interpolation methods were investigated with a third order polynomial fit being selected as the preferred, pragmatic option. Although the best fit equation excluded the SDOs calculated for scenario 5, as they are outliers, the SDOs calculated for all of scenarios 1, 5, 10, 15 and 19 were retained in the analysis, with the best fit equation being used to interpolate the SDOs of the remaining 15 scenarios. This approach produced variable SDOs consistent with variable River Thames baseflows, to be expected from the range of possible climate futures considered.

- **Step 2:** WARMS2 is a behavioural analysis model used to determine the DO for London. For each of the 20 samples of the UKCP09 scenarios the amended groundwater SDOs together with the rainfall, evaporation and flow factors were input into WARMS2 to evaluate the total impact of the climate change scenarios on the London DO. WARMS2 was then run 20 times to provide a range of total DO impacts when compared with the DO at AR17.
- **Step 3:** The DO and SDO impacts of climate change were then input to the London Target Headroom model to provide an assessment of the direct impact on DO and the uncertainty around this expressed as Target Headroom.

London groundwater

U.24 In Step 1, three Environment Agency regional groundwater models, the London basin aquifer model (LBAM), Mole and Vale of St Albans (VSA), were used to analyse climate change impact on the chalk aquifer of the London WRZ. None of these models are calibrated back to 1921, the critical drought year defined for the London WRZ (see from paragraph I.34, Appendix I: Deployable Output). Consequently 1976 was used as a proxy, and groundwater levels for each scenario were compared with the baseline for the relevant period in 1976, to determine the change in groundwater level resulting from climate change.

U.25 There were a number of sources that were simulated in more than one regional model. In these cases, a review of the respective model calibration and source location in the model relative to boundaries was undertaken. For example, the Northern New River Wells (NNRWs) located along the River Lee are located in both the LBAM and VSA model. An average of the predicted water level change from both models was used, as it was considered that both models were equally valid. Resultant groundwater level changes for these sources were very small (<0.2 m). The Epsom group of sources are represented in both the LBAM and the Mole model. A review of model calibration suggests that the LBAM over estimates groundwater level fluctuations in this area, and that the Mole model likely under estimates groundwater level fluctuations. An average of the predicted water level change from both models has therefore been used for these sources.

U.26 The impact of climate change has been assessed using the above approach on 69% of our London groundwater sources. The sources that have not been assessed in this manner are either disused, are emergency sources, or are confined, and the conceptual hydrogeological assessment is that no significant impact occurs on confined chalk groundwater levels. Consequently, zero impact on groundwater SDO is assumed for the confined sources. The groundwater modelling analysis supports this assumption. For example, simulated changes in groundwater level at abstraction boreholes in the confined aquifer are minimal in the climate change scenarios. No significant groundwater level impact occurs on the North London Artificial Recharge Scheme (NLARS), where it is also assumed that the managed aquifer recharge would sustain its current DO.

U.27 Table U-2 shows the total of the groundwater SDOs for each London sub-zone (AR17) as well as for each climate change scenario. The higher the percentile the drier the scenario, with the base position without climate change impacts shown as “No CC”. When the groundwater SDOs are totalled for each of the London sub-zones it can be seen that the only changes to SDO are for the Thames Valley London and south east London sub-zones. This reflects the hydrogeological differences between the London sub-zones, and especially the apparent sensitivity of the unconfined chalk of the North Downs to the recharge changes driven by the potential climate futures. The largest impact is a reduction in SDO for the drier scenarios, e.g. around 5-29 Ml/d reduction on total London SDO. There are also SDO increases, between 2-3 Ml/d, in the total London SDO.

Table U-2: London groundwater source DO 2085/86 (Ml/d)

Scenario	Percentile	Thames Valley GW[*1] DO	Lee Valley GW DO	south east London GW DO	NNRW, CLRG and LNRW	London GW total
No CC	N/A	68.85	37.05	232.14	104.00	338.04
1	99%	60.65	37.05	220.56	104.00	318.26
2	98%	58.63	37.05	216.84	104.00	312.52
3	97%	63.50	37.05	225.63	104.00	326.18
4	96%	57.39	37.05	214.46	104.00	308.90
5	95%	59.67	37.05	221.97	104.00	318.69
6	94%	65.49	37.05	228.78	104.00	331.32
7	93%	64.52	37.05	227.27	104.00	328.84
8	92%	66.37	37.05	229.99	104.00	333.41
9	91%	61.72	37.05	222.33	104.00	321.10
10	90%	63.93	37.05	226.31	104.00	327.29
11	89%	64.60	37.05	227.51	104.00	329.16
12	80%	64.73	37.05	227.67	104.00	329.45
13	70%	65.47	37.05	228.78	104.00	331.30
14	60%	65.65	37.05	228.98	104.00	331.68
15	50%	65.95	37.05	229.62	104.00	332.62
16	40%	65.94	37.05	229.60	104.00	332.59
17	30%	65.36	37.05	228.66	104.00	331.07
18	20%	67.04	37.05	230.77	104.00	334.86
19	10%	68.74	37.05	234.13	104.00	339.92
20	1%	69.08	37.05	234.94	104.00	341.07

Note: In the DO analysis, the Northern New River Wells (NNRW), Lower New River Wells (LNRW) and Central London Rising Groundwater (CLRG) borehole output is treated as part of the Lee Valley reservoir system.

*[*1] GW – groundwater*

London conjunctive use analysis

U.28 On running the data for the 20 scenarios through WARMS2, i.e. Step 2 of the analysis process, the total impact on London's DO for each of the climate change scenarios is calculated; this is presented in Table U-3. WARMS2 has been run using historical hydrological data for 1920 to 2010, with the base London DO without climate change of 2,305 Ml/d, as reported in the AR17.

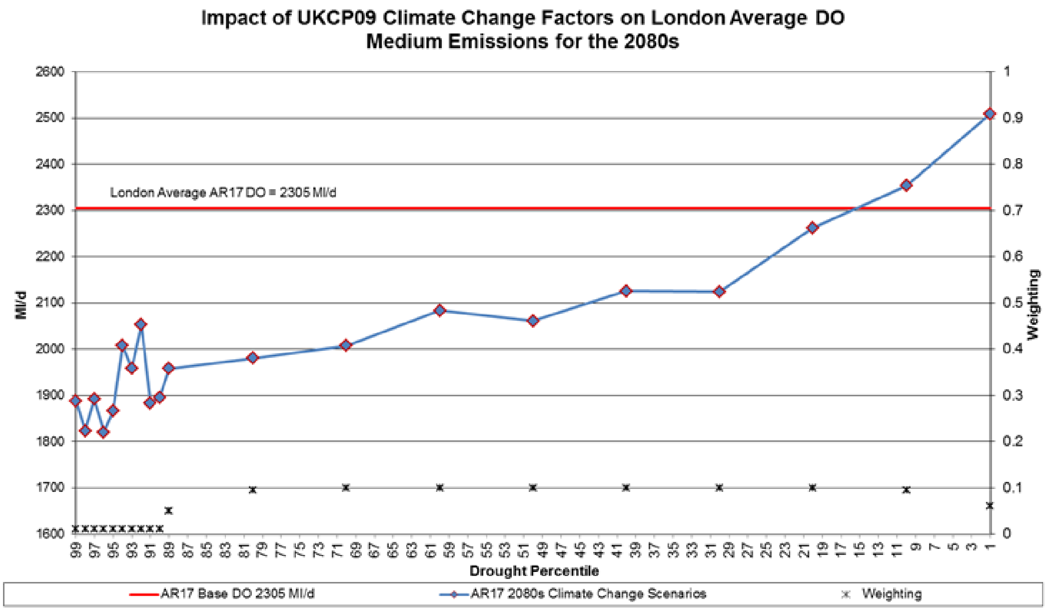
Table U-3: Impact on London average DO 2085/86 using UKCP09 climate change data

Scenario	Percentile	Probability weighting	London DO Ml/d	Impact on London DO Ml/d
No CC	N/A	N/A	2305	Base Position
1	99	0.01	1888	-417
2	98	0.01	1823	-482
3	97	0.01	1892	-413
4	96	0.01	1820	-485
5	95	0.01	1866	-439
6	94	0.01	2008	-297
7	93	0.01	1958	-347
8	92	0.01	2052	-253
9	91	0.01	1883	-422
10	90	0.01	1895	-410
11	89	0.05	1958	-347
12	80	0.095	1980	-325
13	70	0.1	2007	-298
14	60	0.1	2083	-222
15	50	0.1	2061	-244
16	40	0.1	2125	-180
17	30	0.1	2124	-181
18	20	0.1	2262	-43
19	10	0.095	2353	48
20	1	0.06	2509	204

Note: Scenarios: 1 – very dry; 5 – dry; 10 – med-dry; 15 – medium; 19 - med-wet

U.29 Using the sub-sample of 20 climate change scenarios to assess the impact on the London DO gives a range of change by 2085/86 from −485 Ml/d (Dry scenario) to +204 Ml/d (Very Wet scenario) with a "best estimate" of the impact of −187.15 Ml/d. This indicates that the more extreme changes could be highly significant for supply/demand long term planning. The "best estimate" of the climate change impact has been calculated by modelling a discrete probability distribution function (pdf) using the variation in DO data and probability weightings. The Target Headroom model applies Monte Carlo techniques to determine the statistics from the discrete distribution and the mean impact value of -187.15Ml/d has been calculated as the "“best estimate” by 2085/86. On plotting the variation in DO data from Table U-3 it can be seen from Figure U-2 that there is quite a large deviation around a roughly linear trend.

Figure U-2: Impact of climate change on London average DO of 2305 Ml/d



U.30 The recommended discrete distribution was built into the London Target Headroom model to determine the “best estimate” of the climate change impact and the uncertainty around this value. The differences around the “best estimate” is used to create discrete distributions for both groundwater and surface water climate change impacts for each year of the planning period within each London sub-zone. The mean impact of the climate change impacts as determined by Monte Carlo analysis is shown in Table U-4. The full impact is reached by 2085/86 as per the WRPG.

U.31 The climate change analysis for London WRZ Dry Year Annual Average (DYAA) has not been updated between the draft and final WRMP19. However the baseline DOs have been updated within the Target Headroom model to align them with AR17+ figures. For London DYAA the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model in combination with the difference between AR17 and AR17+ DO of -3 Ml/d.

U.32 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the DO for London is consistent with AR17+ and therefore the only difference in impact is due to variation from the Monte Carlo analysis within the Target Headroom model.

Table U-4: Reduction in London average DO 2085/86 using UKCP09 climate change data; AR17+ DYAA figures

Units Ml/d	London	Thames Valley	Lee Valley	South East London
SW DO	181.27	124.31	43.72	13.24
GW DO	5.89	3.03	0.0	2.86
Total	187.15	127.34	43.72	16.10

Impact on SWOX DO

U.33 Analysis has also been undertaken to assess the potential impacts of climate change on the groundwater sources outside London in the Thames Valley and the potential impact that this would have on the SWOX WRZ. This used the same approach as that used for London, as described in Section U.22. The impact on groundwater sources has been updated to reflect the UKCP09 data for the 2080s.

SWOX groundwater

U.34 As the same flow factors can be used to represent both London and SWOX WRZ the approach for SWOX is the same as that used for London. The ranking and the percentile sample extracted for use in the DO impact analysis, and the weights used as input to the discrete distributions to determine the uncertainty around climate change impacts on DO in the Target Headroom analysis, are shown in Table U-1. Five scenarios (Table U-1 grey lines) from the twenty were selected to assess the groundwater system sensitivity to each of the "wet" to "dry" potential futures. The scenarios were selected, based on their percentiles, to focus on drier potential futures, but also to consider wetter scenarios.

U.35 The rainfall and temperature climate change factors for each of the five scenarios were used to generate recharge scenarios for input into four Environment Agency regional groundwater models covering the SWOX WRZ; the Cotswolds, south west Chilterns, Kennet Valley and Middle Thames models. The Middle Thames model encompasses four other regional models, and it was intended that this model would be used to simulate climate change impacts for those sources located close to the River Thames along the south west Chilterns and Kennet Valley model boundaries. Unfortunately, the model was poorly calibrated in this area and had some numerical instability. Due to the inherent uncertainty in the results for these sources, a decision was made not to use this model for the climate change analysis. With the middle Thames model not being fit for purpose, the remaining three regional models were used to undertake hydrogeological analysis of the climate change impacts on the aquifers.

U.36 The critical drought year for the SWOX WRZ is 1976. Groundwater levels for each climate change scenario were compared to the baseline for the relevant period in 1976, to determine the change in groundwater level resulting from climate change.

U.37 Two sources that abstract from the Upper Greensand could not be modelled using regional groundwater models. Although they are located within the south west Chilterns model area, this model only represents the chalk aquifer. An analytical modelling approach using multiple linear regression (MLR) was developed for these sources instead, based upon work by

Bloomfield et al (2003)[7]. Antecedent precipitation was related to observed minimum groundwater levels. Perturbed precipitation data was then put into the MLR model to estimate the effects of climate change on groundwater level minima.

U.38 The impact of climate change has been assessed using the above approach on 89% of our groundwater sources in the SWOX WRZ. As with the London WRZ, those sources that have not been assessed are either disused, are emergency sources or do not show a significant recharge response due to their hydrogeological setting and therefore zero impact on groundwater SDO has been assumed.

U.39 The groundwater level changes derived from the above approaches were then used to assess the impact on AR17 groundwater SDOs. The SDOs for the remainder of the twenty climate change scenarios were derived by interpolation as described in Step 1 in section U.23 above. The average SDOs for each climate change scenario are presented in Table U-5 and the peak SDOs in Table U-6.

[7] Bloomfield, J.P., Gaus, I., and Wade, S.D, A method for investigating the potential impacts of climate change projections on annual minimum groundwater levels. Journal of CIWEM, 17(2), 86-91 2003

Table U-5: SWOX groundwater average source DO 2085/86 (Ml/d)

Scenario	Percentile	Swindon	N OXON (BS from S OXON)	S OXON	Total SWOX SDO Ml/d
No CC	N/A	62.45	50.0	78.17	190.62
1	99	53.67	50.0	75.71	179.38
2	98	52.89	50.0	75.64	178.53
3	97	55.87	50.0	76.07	181.94
4	96	52.59	50.0	75.45	178.04
5	95	56.56	50.0	76.05	182.61
6	94	59.22	50.0	76.56	185.78
7	93	57.26	50.0	76.31	183.57
8	92	62.11	50.0	77.08	189.19
9	91	54.31	50.0	75.71	180.02
10	90	56.42	50.0	76.12	182.54
11	89	57.44	50.0	76.19	183.63
12	80	57.70	50.0	76.17	183.87
13	70	59.17	50.0	76.53	185.70
14	60	59.83	50.0	76.46	186.29
15	50	60.74	50.0	76.85	187.59
16	40	60.67	50.0	76.65	187.32
17	30	59.12	50.0	76.22	185.34
18	20	64.55	50.0	77.58	192.13
19	10	61.80	50.0	77.91	189.71
20	1	60.81	50.0	77.89	188.70

Note: *N OXON – North Oxfordshire*
S OXON – South Oxfordshire
The transfer from S OXON to N OXON is assumed to have a 50 Ml/d capability
Scenarios: 1 – very dry; 5 – dry; 10 – med-dry; 15 – medium; 19 - med-wet

Table U-6: SWOX groundwater peak source DO 2085/86 (Ml/d)

Scenario	Percentile	Swindon	N OXON (BS from S OXON)	S OXON	Total SWOX SDO Ml/d
No CC	N/A	71.50	50.0	86.69	208.19
1	99	61.25	50.0	84.58	195.83
2	98	60.43	50.0	84.50	194.93
3	97	63.58	50.0	84.81	198.39
4	96	60.02	50.0	84.25	194.27
5	95	65.03	50.0	84.76	199.79
6	94	66.90	50.0	85.18	202.08
7	93	64.98	50.0	84.95	199.93
8	92	70.12	50.0	85.65	205.77
9	91	61.96	50.0	84.56	196.52
10	90	64.14	50.0	84.86	199.00
11	89	65.15	50.0	84.97	200.12
12	80	65.41	50.0	85.00	200.41
13	70	66.86	50.0	85.16	202.02
14	60	67.61	50.0	85.23	202.84
15	50	68.52	50.0	85.46	203.98
16	40	68.45	50.0	85.43	203.88
17	30	66.81	50.0	84.98	201.79
18	20	73.30	50.0	86.25	209.55
19	10	73.01	50.0	86.49	209.50
20	1	72.42	50.0	86.48	208.90

Note: *N OXON – North Oxfordshire*
S OXON – South Oxfordshire
The transfer from S OXON to N OXON is assumed to have a 50 Ml/d capability
Scenarios: 1 – very dry; 5 – dry; 10 – med-dry; 15 – medium; 19 - med-wet

SWOX conjunctive use analysis of average DO

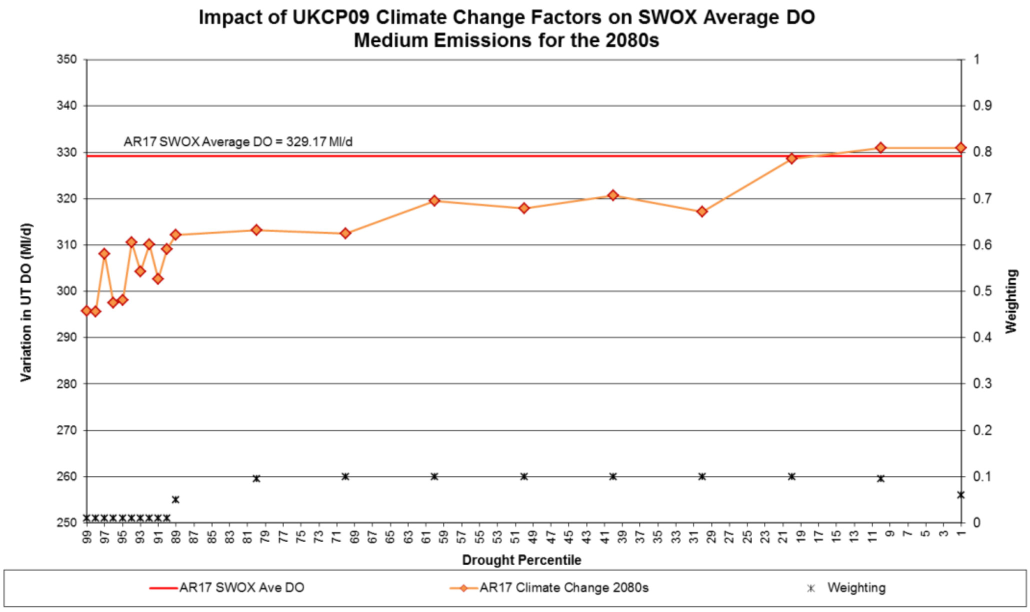
U.40 For each of the 20 samples of the UKCP09 scenarios the amended groundwater SDOs together with the rainfall, evaporation and flow factors were also input to WARMS2 to evaluate the total impact of the climate change scenarios on the SWOX average DO. WARMS2 was then run twenty times using the data for each climate change scenario to provide a range of total DO impacts when compared with the average DO of 329.2 Ml/d. The total impact on the SWOX average DO for each of the climate change scenarios is presented in Table U-7. The trend as seen in Figure U-3 is roughly linear but with wide variation around it and a range of impact by 2085/86 from -33.5 Ml/d to +1.7 Ml/d with a “best estimate” of the impact of −10.6 Ml/d.

Table U-7: Impact on SWOX Average DO 2085/86 using UKCP09 climate change data

Scenario	Percentile	Probability weighting	SWOX DO Ml/d	Impact on SWOX DO Ml/d
No CC	N/A	N/A	329.17	Base
1	99	0.01	295.71	-33.46
2	98	0.01	295.64	-33.53
3	97	0.01	308.07	-21.10
4	96	0.01	297.45	-31.72
5	95	0.01	298.05	-31.12
6	94	0.01	310.56	-18.61
7	93	0.01	304.31	-24.86
8	92	0.01	310.08	-19.09
9	91	0.01	302.71	-26.46
10	90	0.01	309.12	-20.05
11	89	0.05	312.19	-16.98
12	80	0.095	313.17	-16.00
13	70	0.1	312.53	-16.64
14	60	0.1	319.46	-9.71
15	50	0.1	317.85	-11.32
16	40	0.1	320.65	-8.52
17	30	0.1	317.22	-11.95
18	20	0.1	328.58	-0.59
19	10	0.095	330.91	1.74
20	1	0.06	330.89	1.72

Note: Scenarios: 1 – very dry; 5 – dry; 10 – med-dry; 15 – medium; 19 - med-wet

Figure U-3: Impact of climate change on SWOX average DO of 329.2 Ml/d



U.41 The recommended discrete distribution was built into the SWOX average Target Headroom model to be able to determine the uncertainty around the "best estimate" of impact on DO. The difference around this mean value is used to create discrete distributions for both groundwater and surface water climate change impacts for each year of the planning period within each SWOX sub-zone. The "best estimate" of the impact of climate change, as determined from the Monte Carlo analysis for groundwater and surface water by sub-zone, is shown in Table U-8. The full impact specified in the table is reached by 2085 as per the WRPG. Further details are given in Appendix V: Risk and uncertainty.

U.42 The climate change analysis for SWOX WRZ DYAA has not been updated between the draft and final WRMP19. However the baseline DOs have been updated within the Target Headroom model to align them with AR17+ figures. For SWOX DYAA the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model only as a result of the difference between AR17 and AR17+ DO being 0 Ml/d.

U.43 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the difference in 'best estimate' climate change impact is due to variation from the Monte Carlo analysis in combination with the an increase in AR17+ DO and AR18 DO of +1Ml/d.

Table U-8: Reduction in SWOX average DO 2085/86 using UKCP09 climate change data; AR17+ DYAA figures

Units Ml/d	SWOX DYAA	Swindon	N OXON	S OXON
SW DO	6.60	2.18	4.42	0.00
GW DO	4.01	2.59	0.00	1.42
Total	10.62	4.77	4.42	1.42

SWOX conjunctive use analysis of peak DO

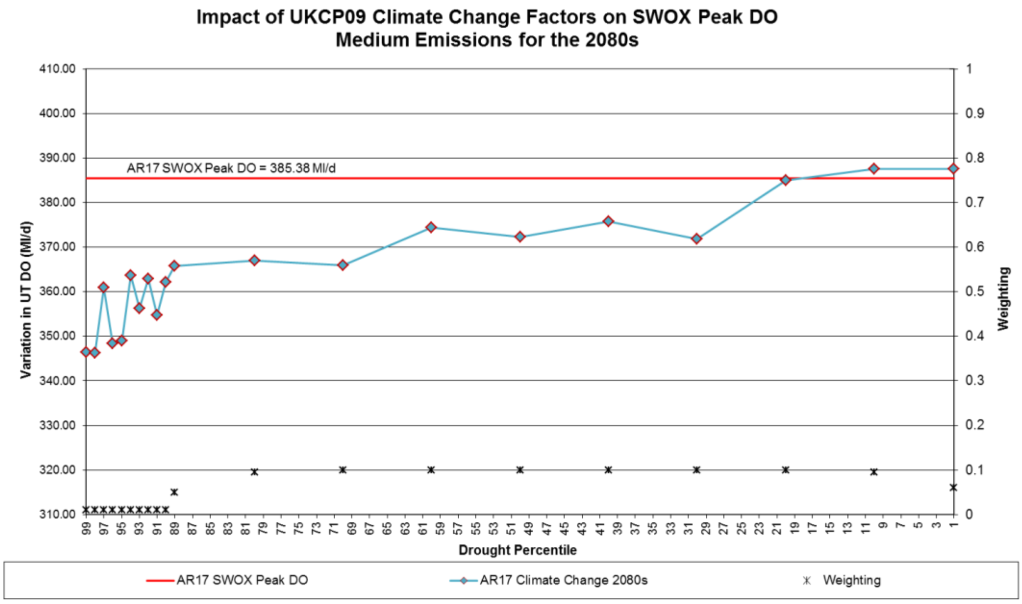
U.44 Similarly using the sub-sample of 20 climate change scenarios to assess the impact on the SWOX peak DO gives a range of change by 2085/86 from −39.0 Ml/d to +2.2 Ml/d with a "best estimate" of the impact of −12.1 Ml/d. Table U-9 shows the results for the SWOX peak impact analysis that reflects the results of the picture for the SWOX average DO. On plotting the variation in DO data from Table U-9 it can be seen from Figure U-4 that the impact on the SWOX peak DO reflects the results of the impact on the SWOX average DO.

Table U-9: Impact on SWOX Peak DO 2085/86 using UKCP09 climate change data

Scenario	Percentile	Probability weighting	SWOX DO Ml/d	Impact on SWOX DO Ml/d
No CC	N/A	N/A	385.38	Base
1	99	0.01	346.38	-39.00
2	98	0.01	346.30	-39.08
3	97	0.01	360.89	-24.49
4	96	0.01	348.43	-36.95
5	95	0.01	348.94	-36.44
6	94	0.01	363.64	-21.74
7	93	0.01	356.27	-29.11
8	92	0.01	362.92	-22.46
9	91	0.01	354.69	-30.69
10	90	0.01	362.13	-23.25
11	89	0.05	365.81	-19.57
12	80	0.095	367.03	-18.35
13	70	0.1	366.00	-19.38
14	60	0.1	374.40	-10.98
15	50	0.1	372.25	-13.13
16	40	0.1	375.79	-9.59
17	30	0.1	371.77	-13.61
18	20	0.1	384.94	-0.44
19	10	0.095	387.56	2.18
20	1	0.06	387.55	2.17

Note: Scenarios: 1 – very dry; 5 – dry; 10 – med-dry; 15 – medium; 19 - med-wet

Figure U-4: Impact of climate change on SWOX peak DO of 385.4 Ml/d



U.45 Similarly the uncertainty around the "best estimate" for the impact on the peak DO is derived using the SWOX peak Target Headroom model. The "best estimate" of climate change impacts on DO is shown in Table U-10 for each SWOX sub-zone.

U.46 The climate change analysis for SWOX WRZ Dry Year Critical Peak (DYCP) has not been updated between the draft and final WRMP19 however the baseline DOs have been updated within the Target Headroom model to align them with AR17+ figures. For SWOX DYCP the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model only as a result of the difference between AR17 and AR17+ DO being 0 Ml/d.

U.47 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the difference in 'best estimate' climate change impact is due to variation from the Monte Carlo analysis in combination with the an increase in AR17+ DO and AR18 DO of +1.19Ml/d.

Table U-10: Reduction in SWOX peak DO 2085/86 using UKCP09 climate change data; AR17+ DYAA figures

Units Ml/d	SWOX DYCP	Swindon	N OXON	S OXON
SW DO	7.68	1.44	6.25	0.00
GW DO	4.46	3.22	0.00	1.24
Total	12.14	4.66	6.25	1.24

Impact on the DO of the Thames Valley WRZs

Thames Valley groundwater climate change impacts

U.48 The results of the groundwater analysis (from paragraph U.21) also provided the basis for the impact assessments for the Thames Valley non-conjunctive use WRZs. The four non-conjunctive water resource zones are: Kennet Valley, Henley, SWA and Guildford. Three Environment Agency regional groundwater models were used to assess climate change impacts in these WRZs; the Kennet Valley, south west Chilterns and Mole models.

U.49 The critical drought year for all of the above Thames Valley WRZs is 1976, except for Guildford, which is 1992. It was considered that groundwater levels after 1990 would include the effects of climate change, and therefore it was decided that 1976 should also be used for Guildford so as not to double count these changes. Groundwater levels for each climate change scenario were compared with the baseline for the relevant period in 1976, to determine the change in groundwater level resulting from climate change.

U.50 The impact of climate change has been assessed using the above approach on 88% of our groundwater sources in the Thames Valley non-conjunctive use WRZs. Those sources that have not been assessed are either disused, are emergency sources or are hydrogeologically confined, and zero impact on groundwater SDO has been assumed. The total average and peak SDO in each of the Thames Valley WRZs for the five climate change scenarios is presented for the average in Table U-11 and the peak in Table U-12. Comparison is made between the AR17 SDO and the climate change scenarios from "Very Dry" to "Med-wet".

Table U-11: Total average SDO for the Thames Valley WRZs with climate change

Groundwater SDO average (Ml/d)	SDO AR17	Very dry	Dry	Med-dry	Med	Med-wet
Kennet Valley	80.8	80.2	80.3	80.3	80.4	80.8
Henley	25.7	25.7	25.7	25.7	25.7	25.7
SWA	183.3	179.1	179.6	180.2	181.5	183.6
Guildford	39.0	39.0	39.0	39.0	39.0	39.0

Table U-12: Total peak SDO for the Thames Valley WRZs with climate change

Groundwater SDO peak (Ml/d)	SDO AR17	Very dry	Dry	Med-dry	Med	Med-wet
Kennet Valley	92.8	91.7	91.8	91.9	92.1	92.7
Henley	25.9	25.9	25.9	25.9	25.9	25.9
SWA	213.3	209.4	210.1	210.7	212.3	213.5
Guildford	44.9	44.9	44.9	44.9	44.9	44.9

Thames Valley surface water climate change impacts

U.51 The flow factors derived from the HR Wallingford work for the 2080s are the basis for the impact assessment of the DO from Fobney WTW in the Kennet Valley WRZ and the DO from Shalford WTW in the Guildford WRZ, both of which abstract from rivers and do not have reservoir storage available. The potential impact on the DO of Fobney WTW from the 20 sample scenarios is shown in Table U-13. The impact on the DO for each percentile forms the input to the Target Headroom modelling with the sample mean contributing to the "best estimate" of the impact for the Kennet Valley WRZ, and scaled accordingly across the planning period. The calculation of DO for Fobney and Shalford is explained in Appendix I: Deployable Output.

Table U-13: Impact on average DO for Kennet Valley WTWs with climate change

Critical year 1975/76	Theale flow (Ml/d)	West Berks groundwater scheme (Ml/d)	Total flow (Ml/d)	Labyrinth Weir (Ml/d)	Potential abstraction (Ml/d)	Process water losses 7% (Ml/d)	DYAA DO (Ml/d)	Loss in DO (Ml/d)
Percentile	117.5	66.5	184.0	103.2	72.7	3.9	55.0	-
99	42.83	66.5	109.3	44.8	44.8	2.9	41.9	13.1
98	39.85	66.5	106.4	42.5	42.5	2.8	39.7	15.3
97	37.04	66.5	103.5	40.3	40.3	2.6	37.7	17.3
96	42.59	66.5	109.1	44.6	44.6	2.9	41.7	13.3
95	50.54	66.5	117.0	50.8	50.8	3.3	47.5	7.5
94	46.60	66.5	113.1	47.8	47.8	3.1	44.6	10.4
93	58.42	66.5	124.9	57.0	57.0	3.7	53.3	1.7
92	45.40	66.5	111.9	46.8	46.8	3.1	43.8	11.2
91	46.04	66.5	112.5	47.3	47.3	3.1	44.2	10.8
90	43.87	66.5	110.4	45.6	45.6	3.0	42.6	12.4
89	48.37	66.5	114.9	49.1	49.1	3.2	45.9	9.1
80	50.14	66.5	116.6	50.5	50.5	3.3	47.2	7.8
70	61.79	66.5	128.3	59.6	59.6	3.9	55.0	0.0
60	43.79	66.5	110.3	45.6	45.6	3.0	42.6	12.4
50	69.67	66.5	136.2	65.8	65.8	3.9	55.0	0.0
40	66.53	66.5	133.0	63.4	63.4	3.9	55.0	0.0
30	65.41	66.5	131.9	62.5	62.5	3.9	55.0	0.0
20	59.22	66.5	125.7	57.6	57.6	3.8	53.9	1.1
10	70.15	66.5	136.6	66.2	66.2	3.9	55.0	0.0
1	114.26	66.5	180.8	100.7	72.7	3.9	55.0	0.0

U.52 Similarly Table U-14 shows climate change impact on the peak DO of Fobney WTWs.

Table U-14: Impact on peak DO for Kennet WTWs with climate change

Critical year 1975/76	Theale flow (Ml/d)	West Berks groundwater scheme (Ml/d)	Total flow (Ml/d)	Labyrinth Weir (Ml/d)	Potential abstraction (Ml/d)	Process water losses 7% (Ml/d)	Peak DO (Ml/d)	Loss in DO (Ml/d)
Percentile	82.9	66.5	149.4	76.2	72.7	4.6	65.0	-
99	42.83	66.5	109.3	44.8	44.8	2.9	41.9	23.1
98	39.85	66.5	106.4	42.5	42.5	2.8	39.7	25.3
97	37.04	66.5	103.5	40.3	40.3	2.6	37.7	27.3
96	42.59	66.5	109.1	44.6	44.6	2.9	41.7	23.3
95	50.54	66.5	117.0	50.8	50.8	3.3	47.5	17.5
94	46.60	66.5	113.1	47.8	47.8	3.1	44.6	20.4
93	58.42	66.5	124.9	57.0	57.0	3.7	53.3	11.7
92	45.40	66.5	111.9	46.8	46.8	3.1	43.8	21.2
91	46.04	66.5	112.5	47.3	47.3	3.1	44.2	20.8
90	43.87	66.5	110.4	45.6	45.6	3.0	42.6	22.4
89	48.37	66.5	114.9	49.1	49.1	3.2	45.9	19.1
80	50.14	66.5	116.6	50.5	50.5	3.3	47.2	17.8
70	61.79	66.5	128.3	59.6	59.6	3.9	55.7	9.3
60	43.79	66.5	110.3	45.6	45.6	3.0	42.6	22.4
50	69.67	66.5	136.2	65.8	65.8	4.3	61.5	3.5
40	66.53	66.5	133.0	63.4	63.4	4.1	59.2	5.8
30	65.41	66.5	131.9	62.5	62.5	4.1	58.4	6.6
20	59.22	66.5	125.7	57.6	57.6	3.8	53.9	11.1
10	70.15	66.5	136.6	66.2	66.2	4.3	61.8	3.2
1	114.26	66.5	180.8	100.7	72.7	4.6	65.0	0.0

Table U-15: Impact on average and peak DO for Shalford WTWs with climate change

Critical year	1955/1956	1991/1992	Potential abstraction	Process water losses 12% (Ml/d)	Average and peak DO
	Minimum daily mean flow (Ml/d)		Average and peak scenarios		
River Wey minimum	49.7	84.4	1955/1956		
Tillingbourne minimum	30.5	19.0	Base = 30 Ml/d	Process water Loss 12%	Base = 26.4 Ml/d
Total flow -->	80.19	103.42	--	--	--
Percentile	--	--	--	--	--
99	51.1	55.1	30	3.6	26.4
98	49.7	51.3	30	3.6	26.4
97	46.1	47.7	30	3.6	26.4
96	48.9	54.8	30	3.6	26.4
95	57.8	60.5	30	3.6	26.4
94	55.4	59.0	30	3.6	26.4
93	53.4	57.9	30	3.6	26.4
92	54.2	58.4	30	3.6	26.4
91	51.6	59.3	30	3.6	26.4
90	48.2	56.5	30	3.6	26.4
89	52.1	62.3	30	3.6	26.4
80	52.8	64.5	30	3.6	26.4
70	59.7	79.5	30	3.6	26.4
60	51.5	56.4	30	3.6	26.4
50	60.3	80.7	30	3.6	26.4
40	61.9	83.4	30	3.6	26.4
30	81.1	84.2	30	3.6	26.4
20	68.2	76.2	30	3.6	26.4
10	66.0	88.9	30	3.6	26.4
1	88.3	97.1	30	3.6	26.4

U.53 The same approach is taken for Shalford WTW in the Guildford WRZ, however here this is more complicated as there are two potential abstraction points from the River Wey and the Tillingbourne. However, as can be seen from Table U-15 there is no impact on the DO of Shalford as there is sufficient flow to allow abstraction to the maximum 30 Ml/d under the 20 UKCP09 climate change scenarios sampled. As both the average and peak abstraction licence at Shalford is 30 Ml/d the impact assessment is the same for the average and peak DO.

U.54 The uncertainty around the “best estimate” for the impact on the DO is derived using the appropriate average or peak Target Headroom model. The “best estimate” of climate change impact 2085/86 on the average DO is shown in Table U-16 for each Thames Valley WRZ and Table U-17 for the peak DO.

U.55 The climate change analysis for Thames Valley WRZs DYAA and DYCP has not been updated between the draft and final WRMP19 however the baseline DOs have been updated within the Target Headroom model to align them with AR17+ figures.

U.56 For Kennet Valley, SWA and Guildford DYAA the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model in combination with the difference between AR17 and AR17+ DO being +8.1 Ml/d, +1.8 Ml/d and +0.40 Ml/d respectively. For Henley DYAA the discrepancy introduced by using AR17 climate change analysis with AR17+ DO on climate change impact on DO for 2016/17 is due to variation from the Monte Carlo analysis within the Target Headroom model only as a result of the difference between AR17 and AR17+ DO being 0 Ml/d.

U.57 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the DO for London is consistent with AR17+ and therefore the only difference in impact is due to variation from the Monte Carlo analysis within the Target Headroom model.

U.58 For Kennet Valley, SWA and Guildford DYCP the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model in combination with the difference between AR17 and AR17+ DO being -2.4 Ml/d, +1.1 Ml/d and +0.40 Ml/d respectively. For Henley DYAA the change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO for 2016/17 is due to variation from the Monte Carlo analysis within the Target Headroom model only as a result of the difference between AR17 and AR17+ DO being 0 Ml/d.

U.59 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the DO for London is consistent with AR17+ and therefore the only difference in impact is due to variation from the Monte Carlo analysis within the Target Headroom model.

Table U-16: Reduction in Thames Valley average DO 2085/86 using UKCP09 climate change data; AR17+ DYAA figures

Units Ml/d	Kennet Valley	Henley	SWA	Guildford
SW DO	11.72	N/A	N/A	0.40
GW DO	0.30	0.00	3.46	0.00
Total	12.01	0.00	3.46	0.40

Table U-17: Reduction in Thames Valley peak DO 2085/86 using UKCP09 climate change data; AR17+ DYAA figures

Units Ml/d	Kennet Valley	Henley	SWA	Guildford
SW DO	8.88	N/A	N/A	0.40
GW DO	0.10	0.00	2.31	0.00
Total	8.98	0.00	2.31	0.40

D. Supply side climate change impacts

Impact on Deployable Output

Climate change "best estimate"

U.60 The impact of climate change uncertainty is based upon the DO at the time of the assessment. The "best estimate" of the impact by the 2080s (2085/86) is shown for average and peak DOs for all WRZs in Table U-18. The WRPG requires that the "best estimate" of the impact is deducted directly from the DO of each WRZ. This amount is dependent however upon the scaling factor used in any year of the planning period as defined in the WRPG. The impact of the "best estimate" scenario for each of the WRZ's average DO over the planning period is shown in Table U-19 and for peak DO in Table U-20.

U.61 The climate change analysis has not been updated between the draft and final WRMP19 however the baseline DOs have been updated to align them with AR17+ figures. The change introduced between draft and final WRMP19 by using AR17 climate change analysis with AR17+ DO on climate change impact on DO in 2085/86 is due to variation from the Monte Carlo analysis within the Target Headroom model in combination with the difference between AR17 and AR17+ DOs.

U.62 This process of updating the baseline DOs and not updating the climate change analysis between draft and final is consistent with our process for preparing our Annual Review DO submissions between WRMPs. This is because the climate change analysis is only completed once every five years as part of the WRMP process and it has resulted in a marginal change in climate change impact. For AR18 the change to the baseline DO in SWOX and re-running

Monte Carlo within the Target Headroom model has marginally changed 'best estimate' or mean climate change impact value again.

Table U-18: The "best estimate" of climate change impact by the 2080s (2085/86) including AR17 and AR17+ figures for DYAA and DYCP

WRZ	Best estimate reduction in DO due to climate change by 2080s (Ml/d)			
	DYAA AR17	DYAA AR17+	DYCP AR17	DYCP AR17+
London	-184.9	-187.2	N/A	N/A
SWOX	-10.6	-10.6	-12.1	-12.1
Kennet Valley	-4.0	-12.0	-11.5	-9.0
Henley	0.0	0.0	0.0	0.0
SWA	-1.8	-3.5	-1.2	-2.3
Guildford	0.0	-0.4	0.0	-0.4

Table U-19: Climate change impact on AR17+ DYAA DO

WRZ	Reduction in DYAA DO due to climate change (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	19.70	34.48	59.10	83.73	100.38	108.89	117.40
SWOX	1.12	1.96	3.35	4.75	5.69	6.18	6.66
Kennet Valley	1.26	2.21	3.79	5.37	6.44	6.99	7.54
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.36	0.64	1.09	1.55	1.85	2.01	2.17
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Reduction in DYAA DO due to climate change (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	125.90	142.92	159.93	176.94	193.96	210.97
SWOX	7.14	8.11	9.07	10.04	11.00	11.97
Kennet Valley	8.08	9.17	10.27	11.36	12.45	13.54
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.32	2.64	2.95	3.27	3.58	3.90
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

Table U-20: Climate change impact on AR17+ DYCP DO

WRZ	Reduction in DYCP DO due to climate change (Ml/d)						
	2016/17	**2019/20**	**2024/25**	**2029/30**	**2034/35**	**2039/40**	**2044/45**
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	1.28	2.24	3.83	5.43	6.51	7.06	7.62
Kennet Valley	0.94	1.65	2.83	4.02	4.82	5.22	5.63
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.24	0.43	0.73	1.03	1.24	1.34	1.45
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Reduction in DYCP DO due to climate change (Ml/d)					
	2049/50	**2059/60**	**2069/70**	**2079/80**	**2089/90**	**2099/00**
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	8.17	9.27	10.37	11.48	12.58	13.69
Kennet Valley	6.04	6.86	7.67	8.49	9.30	10.12
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	1.55	1.76	1.97	2.18	2.39	2.60
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

Climate change uncertainty

U.63 The uncertainty around the "best estimate" value is included in Target Headroom. We sought advice and peer review from notable experts in climate change including Professor Nigel Arnell (Director of the Walker Institute and Professor of Climate Science), Professor Jim Hall (Director of the Environmental Change Institute and Professor of Climate and Environmental Risk, University of Oxford) and Dr Steven Wade (Head of the Met Office's Scientific Consultancy). It was decided that consideration of a discrete distribution of the climate change impacts was most appropriate as it takes into account the full variability of the calculated impacts. A discrete distribution was built into the Target Headroom models to be able to determine the uncertainty around the "best estimate" of the impact on DO.

U.64 The difference around this "best estimate" value is then used to create discrete distributions for both groundwater and surface water climate change impacts for each year of the planning period within each WRZ. The methodologies developed have allowed us to derive uncertainties around the possible outcomes such that a Target Headroom can be calculated for each of the WRZs. Details of the headroom modelling are given in Appendix V: Risk and uncertainty. The uncertainty around the climate change in Target Headroom for the DYAA is given in Table U-21 and for DYCP in Table U-22.

U.65 A correction has been made to climate change scaling factors within the Target Headroom model between the draft and final WRMP19 which explains the step in final climate change uncertainty for the 2080s. For AR17 the Target Headroom model was updated to reflect the updated climate change methodology used to assess climate change impacts for the WRMP19. This update was a step change from using climate change UKCP09 medium emissions impacts for the 2030s time slice (2035/36) to using the 2080s time slice (2085/86). The AR18 review has identified and corrected one omission to the Target Headroom model update, namely ensuring that the model is using 2080s as opposed to 2030s scaling factors to scale the climate change impacts through the planning horizon. The impact of this correction is a reduction in the climate change component of Target Headroom uncertainty from 25.2 Ml/d for AR17 (29.2 Ml/d AR17+) to 19.07 Ml/d for AR18.

Table U-21: Uncertainty around climate change in Target Headroom for AR17+ DYAA

WRZ	Climate change uncertainty for DYAA Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	29.2	28.1	40.3	47.4	49.1	43.9	37.6
SWOX	2.30	2.14	2.98	3.27	3.38	3.05	2.71
Kennet Valley	0.61	0.49	0.82	1.11	1.21	1.13	1.06
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.36	0.36	0.53	0.65	0.71	0.65	0.62
Guildford	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WRZ	Climate change uncertainty for DYAA Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	37.6	37.6	37.6	37.6	37.6	37.6
SWOX	2.71	2.71	2.71	2.71	2.71	2.71
Kennet Valley	1.06	1.06	1.06	1.06	1.06	1.06
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.62	0.62	0.62	0.62	0.62	0.62
Guildford	0.00	0.00	0.00	0.00	0.00	0.00

Table U-22: Uncertainty around climate change in Target Headroom for AR17+ DYCP

WRZ	Climate change uncertainty for DYCP Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	2.92	2.70	3.75	4.28	4.36	4.12	3.59
Kennet Valley	0.74	0.60	0.97	1.12	1.22	1.14	0.95
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.38	0.38	0.56	0.71	0.76	0.70	0.68
Guildford	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WRZ	Climate change uncertainty for DYCP Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	3.59	3.59	3.59	3.59	3.59	3.59
Kennet Valley	0.95	0.95	0.95	0.95	0.95	0.95
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.68	0.68	0.68	0.68	0.68	0.68
Guildford	0.00	0.00	0.00	0.00	0.00	0.00

Total impact of climate change

U.66 Therefore it can be seen that the impact of climate change on the supply demand balance for the DYAA conditions is as presented in Table U-23 and for the DYCP conditions in Table U-24.

Table U-23: Total impact of climate change for AR17+ DYAA

WRZ	Climate change impact for DYAA Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	48.90	62.58	99.40	131.13	149.48	152.79	155.00
SWOX	3.42	4.10	6.33	8.02	9.07	9.23	9.37
Kennet Valley	1.87	2.70	4.61	6.48	7.65	8.12	8.60
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.72	1.00	1.62	2.20	2.56	2.66	2.79
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Climate change impact for DYAA Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	163.50	180.52	197.53	214.54	231.56	248.57
SWOX	9.85	10.82	11.78	12.75	13.71	14.68
Kennet Valley	9.14	10.23	11.33	12.42	13.51	14.60
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.94	3.26	3.57	3.89	4.20	4.52
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

Table U-24: Total impact of climate change for AR17+ DYCP

WRZ	Climate change impact for DYCP Target Headroom (Ml/d)						
	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40	2044/45
London	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	4.20	4.94	7.58	9.71	10.87	11.18	11.21
Kennet Valley	1.68	2.25	3.80	5.14	6.04	6.36	6.58
Henley	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SWA	0.62	0.81	1.29	1.74	2.00	2.04	2.13
Guildford	0.04	0.07	0.13	0.18	0.21	0.23	0.36

WRZ	Climate change impact for DYCP Target Headroom (Ml/d)					
	2049/50	2059/60	2069/70	2079/80	2089/90	2099/00
London	N/A	N/A	N/A	N/A	N/A	N/A
SWOX	11.76	12.86	13.96	15.07	16.17	17.28
Kennet Valley	6.99	7.81	8.62	9.44	10.25	11.07
Henley	0.00	0.00	0.00	0.00	0.00	0.00
SWA	2.23	2.44	2.65	2.86	3.07	3.28
Guildford	0.37	0.41	0.45	0.38	0.41	0.45

E. Demand side climate change impacts

U.67 HR Wallingford were commissioned to carry out a study[8] to estimate the likely impacts of climate change upon household demand (HR Wallingford, 2003). No climate change effects are assumed for other components of demand based on the findings of the UKWIR report on the impacts of climate change on water demand[9].

U.68 HR Wallingford undertook a statistical analysis of available data in order to derive empirical relationships that describe how weather and other factors affect household demand for water in our supply area.

U.69 We provided the following data sets:

- DWUS unmeasured PCC by property type (2000-2010)
- PCC by property type for testDWUS[10] panel (2002-2004)
- Demand data (distribution input – minimum night line, 1998 onwards)
- Climate data (temperature, rainfall and sunshine hours, 1998 onwards)

[8] HR Wallingford, EX6828 Thames Water Climate Change Impacts and Water Resource Planning. Thames Water Climate Change Impacts on Demand for the 2030s, 2003
[9] UKWIR 2013 Impact of Climate Change on Water Demand 13/CL/04/12
[10] testDWUS – A temporary panel of unmeasured customers used to validate DWUS

U.70 The DWUS dataset is comprised of a panel of customers who have, voluntarily, had meters installed but are charged on an unmeasured basis. This dataset has monitored the consumption of customers for over 10 years across our entire supply area. It also shows how usage changes with differing weather patterns and occupancy information is available for each member of the panel.

U.71 HR Wallingford used multiple linear regression to analyse data and to produce predictive equations.

U.72 Three climate variables were considered in the statistical analysis; temperature, rainfall and sunshine hours. However, sunshine hours were removed as it was found to be highly correlated with temperature, and temperature provided a stronger and better understood climate change signal which would increase confidence in the model. Including both sunshine hours and temperature could have resulted in instability within the model. For the DYAA model both rainfall and temperature were included. For the average day peak week scenario ADPW model only temperature was included as an explanatory variable, this was due to insufficient data as for most years there was no rainfall in the peak period.

U.73 To estimate the impacts of climate change, the full sample of 10,000 UKCP09 climate change projections for maximum temperature and rainfall in the Thames Valley basin in the 2030s medium emissions scenario, was used. These scenarios provide climate change factors that are applied to the regression models.

U.74 The climate change factors are reported as the change between the baseline period (1961-1990) and the future period (2021-2050). As the baseline for the WRMP14 was 2011 a scaling factor was calculated:

$$ScalingFactor = \frac{2035 - BaseYear}{2035 - 1975}$$

U.75 As the base year was 2011 this results in a scaling factor of 0.4, i.e. 60% of the climate change between 1975 and 2035 has already been assumed to have occurred.

U.76 These factors were then used with the regression relationships, described above, to provide estimates of PCC change due to climate change in the 2030s. The results of this gave 10,000 potential future PCC factors. The 10th, 50th and 90th percentiles of these factors were extracted to represent lower, mid and upper estimates of impact on PCC. The mid estimate was used in the demand forecasting models while the upper and lower estimates were used in headroom modelling (see Section 5: Allowing for Risk and uncertainty).

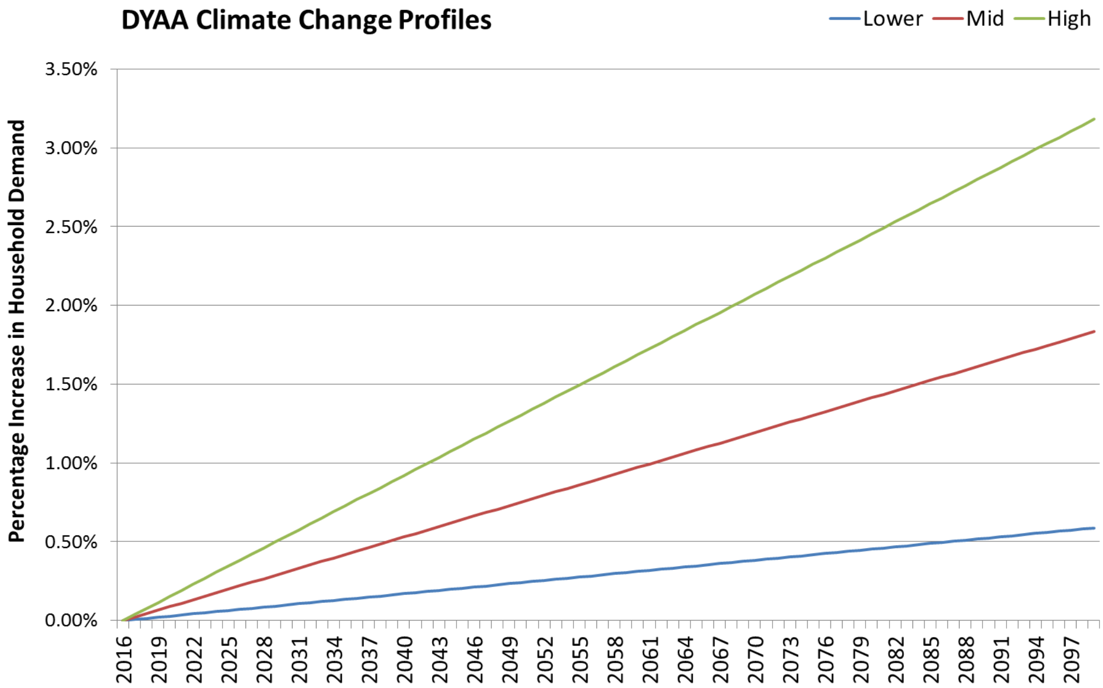
U.77 The climate change profiles for lower, mid and upper estimates are shown for the DYAA in Figure U-5 and the ADPW scenario in Figure U-6.

U.78 The impacts of climate change for the DYAA scenario are shown in Table U-25. These values are applied to all our WRZs.

Table U-25: The impacts of climate change for the DYAA scenario

	Base year	2014/15	2019/20	2024/25	2029/30	2034/35	2039/40
Impact	0.00%	0.18%	0.40%	0.62%	0.84%	1.28%	1.83%

Figure U-5: Climate change impact on demand profile – Dry Year Annual Average (DYAA)

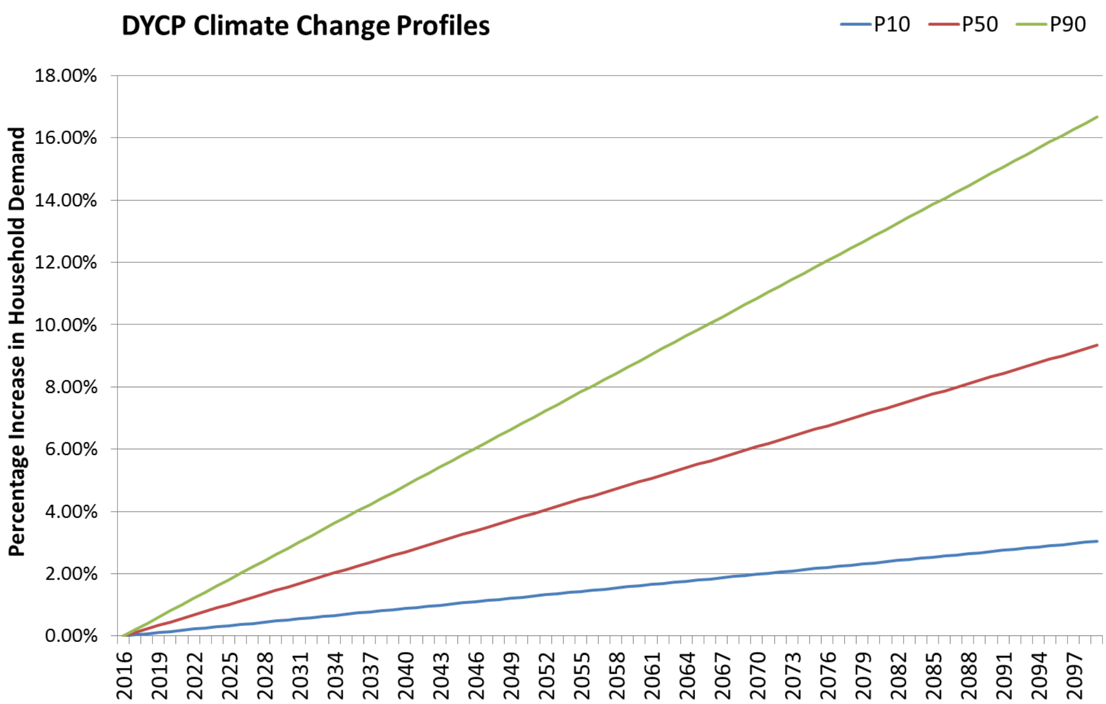


U.79 The impacts of climate change for the ADPW scenario are shown in Table U-26. These values are applied to all our Thames Valley WRZs.

Table U-26: The impacts of climate change for the ADPW scenario

	2016/17	2024/25	2034/35	2044/45	2054/55	2074/75	2099/2100
Impact	0.00%	0.90%	2.03%	3.15%	4.28%	6.53%	9.34%

Figure U-6: Climate change impact on demand profile – Average Day Peak Week (ADPW)



Climate change impact for dry year annual average

U.80 The mid estimates shown in Figure U-5 were used in the production of the demand forecast. The effect on output values can be seen across the forecast period in Figure U-7 and is summarised in Table U-27. The effects of climate as can be seen are minor for demand in a dry year.

Figure U-7: Climate change volume impact on demand profile – DYAA

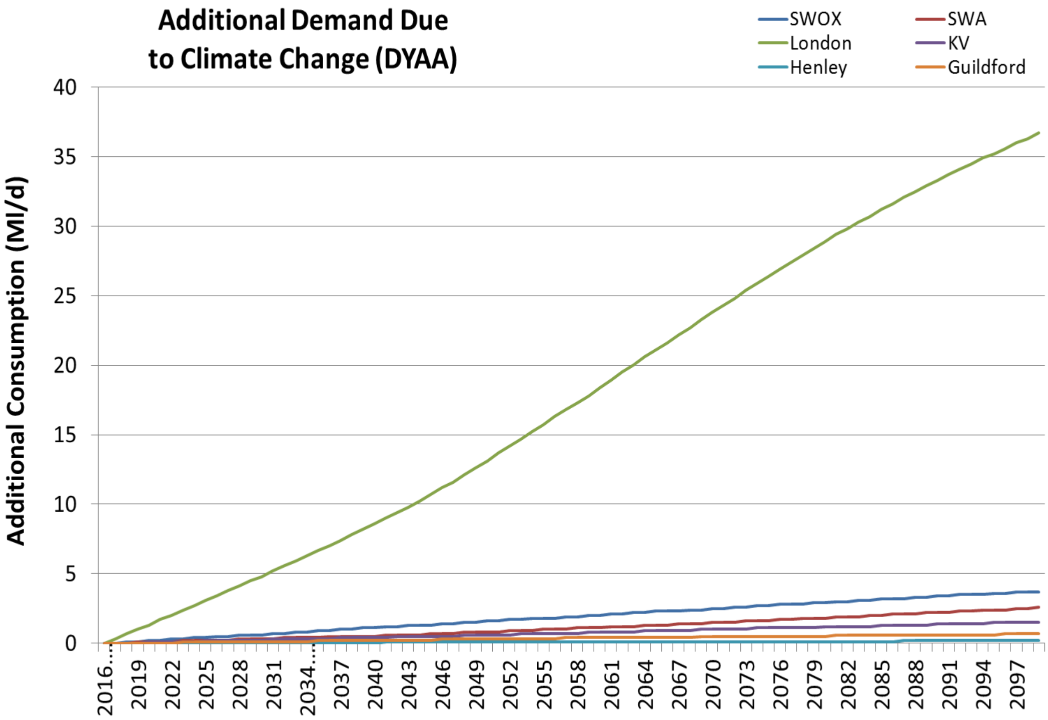


Table U-27: DYAA Additional demand due to climate change

Units Ml/d	2016/17	2024/25	2034/35	2044/45	2054/55	2074/75	2099/2100
Guildford	0	0.1	0.1	0.2	0.3	0.5	0.7
Henley	0	0	0	0.1	0.1	0.1	0.2
Kennet Valley	0	0.1	0.3	0.5	0.7	1.1	1.5
London	0	2.7	6.3	10.2	15.2	25.9	36.7
SWA	0	0.2	0.4	0.6	0.9	1.6	2.6
SWOX	0	0.4	0.8	1.3	1.8	2.7	3.7

Climate change impact for average day peak week

U.81 The mid estimates in the profiles shown in Figure U-6 were used in the production of the demand forecast. The effect on output values can be seen across the forecast period in Figure U-8 and is summarised in Table U-28. Although the additional demand is significantly higher than those for the DYAA they are still relatively minor compared to the total demand for their respective WRZs.

Figure U-8: Climate change volume impact on demand profile – ADPW

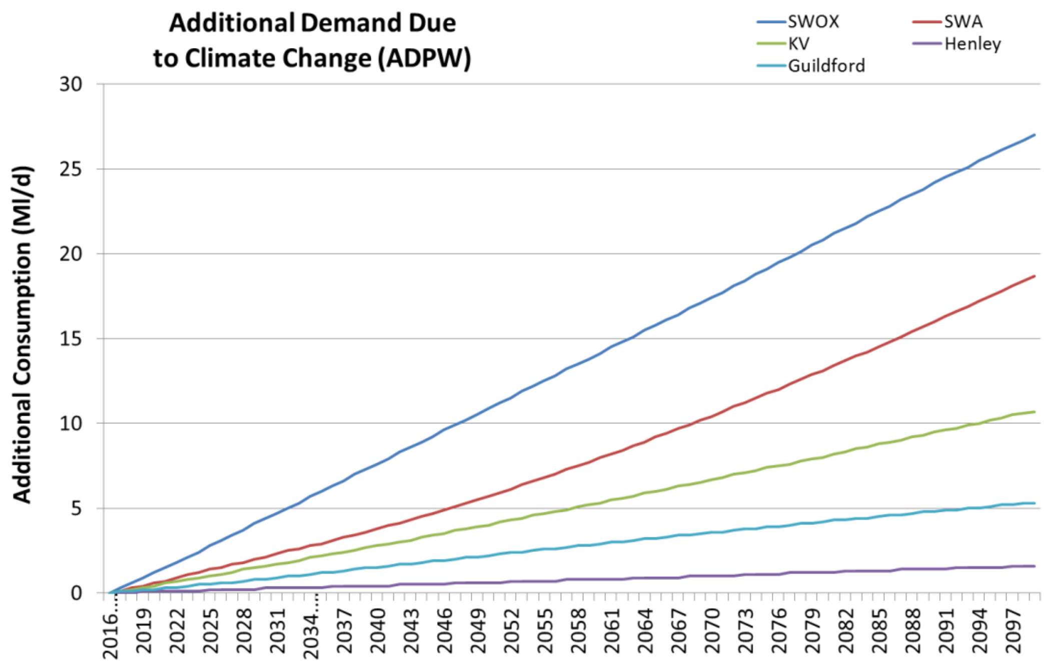


Table U-28: ADPW Additional demand due to climate change

Units Ml/d	2016/17	2024/25	2034/35	2044/45	2054/55	2074/75	2099/2100
Guildford	0	0.5	1.1	1.8	2.5	3.8	5.3
Henley	0	0.1	0.3	0.5	0.7	1.1	1.6
Kennet Valley	0	0.9	2.1	3.3	4.6	7.2	10.7
SWA	0	1.2	2.8	4.5	6.6	11.5	18.7
SWOX	0	2.4	5.7	8.9	12.2	18.8	27

F. The consequence of scaling climate change impact

Environment Agency planning guidelines

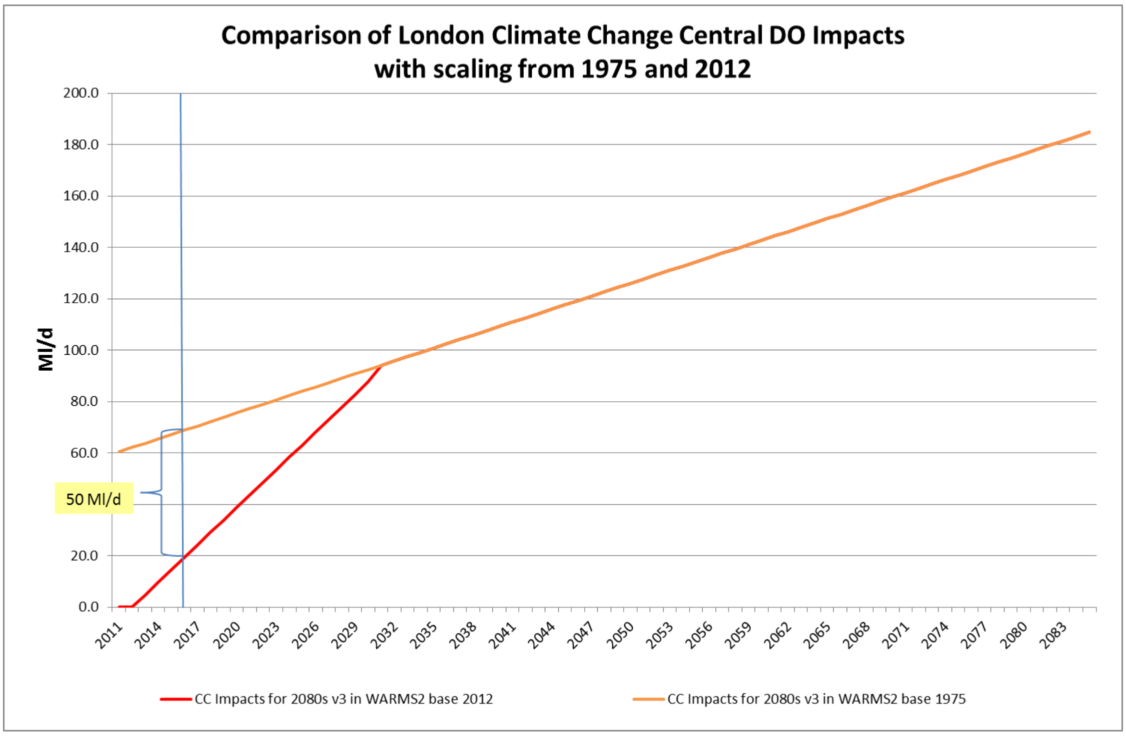
U.82 The Environment Agency published supplementary 2016 guidance[11] that recommends the use of the 2080s time-horizon for assessing the impacts of climate change on river flows. A scaling factor is then used to produce a profile of impact for each year over the planning horizon which will be subtracted directly from DO.

U.83 For the draft WRMP19 the scaling provided in the guidance was originally as follows:

$$\text{Scale factor} = (\text{Year} - 1975) / (2085 - 1975) \quad (1)$$

U.84 However, further guidance from the Environment Agency was sought when we identified that this would have an immediate significant impact on DO in the AMP6 period. The reason for this can be seen in Figure U-9 where for London, if the guideline were to be introduced immediately, this would result in a reduction in DO in London at AR17 of around 50 Ml/d.

Figure U-9: Impact of climate change scaling on London DO



U.85 Similarly smaller impacts for SWOX average of around 2.8 Ml/d and SWOX peak of around 3.2 Ml/d would also be seen. In response further guidance from the Environment Agency[12] indicates that as we experience this impact we should apply a scaling factor that will provide a

[11] Environment Agency, Supplementary note on climate change and the impact on supply, June 2016
[12] Supplementary note "20170223CC", an amendment to the Environment Agency's 2016 WRPG, pers. comm. February 2017; published within Section 4.8 the Final 2017 WRPG.

more gradual move to the climate change projection and will be more aligned with that previously forecast in WRMP14. The scaling factor used over the period to 2030 aims to provide a relative increase in the climate change impact so that there is a smooth transition to the Environment Agency's guidance on scaling. The scaling factor applied is as follows:

(2) *Scale factor = (Year – 2012) / (2050 – 2012)*

U.86 Then from 2031/32 to the end of the planning period the scale factor shown in (1) above is used.

G. Climate change impact on London

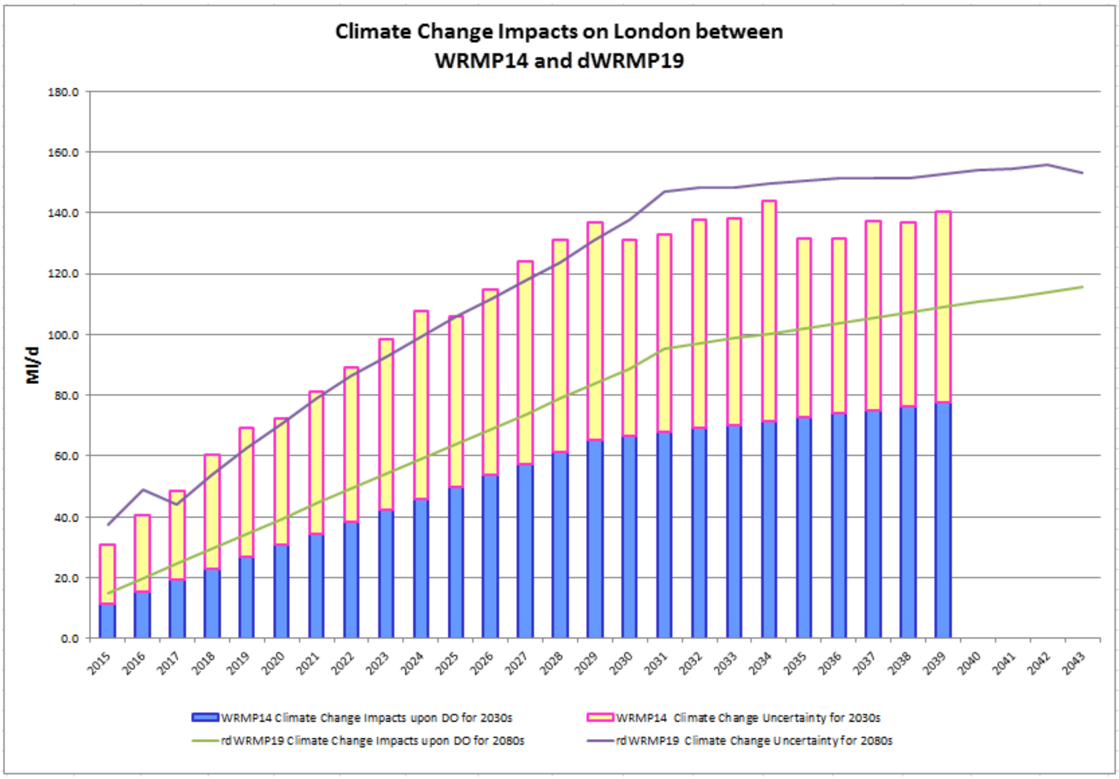
Comparison of climate change impacts between WRMP14 and the WRMP19

U.87 As set out in the WRPG, the "best estimate" of the modelled climate projection is applied as a reduction in DO and the uncertainty around this projection is handled in Target Headroom. The Target Headroom methodology (Appendix V: Risk and uncertainty) shows climate change to be the most significant uncertainty on the supply side. The London Target Headroom model has been run with the latest UKCP09 data for the 2080s where the "best estimate" impact on DO is seen to be 187.15 Ml/d by 2085/86. This is an update from WRMP14, which now includes the assessment of impacts for the 2080's on the groundwater SDOs. For London the direct impact of climate change on DO plus the uncertainty can be seen in Table U-23 and is in the range from around 62.58 Ml/d by the end of AMP6 to 155.00 Ml/d by the end of the period to 2044/45, increasing to 248.57 Ml/d by 2099/00, see Appendix V: Risk and uncertainty. The largest impact of climate change is on the London DO.

U.88 A correction has been made to climate change scaling factors within the Target Headroom model between the draft and final WRMP19 which explains the step in final climate change uncertainty for the 2080s in Figure U-10. For AR17 the Target Headroom model was updated to reflect the updated climate change methodology used to assess climate change impacts for WRMP19. This update was a step change from using climate change UKCP09 medium emissions impacts for the 2030s time slice (2035/36) to using the 2080s time slice (2085/86). The AR18 review has identified and corrected one omission to the Target Headroom model update namely ensuring that the model is using 2080s as opposed to 2030s scaling factors to scale the climate change impacts through the planning horizon. The impact of this correction is a reduction in the climate change component of Target Headroom uncertainty from 25.2 Ml/d for AR17 (29.2 Ml/d AR17+) to 19.07 Ml/d for AR18.

U.89 The comparison of supply-side climate change impacts between those in the WRMP19 and the UKCP09 analysis for the final WRMP14 can be seen in Figure U-10.

Figure U-10: Comparison of climate change impact on London between WRMP14 and the WRMP19



U.90 The "best estimate" impact on London's DO by 2085/86 amounts to a reduction in DO of 187.15 Ml/d compared with the WRMP14 estimate of 72.7 Ml/d by 2035/36. This amounts to a comparable increase by 2039/40 of 31.0 Ml/d of impact. The climate change uncertainty component of the Target Headroom for the WRMP19 is also somewhat greater than the WRMP14, which together means that the overall increase in the climate change impact by 2039/40 amounts to 15.6 Ml/d with the total increasing from 140.2 Ml/d to 152.8 Ml/d: Table U-31. The variance in the supply side climate change impact for London can be seen in Table U-29. The data is only extended to 2039/40, rather than 2100, to enable like for like comparison with WRMP14. The WRMP14 climate change impacts were assessed against the base year DO in 2011/12 of 2146 Ml/d. With the changes in DO since WRMP14, as described in Appendix I: Deployable Output, the base year DO in 2016/17 has increased to 2306 Ml/d.

Table U-29: Central estimate impacts on London between WRMP14 and the WRMP19 AR17+ figures

	Base year DO	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40
WRMP14	2146	15.32	26.80	45.95	65.09	71.54	77.60
WRMP19	2306	19.70	34.48	59.10	83.73	100.38	108.89
Difference	160	4.38	7.67	13.15	18.63	28.85	31.29

U.91 Overall the analysis demonstrates that there is an increase in the “best estimate” of climate change impact on DO and a decrease in the uncertainty since the WRMP14. The reason for the sizeable increase in the ‘best estimate’ is that the DO has increased in London with the development of WARMS2 and the impact by 2080s generates a larger uncertainty. The increase in the “best estimates” impact for both supply and demand is shown in Table U-29. The decrease in the uncertainty between the WRMP14 and the WRMP19 is shown in Table U-30 and this is due to the model using 2080s as opposed to 2030s scaling factors to scale the climate change uncertainty through the planning horizon. It can be seen in Table U-30 that the uncertainty increases in the first instance with time but as greater risk is taken the further into the planning period then the uncertainty element of the climate change impacts reduces. The changes resulting from the combined impact from climate change is shown in Table U-31.

Table U-30: Climate change uncertainty for London between WRMP14 and the WRMP19 AR17+ figures

	Base year DO	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40
WRMP14	2146	25.16	42.53	61.61	71.64	72.19	62.63
WRMP19	2306	29.1	28.1	40.3	47.4	49.1	43.9
Difference	160	3.94	-14.43	-21.31	-24.24	-23.09	-18.73

Note: The uncertainty around the climate change impacts on demand is very small and is indistinguishable from the variability caused by the Monte Carlo sampling.

Table U-31: Total climate change impacts on London between WRMP14 and the WRMP19 AR17+ figures

	Base year DO	2016/17	2019/20	2024/25	2029/30	2034/35	2039/40
WRMP14	2146	40.48	69.33	107.56	136.73	143.73	140.23
WRMP19	2306	48.8	62.58	99.4	131.13	149.48	152.79
Difference	160	8.32	6.75	8.16	5.6	5.75	12.56