Evidence

Climate change approaches in water resources planning – overview of new methods

Report – SC090017/R3

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Miranda Kavanagh

Director of Evidence

Executive summary

This is the final report of research project SC090017, *Climate change and water supply planning*, which was co-funded by the Environment Agency and UK Water Industry Research (UKWIR).

The aim of the project was to examine how climate change has been built into water resource management plans (WRMPs) to date, and to recommend best and appropriate practice for the future, with particular reference to the use of the detailed tools and probabilistic climate data in UKCP09, published in July 2009 (Murphy *et al*., 2009) and the outputs of the Future Flows project (Prudhomme *et al*., 2012).

The water resources management and planning framework used in England and Wales has developed considerably over the past decade. Methods for incorporating climate change into the analysis have become more advanced over this time, at a cost of time and complexity that may not always have been proportionate to the situation faced by individual water companies.

Previous guidance has defined a common minimum standard of assessment that most companies have followed. In some cases, though, companies have completed detailed climate change analyses when the impacts of climate change have been negligible compared to those from other risks and uncertainties; whilst in other cases, the minimum approach has been adopted when a more detailed assessment was justified by the risks posed by climate change.

UKCP09 was published too late to be included in Environment Agency guidance for WRMP09 and PR09, and too late for inclusion in water company business plans. Companies' determinations of climate change impacts and justifications of investment need for PR09 had accordingly to be based on prior climate scenarios data (UKWIR06) (UKWIR, 2007), and cases for PR09 investment based solely on climate change considerations were disallowed by the economic regulator, Ofwat. Companies materially affected can contact Ofwat for advice.

In October 2009, Ofwat provided companies with technical advice on the use of the new UKCP09 tools and data, and advised companies that they could submit claims for additional climate change driven expenditure arising from the use of those new data, as a 'notified item'.[1] Ofwat's advice to companies in this regard stressed the need for assessments of climate change impacts on the supply-demand balance to be risk-based and robust, and for plans and investment needs to be determined in close consultation with stakeholders. Our work supports the need for climate change assessments to be 'situation-reflective', with analytical depth being kept proportionate to each resource zone's vulnerability to climate change, and with analytical rigour being commensurate with the level of investment required to maintain security of supply and levels of service in the face of climate change and other risks and uncertainties.

1. Risk-based approach
    - Companies' investment proposals must be derived from a reasonable, risk-based, analysis consistent with the range of projected outcomes reflected in the application of a suitable analytical tool to UKCP09.
2. Robust analysis.
    - Analysis must go beyond a simple application of the summary headlines from UKCP09 and must apply UKCP09 data sources, utilising appropriate analytical tools, at a water resource zone level and be consistent with the

[1] For full letter see http://www.ofwat.gov.uk/publications/rdletters/ltr_rd1310idok

UKCP09 User Guidance. The application of ‘appropriate analytical tools’ includes weather generators, maps or other processes or tools developed by the UK Climate Impacts Programme or associated research projects. Companies should predict supply using bespoke modelling driven by the outputs generated by the application of appropriate analytical tools to UKCP09.

3. Engagement

- Water companies should, as early as possible, discuss their approach towards utilising UKCP09 with Ofwat and the Environment Agency and should continue to engage with them throughout.
- Companies should continue to follow the Environment Agency’s water resource management plan guidance, as amended from time to time, both in general and in respect of determining the effect of climate change on supply, demand and greenhouse gas emissions.

From a water company perspective, this project should support the development of clear guidance so that firms know what is needed to meet regulatory requirements, what is a reasonable ‘risk-based’ approach and what would provide an exemplar analysis of potential climate change risks. As UKCP09 provides several orders of magnitude more climate change data than previous assessments, a new framework is needed that offers both flexibility and guidance on different climate change approaches. However, there are number of barriers to completing more advanced climate change assessments for plans in 2014, such as:

- The wide range of Deployable Output methodologies currently used by water companies in England and Wales with respect to the availability of good longer term hydrological data, application of hydrological models, the use of flow factors as an alternative approach to rainfall-runoff modelling, and incomplete uptake of water resources models means the companies are starting their assessments from very different points.
- The distinct difficulties of modelling the impacts of climate change on groundwater Deployable Outputs. Although England and Wales now have good coverage of modern groundwater models it still remains a significant task to run large numbers of scenarios through distributed groundwater models and then translate the results in to source yields.
- The timescale available to complete assessments is relatively short and challenging for some water companies. As well as changes to methodology on climate change there are new and rather complex methods proposed to update the Economics of Balancing Supply and Demand (EBSD). Some companies may not have the capacity (knowledge, data and information, processes and financial budgets) in place to complete advanced assessments.

The framework presented includes different levels of assessments to accommodate some of these issues and, where possible, additional comments are made on where and how climate change assessment may be simplified to make it manageable in the available timeframes for PR14.

Acknowledgements

The project was support by a Project Steering Group drawn from the Environment Agency, the water companies and Ofwat.

Thames Water, Southern Water and Welsh Water for providing data for case studies on the impacts of climate change on Deployable Output. Data from Southern Water were used to develop a **hypothetical case study**, which made use of simplified water resources zone assessment with one run of river source and one small reservoir.

Professor Nigel Arnell and Matt Charlton who provided some additional hydrological modelling work.

Lan Haong from Exeter University for providing additional modelling work for one case study.

Contents

1 Introduction

1.1 Project aims and objectives

The aim of this project was to explore potential changes in how climate change impacts are incorporated into the water resources planning process in England and Wales. A similar approach is taken in Scotland and Northern Ireland, so many of the methods discussed in this report are equally relevant in these countries.

The proposed changes make use of the UK Climate Change Projections (UKCP09), published in 2009 (Murphy *et al*., 2009) and accommodate the use of outputs from the Future Flows project, published via the CEH website and provide a complementary set of climate and flow scenarios (Prudhomme *et al*., 2012).

As a jointly funded Environment Agency and UKWIR Ltd project it aims to provide approaches based on the latest scientific evidence that are practical and meet the requirements of both the water companies and the regulators.

The original project objectives were as follows:

- critically appraise the way in which climate change is built into current water company water resources plans;
- review the approaches that water companies have taken to climate change in their 2009 plans;
- identify options and make recommendations for changes to methods and approaches to integrate climate change adaptation and mitigation into the water resources planning process;
- consider the benefits of these changes;
- identify options and make recommendations about the extension of water resources plans to consider other aspects of climate change, including changing frequency of storms, floods and heat waves;
- produce technical guidelines for any new methods or options that are adopted (note that the preparation of a detailed planning guideline is not expected from this project).

A process of technical review, stakeholder engagement and discussion with the Project Steering Group refined the objectives to focus on the assessment of Deployable Outputs, Peak Demands and decision-making under climate change uncertainty. Some of the broader issues related to the extension of water resources plans are reviewed in the project conclusions.

1.2 Approach

The Project Steering Group included representatives from the Environment Agency, the Department for Environment, Food and Rural Affairs (Defra), UKWIR, Ofwat and the water industry.

Due to the wide scope of work, a staged approach was adopted that started with a broad review of potential methodological improvements and then developed detailed case studies in specific technical areas.

The project was divided into five stages:

Stage 1: Literature review of existing approaches to climate change in water resource and drought planning in the UK and overseas, including the recent water resource plans submitted for PR09 and research approaches that may not yet be in use.

Stage 2: Recommendations for new methods based on the findings from Stage 1 and a 'sandpit' workshop with participation from the Environment Agency, UKWIR, Defra, Ofwat, water company representatives and the full Project Team.

Stage 3: Development of new approaches and methods for several aspects of the water supply planning process, including cost-benefit analysis and development of prototype tools for trialling methods.

Stage 4: Testing of the proposed new approaches in three different resource zones in England and Wales in a series of workshops with the Project Steering Group, the Project Team, selected water companies and partners to demonstrate the application of the new methods.

Stage 5: Production of draft guidelines for feedback from the Environment Agency.

A series of interim reports and technical notes were produced at each stage of the project. These are not duplicated in this final report (see 'roadmap').

1.3 Purpose of this report

This report provides a synthesis of the research completed on the project, including the main research findings, case studies of the application of UKCP09 and new methods and high-level guidelines.

The Environment Agency's Water Resources Planning Guidelines (Environment Agency 2009, updated 2011) are the key resource for statutory guidance and take precedent over this research report.

A considerable amount of analysis was completed as part of this project and it is not possible to include all these details in a readable final report. The synthesis provided here was aimed at water resources practitioners to highlight potential changes to the WRPGs.

More detailed outputs of stages 1 to 3 were published in internal Environment Agency reports and were circulated within the Project Steering Group[2]. Final results will be submitted as peer reviewed papers for wider publication.

1.4 Roadmap for climate change and water resources planning research and guidance

This research forms part of a larger programme of Environment Agency and UKWIR funded activities aimed at updating water supply planning methods for PR14. Table 1 highlights the main activities relevant to this report and to projects that will be responsible for producing the final WRPG.

[2] Interim outputs may be requested from the Environment Agency or the research contractor.

Table 1.1 Relevant research and planning activities on climate change impacts informing the final WRPG

Theme	This project (interim report or section in this report)	Key projects (past and *on-going*)	Links
Current methods	Section 2 – provides a brief overview only, for full details refer to WRPG. This section provides the background for Sections 3 to 7. Interim Report – HR Wallingford, 2011. Climate change approaches to water resources planning – Technical review.	Water Resources Planning Guideline 2011 *(note that this update has a placeholder for new climate change guidance due 2012*).	http://www.environment-agency.gov.uk/business/sectors/39687.aspx
Vulnerability assessment	Section 3 – describes how to consider existing evidence to select methods that are proportionate to climate risks	Water company Drought Plans, Water Resources Management Plans and Adaptation Reporting Power reports may all contain relevant material to support vulnerability assessment.	Reports available on individual water company web sites and via Defra web site. http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/reporting-authorities-reports/
Climate change projections (UKCP09)	Interim Report – examples of applying UKCP09 are included in Sections 4 to 7.	UK Climate Projections 2009. Note that several updates and additional guidance has been published since 2009 and is available on the UKCP09 web site.	http://ukclimateprojections.defra.gov.uk/
River flows	Section 4 – Case studies.	The hypothetical case study is similar to medium sized water resources zones in several south east company supply areas. Thames Water – WRMP *Future Flows project – a major NERC-UKWIR-EA research project that aims to provide climate change outputs for the water sector.*	http://www.thameswater.co.uk/cps/rde/xchg/SID-5C1DB1AF-FCF9837C/corp/hs.xsl/5373.htm http://ukclimateprojections.defra.gov.uk/content/view/2306/521/
Groundwater levels	Section 4 – One hypothetical case study includes an assessment of climate change on groundwater levels.	Southern Water and South East Water's WRMPs include similar groundwater analysis. *Future Flows project – this includes an assessment of groundwater levels.*	http://www.southernwater.co.uk/
Deployable Outputs	Section 4 – South East and North Wales case study.	Welsh Water – Draft WRMP.	As above http://www.welshwater.com/
Average Demand	Interim Report – not covered in this research as regarded as relatively straightforward.	*CU-02 UKWIR Customer Behaviour and Water Use.*	http://www.ukwir.org/content/default.asp?PageId=65201
Peak Demand	Section 5 – based on UKWIR Peak Demand Methodology case studies with UKCP09.	UKWIR Peak Demand Methodology. *CU-02 UKWIR Customer Behaviour and Water Use.* *CL-04B UKWIR Impact of climate change on demand (Dissemination workshop in April 2012).*	http://www.ukwir.org/reports/06-wr-01-7/91316/90140//90140 http://www.ukwir.org/content/default.asp?PageId=65201
Scaling of impacts	Section 6 – summarises research on scaling flow and DO impacts for 2020s, 2030s and beyond.	Water Resources Planning Guidelines 2011.	http://www.environment-agency.gov.uk/business/sectors/39687.aspx
Headroom	Section 7 – South East case study.	*WR-27 Water resources planning tools.*	http://www.ukwir.org/content/default.asp?PageId=65201
Supply-demand balance	Section 7 – South East case study.	*WR-27 Water resources planning tools.*	http://www.ukwir.org/content/default.asp?PageId=65201
Adaptation options	Section 7– South East case study.	*WR-27 Water resources planning tools.*	http://www.ukwir.org/content/default.asp?PageId=65201
Economics of Balancing Supply and Demand	Section 7– South East case study.	*WR-27 Water resources planning tools.*	http://www.ukwir.org/content/default.asp?PageId=65201

2 Including climate change in water supply planning

The project's interim technical review considered approaches used in the UK and internationally. This chapter provides a brief overview of current approaches.

2.1 The current approach (and how it is implemented in practice)

The Environment Agency's Water Resources Planning Guideline (WRPG) describes how climate change should be accounted for in Water Resources Management Plans in England and Wales (Environment Agency 2009, updated 2011). As shown in Figure 2.1, climate change is typically considered explicitly in the supply and demand forecast, with uncertainty in the projected impacts included as part of the Target Headroom allowance. The WRPG guidance also states that climate change should also be explicitly considered in the options appraisal process used to deliver a schedule of measures to maintain the supply-demand balance over the 25-year planning horizon.

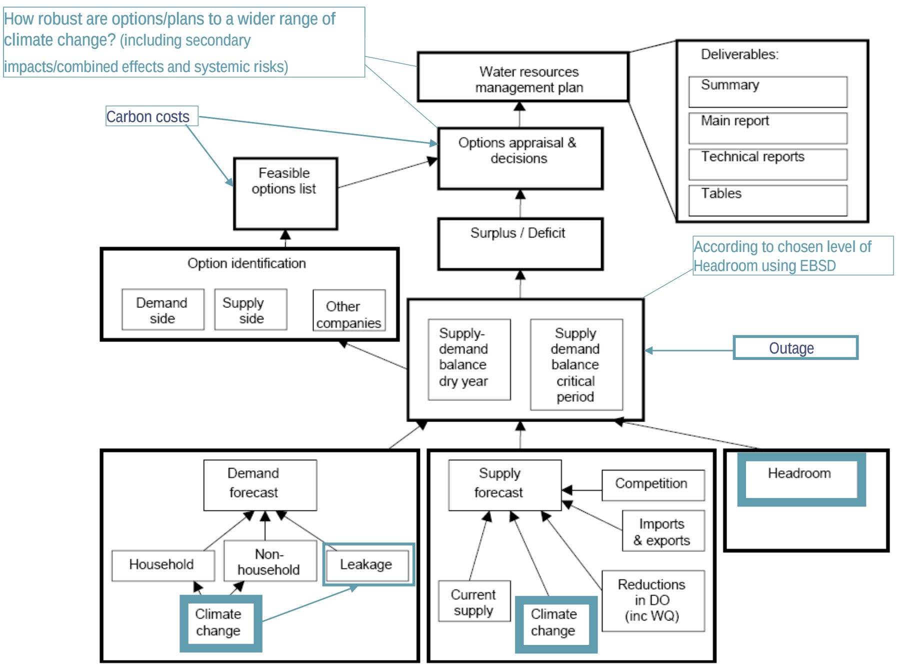


Figure 2.1 Schematic illustrating the current water resource planning process including climate change. (Adapted from the Environment Agency WRPG, 2009 and updated in 2011).

The impacts of climate change on average demand are based on the *Climate Change and Demand for Water – CC:DeW* project, which suggested small increases on household demand of one or two per cent over 25 years (Downing *et al*., 2003. The WRPG recommends that these uplifts are applied directly to Dry Year Average Annual (DYAA) demands. This work is considered to be out of date and some companies have completed their own detailed assessments. An on-going UKWIR project is reviewing methods and will report in 2012. Therefore it is likely that some companies may wish to update their demand forecasts and headroom assessments using these new results.

- For supply, climate change is normally considered by applying factors to historical climate series or river flow records and thereby changing the magnitude and duration of historical hydrological droughts, whilst preserving both the frequency of droughts and their temporal sequences (UKWIR, 2007). In practice, Deployable Outputs have been reported for specific sources and/or at the water resource zone scales, with or without reference to specific water company Levels of Service and based on different lengths of record, which can make it difficult to clearly present risks to water supply. For this and other perceived limitations, some reviewers have called for major changes in water resources planning methods (Hall, 2007).

Headroom is an important concept used in water resources planning to deal with uncertainties in the supply demand balance. The 'new' headroom methodology developed by UKWIR in 2002 considers uncertainties related to both water supplies and demands, including those related to climate change impacts (in bold in the box below). Climate change may also indirectly influence a number of other factors (shown in italics):

Supply Factors *S1-Vulnerable surface water licences* *S2-Vulnerable groundwater licences* *S3-Time limited licences* *S4-Bulk transfers* *S5-Gradual pollution of sources causing a reduction in abstraction* S6-Accuracy of supply side data **S8-Uncertainty of impact of climate change on source yields** S9-*Uncertainty over new sources*	Demand Factors D1-Accuracy of sub-component data D2-Demand forecast variation **D3-Uncertainty of impact of climate change on demand** *D4-Uncertainty of impact of demand management*

The final component that should consider climate change is the identification of options in terms of both carbon costs and their performance under climate change scenarios. Early consideration of climate change can help to identify 'low regret' options that perform well under a range of possible future conditions and ensure that plans are robust. The WRPG suggests that climate impacts on the yield or savings of new schemes should be included in Options Appraisals, and that the uncertainty around best estimates thereof should be included in the final planning scenario estimate of Target Headroom. Doing so may bring forward investment just to cope with the uncertainty of the yield/savings estimates of new schemes, but the approach is internally consistent.

2.2 UKCP09 climate projections

The UK Climate Projections 2009 (UKCP09) are 'probabilistic' in the sense that they reflect a range of changes in climate based on observations, a large number of models and expert judgement (Murphy *et al*., 2009). Their probabilistic nature presents an opportunity for more informed risk assessments but it should also be recognised that changes in climate may occur outside of the range of UKCP09, so complementary strategies, such as sensitivity analysis, may be needed to support some decisions[3].

[3] See updates to the UKCP09 guidance for details http://ukclimateprojections.defra.gov.uk/content/view/922/500/.

The additional information and large amounts of data provided by UKCP09 may also lead to a significant increase in workload for practitioners, which may not be practical or appropriate for all water resources zones, particularly those where the consequences of climate change are negligible or low, or are low compared to the impacts of other drivers such as the Water Framework Directive. UKCP09 could be used to provide background evidence and context for simpler analysis, in cases where practitioners can demonstrate that the risks of climate change are relatively low.

In the previous set of Water Resources Management Plans (WRMPs) in 2009, climate impact assessments made use of six Global Climate Models (Medium Emissions, 2020s) (UKWIR, 2007) or simplified 'mid', 'wet' and 'dry' scenarios, according to Environment Agency guidance (Environment Agency, 2009, updated 2011). UKCP09 presents 10,000 projections for three emission scenarios (Low, Medium, High)[4] for seven, stationary 30-year climates, from 2020s (2010 to 2039) to 2080s (2070 to 2099). UK Climate Impacts Programme (UKCIP) guidance suggests that the projections can be used in a number of ways but generally recommends the application of a large number of UKCP09 'samples'; for example, 100 runs is the minimum suggested for application of the Weather Generator (for each emissions scenario and time period).

In addition to the UKCP09 probabilistic projections, other products are available for water companies to use for water resources planning. These include:

- the UKCP09 Weather Generator
- Met Office Regional Climate Model (RCM) projections (not probabilistic)
- products derived from these RCMs, such as the Spatially Coherent Projections (SCPs)
- projections of precipitation, potential evapotranspiration and flow from the Future Flows project, which are based on bias-corrected RCM data.

Each of these products has benefits and limitations in terms of water resources planning. Identifying the appropriate tool(s) and using them according to updated guidelines is important for the next round of plans. This is discussed in more detail as part of Chapters 4 and 5.

2.2.1 The impact of UKCP09 on river flows

A rapid assessment of UKCP09 and its impacts on monthly river flows was completed in September 2009 (UKWIR, 2009; Vidal *et al*., 2012). For the medium emissions scenario and central estimate (50 per cent probability), this assessment indicated changes to river flows ranging from approximately plus 15 per cent in winter to minus 33 per cent in summer months for the 2020s compared to the 1961-1990 period (Figure 2.2). These results were generalised to the UKCP09 river basin regions (Figure 2.3) based on averaging the results of between four and eight catchments per region and changes may be significantly outside this range for individual river catchments.

The data from this project were provided to the water industry (UKWIR, 2009) to allow their use as part of interim assessments, but it should be noted that the outputs of this 'rapid assessment' may be superseded by results from the Future Flows project which were published in late 2011 as part of the UK Government's Water White Paper and

[4] This is the 'full sample' of climate changes for three emissions scenarios. It is important to note that the direct application of the mapped probabilistic data (e.g. 10^{th}, 50^{th}, 90^{th} exceedence probabilities for monthly rainfall) will lead to misleading results and is contrary to the published guidance. See http://www.ukcip.org.uk/.

supporting research from the Environment Agency[5]. This research indicates the potential for much larger changes in summer (June, July, August) flows by the 2050s, ranging from +20 per cent to -80 per cent. (Prudhomme *et al*., forthcoming).

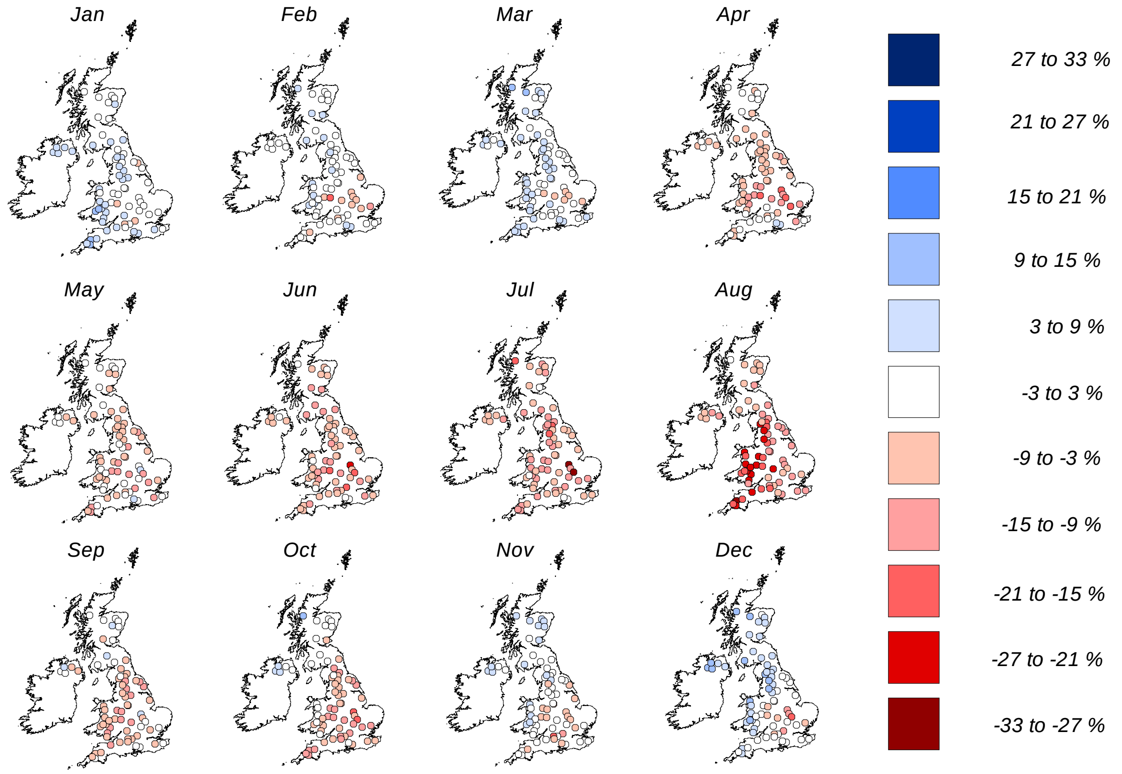
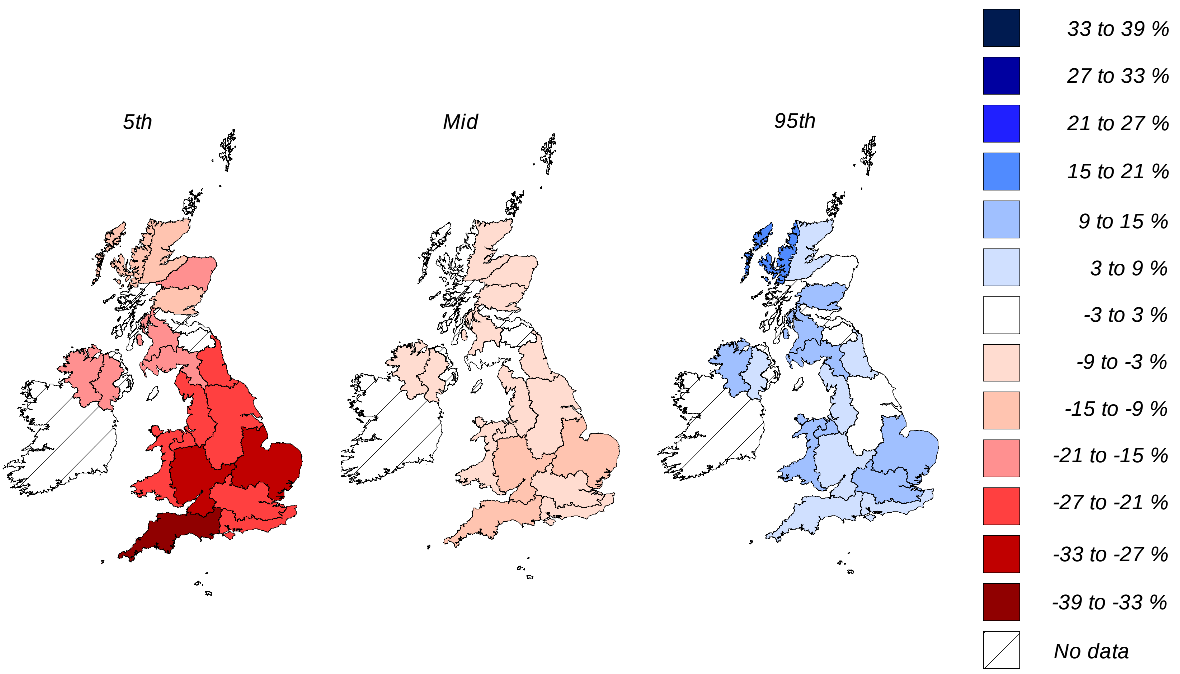


Figure 2.2 Central estimates of changes in flow for 70 modelled catchments for the 2020s medium emissions scenario based on UKCP09.



[5] http://www.environment-agency.gov.uk/research/planning/135501.aspx

Figure 2.3 Change in Q95 for UKCP09 river basin areas for the 2020s medium emissions scenario.

2.3 Potential improvements to dealing with climate change

The water industry regulators have stated that climate change impact assessment methods must be improved, including explicitly making use of UKCP09, in order to justify any new climate change driven investment. Ofwat set out its view in a letter to the water companies in October 2009 that outlined some of the requirements of new approaches (See Box 1).

Box 1. Summary of Ofwat guidance to water companies in England and Wales on climate change impacts assessment

Risk-based approach

- Companies should apply a reasonable, risk-based, analysis consistent with the range of projected outcomes reflected in the application of suitable analytical tools (UKCP09).

Robust analysis

- The application of 'appropriate analytical tools' includes weather generators, maps or other processes or tools developed by the UK Climate Impacts Programme or associated research projects.
- Analysis must go beyond a simple application of the summary headlines from UKCP09.
- Companies should predict supply using bespoke modelling driven by climate models.

Engagement

- Water companies should, as early as possible, discuss their approach with the regulators.
- Companies should continue to follow the Environment Agency's water resource management plan guidance, as amended from time to time, on climate change for assessing demand and greenhouse gas emissions.

Based on this regulatory guidance and our project workshops, five principles have been used to guide the design of new approaches for climate change impact assessment for water supply planning:

Proportionality. Any climate change modelling should be proportionate to the risks presented by climate change for each specific water resources zone.

Transparency. All climate change, hydrology and water resources modelling needs to be clear and transparent, plainly demonstrating the impacts of climate change on the supply-demand balance and distinguishing the climate change related components of Target Headroom.

Risk-based. The supply-demand balance, including the consideration of climate change, should move towards a 'risk-based' approach such that the likelihood and magnitude of different outcomes are evaluated and used to inform the decision-making process.

Robustness. The performance of the water resources system should be evaluated across a range of possible climate futures.

Participatory. Water companies should work closely with the Environment Agency and Ofwat to develop and agree the approach to be adopted for the climate change risk assessment in advance. Regulators need to work with each other and water companies to support the implementation of UKCP09 methods without disproportionately increasing the regulatory burden on companies.

2.3.1 The proposed framework

This proposed framework is presented in Figure 2.4 and includes two additional tasks (the second of which is advised as good practice in the current WPRG but has not always been implemented) and minor modifications to existing tasks (refer to Figure 2.4). In this way, the revised approach may be considered a refinement of the existing methodology that also indicates the anticipated direction that future changes to the process may take in the longer term.

- The first additional task is a **vulnerability assessment** (Chapter 3), which provides the background information to justify decisions on climate change impact assessment methods. A key principle is proportionality, and where climate risks (as a function of likelihood and magnitude) are low, water companies may adopt a simple approach based on existing methods and tools, such as making use of the outputs from the UKCP09 rapid assessment (UKWIR, 2009). Where risks are medium or high, further work is recommended that makes use of sub-sets of UKCP09, the Future Flows data set and/or the UKCP09 weather generator (Chapter 4).
- The second change is to formally require (currently advised as good practice) a **sensitivity analysis of climate change on options** (Chapter 7) considered as part of the options appraisal process, with the level of detail proportionate to the level of investment associated with each option.
- A third minor modification is also proposed to **the reporting and presentation of Headroom** (Chapter 7): that the climate change related components are distinguished from other components to clearly highlight the influence of climate change to the overall level of uncertainty.
- Finally, it is recommended that an **internally consistent and agreed approach** is developed (and adhered to and carried through) between water companies and regulators during the inception stages of any assessment. This requires decisions as to what is/are the most appropriate products from UKCP09 and Future Flows for water resources planning purposes (Chapters 4 and 5).

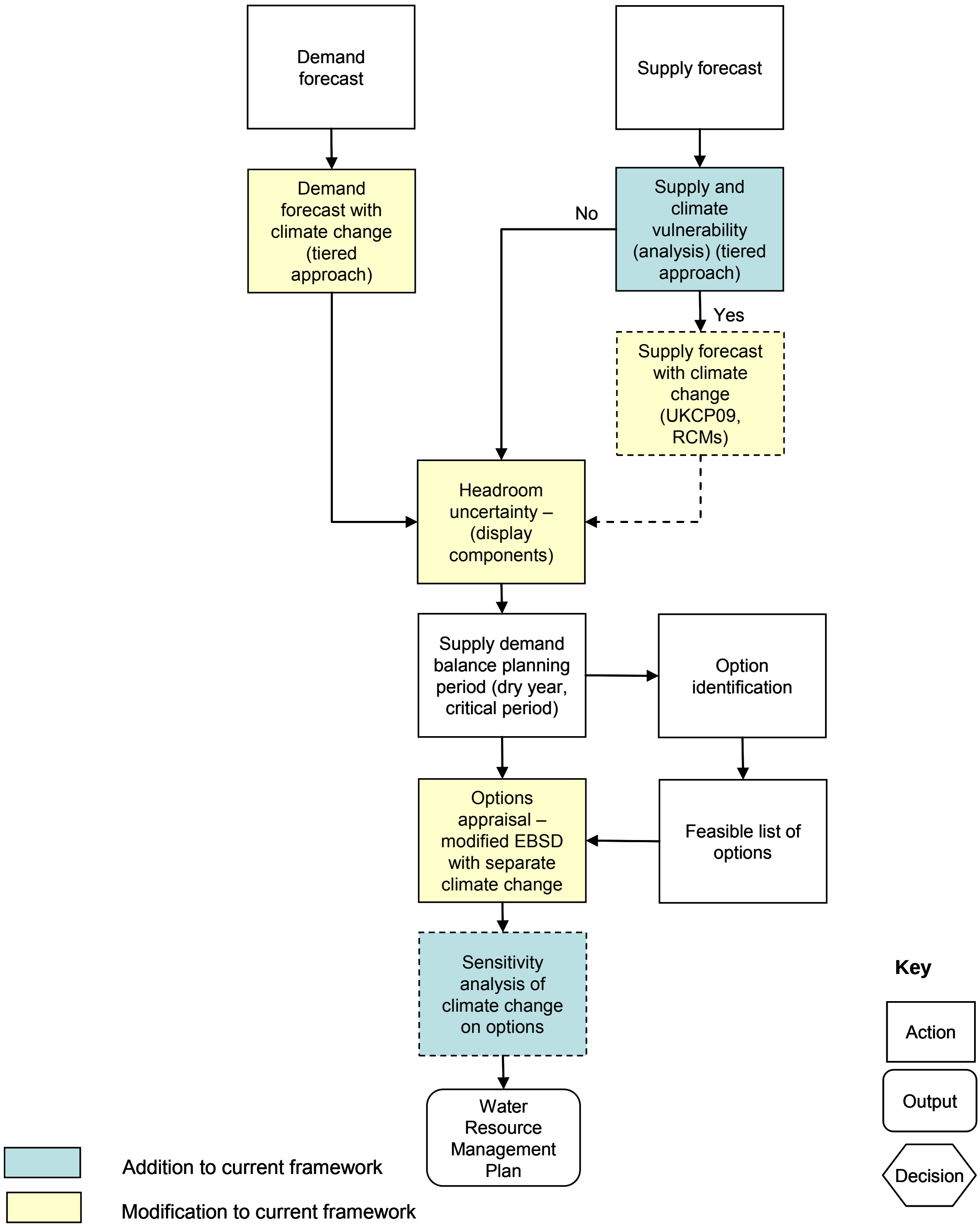


Figure 2.4 Illustration of proposed modifications to current framework.

3 Vulnerability Assessment

3.1 Introduction

Water companies and the Environment Agency already consider the sensitivity and vulnerability of water resource zones as part of the water resources planning, drought planning and June Return processes. In addition, following the Climate Change Act (2008), water companies submitted Adaptation Reporting Power (ARP) reports to Defra that included high-level assessment of risks related to climate change. This project proposes that the same information or similar analyses can be used to explicitly justify the level of detail adopted for climate change impacts assessment.

- **Definition**
- **Vulnerability** - Climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity.
- **Sensitivity** - The degree to which a system is affected, either adversely or beneficially, by climate variability or change.
- In the context of water resources planning, planners make use of supply-demand forecasts, hydrological, hydrogeological and behavioural models to understand the vulnerability of systems. Systems are particularly vulnerable if existing drought management measures (demand management, emergency storage, alternative sources and so on) would be insufficient to deal with historic droughts (including 19th century) and plausible future drought scenarios.

A tiered approach to vulnerability assessment was developed in Stage 3 of this project (Figure 3.1) and the proposed methodology was tested for the four pilot study zones selected for this study: A hypothetical case study with reservoir, run of river and groundwater sources (South East England), Colliford (South West Water), London (Thames Water) and North Eryri Ynys Mon (NEYM - Welsh Water). The aim was to test the tiered approach and identify particular strengths and weaknesses of the methodology. The outcomes from the pilot study were used to refine the method, particularly identifying the data sources and steps necessary for undertaking an assessment.

The proposed approaches help to justify methods used for climate impacts assessment and can also help to communicate the results of modelling in a simple way to stakeholders. The basic 'Level 1' approach does not involve a significant workload. Intermediate 'Level 2' methods require some additional analytical work but both should be cost beneficial in terms of reaching an agreed approach with regulators and ensuring that plans are robust to a range of climate conditions. We found that the most complex 'Level 3' vulnerability and sensitivity analysis approaches ((HR Wallingford, 2011) were **not** practical for water companies at this stage, although these provide an area for further research.

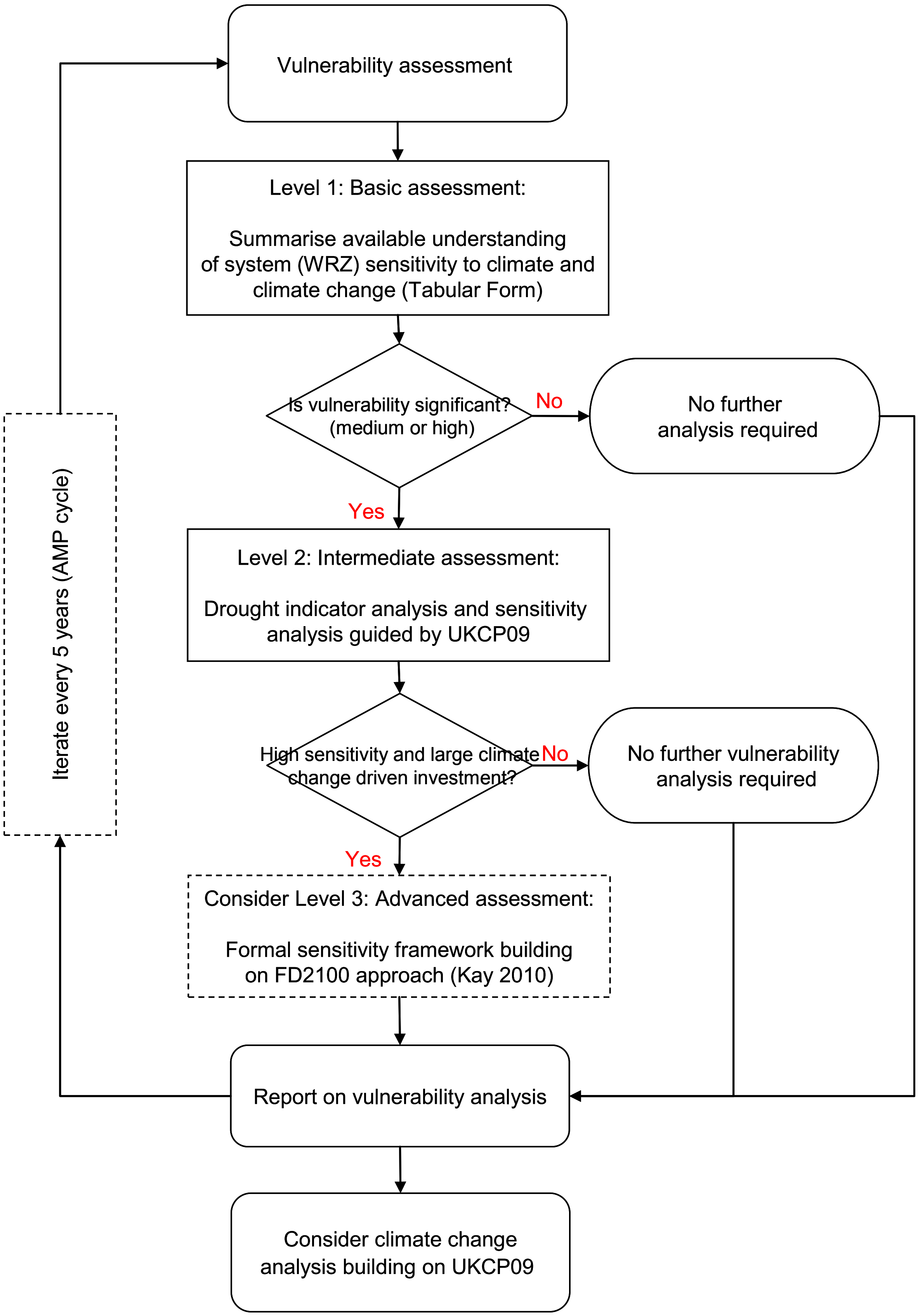


Figure 3.1 Schematic illustrating the vulnerability assessment approach developed in the initial stages of the project.

3.2 Basic approach (Level 1)

The basic vulnerability assessment is envisaged to be largely qualitative, based on current knowledge of system vulnerabilities already available from the preparation of drought and water resource management plans and previous climate change analysis. The main aim of the Level 1 assessment is to provide an overview of the vulnerabilities in a consistent manner that can feed into subsequent detailed climate change impact assessments. It would include a simple tabular summary and supporting evidence that can be used to judge vulnerability as 'high', 'medium' or 'low', and therefore justify the level of detail of climate change impacts assessment.

As a minimum, the assessment would include the information listed in Table 3.1. However, further information of relevance to a particular system could also be included. It was considered important that this step is not too prescriptive but provides an opportunity to present all information pertaining to vulnerability in one place using indicators that individual companies feel are pertinent to their zones. It should aim to provide a summary and links to other information rather than creating a very detailed report that repeats information in other plans.

The assessment may be based on previous climate change impact assessment results. One approach is to use the concept of a magnitude versus sensitivity plot, which is a common approach in Environment Impact Assessment. To illustrate this, Figure 3.2 shows the Deployable Output (DO) change, as an **example** indicator, for a 'mid' climate change scenario plotted against the uncertainty range calculated as the difference between the 'wet' and 'dry' scenarios for 88 water resource zones across England and Wales[6]. The data were derived from draft and final company plans.

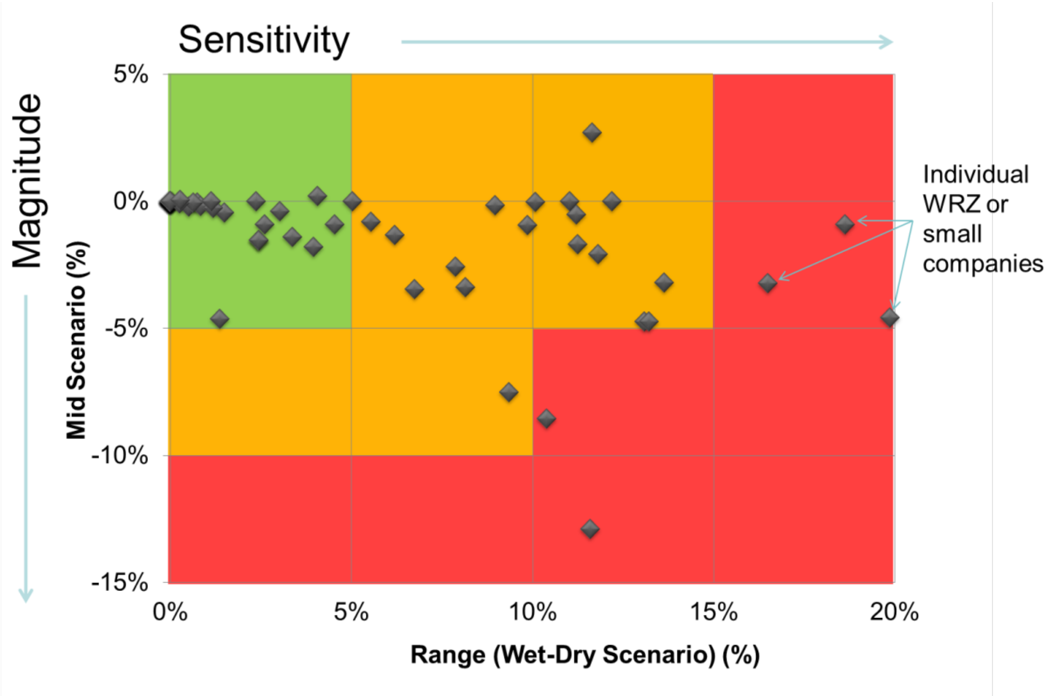


Figure 3.2 Climate change mid scenario versus uncertainty range (DO change %) for WRZs in England and Wales based on WRMPs from 2009 (Note: the numbers are based on best available data extracted from WRMPs and are for a Medium Emissions scenario).

[6] As such the plot is indicating vulnerability to climate change (annual to decadal scales) rather than vulnerability year to year.

Table 3.1 Information required for basic vulnerability assessment per Water Resource Zone (WRZ).

Description	Source	Comments	Presentation
Critical drought years (top three)	DMP/WRMP	Need to state if different for surface water and groundwater.	List in a table.
Period used for analysis	DMP/WRMP	As above. This is important to help understand the return periods of droughts considered. In addition, it is essential to clearly state assumptions related to Levels of Service, assumed demand profiles and other factors influencing DO assessment.	As above.
Sources	WRMP	Sources of water and key characteristics (surface water, groundwater, transfers etc.). Record of whether sources are constrained by hydrology/hydrogeology, licence or works constraints. What sources may become hydrologically constrained due to climate change? What is the threshold (e.g. per cent change in summer flows) when sources may be affected?	Tables or a map .
Supply-demand balance (base year)	WRMP	With a clear description of design conditions and any key assumptions.	Tables or a map.
Water supply or water scarcity indicators	June Return or Adaptation Reporting Power Reports	For example, Security of Supply or volume of licenses at risk.	Tables or a map.
Critical climate variables (e.g. summer rain, winter recharge)	Drought Plan	Need to state if different for surface water and groundwater and comment on importance/split.	As above. Illustrative graphs showing climate and critical flows/ groundwater levels at key locations.
Climate change DOs (Dry, Mid, Wet scenarios)	WRMP (2009)	Readily available from previous water resources plan.	List in table. Present graphically e.g. Mid versus difference between Dry and Wet
Adaptive capacity (List of available sources and drought measures)	Drought Plan	Comment on sources and potential for long term usage including performance during dry periods. If there are very limited options during droughts, this may provide the rationale for increasing the vulnerability rating.	List available drought measures in table. Comment on performance of measures/plan in any recent droughts.
Sensitivity (low/medium/high)		Based on information above.	List in table.
Action needed		Indicate time scales for action for example PR14, PR19.	List in table.

Figure 3.2 immediately shows that climate impacts for the 2020s Medium Emission scenario are of the order ‘no change’ to minus five per cent, for the majority of zones considered. However the range of changes in DO, from the ‘wet’ to the ‘dry’ scenario, is

generally larger than the magnitude of the 'mid' scenario, illustrating sensitivity to different future conditions (and potentially different modelling approaches). In this example, the per cent changes used to define criteria for vulnerability classification based on this relationship are suggested in Table 3.2. Using these criteria, 47 WRZs would be classed as 'low', 9 as 'medium' and 32 as 'high' vulnerability, indicating that a basic assessment may be sufficient for at least half the zones in England and Wales.

Individual companies may wish to consider changes in DO in terms of Ml/d, the overall supply-demand balance or investment costs (Chapter 7) in a similar way, but the basic premise of above plot remains the same. Table 3.2 provides an example of this approach based on a DO indicator, which is very straightforward to complete, but companies may wish to use different indicators and define their own thresholds in consultation with the relevant regulators.

Table 3.2 Vulnerability scoring matrix.

Uncertainty range[1] (Wet-Dry % change)	Mid scenario (DO – % change)		
	>-5 %	>-10%	>-15
<5%	Low	Medium	High
<10%	Medium	Medium	High
<15%	Medium	High	High
>15%	High	High	High

1) The uncertainty range will depend on the approach taken to assessing the wet and dry scenarios (see water resources guidelines for details).

This basic analysis was completed for the four case study zones and indicated that further analysis would be required for all four. However, Colliford was shown to be much less sensitive to climate change than London and NEYM. The results for the South East hypothetical zone indicated limited sensitivity to climate change but there was still sufficient uncertainty, and a lack of capacity in the system to deal with severe droughts, to warrant an intermediate analysis.

For the pilot study, two zones – London RZ and 'South East' RZ – have been taken forward for an intermediate analysis. The outcome of the analysis is summarised in Figure 3.7.

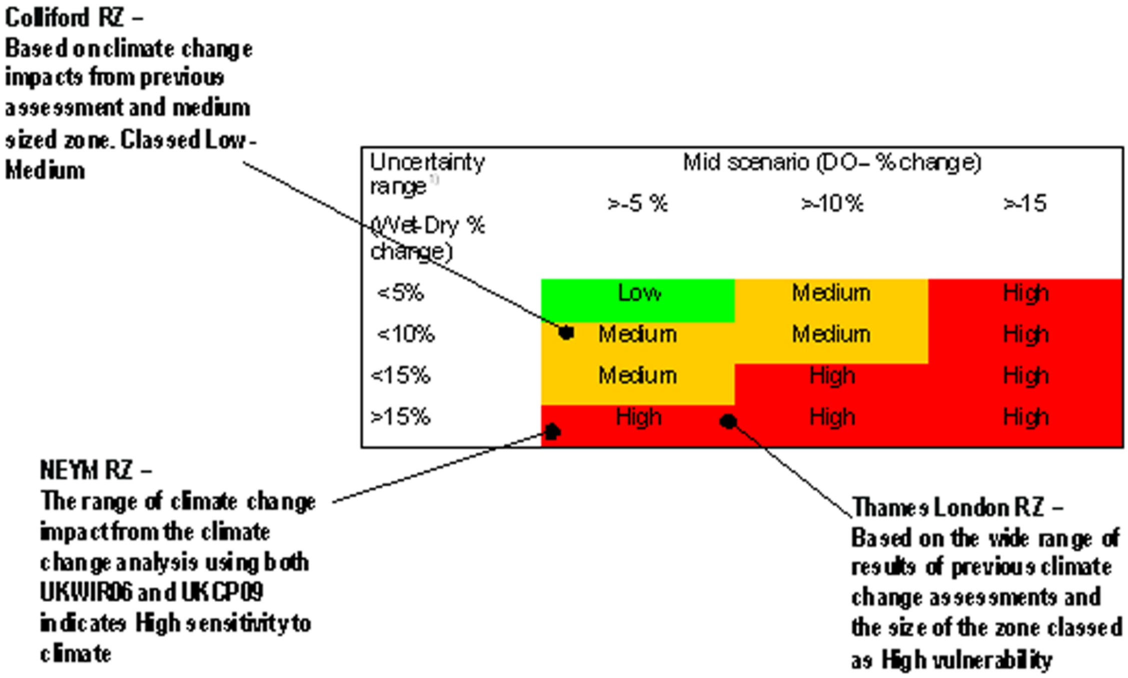


Figure 3.3 Basic assessment using vulnerability scoring matrix.

Table 3.3 Example of summary of information for basic vulnerability analysis for the NEYM, Welsh Water.

Description	Source	Data	Comment
Critical drought years (top three)	DMP/WRMP	1959,1984 and 1996/97.	Cwellyn drawdown is critical in 1959 and 1984 and defines DO, Alaw drawdown is more extreme in 1996/97.
Types of sources	WRMP	Four upland reservoirs with small steep catchments on mainland, two lowland reservoirs on Anglesey (Ynys Môn).	The performance of Llyn Cwellyn (mainland) is the main driver for DO in this zone – DCWW abstract from an artificially elevated top-slice of this natural lake.
Period used for analysis	DMP/WRMP	1958-2010.	
Supply-demand balance (base year)	WRMP	For DYAA, baseline DO (dWRMP) is 52.8 Ml/d. 4.5 Ml/d surplus in base year under DYAA (approx). 4.0 Ml/d surplus in base year under DYCP (approx).	Both planning scenarios are in surplus until approximately 2017/18. From that point onwards the deficit increases under the Annual Average scenario to a maximum of 1.63 Ml/d in 2024/35 and under the Critical Period scenario to a maximum of 3.19 Ml/d in 2029/30.
Critical climate variables (e.g. summer rain, winter recharge)	Drought Plan	Prolonged lack of spring or summer rainfall.	Results in drawdown of Llyn Cwellyn to levels at which DCWW can only abstract 10 Ml/d.
Climate change DOs (Dry, Mid, Wet scenarios)	WRMP	For DYAA, baseline DO (dWRMP) is 52.8 Ml/d. Under UKWIR06: Dry = 37.4 Ml/d (-29%) Mid = 54.2 Ml/d (+3%) Wet = 54.2 Ml/d (+3%) Under UKCP09: Min = 33.4 Ml/d (-37%) Max = 54.2 Ml/d (+3%)	See Entec report 25373 N177i4 for full details including DYCP, effects of with/without LoS constraints and the constraint on DO. Large range of results.
Adaptive capacity (List of available sources and drought measures)	Drought Plan	Variation to 10 Ml/d licence constraint?	
Sensitivity (low/medium/high)		High	The range of climate change impact from the climate change analysis using both UKWIR06 and UKCP09 indicates high sensitivity to climate.
Action needed		More detailed hydrological modelling of Cwellyn.	

3.3 Intermediate approaches (Level 2)

The intermediate approach would typically be undertaken for zones classed as being of medium or high vulnerability in the basic assessment. As part of this research project, an intermediate analysis has been carried out for London RZ and the South East RZ.

The research found that these approaches worked far better for London, a large zone with significant storage, than the South East zone, a smaller zone with less storage and license conditions that made sensitivity to climate more difficult to generalise. This section provides an overview of the London results.

There are three steps to the analysis:

- Step 1 – Demonstrate the link between the current water resources system and climate variability, which can be based on a simplified relationship between climate indicators and water availability (e.g. reservoir stocks, groundwater levels).
- Step 2 – Consider the ranges of change in the latest climate scenarios or projections.
- Step 3 - Complete a simple sensitivity analysis to indicate possible ranges of future changes based on a simplified relationship defined in Step 1.

The outcomes of the analysis include some evidence on the sensitivity of the system and a view as to which UKCP09 or Future Flows variables are the most important. This information can then be used to define the climate impacts modelling strategy based on a practical number of UKCP09 or plausible scenarios using Future Flows.

The reason for defining a simplified relationship between climate and water availability is to ensure that the vulnerability assessment is a simple piece of work rather than becoming a full impact assessment involving hydrological and water resources system modelling. However, companies with advanced modelling tools may wish to make use of a more detailed modelling approach.

The generic process is as follows:

1. Step1 – Showing the links between water resources and climate
    a. Choose suitable indicators of water availability
    b. Explore the links between these indicators and monthly, seasonal or annual climate and ideally river flows and recharge data using hydrographs and statistical analysis;
    c. Derive an equation using multiple linear regression or other techniques that estimate water availability as a function of monthly climate information;
    d. Clearly summarise the relationship, its predictive power and the key climate variables affecting water availability.
2. Step 2 – Reviewing the latest climate projections
    a. Refer to UKCP09 sampled data and/or other climate change information, for example future flows;
    b. Use the outputs of 1d the final point of Step 1 to set up a simple matrix of the most important climate variable versus the second most important variable (or a generalised version of this if there are a large number of relevant variables);

c. Analyse the UKCP09 data to show the likelihood of future climates in the 2030s for each of the matrix cells. Add other evidence, if available, for example recent trends or where the outputs of Future Flows sit in this matrix.

3. Step 3 – Combining Step 1 and Step 2 in a simple sensitivity analysis

    a. If Steps 2 and 3 have been successful, the UKCP09 data could be used to perturb historic climate data and provide an approximate sensitivity matrix showing the effect of changes in two climate variables on water availability;

    b. Reflect on whether any of the results present significant consequences for the water company, consider the risks and use this knowledge to inform impact assessment (Section 4).

For hydrogeological assessment, Steps 1b and 1c are similar to the 'GR1' groundwater modelling method that was promoted in the previous UKWIR CL04 reports, published in 2006 and 2007 and used for the last set of plans. Existing groundwater regression equations may be appropriate for completing an intermediate vulnerability assessment.

3.3.1 An example of the vulnerability of London's system to climate variability

A detailed drought indicator analysis was completed for London (HR Wallingford, 2010). The analysis indicated that the best and most practical indicators of reservoir level drawdown (or water resources availability) were (i) relative aridity using 12 monthly rainfall and temperature and (ii) four month rolling flow averages (four-month flow deficiencies, the threshold methods and the Sequent Peak Algorithm (SPA) all produced similar results).

The relative Aridity Index was developed by Cole and Marsh (2006):

$$\text{Aridity Index (AI)} = -\frac{\text{Rainfall - Mean rainfall}}{\text{SD}_{\text{rainfall}}} + 0.5\left[\frac{\text{Temperature - Mean temperature}}{\text{SD}_{\text{temperature}}}\right]$$

For London RZ the strongest relationship between reservoir storage and aridity was found with a weighting of 0.3 rather than 0.5, indicating the greater relative importance of rainfall over temperature in the response of the Thames system to drought. In years with a high aridity index reservoir stocks were low, and in years with a low index reservoirs remained full. The use of this indicator was able to predict reservoir storage in any individual year with coefficient of variation (R^2) of ca. 65% but more importantly predict reservoir drawdown in the most significant drought years. Therefore a simple regression relation was developed between annual DO and the aridity indicator. Further detail of the drought indicator analysis is provided in a separate Thames Water report (Christierson, 2010).

3.3.2 Consider the range of changes in the latest climate change projections or scenarios

Understanding that system output is sensitive to annual rainfall and temperature is very useful for dealing with the complex UKCP09 projections as they can then be transformed to a simpler set of scenarios with different amounts of annual warming and temperature change as shown in Table 3.6. This shows the UKCP09 probabilities for future climate being in specific broad classes, for example according to UKCP09 there is an approximately 22% chance that it gets a degree warmer and a little drier and a similar chance that it is a little wetter (column 2, rows 2 and 3). This also shows that that there is a small chance of the climate being much hotter (3%) and reasonable chance it could be wetter (10% chance for a greater than 5% increase in annual rainfall). Most of the sample is contained in the pink shaded area. Some other scenarios of interest are highlighted in the tan shade. It should also be noted that for a proportion of the scenarios there are increases in rainfall.

At this point, the analysis may make use of probabilistic data to support a risk based approach (as promoted by Ofwat, Section 2). This form of presentation provides a way of simplifying UKCP09 and could also be updated as and when new climate change scenarios or projections become available.

Table 3.6 Annual temperature and rainfall change 2020s A1B Thames River Basin (% of 10,000 UKCP09 samples).

	Values in cells are proportions of UKCP09 sample	Temperature				
		Little change (< 0.5 ^{O}C)	Warmer (0.5 -1.5 ^{O}C)	Hotter (1.5 -2.5 ^{O}C)	Much Hotter (> 2.5 ^{O}C)	Sub-total
Rainfall	Drier (< -5%)	0.2	3.4	2.9	0.2	6.7
	Little drier (-5 -0 %)	1.1	**21.8**	17.4	1.3	41.6
	Little wetter (0 – 5 %)	1.3	**21.7**	17.9	1.3	42.1
	Wetter (> 5%)	0.4	5.0	4.0	0.4	**9.7**
	Sub-total	2.9	51.8	42.2	**3.1**	100.0

3.3.3 Complete a simple sensitivity analysis

Using the mid-points from this table, e.g. zero, one, two….. or using the full UKCP09 data set, the simple regression defined in Step 1 can be used to estimate Deployable Outputs. These results are shown in Table 3.7 and show possible changes in DO from approximately +10 % for the wettest scenario to -22% for the driest. The most likely impacts are in those cells shaded pink, which contain 79% of the UKCP09 medium emissions scenario data set. If these are considered the impacts are likely to fall between -1% to -12 % of DO. Cells in the tan shade correspond with those in Table 3.6. Consideration should also be given to the scenarios where there is an increase in rainfall.

If the cell values in Table 3.6 are multiplied by the cell values in Table 3.7 and then summed, this provides an approximate probability weighted mean 'water availability' loss of 6%, just above the 5% DO impact reported in the company's last plan based on UKWIR06 scenarios.

Table 3.7 Simplified estimate of Deployable Output for the 2020s A1B Thames River Basin.

Values in cells are %	Temperature			
	Little change	Warmer (0.5 -1.5	Hotter (1.5 -2.5	Much Hotter

	change in DO	(< 0.5 ^{O}C)	^{O}C)	^{O}C)	(> 2.5 ^{O}C)
Rainfall	Drier (< -5%)	-0.6	-7.8	-15.0	-22.2
	Little drier (-5 -0 %)	2.8	-4.4	-11.6	-18.8
	Little wetter (0 – 5 %)	6.2	-1.0	-8.2	-15.4
	Wetter (> 5%)	9.6	2.3	-4.9	-12.1

More importantly this simple calculation shows that:

- the consequences may be positive or negative;
- the largest negative numbers present significant consequences that are not accommodated in existing plans (through the combination of impacts on DO and DO uncertainty in Target Headroom);
- the zone requires a more detailed assessment because the range of potential impacts is very large, from around +10% to minus 20%, confirming the findings of Figure 3.3 and the analysis completed by the water company in their water resources plan in 2009.

3.4 Recommendations

- The basic vulnerability analysis (level 1) provides a rough indication, based on existing evidence, of likely sensitivity to climate change, critical parameters and the need for further analysis.
- The value of the intermediate sensitivity analysis (level 2) is that it can provide an initial view of the possible spread of results from a UKCP09 analysis or assessment using different climate scenarios or projections. Identification of the key variables in a simple table may make communication of risks simpler for managers and stakeholders.
- However, its value may be limited in cases where drought indicators cannot be used for estimating future DO. For certain types of catchments with several different types of sources (for example, run-of-river combined with small reservoirs) it may be more difficult[7] or not be possible to define a suitable drought indicator to use for classifying the UKCP09 dataset.
- In some cases it may be more time and resource efficient to undertake a simple climate change analysis straight away and skip the intermediate vulnerability/sensitivity analysis.

[7] Outside of this project, the project team has applied the method to several more complex zones with more groundwater resources and others with flashy upland reservoirs. While it was possible to develop good relationships these were more complex and difficult to develop than indicated in the Thames case study. This raises some issues with respect to whether companies have the capacity (time, resources, statistical expertise and so on) to complete intermediate assessments.

4 Assessing the impacts of climate change on Deployable Output

4.1 The current approach

A summary of the methodology for incorporating climate change effects into estimates of Deployable Output (DO) and target headroom (TH) for WRMP09 and PR09 was set out in the April 2007 version of the Environment Agency's Water Resources Planning Guideline (WRPG). Supplementary Guidance on climate change to that edition was issued in January 2008. A consolidated version of the WRPG including the revised guidance for climate change was issued in November 2008.[8]

The approach to incorporating climate change into DO assessments essentially involves:

i. estimation of the effect of the central, or 'mid' projection of a 'core' climate scenario on the Deployable Output of a given resource zone (RZ) by the 2020s[9];

ii. estimation of the effects on DO of 'dry' and 'wet' climate projections, to represent the range of potential impacts on DO around the 'mid' impact estimate;

iii. interpolation of the estimated impacts on DO between the current year (2007 in the latest plans) and 2025, and extrapolation to 2035;

iv. incorporation of the 'mid' estimate into the baseline DO forecast, and the 'dry' and 'wet' estimates into component S8 (uncertainty in source yields) of target headroom[10].

The method was developed to be practical and feasible for all water companies to undertake without the need for complex modelling. The methodology was constrained by the following three considerations:

1) most companies do not have catchment or aquifer models for most of their resource zones;

2) most companies do not have the time or resources to run a large number of scenarios;

and 3) methods need to be based on existing water resources planning tools such as the Environment Agency planning spreadsheets, the climate change spreadsheets produced by HR Wallingford for UKWIR (UKWIR, 2009) and the headroom and outage calculation tools provided as UKWIR project outputs.

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[8] A subsequent edition distinguishing the general protocols for adoption in Wales compared to England was published in 2011. This made no changes in respect of DO estimation.
[9] The appropriate period for plans in 2014 will be the 2030s rather than 2020s .
[10] In practice, whilst most companies appear to have included the best estimate of climate change on DO directly into their baseline DO estimate, and the variation around that best estimate into target headroom, some companies included all impacts into headroom, and not into baseline DO estimates.

There are a number of issues with the methodology as presented in the WRPG, and with its application in practice. The most significant issues identified during this project were:

- The overall approach of the WRPG is to produce ‘best’ estimates of future baseline Deployable Output, demand and the supply-demand balance, and to develop a strategy to deliver an acceptable final planning balance given changes in supply and demand. The methodology tends to produce a single realisation of the effects of climate change on the supply-demand balance. It does not, by contrast, encourage the adoption of a scenario-based approach to evaluating level of service performance across a number of feasible scenarios, and combining the uncertainties from different origins in a risk-based manner.
- In practice, most companies apply a flow factor approach to construct time series of flows and recharge purporting to represent a changed climate. Only a few use climate scenarios to drive hydrological or recharge models so as to generate river flow and groundwater resource futures that represent the full potential range of future variability, rather than just changes in the mean condition (at monthly resolution). The problem with flow factors is that they are not appropriate when climate change alters the timing of flows. Furthermore, the use of flow factors may underestimate the effect of climate change on year-to-year variability, and can hide regional variability in hydrological regimes. In the original UKWIR work on climate change impact assessment, the use of flow factors was regarded as a short-term response to the lack of catchment hydrological or recharge models (UKWIR, 1997). More than a decade later, though, flow factors are still the most widely used approach for considering the impact of climate change on DO.
- The hitherto recommended climate change assessment methodology is based on the use of three climate scenarios – ‘mid’, ‘wet’ and ‘dry’. These scenarios were ultimately based on six different global circulation climate models (GCMs). Mid, wet and dry flow factors are defined from the mean, the 95th percentile (95%) and the 5th percentile (5%), respectively, of estimated probability distributions for change in flows in each month of the year. These ‘mid’, ‘wet’ and ‘dry’ scenarios can thus be seen as synthetic scenarios, and are not the result of any one climate model – indeed, it is not self-evident that the changes embedded in the wet and dry scenarios are physically consistent (a scenario with reductions in rainfall throughout the year, for example, may not be physically realistic). Moreover, it is problematic to assign a likelihood range to the difference between ‘wet’ and ‘dry’ scenarios. In some cases, the ‘wet’ and ‘dry’ scenarios produce changes outside the range of any of the individual climate model scenarios.
- On a practical level, in PR09 there was some confusion amongst companies over whether to include the climate change effect in the planning spreadsheets directly in the estimated Deployable Output forecast, or as a separate line item. Although the end result on water available for use and the supply-demand balance at the bottom of the spreadsheet is the same, this confusion made it difficult to assess the aggregate impact, across all companies, of the effect of climate change.
- Some companies chose to include central and range estimates of the impact of climate change on DO into baseline Target Headroom alone, and not into baseline DO (as explicitly recommended in the WRPG). This made inter-company comparisons difficult (of baseline DO, of the impact of

climate change on the supply-demand balance and on investment needs, and of the uncertainties due to different factors).

- The WRPG allowed companies to use either the ‘old’ or ‘new’ UKWIR headroom methodology, and the climate change guidelines provided guidance on both. Most companies used the new methodology, but three companies used the old approach for the last WRMP. The headroom point scoring system for climate change under the old methodology assumes that there are four climate scenarios, but under the PR09 climate change methodology there are only three scenarios. This is a minor inconsistency. Moreover most water companies do not provide data for the individual components of TH, which makes an assessment of the uncertainties associated with the overall supply-demand balance and climate change difficult. The method allows specification of the individual components but in practice this is rarely done.

4.2 Situation-Reflective Practice for the Future

The approach to assessing climate change impacts on resources prior to and at WRMP09/ PR09 can be regarded as a compromise between best practice in climate change impact assessments and the requirement for a quick and easily applicable method. The methodologies used to date have been constrained by the water resources assessment context. Such pragmatism is always likely to be needed, commensurate with the incremental value likely to be obtained from more detailed analysis. Future climate change projections are highly uncertain and therefore assessments will indicate wide ranging uncertainty in future supply, demand, the supply-demand balance, levels of service and investment plans. The challenge, as ‘futures data’ become more comprehensive and more complex to apply, is to define the minimum essential analyses that needs to be applied in all situations, and the ‘extra-over’ analyses whose use is warranted in situations where potential climate change threatens the supply-demand balance.

Vulnerability assessment and tiered analysis proportionate to the risk faced is the cornerstone of recommended practice for the future, here in regard to DO, as elsewhere.

The challenge of this project has been to develop a reliable (improved) method for DO assessment making use of the comprehensive suite of UKCP09 and Future Flows datasets, whilst keeping modelling requirements at a reasonable level. The underpinning philosophy has been to develop a flexible framework with different levels of analysis proportionate to the risk faced by individual water companies.

Figure 4.1 illustrates the overall framework of risk-related analysis proposed, based on assessment of a given RZ’s vulnerability to the effects of possible climate futures. Eight different methods are shown from left to right. Each method has three boxes associated with it, the first is concerned with selecting climate scenarios, the second with hydrological or hydrogeological modelling and the final box with water resources systems modelling.

Four ‘Level 1’ options and four ‘Level 2’ options are given. The first two options (1, 2) in each category (Level 1, Level 2) use UKCP09 data, while the second two options (3, 4) in each category use Future Flows data. It will be noted that the use of flow factors is restricted to the Level 1 set (and to three of the four options in that category) and as such we are indicating that rainfall-runoff modelling is the recommended approach for medium and high vulnerability water resources zones.

The following sections describe the available options and provides some outline guidance on the costs, benefits and suitability of each option for different situations.

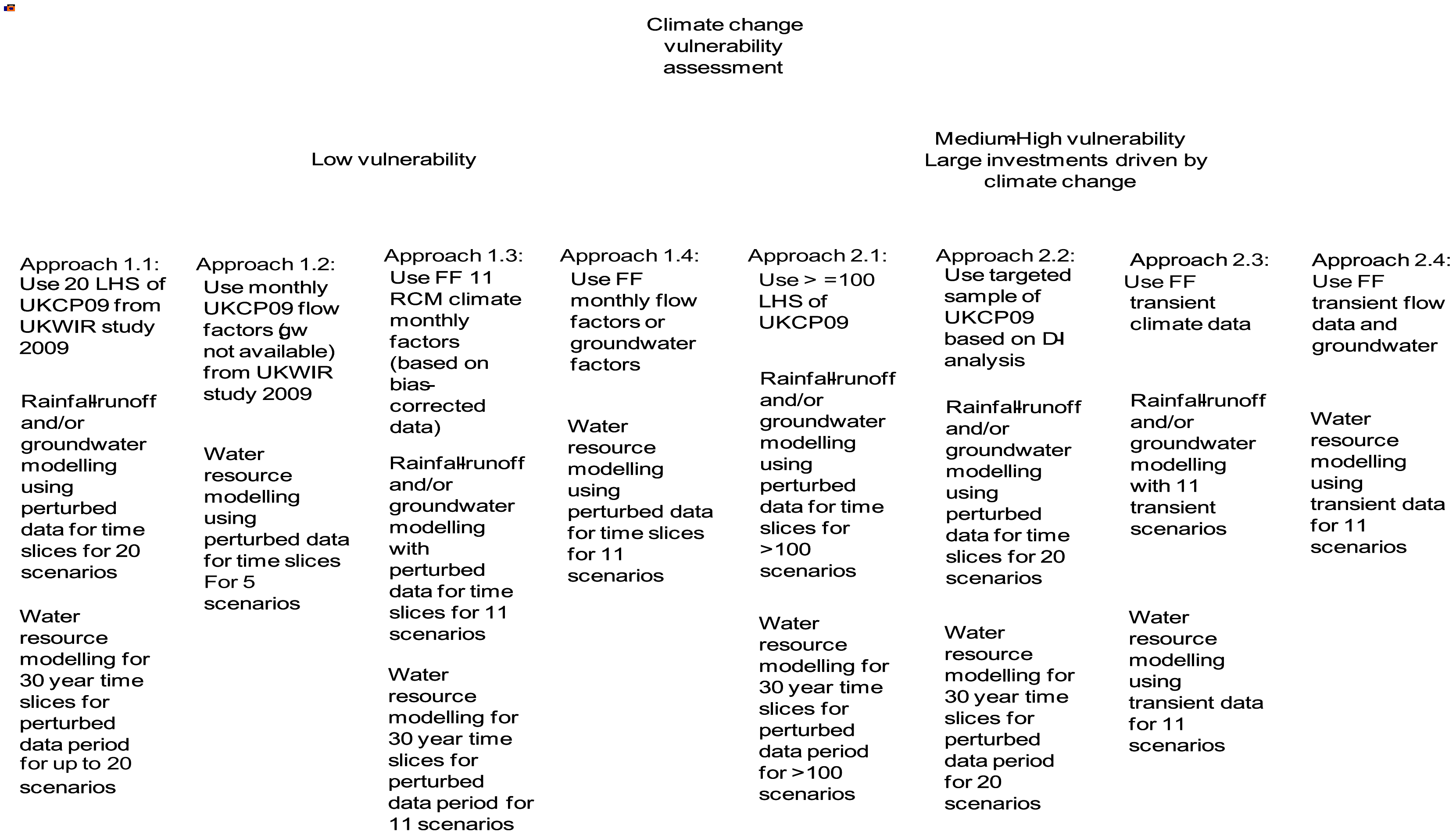

Figure 4.1 Proposed framework for climate change and DO assessment.

4.3 Future Practice: Level 1 Analysis for Low Vulnerability Situations

For water resource zones assessed to be of low vulnerability to the impacts of climate change, a simple approach adopting methods that are similar to those previously used is proposed. The key difference is that the recommended Level 1 practice for WRMP14/PR14 makes use of UKCP09 monthly climate or river flow factors, or Future Flows climate or flow factors, rather than UKWIR06 or UKCIP02 data and factors, and one non-factor based option is also provided in the Level 1 category.

4.3.1 Methods 1.1 and 1.2

The proposed approach to using UKCP09 outputs builds on the rapid assessment of the UKCP09 probabilistic data sets, and the impacts of those future climate projections on monthly river flows published as an UKWIR report in September 2009 (von Christierson *et al*., 2009). This project applied a Latin Hypercube Sampling (LHS) method to the full UKCP09 data set for each major river basin district across the UK to produce smaller sets of UKCP09 climate factors for use in hydrological modelling. An LHS-based sample of 20 projections from the full 10,000 projections available in UKCP09 was judged able to provide a reasonable compromise between accuracy and modelling effort. This was validated through work on the Thames and Ribble basins but was not tested across the UK.

LHS sample data sets were provided for all UK river basins and modelled flow factors for 70 basins and averaged by UKCP09 basin area (provided in Excel sheets on the CD Rom in UKWIR, 2009)

Method 1.1 uses the 20 LHS sub-sample of the UKCP09 data to provide perturbed climate input data into hydrological and then water resources models, to determine DO under projected future climate conditions.

Method 1.2 uses a set of five flow factors derived from the 20 LHS sample of the UKCP09 data to determine DO under that representation of climate change. This approach matches that defined in the Environment Agency's (2011) WRPG, using UKCP09 data.

Where zones are 'low vulnerability' it is likely that companies use flow factors (Method 1.2). In addition this method and simplified versions of methods 1.1 and 1.2, with five or even three scenarios[11], may be suitable for use in multi-criteria analyses for options screening or appraisal. As most companies consider hundreds of potential supply and demand options, simple screening methods are needed.

4.3.2 Methods 1.3 and 1.4

Approaches 1.3 and 1.4 (Figure 4.1) also make use of monthly climate factors (method 1.3) and monthly flow factors (method 1.4). Here, though, the factors are based on Future Flows project data derived from eleven regional climate models developed by the UKMO's Hadley Climate Centre (11 HadRCMs).

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[11] Note that the original spreadsheets, provided to UKWIR and the water companies in 2009, included sets of 20 scenarios for changes in rainfall and PET, simplified 'mid', 'wet' and 'dry' climate scenarios and five flow factors based on the 5th , 25th , 50th, 75th and 95th percentiles of changes in monthly flow. However all these data are for the 2020s and therefore companies will either need to accept that 2020s provides a reasonable estimate, resample for the 2030s, or scale the outputs using a standard scaling formula (see Section 6).

This approach does not capture the full range of uncertainty included in the UKCP09 data, but nor do the sampling methodologies used in approaches 1.1 and 1.2. There are a number of cases where it may be preferable to use Future Flows data (approaches 1.3 and 1.4) rather than UKCP09 rapid assessment outputs (1.1 and 1.2):

- in areas where potential climate risks are expect to vary significantly within a region due to catchment characteristics;
- in ungauged catchments where the tools provided in Future Flows may provide the only reasonable estimates of changes in flows;
- in broad-scale studies that are considering major transfers across the UK as the Future Flows data provides scenarios that are 'spatially coherent'; that is, they include information of possible regional variations in climate change and changes in flow.

It is preferable for companies to have developed their own catchment hydrological and water resources models and therefore approach 1.3 would be used. However, there are still many water resources zone that do not have hydrological models, in which case approach 1.4 would be used. The Future Flows hydrological models are robust and each model includes diagnostic information on how well it fits local data so that companies and the EA can assess whether these models are fit for purpose for water resources planning.

In other cases, methods 1.1 and 1.2 may be preferable, for example:

- In cases where companies have their own rainfall-runoff models that reproduce flows better than the regional Future Flows hydrological model, 1.1 would be preferable

In cases where companies have needed to progress WRMP programmes of work in advance of the release of the Future Flows outputs, the choice of an appropriate method is not straightforward and depends upon the context with respect to the availability of climate data, hydrological models, catchment size and the importance of regional transfers. Early discussion with the EA is recommended to discuss these issues.

Either of these simple approaches (1.1, 1.2 and 1.3 and 1.4) are judged to be adequate for zones whose supply-demand balance has low vulnerability to climate change, and where future investment needs are unlikely to be climate change driven. In addition, use of all or some of the Future Flows scenarios would be appropriate for options screening and appraisal.

Should the use of these simple approaches indicate a risk of more significant impacts than previous assessments based on UKWIR06 data, and therefore a higher vulnerability than initially assumed, one of the more detailed approaches described below should be considered.

4.4 Future Practice: Level 2 Analysis for Higher Vulnerability Situations

For water resource zones judged to be of medium to high vulnerability to climate change, a number of more detailed approaches using either UKCP09 or Future Flows/RCM data are available.

The first two of the Level 2 approaches (2.1, 2.2) use UKCP09 data, but based on a higher sampling density or more targeted sampling strategy than is the case in the Level 1 approaches that use UKCP09 data. The second two of the Level 2 approaches

(2.3, 2.4) use Future Flows data, but in this case in the form of transient data for defined time-slices, and not in terms the simple monthly factors used in the counterpart Level 1 approaches. The choice between the available methods is again made by reference to the specifics of the situation. In all cases, the return for the extra investment in time and cost required is a more accurate assessment of potential risks and, in turn, greater confidence in the results obtained and the decisions made upon those results.

Method 2.1

The first Level 2 Approach (2.1 in Figure 4.1) makes fuller use of the UKCP09 data set, using an LHS sample of ≥100 projections from the full 10,000 population of projections. The increased sample size of greater than or equal to 100 samples here, compared to the 20 samples used in the Level 1 analyses, confers increased confidence in the results obtained. This is because a small number of samples based on, for example, changes in annual precipitation and temperature, will not include all the possible combinations of seasonal and monthly changes in climate and may miss particular circumstances that are challenging for a specific water resources zone. In the original UKWIR UKCP09 rapid assessment study, the benefits of larger sample sizes were demonstrated for two case studies (and the choice of 20 samples was based on the minimum number that provided a good estimate of mean changes and the spread of changes in flow for two case studies) (UKWIR, 2009).

Method 2.2

An alternative approach (2.2) using the UKCP09 data sets is a two-staged analysis incorporating a more detailed assessment of vulnerability to climate change than the approach set out in Chapter 3. This approach involves undertaking a drought indicator (DI) analysis (as per the intermediate vulnerability assessment, Section 3.3), in order to determine the sensitivity of the system to water availability in drought spells, and would be undertaken in cases where DO is considered to be sensitive to drought frequency/severity. In this situation (drought sensitivity having been confirmed), the UKCP09 data set would be sampled in two stages:

- First using LHS sampling to develop a minimum of 100 climate projections[12];
- Secondly, by creating a sub-sample based on the drought indicator that deliberately focuses on getting sufficient samples at the dry end of the scale as well as a reasonable spread across the full sample.

We have called this approach ‘smart sampling’ as it uses information from the vulnerability assessment to target modelling effort intelligently and avoids running a large number of ‘wet’ scenarios that would not ‘stress’ the system (and may be regarded as a waste of time and money).

Methods 2.3 and 2.4

The alternative to using UKCP09 in DO assessments is to make use of the Future Flows dataset instead (approaches 2.3 and 2.4 in Figure 4.1). Transient Future Flows data could be used for testing the sensitivity and resilience of water resources systems to a range of different drought conditions as well as providing inflows for Deployable Output assessment.

The future flows transient flow data may provide a good approach for any companies who are still unable to conduct their own rainfall-runoff modelling. The Future Flows project is developing methods for estimating changes in flow at ungauged sites.

[12] Note that this sampling work has already been completed in the previous UKWIR study and the full results are available from HR Wallingford.

One of the advantages of using Future Flows transient data (for 1950-2098) over UKCP09 data is that the Future Flows analysis considers droughts not previously experienced within the historic record, and this may therefore produce a more robust assessment.

Preliminary future flows data were tested as part of this research project (Box C) but work is still on-going on the data set to confirm its reliability at reproducing historical droughts and how the series should be used for impacts or risk assessment.

Box A: Case study - Hydrological and water resource modelling for a South East zone using UKCP09

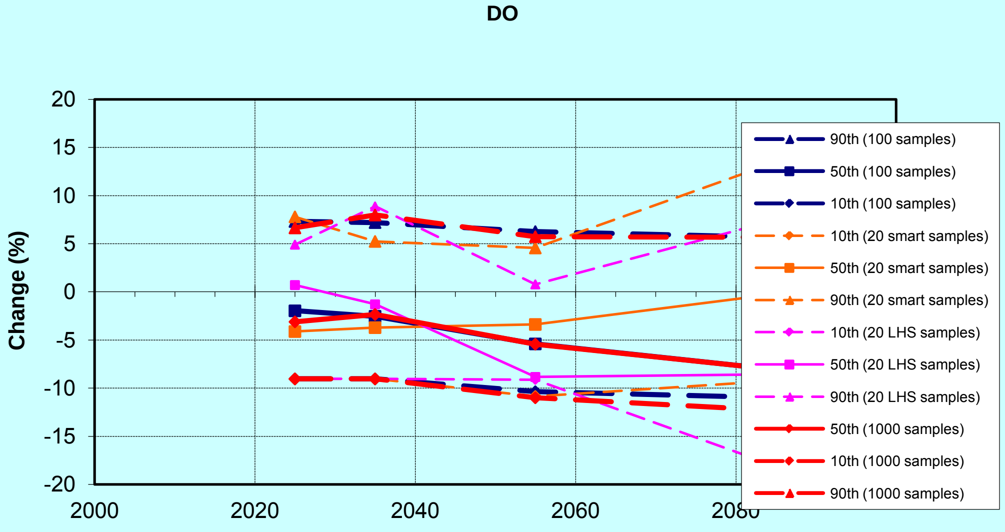
Aim: This case study investigated the implications of using different sampling methods for the UKCP09 dataset of 10,000 monthly climate factors for conjunctive use modelling of DO.

Approach: The hypothetical case considered included a run of river source in a catchment with a reasonable base flow and some faster runoff, plus a small surface water reservoir. Catchmod models and a simple conjunctive model developed in VB.net were used in batch mode for testing the effect of different numbers of climate scenarios. The study was limited to assessing climate change impacts on a large surface water source and a small reservoir whereas groundwater sources were assumed unaffected by climate change.

Four different sets of scenarios were tested:

- the simple Latin Hypercube Sample (LHS) of 20 from the UKWIR project;
- a targeted 'smart sample' approach based on drought indicator analysis and more detailed sampling at the dry end of the climate change spectrum;
- simple LHS sampling of 100;
- random sample of 1,000 using the UKCP09 web-site tool.

Results: The DO modelling indicated that for earlier time slices, such as the 2020s and 2030s, reasonable results can be obtained using only 20 samples. In terms of the sampling techniques there did not seem to be any advantage of using the 'smart sample' over the standard LHS sample for this particular system. The 'smart sample' may be slightly better than the LHS for the 2020s but for the other time slices there was no improvement. A selection of 100 samples seemed to provide a reasonable representation of DO for all time slices. There was a small amount of variation in the results but overall the average reduction in DO over time and range of uncertainty seemed well-represented using this sample size.



Conclusions:

- Smaller samples of 20 LHS are reasonable for the 2020s and 2030s but looking further ahead a larger sample is required.
- A small number of sub-samples are suitable for water resource zones with large, fairly slow-responding reservoirs but less so for resource zones characterised by run-of-river sources and small reservoirs that tend to be more sensitive to month-to-month variations in rainfall and PET.
- This zone appeared not to be very sensitive to climate change for the planning period until 2040 as indicated by a basic vulnerability analysis. Impacts for the 2030s are very similar to the 2020s with average impacts on DO of approximately 2.5% (~ 1.7 Ml/d). Impacts could potentially be as high as -9% but this is still low compared to many other systems such as the London RZ.

4.5 Future Practice: Choosing between the available Level 1 and Level 2 options

As noted above, the choice between the use of Level 1 or Level 2 options hinges upon the outcome of vulnerability assessments of each individual resource zone. However, circumstances inevitably arise where the choice is less than clear-cut. We have accordingly undertaken a series of case studies to examine the costs and benefits of using different approaches, to better inform the choice between options.

The implications (for impact assessment, and investment decisions) of using different numbers of climate scenarios and sampling techniques with UKCP09 data have been investigated for two different situations, in the South East RZ (see Box A) and in Thames Water's London RZ (Box B).

The South East study indicated that the impacts of climate change on DO are reasonably well represented for the 2020s and 2030s using both the simple LHS 20 sample regime (approach 1.1) and the more detailed 100 LHS samples plus 20 drought targeted samples (approach 2.2). But looking further ahead to the 2050s, the results show that the Level 1 1.1 approach becomes unreliable and that a more detailed sampling regime with at least 100 LHS samples scenarios is required.

The targeted sampling method using drought indicator analysis proved successful for the Thames London Resource Zone (Box B), where a drought indicator of annual aridity (which combines rainfall and temperature into one measure of drought) was a good proxy for reservoir levels (and therefore water availability). This could then be used for examining projections with the most severe impacts on DO in more detail, as a more effective sampling strategy for the situation than selecting equally weighted projections would have been. For Thames Water, this approach provided a practical solution to judging vulnerability to droughts whilst keeping modelling requirements at a reasonable level (particularly for groundwater modelling studies).

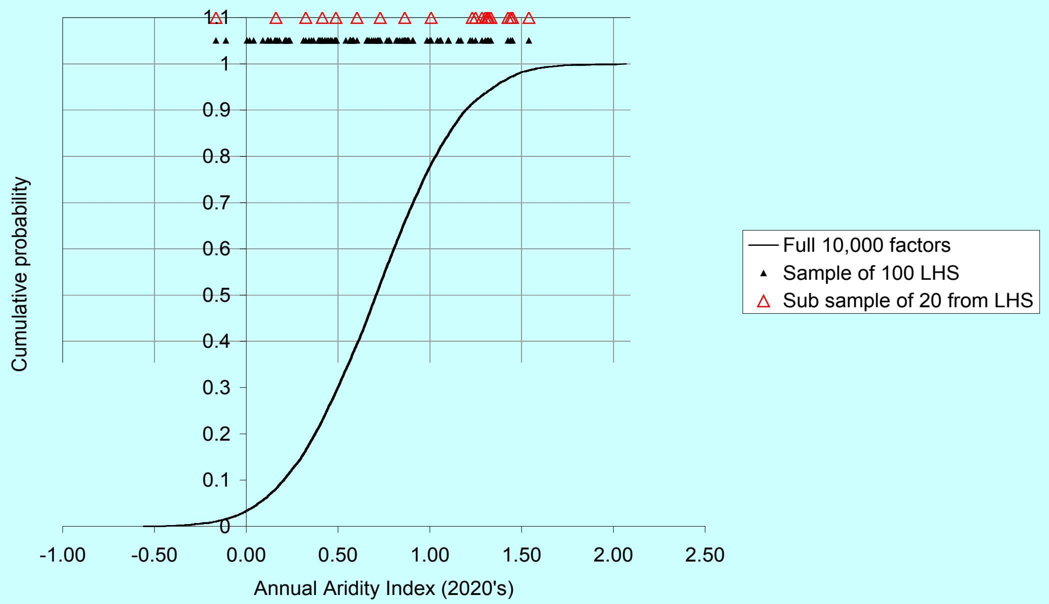
For the South East case study, on the other hand, the same two-stage analysis with drought-targeted sampling did not produce an improved assessment compared to using a basic (Level 1) 20 LHS sampling regime, for assessments to 2030. This is thought to be due to the fact that this system had a faster response to rainfall than the London RZ, which has a number of large reservoirs. Annual aridity seemed to be a reasonably good predictor of drought conditions looking at historic river flows, but more detailed water resources modelling revealed that the month-to-month variation of climate in the summer was very significant for the conjunctive use DO. The two case studies serve to indicate the importance of considering the particulars of the situation in choosing appropriate projection sampling strategies.

Based on the case studies for the South East and London, it would appear that a small number of targeted sub-samples are suitable for determining the climate change impacts of water resource zones with large, fairly slow-responding reservoirs, but less so for resource zones characterised by run-of-river sources and small reservoirs that tend to be more sensitive to month-to-month variations in rainfall and PET. Where the targeted sampling approach is selected, care must be taken in interpreting the results, and making sure the chosen drought indicator really is a good measure of water resource availability. In some cases, it may be necessary to consider more scenarios than the 20 originally selected, or moving on to an analysis considering 100 LHS projections.

Box B: Case study - Targeted sampling approach of UKCP09 for the London RZ

Aim: The purpose of this study was to develop a practical method for assessing the impact of climate change using UKCP09 on water resources (conjunctive use) in the London RZ without the need for a full scale modelling study running the set of 10,000 projections through Thames Water's resource model WARMS.

Approach: For practical purposes a limited number of climate change scenarios could only be considered in the analysis, both due to the data-processing involved and water resource modelling required for assessing the impact on DO, but also since the impact on groundwater sources must in part be assessed manually. A targeted sampling approach was therefore developed, which made use of a combination of Latin Hypercube sampling and drought indicator analysis. A LHS sample of 100 was initially extracted from the dataset of 10,000 and sub-sampling of this was undertaken by ranking each of the 100 scenarios by maximum annual relative aridity (a suitable measure of drought in the Thames region). A sample of 20 was extracted by selecting 10 across the range of aridity and the 10 driest scenarios with the highest maximum aridity. For groundwater only five of the 20 scenarios could be considered in the analysis. These were selected for analysis corresponding to the 10th, 50th, 90th, 95th and 99th percentiles for the 20. This number ensured a reasonable spread whilst allowing a closer examination of the drier end of the distribution.



Results: An analysis of the climate factors for the 20 samples indicated a reasonable spread compared to the full sample of 10,000. Furthermore, river flow modelling at Teddington indicated similar results. The conjunctive use modelling using the 20 targeted samples indicated a gradually decreasing DO with increasing maximum annual aridity as expected, and in fact based on the WARMS modelling a simple linear relationship between RZ DO and maximum aridity was developed. The climate change analysis based on 20 UKCP09 scenarios produced an average DO reduction of 3% compared to 5% using UKWIR06. Furthermore a more detailed headroom distribution was developed with a larger spread around the dry end.

Conclusions:
- The targeted climate change approach based on LHS and drought indicator analysis was applied successfully for the London RZ allowing a more detailed description of the uncertainties at the dry end of the spectrum.
- The DO assessment indicated slightly smaller average impacts on DO than UKWIR06 but a larger range of uncertainty.
- Overall this type of approach provided a practical solution for a complex system keeping modelling requirements at a reasonable level.

4.5.1 Special considerations for groundwater modelling

In addition, the case studies have revealed some of the difficulties related to modelling the impacts of climate change on groundwater systems or conjunctive use systems, where the groundwater component (and how it is managed during drought) has an overriding impact on resource zone outputs. In such cases, there is a requirement for pragmatism and innovation, rather than necessarily following the approaches used in these case studies. For example:

- Running large numbers of climate scenarios through a distributed groundwater model and then translating outputs for large numbers of individual sources is a major task; it may be possible to reduce the number of runs, for example to around ten, and get defensible results.
- If the intermediate vulnerability methods fail to find clear links between climate and groundwater level, other approaches can be developed based on completing recharge modelling (which is straightforward) for large numbers of runs (100s-1000s) and then selecting a sub-sample or 'smart sample' of the recharge results (5, 10, 20) for more detailed groundwater modelling.

Whatever approach is adopted, any simplification needs to be justified and reduced numbers of runs placed in the context of the full UKCP09 or Future Flows data sets. This can be done by showing where the selected annual recharge estimates sit amongst a larger distribution.

4.5.2 Using Future Flows

A case study using preliminary Future Flows data to estimate climate change impacts on DO was also undertaken, using Dwr Cymru/Welsh Water's North Eryri Ynys Mon (NEYM) RZ. The case is summarised in Box C. It showed that the average modelled DO obtained using Future Flows data and Method 2.3 (using transient climatic data) was fairly close to that obtained using the 20 LHS regime from the UKWIR project. The uncertainty range around the best estimate of the two approaches was also very similar. This was not as expected, but is thought to be due to the fact that the DO of the system is determined by specific droughts within the RCM records. A smaller range of uncertainty would probably have been obtained had the data been turned into monthly factors and used for perturbing historic records. In other words, natural variability in the transient dataset results in more variability in the modelled DOs than would be the case were more generalised climate factor data was used.

The NEYM case study also confirmed that the time period considered in the analysis is critical in terms of the DO results obtained. It is important to consider the full record to the end of the planning period (in this case, from 1961) rather than taking data from shorter time slices. The transient model runs may also useful for doing return period analysis, for example on reservoir drawdown, which may be useful for assessing the effects of climate change on levels of service (although the concept of return periods become complex in a non-stationary climate).

Finally, the use of the Future Flows (RCM) data allows consideration of trajectories of individual projections, whereas using UKCP09 data trajectories will either have to be assumed based on one time slice (for example the 2030s) or the data will have to be presented as percentiles. The scaling of results from one or other time period to a longer one is a general issue which is touched on below in the context of DO, and more generally in Chapter 6.

4.6 Approaches to scaling

Approaches to scaling DO over the short term and medium term have been developed, using the case study work described above. The main issue in scaling is the way in which natural variability is handled, and whether several or just one time slice is considered. Potential methods along with a discussion of the most suitable datasets to use in DO assessments are discussed in Chapter 6.

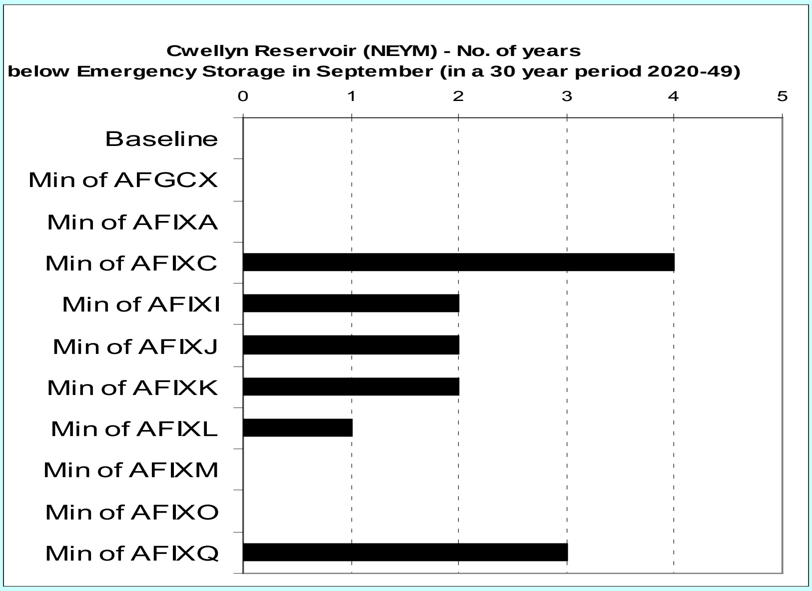
The current EA method, modified to be centred on the 2030s (rather than the 2020s, as previously) generally produces reasonable trajectories with both UKCP09 and RCM data. Scaling approaches using RCM data - including the use of Spatially Coherent Projections (SCPs) and temperature scaled RCMs – have also been examined. Chapter 6 provides details.

Box C: Case study - Hydrological and water resource modelling for NEYM in North Wales using Future Flows data including a comparison with UKCP09

Aim: The purpose of this study was to test the use of transient climate data available from Future Flows (rainfall and PET) for assessing the impacts of climate change in the NEYM resource zone and compare the results to a previous analysis based on UKCP09 for the 2020s.

Approach: The approach involved the application of 10 available HADRCM Future Flow Time Series (one is still being checked by the Centre for Ecology & Hydrology (CEH)) to derive rainfall and potential evaporation sequences for the period 1950 to 2098, which were then used to derive flow sequences using the HYSIM rainfall runoff model at the 5 sources in the NEYM WRAPSIM water resources model.

Results: The DO modelling showed that the time period considered is critical in terms of DO. Considering the period from 1958-2040 very similar results to a previous analysis using 20 UKCP09 samples from the UKWIR rapid assessment in terms of average DO and range of uncertainty were produced. However if the time slice corresponding to the 2030s (i.e. 2020-49) was selected, the resulting DO would be somewhat higher. This is due to the more extreme droughts being simulated in the period pre-2020s. The range of uncertainty modelled using the transient data is generally similar to the range obtained using UKCP09, which was somewhat surprising. This is thought to be due to the fact that particular droughts within the modelled RCM records determine the DO. If monthly factors rather than the transient data had been used, the uncertainty range would be smaller. Finally, a return period analysis of drawdown for the period from 2020-2049 (see Figure below) indicates significantly higher frequencies of severe drought than currently experienced.



Conclusions:

- The time period considered in the analysis is critical in terms of average DO obtained. For assessing the impacts on DO for the next planning period to 2040, the period from 1961 to 2040 should be considered rather than just a time slice.
- The uncertainty range was similar to that obtained based on UKCP09 data. This is due to the fact that specific droughts determine UKCP09 and there is considerable variability within the records.
- The Future Flows climate time series are useful in testing the sensitivity and resilience of the system to a range of different drought conditions as well as providing inflows for Deployable Output assessment
- The provisional PET records used in this study deviate considerably from the baseline data (by up to 15%) used in existing water company hydrological models. This is a significant limitation and requires either some additional correction of the data or re-calibration of existing models. CEH are currently undertaking further work to understand the cause of the differences and improve the data.

4.7 Limitations and issues with the different approaches

The main limitations, issues and indications that emerged from applying the various recommended methods in real test cases were as follows:

- The basic Level 1 vulnerability analysis is to some extent subjective, and it may therefore in some cases be difficult to decide which method is appropriate for a particular water resource zone. It is recommended that a robust assessment of vulnerability is adopted and/or that a staged approach involving drought sensitivity analysis be considered.
- The use of the simple 20 LHS will capture a reasonable but not the full uncertainty range of the full (10,000) set of UKCP09 projections. The same limitation applies with respect to the use of Future Flows monthly factors, which will produce a smaller range than the UKCP09 full population data set, particularly for the earlier time slices of the 2020s and 2030s.
- The 2009 UKWIR rapid assessment did not produce groundwater recharge factors, so these will need to be generated from first principles, or climate factors will have to be used with individual recharge and/or groundwater models. That said, translating monthly time series of precipitation and PET into effective rainfall or recharge is a straightforward task.
- Using 100 or more UKCP09 scenarios for the more detailed analysis increases the precision of the assessment, but also the degree of hydrological, groundwater and water resource modelling required to determine impacts on DO. An analysis of this scale is only likely to be feasible for the larger water companies, or in cases where climate change constitutes a significant influence on the supply-demand balance and on investment needs. In cases where water resources or groundwater modelling is the main constraint, hydrological or simple recharge models could be run for 100+ scenarios and then a only a sub-set of these used for systems modelling, using the same kinds of sampling approaches adopted for climate factors.
- The drought targeted sampling approach proved successful and worthwhile in the London RZ case study, but was less successful for the faster responding South East case study and for modelling the 2050s in this specific zone. Care must be taken in selecting the right approach for the situation, in interpreting results and in ensuring that the chosen drought indicator really is a good measure of water resource availability in that situation. This study has only looked at four specific case studies and individual water companies, and regional Environment Agency staff are best placed to consider approaches for individual river catchments.
- The use of transient Future Flows data for climate change-influenced DO analysis requires a large degree of modelling effort. The draft Future Flows data used in the case studies showed large discrepancies between the historic baseline and modelled baseline period, which means that any results may be unreliable. While this will be fixed prior to Future Flows release, data checks may still be needed to understand differences between national and local climate data sets. (In this case it was unclear whether this pointed to an issue with the local baseline data, the draft Future Flows data set, or a combination of both).

- DO profiles based on Future Flows transient data produces a varied trajectory with uncertainty ranges similar to UKCP09. As part of this study, no checks were carried out to test whether RCM produced droughts were realistic compared to observed droughts. Further work may be needed to check the Future Flows climate data.
- There is a gap in the assessment of groundwater, however detailed case study work on groundwater modelling was outside the requirements of this project. The same principles of vulnerability assessment, followed by an impacts assessment apply to groundwater. However, there may be limitations to the number of times complex distributed groundwater models can be run. In such cases, detailed analysis of annual recharge can be completed and a smaller number of recharge scenarios could be assessed in more detailed models.

5 Assessing the impacts of climate change on the demand for water

5.1 Current approach

The approach to the assessment of climate change impacts on household demand recommended in the current Water Resources Planning Guidance (WRPG; Environment Agency, 2009 is to apply change factors from the Climate Change and the Demand for Water (CCDeW) project (Downing *et al.*, 2003) to baseline demand, at resource zone (RZ) level. The WRPG states that the factors presented in the CCDeW report 'refer to 2030 and should be scaled linearly between the base year and 2030' (Environment Agency, 2009, p8)[13].

In the case of household demand in periods of peak demand, the WRPG advises that where investment is driven by peak demand, climate change can be factored into peak demand based on a well-argued case. This would need to demonstrate the link between peak demand and climate and how this link might develop under a changed climate.

For non-household demand, the WRPG states that companies can base their assessment on the CCDeW report, or can assume that there will be no impact. Where there is a significant agricultural component of demand that can be attributed directly to irrigation, the WRPG indicates that companies can make allowances for climate change using the CCDeW report. Otherwise, no allowance for climate change on agricultural water demand should be made. In all cases, the WRPG emphasises that companies should clearly state the assumptions they have made with respect to climate change.

The WRPG indicates that companies should include best estimates of climate change impacts on demand in baseline demand forecasts, with uncertainty around the best estimates being included in the D4 component of Target Headroom (TH). In practice, while some companies did this, others included best estimates as well as range estimates of climate change impacts on demand in TH. This made direct comparison of companies' demand forecasts problematic, especially where the practice adopted was not clearly stated.

Water resources practitioners consulted as part of this project indicated a general view that current methods of climate change analysis for annual average demand remain appropriate, given the impact that is likely to arise is relatively small. It is recommended that the current approach should continue to be used for assessing the impact of climate change on annual average demand. Any updates to this methodology (e.g. to take account of UKCP09 climate projections) should retain a similar level of analytical simplicity to the current method.

Water resources practitioners also indicated that the current method provided insufficient detail to enable the impact of climate change on peak demands to be assessed in a suitable way – especially in water resources zones where the dry year critical period scenario drives investment. As a result, it was agreed that the focus of this part of the study should be on the development of methods to assess the impact of climate change on critical period demands. A range of different approaches have been

[13] Downing *et al.* (2003) presents factors for the 2020s, not 2030 as stated in the WRPG.

developed that enable practitioners to employ methods appropriate to the prevailing supply-demand balance in a particular water resources zone. These methods are described and illustrated with case studies in the following sections.

5.2 Situation-Reflective Practice for the Future

For the future, our recommendation for incorporating the impacts of climate change into demand and uncertainty forecasts is that companies should choose an approach and a set of methods that reflects the particular situation of each resource zone. As for the supply side of the balance, the challenge, as 'futures data' become more comprehensive and more demanding to apply, is to define the Level 1 (minimum essential) analyses that need to be applied in all situations, and the 'extra-over' Level 2 analyses whose use is warranted in situations where potential climate change threatens the supply-demand balance.

Our recommendations for treating the impacts of climate change on demand are shown in Figure 5.1. They are clear-cut. Unless a resource zone is critical period-driven, and is likely to have an investment need within the planning period driven by forecast shortfalls in that critical period, it is recommended that the impact of climate change on (household and non-household) demand and uncertainty forecasts continues to be determined through the use of the change factors given in the CCDeW report or similar factors developed using local water company data. If critical period shortfalls drive the plan, and the investment programme, more detailed analyses of demand in the particular critical period of the year need to be undertaken to confirm positions and options, and to justify investment proposals.

5.3 Future Practice: Level 1 Analysis for Low Vulnerability Situations

In water resources zones where the critical period supply-demand balance (SDB) is not a driver for investment, even under climate change scenarios, the impact of climate change on annual average demand (and critical period demand, if required) should continue to be estimated using the demand change factors given in the CCDeW report (Downing et al., 2003). The best (mid, central) estimate of the impact of climate change on household and non-household demand (and on derivatives like household per capita consumption, PCC) should be reported as a demand change time series, for each year of the planning period, and added into the baseline forecast of demand for the RZ. Lower and upper estimates of the impact of climate change on demand should be used to define uncertainty in demand brought by climate change, as component D3 of the TH analysis. The uncertainty due to the effect of climate change on demand should be reported separately, and as part of overall TH.

In water resources zones where the potential impact of climate change on demand (in the baseline forecast, and in baseline uncertainty) in the critical period is small and/or unlikely to affect investment planning, a limited consideration of peak demand drivers is appropriate. Practitioners should consider how peak demand in a particular zone is currently affected by climate variables. Some companies have developed models that relate peak demands to temperature, sunshine hours and rainfall parameters; others base their forecasts of future demand in peak periods on historical demand profiles, with an adjustment being made for anticipated changes in climatic variables.

High-level outputs from the UKCP09 website include probabilistic projections of climate variables. These can be accessed and used to provide an indication of future trends in key variables, such as temperature. These high-level outputs may be used to provide a rapid, semi-quantitative assessment of the potential effects of climate change on peak demands in situations where companies have some existing methods relating peak demands to climate variables. If companies do not have any such tools or methods available, practitioners could undertake sensitivity analysis based on professional judgement.

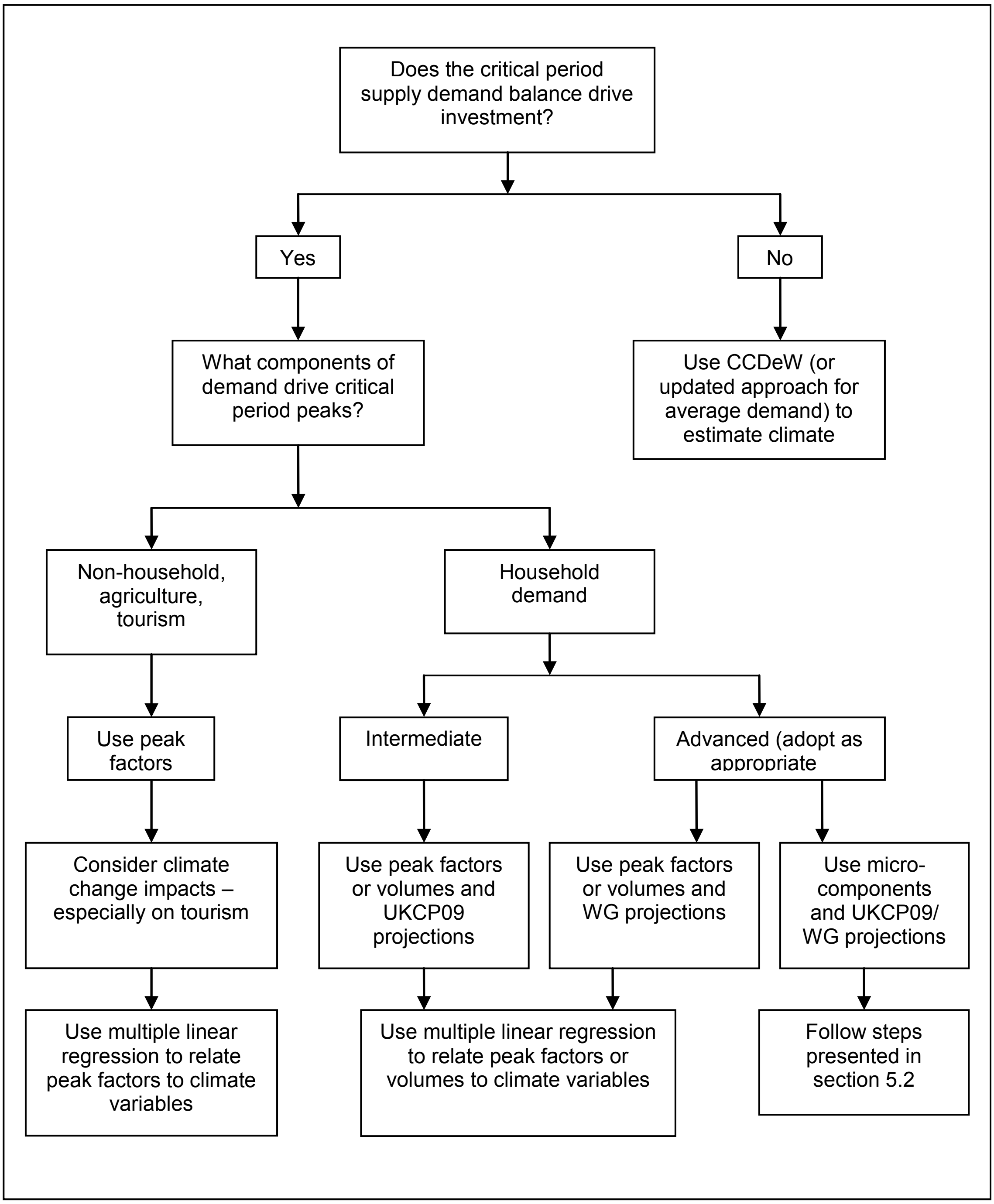


Figure 5.1 Flow chart illustrating options for climate change and demand analysis.

5.4 Future Practice: Level 2 Analysis for Higher Vulnerability Situations

More advanced approaches are needed in water resources zones that have a critical period supply-demand balance that may drive investment. A range of more advanced approaches have been developed as part of this project, as illustrated in Figure 5.1. This section explains the options available, and presents three case studies to provide practitioners with examples of how these new approaches may be implemented.

Two distinct Level 2 methodologies are proposed for household demand. The first (Level 2.1) is based on existing approaches to peak demand forecasting, as presented in the UKWIR peak demand forecasting methodology (UKWIR, 2006), but using UKCP09 climate projections. The second (Level 2.2) is based on disaggregation of the estimation of the impact of climate change on demand to demand component and micro-component level, again making use of UKCP09 data and tools. The approach for non-household demand (Level 2.3) corresponds, in broad terms, to the Level 2.1 approach for household demand.

<u>Level 2.1 approaches</u>

This UKWIR 2006 report presents a framework approach to peak demand forecasting, with choice from a range of available methods being based on the nature and drivers of peak demand in a particular resource zone. A brief summary of the UKWIR peak demand forecasting methodology is presented in a separate project technical note, and it is recommended that practitioners refer to this guidance and also the original UKWIR methodology before applying the approaches presented here. In particular, modellers should determine which of the 'peak factors' or 'peak volume' approaches are most appropriate for their specific circumstances, as this is likely to have a bearing on the climate change analysis to be adopted.

Boxes D and E present summaries of case studies that illustrate how peak factor and peak volume based regressions, derived using the principles of the UKWIR peak demand forecasting methodology, could be applied using UKCP09 data. There are some important caveats and assumptions associated with the case studies presented. Further details of these important considerations are presented in Appendix A. This appendix also compares the use of data drawn from the UKCP09 probabilistic projections, on the one hand, and data derived using the UKCP09 Weather Generator tool, on the other. The findings suggest that water companies should consider undertaking analyses using both sources of climate predictions, when undertaking climate change analysis of peak demand in vulnerable water resource zones.

The equations used are taken from the UKWIR peak demand forecasting methodology. They were developed for specific areas and situations, and they should not be used generically, beyond the limits and conditions of the original data. Companies wishing to pursue this approach should develop their own relationships and test them under a range of historic and climate change scenarios.

Box D: Case study – Application of a typical peak factor linear regression model

Aim: This case study investigated how a typical peak factor linear regression model could be used to determine the effect of UKCP09 probabilistic climate change projections on critical period demand.

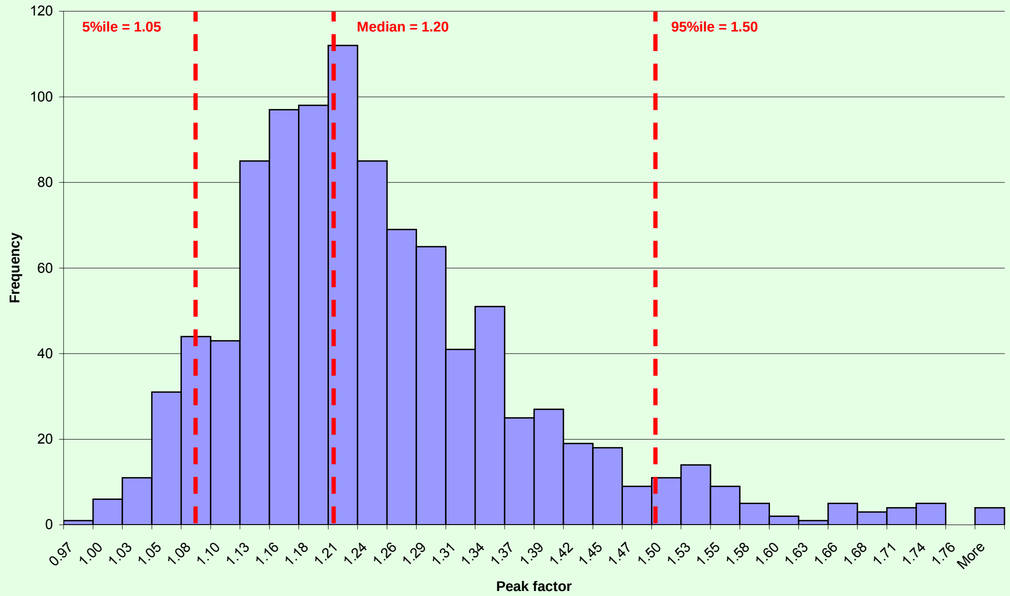
Approach: The UKWIR peak demand forecasting methodology includes five worked examples in its Appendix A. They include the use of regression analysis to explain historic variation in peak demands. Peak demand is often strongly related to summer weather, particularly temperature, and also the characteristics of the customer base (e.g. meter penetration). Historical consumption data can be extended using historical climate data (with other influential variables such as meter penetration given suitable values). The resultant equations may also be used to consider the effect of future climate on peak demands (see Table 5 in the UKWIR, 2006 report).

The case study used UKCP09 probabilistic projections of climate change, derived from the UKCP09 User Interface website. Further information on the 'job details' used for this case study are presented in Appendix A. The 'predictive peak factor model' was selected using the following relationship (based on the correlation coefficient R^2, and its ability to reproduce historical peak volumes):

$$PF = 0.0015(Temp - 18)^{2.73} - 0.013(Rain)^{0.776} + 0.0012 * Year - 1.12$$

where: 'Temp' is maximum monthly temperature in July (°C); 'Rain' is total rainfall in July (mm); and 'Year' is calendar year. The equation was applied to the UKCP09 probabilistic projections of climate change over land (derived from the UKCP09 User Interface), which are 1,000 projections of possible future climate for 2020s.

Results: The results of the analysis are shown in the figure below. They show a median peak factor value of 1.2 (x AAD), and 5th and 95th percentile factor values 1.05 and 1.50, respectively.



Analysis of the results showed that of the 1,000 scenarios, the maximum peak factor returned was 1.78. This is driven by a combination of low July rainfall (21mm) and high maximum monthly temperature (27°C). Only one combination of rainfall and temperature data returned a peak factor of less than 1.0 (20.5°C, 71mm of rain), whilst six scenarios returned factors of 1.0. Hence 7 of the 1,000 simulations returned a peak period demand value of or less than the annual average value, whereas 993 returned peak period demand factors greater than 1.0, with a median of 1.2 and a maximum of 1.78.

Conclusions:

- Application of UKCP09 climate variables to peak demand models results in a large range of potential peak demand and larger increase in peak demand compared to annual average demand.

Box E: Case study – Application of a typical peak volume linear regression model

Aim: This case study investigated how a typical peak volume linear regression model could be used to determine the effect of UKCP09 probabilistic climate change projections on critical period demand.

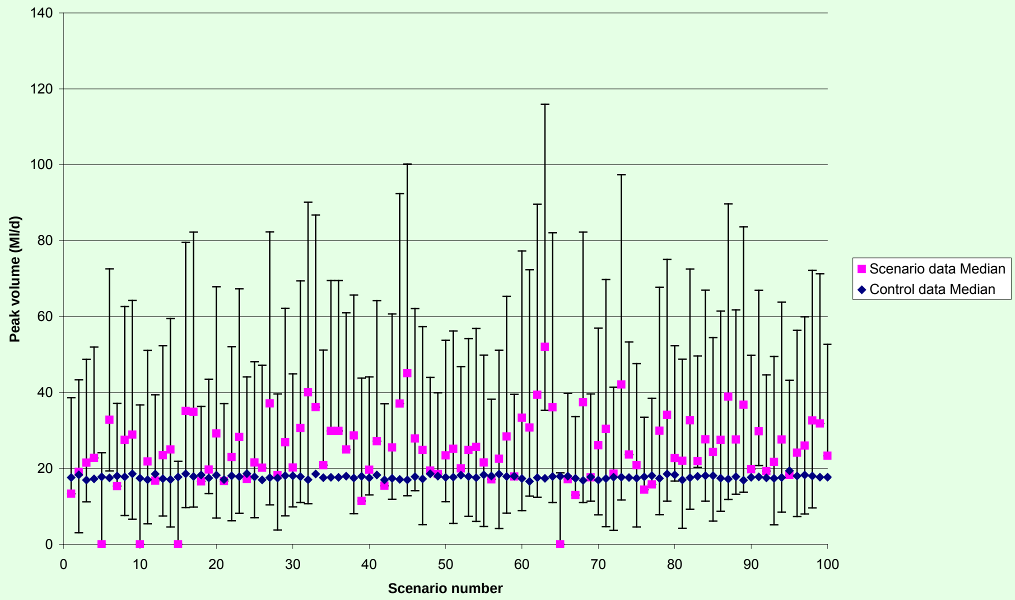
Approach: The UKWIR peak demand forecasting methodology includes five worked examples in its Appendix 1. For this case study, a worked example that estimated the effect of climate variation on peak volume was used. The case study uses a linear regression model that includes 'sunshine hours' as the key independent variable. This variable can only be derived from the Weather Generator, and not from the UKCP09 probabilistic projections. The implications of this are discussed below.

Further information on the 'job details' used for this case study are presented in Appendix A. The 'predictive peak volume model' was selected using the following relationship (based on the correlation coefficient R^2, and its ability to reproduce historical peak volumes):

$$PV(Ml/d) = 0.18(Temp - 18)^{2.3} - 462(Sun - 130)^{-1.67} + 15.9$$

where: 'Temp' is maximum monthly temperature in July (°C); and 'Sun' is total sunshine hours in July. Maximum monthly temperatures, by month, are available from the UKCP09 probabilistic projections, however sunshine hours projections are only available from the Weather Generator. For this example, Weather Generator projections are used for both variables. The Weather Generator produces a user-defined number of random samples from possible future climates, and provides a baseline equivalent for each of these results. Therefore the baseline situation should be derived from these scenarios, rather than from long-term average historical climate, to ensure comparison with like-for-like data.

Results: The Figure shown below shows the output of the assessment, comparing the median values of the control data with the scenario data for each of 100 scenarios. The error bars indicate the range between the 5th and 95th percentiles in the scenario data. The analysis shows that for the control set of data, the median peak volume is calculated at 16.6 to 19.4Ml/d, with an average of 17.7Ml/d. Using the scenario data set, the median peak volume ranges from 0 to 44.9Ml/d, with an average of 24.6Ml/d. Under this analysis, the average peak volume increases by 6.9Ml/d from 17.7Ml/d to 24.6Ml/d.



Conclusions:

- Linear regressions using climate variables that can only be derived via the Weather Generator require significantly more analysis to process the outputs from this tool into a form that can be analysed as described here.

Level 2.2 approach

The second (Level 2.2) approach developed in this study is based on a micro-component approach to peak demand and climate change analysis. Micro-component analysis allows practitioners to analyse how changes in climate variables, such as temperature, could affect customer behaviour, such as personal washing and garden watering. A literature review conducted as part of this study was unable to identify any research that had explicitly explored the relationships between the micro-components of domestic water use and climate variables. Therefore this study developed a theoretical relationship between daily maximum temperature and showering frequency, to illustrate how the approach might be applied for individual demand components. This case study is presented in Box F.

Practitioners may wish to develop similar relationships between other climate variables and other behaviour-influenced micro-components, such as soil moisture deficit and frequency of garden watering. Further research would be required to enable any such relationships to be confirmed.

5.5 Limitations and issues with the different approaches

The main limitations and issues encountered in the case studies using the different data sets are summarised below:

- As with the supply-side methods, the vulnerability analysis is to some extent subjective and it may therefore in some cases be difficult to decide which method is appropriate for a particular water resource zone. A robust assessment is therefore necessary up front. Alternatively, a staged approach should be considered.
- The linear regression methods presented in this section must only be applied when water companies have developed relationships between climate variables and demand for their own specific regional situations. In these situations, practitioners must carefully consider the most appropriate spatial basis for UKCP09 data. This choice will influence the climate projections available, so compromise may be necessary. Modellers need to be very familiar with the range of outputs available from UKCP09 as well as Weather Generator outputs.
- It is important to remember that the linear regression equations were developed to try to understand the causes behind historic year-on-year-variation in peak demand (defined as either peak volumes or peak factors). Therefore these equations may not accurately predict the effect of climate change on peak volumes when projected climate variables are greater than or less than the historic range.
- The changes in climate in the Weather Generator outputs are expressed as 30-year long-term averages.

Box F: Case study – Use of micro-components in critical period demand/climate change analysis

Aim: This case study investigated how climate change may produce changes in individual components of domestic water use, and how this may be analysed using micro-components analysis (MCA). It does not include examination of how long term climate change may influence wider behaviours such as tourist numbers, changes in appliance ownership or changes in garden plant species. Such issues would be included as part of a wider-based MCA of future demand.

Approach: The following process has been developed and piloted to test an approach that applies climate change to micro-component modelling of per capita consumption in a water resources zone.

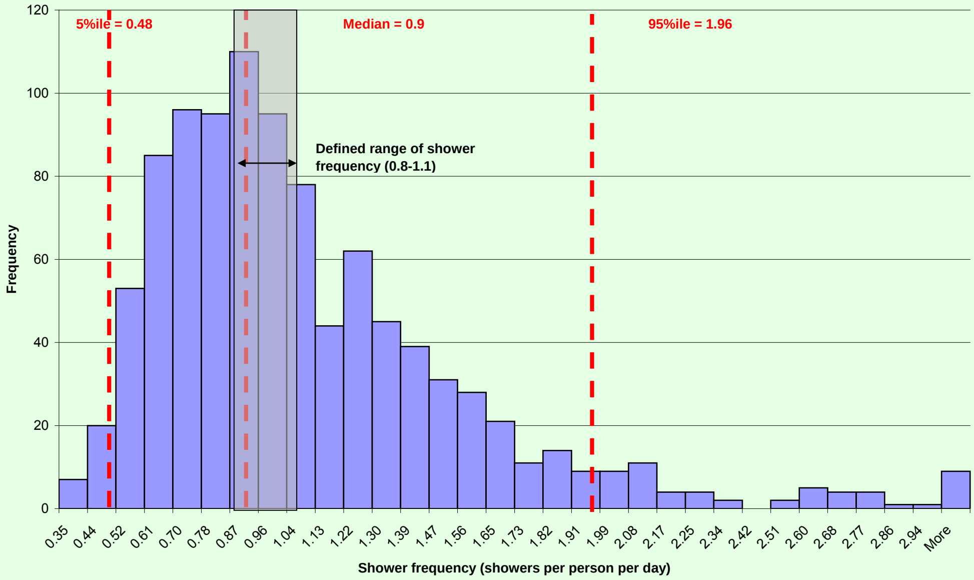
- Define the micro-components where the frequency of use may be affected by climate variables, and identify the relevant climate variables that affect critical period demands e.g. maximum daily temperature and/or sunshine hours.
- Determine the climate data that will be used to estimate base year demand and the specific climate projections that will be taken from UKCP09.
- Use the UKCP09 User Interface to generate relevant climate change data for the demand area in question.
- Define how the micro-components will respond in relation to the climatic changes presented in the UKCP09 data. This study has assumed that the changes would be observed in frequency of use rather than in ownership or volume of use data changes.
- Substitute the 'climate change' frequency of use values for a relevant year (e.g. 2025) in a peak period micro-component model, and compare the overall per capita consumption (PCC) with the original critical period PCC forecast for that year (with no climate change).

For the purpose of this assessment, the relationship is assumed to be described by the formula:

$$SF = \frac{34.5}{(1 + EXP)^{(-0.315*(Temp-34.5))}}$$

where 'SF' is the frequency of showering (in times per person per day), and 'Temp' is Maximum air temperature in July (°C).

Results: The following Figure shows the distribution of 1,000 estimated values of the frequency of showering, calculated by the above formula. For the purpose of this assessment, a 'current climate' maximum and minimum frequency of use for showering was set at 0.8 and 1.1 showers per person per day respectively. This is illustrated by the shaded area in the Figure. The changes from this initial frequency of 0.8 to 1.1 showers per person per day to an 'under climate change' modelled frequency of 0.35 to around 3.0 uses per person per day results in a median increase of 13.5 litres/head/day for showering.



Conclusions:

- The relationship between climate variables and the micro-components of household demand are poorly understood. A theoretical relationship has been developed for illustrative purposes in this study, which indicates that very small changes in temperature could result in large changes in shower frequency and consumption associated with this micro-component

- The pros and cons of using probabilistic and/or Weather Generator outputs needs to be appreciated. The choice of method will be determined by the climate variables used in linear regression models. Weather Generator-based analysis is significantly more time consuming and data intensive than the use of probabilistic outputs, therefore practitioners may want to design linear regressions to take account of this.
- There appears to be a lack of any quantitative research that provides firm relationships between climate variables and the micro-components of household demand. Further research is required before the value of this kind of approach can be fully realised. It can, on the other hand, be argued that the act of disaggregation in and of itself provides the basis for a sufficiently rational analysis of the effects of defined climate changes on Ownership (O), Frequency of use (F) and Volume of use values for individual activities (like garden watering, showering etc), and hence enables a targeted consideration of the parts of demand affected by changes in climate.
- The micro-component approaches presented here provide a way of assessing how climate change could affect the day-to-day water-using behaviour of household customers. It does not consider how a changing climate could trigger ‘structural alterations’ in water use – e.g. through the adoption of more water efficient technologies or more drought-tolerant plant species. Those and related possibilities should be considered when making judgements about demand at component and micro-component level over a long forecast horizon.

5.6 Recommendations

This study has demonstrated that UKCP09 outputs are appropriate for modelling potential climate change outputs on peak demand. The UKCP09 projections are easier to extract from the UKCP09 User Interface and do not require as much post-processing as do Weather Generator outputs. UKCP09 projections can be readily analysed in terms of probabilistic impacts on peak factors or peak volumes. However, UKCP09 projections are not available for some of the climate variables that may affect peak demand, including sunshine hours and soil moisture deficit. This means that the use of UKCP09 and/or Weather Generator outputs will depend on the parameters that demand forecasters consider most influential in affecting peak demand in their water resources zones.

Practitioners who need to undertake more advanced analysis of climate change impacts on peak demands may need to compare the effects of using UKCP09 and Weather Generator outputs, using comparable ‘job definitions’ in the User Interface – especially in terms of the number of samples/simulations and spatial coverage.

This work represents the beginning of detailed assessment into the relationship between climate and climate sensitive water demands. It is theoretical and is based on a range of assumptions. Very little prior analysis of such relationships has been undertaken and reported, and so it is unrealistic to expect this study to provide detailed and robust analysis of the relationship between climate and customer behaviour. What this study does do is to propose a methodological framework, the details of which will require more investigation.

Further research into the relationships between climate variables and the micro-components of household demand is recommended. This should focus on the micro-components that are most likely to be influenced by climate – e.g. frequency of showering and garden watering volumes. UKWIR have commissioned another short study on the potential impacts of climate change on Average Demand and Peak Demand in a Dry Year. This is due to report in 2012.

6 Scaling the impacts of climate change from the base year to 2040

Scaling of climate change impacts on supply for a planning horizon is critical for deciding the needs for developing and implementing new resource schemes. This section explores short term and medium term scaling issues using different climate datasets, time slices and emissions scenarios. The aim of the work has been to develop an approach to scaling, which will be relatively straightforward and suitable for all water companies for water resource planning until the end of the next planning period in 2040.

The work has looked at using different types of climate data such as UKCP09 and Future Flows data to ascertain both the type and degree of modelling required and the most appropriate scaling equations to use, similar to those used in current planning (Environment Agency 2009, updated 2011).

6.1 Current approach

The interpolation of climate change impacts is based on the following approach (Environment Agency 2009, updated 2011) originally developed by Arnell and Reynard in 2008:

i. Assume present Deployable Output to 2011.

ii. From 2020-21 onwards, estimate Deployable Output in each year by scaling the change in Deployable Output by Equation 1, where *Year* is the year of interest[14], and adding the scaled change to the present Deployable Output.

$$Scale \quad factor = \frac{Year - 1975}{2025 - 1975} \qquad \text{(Equation 1)}$$

iii. Deployable Output from 2012-13 to 2019-20 inclusive should be estimated by interpolating linearly between the 2011-12 and 2020-21 values. This can be done by scaling the change in Deployable Output using Equation 2:

$$Scale \quad factor = \frac{Year - 2011}{2021 - 2011} \qquad \text{(Equation 2)}$$

This approach uses the following assumptions:

1. The effects of historic climate change in the baseline period up to the current year are included implicitly as the climate in this period is used to compute the baseline DO. The water companies previously used 2007 as the base year, which could result in very different trajectory in the short term.
2. The effects of climate change in the 2020s are centred on the year 2025.
3. Climate change beyond the year 2020 occurs at the same rate as the change in climate between the baseline (1961-90) and the 2020s.

[14] This formula is based on the fact that the scenarios represent changes by the 2020s (2025) relative to 1961-1990 (1975).

The equivalent equations centred on the 2030s and updated for 2012 are included below:

$$Scale \quad factor = \frac{Year - 1975}{2035 - 1975}$$ (Equation 1b)

$$Scale \quad factor = \frac{Year - 2012}{2031 - 2012}$$ (Equation 2b)

6.2 Research findings

6.2.1 What should be scaled?

Scaling can be undertaken in two different ways:

- scale climate projections for each year of the planning period and feed this through hydrological and water resource models to assess the impacts on water availability;
- feed climate change projections through hydrological and water resource models and scale the water resource indicator (for example Q95 or DO) for each year of the planning period.

Climate change impact assessments currently scale the water resource indicator, as this is relatively straightforward compared to scaling the climate. The advantage of scaling the climate is that this would reveal non-linearalities, which would not show up scaling water resource indicators. While this is not practical now, future climate projections may take this approach and therefore provide climatology for the base year and each future decade or even year to 2100 (Met Office Hadley Centre, pers. comm.).

In the current study it is recommended that water resource indicators, such as Q95 or Deployable Output, continue to be used.

6.2.2 Available data sets and limitations

A number of different climate change projections are currently available (see Table 6.1). Each set of scenarios has different characteristics that may affect the choice of scaling method, including number of scenarios to use.

Spatial coherence is not particularly significant when it comes to scaling into the future, but whether the data sets are temporally smooth or not can affect both the selection of time slices for the analysis and well as the scaling equations applied to the data.

Table 6.1 Available climate change projections.

Scenario set	Comments	Spatial coherence?	Temporally-smooth?
UKCP09 percentiles	From all 10k or a subset	N	Y (if lots)
UKCP09 subset	Individual UKCP09 scenarios	N	N
UKCP09-RCM	e.g. FutureFlows	Y	N
UKCP09-SCP	based on RCMs	Y	N
scaled UKCP09-RCM	not a UKCP09 product	Y	Y
scaled other models	e.g. UKCIP02, UKCIP98, UKWIR06	Y	Y

6.2.3 Proposed approaches

Different approaches may need to be considered for scaling DO and headroom depending on the time horizon considered and the type of climate scenarios selected for the analysis:

Option 1) For medium term planning up to 2040 it is considered sufficient to assess one climate change scenario, for example the 2030s, using a modified version of the current Environment Agency method. A couple of time slices for the 2020s and 2030s could alternatively be used, if for example some analysis has already been undertaken for the 2020s. Temporally smooth data is preferred if more time slices are considered, but this depends on whether a fairly 'jagged' response is deemed acceptable.

Looking beyond 2040, two different approaches could be taken depending on whether the climate scenarios selected are temporally smooth or not:

Option 2) For temporally smooth scenarios additional scenarios could be considered in addition to the 2030s such as the 2040s and 2050s and scaling would simply involve interpolation between the scenarios.

Option 3) For scenarios that are not temporally smooth, it is preferable to use one future time slice, for example the 2050s, and then scale back using the current Environment Agency equation (Option 1). This does again to some extent depend on whether the fact that a set of climate scenarios is not temporally smooth is considered a problem. If a pattern of change is not a problem, then method 2) could be used.

From a water resources planning perspective, there are several key questions that this work may address:

- What scaling method provides reasonable estimates of Q95 and DO for the end of the planning period?
- What period should the water companies model in order to estimate the impacts of climate change for the period 2011 to 2040?
- What base year should be chosen for the short term?
- What approach is needed for longer-term assessments?

6.2.4 Case studies to examine trajectories of climate impacts on water resources

As part of this research we developed a number of case studies to examine how DO and Q95 impacts may evolve over time (Table 6.1).

Trajectories of climate change have been developed using two types of climate data:

- UKCP09 monthly climate factors for time slices 2020s, 2030s, 2040s, 2050s,..,2080s applied to historic climate from 1961-90.
- 11 transient records of Future Flows[15]/HadRCM rainfall and PET from 1950-2100

Although this work was completed to examine change over time it also demonstrated the variation in results obtained from different modelling strategies (Table 6.2 and Figure 6.1).

Table 6.2 Climate change impact trajectories modelled.

Trajectory variable (modelling approach)	Data source (n = number of simulations)	Resource Zone/ Catchment	Confidence
Deployable Output based on annual aridity (regression)	UKCP09 (n=100 Latin Hypercube Sample)	London RZ (Thames at Kingston)	Low
Deployable Output based on annual aridity (regression)	RCM future flows transient climate data (n=10)	London RZ (Thames at Kingston)	Low
Q95 flow (Catchmod)	RCM future flows transient climate data (n=10)	Thames at Kingston	Medium-High
Q95 flow (PDM by Charlton and Arnell)	RCM climate data as factors (not bias-corrected) (n=11)	Thames at Eynsham Conwy	Medium-High
Q95 flow (PDM by Charlton and Arnell)	RCM climate data 're-scaled' as factors (temperature scaling from 2080s) (n=11)	Thames at Eynsham Conwy	Medium-High
Q95 flow (PDM by Charlton and Arnell)	UKCP09 (n=10,000)	Thames at Eynsham Conwy	Medium-High
Q95 flow (Catchmod)	UKCP09 (n=1000 random samples)	Western Rother	Medium-High
Q95 flow (PDM by Charlton and Arnell)	Spatially Coherent Projections as factors (n=11)	Thames at Eynsham Conwy	Medium-High

Table 6.3 Comparison of climate change impacts on Q95 for the 2030s (2035) for different catchments and climate datasets.

[15] Note: For this study CEH provided 10 of the Future Flows climate data sets for the Thames (one data set was still being checked).

Catchment/Water Resource zone	Climate data	Average change (%)	Range (%) (10^{th}-90^{th} percentiles)
Thames at Eynsham	UKCP09	-34.7	57.6
	RCMs	-27.2	14.1
	SCPs	-40.6	26.2
	Pattern scaled RCMs	-31.2	25.7
Conwy	UKCP09	-22.3	40.2
	RCMs	-14.9	16.2
	SCPs	-18.0	30.0
	Pattern scaled RCMs	-15.2	16.8

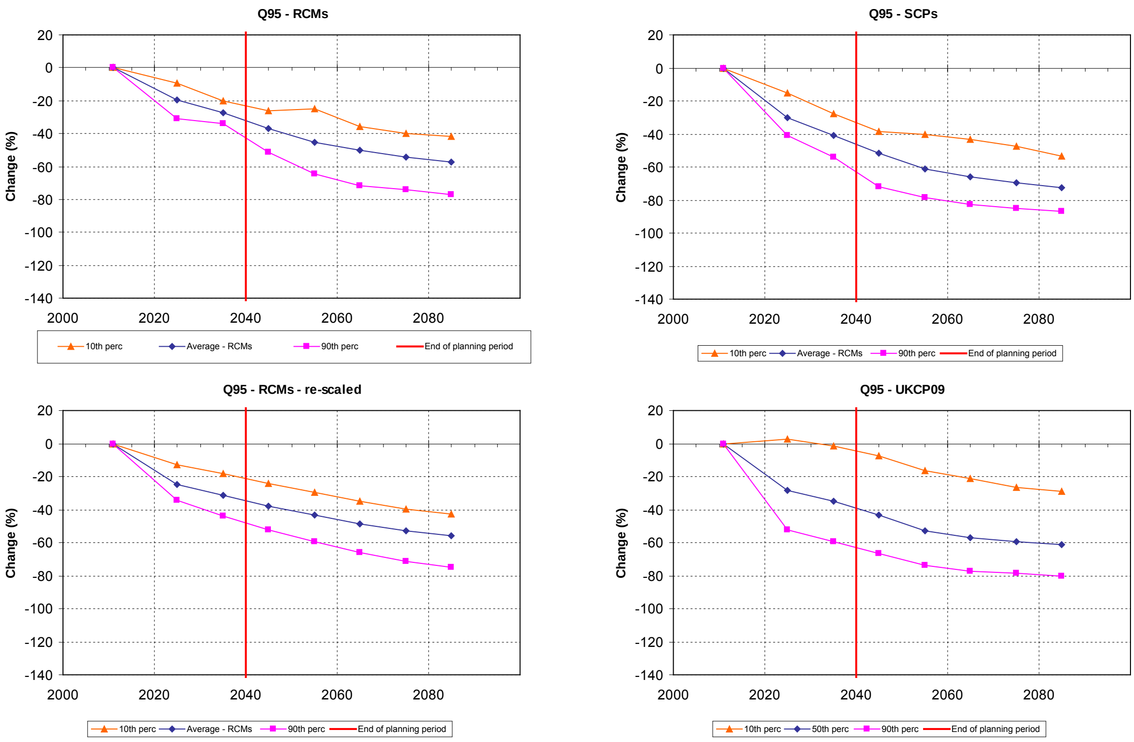


Figure 6.1 Trajectories for the Thames at Eynsham using different climate data (based on PDM modelling by the Walker Institute).

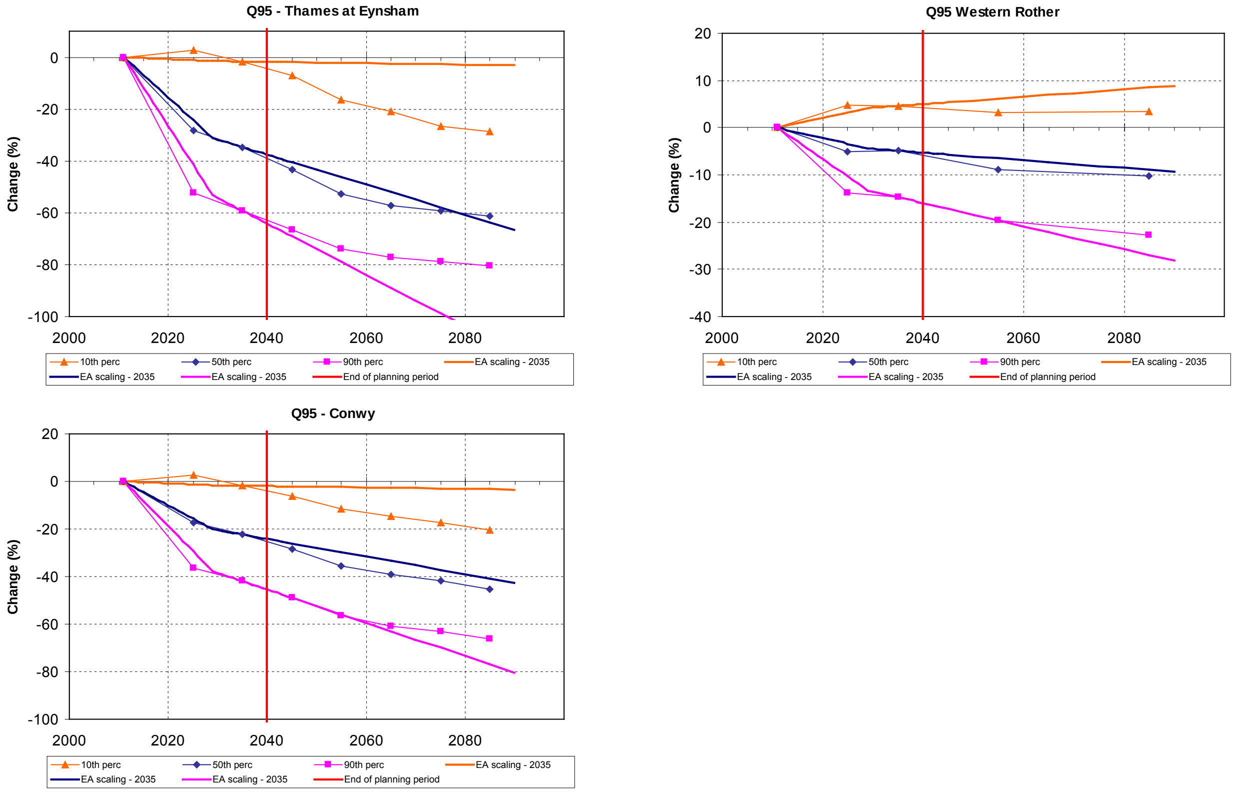


Figure 6.2 Environment Agency equations centred on the 2030s fitted to trajectories of Q95 change (%) using UKCP09 data.

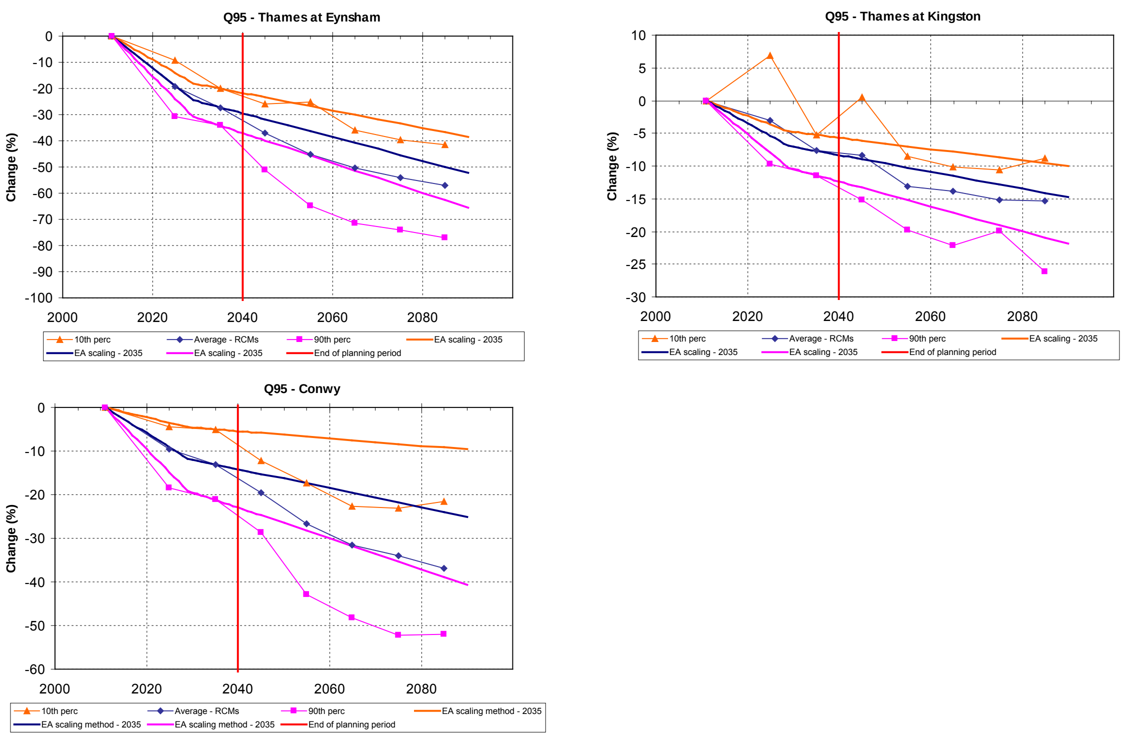


Figure 6.3 Environment Agency equations centred on the 2030s fitted to trajectories of Q95 change (%) using Future Flows/RCM data.

6.2.5 Selection of base year

The selection of base year could have an impact on the timing of proposed investments in water resource plans. Previously, water companies have tended to assume that climate change is implicitly included in DO up until present. However, since DO is typically determined based on historic droughts occurring in 1921 or 1976, this approach could potentially lead to an underestimation of the risk to supplies.

There is currently no reliable published research available which can help quantify how much climate change may have already influenced the risks of drought. Some authors have attempted to attribute hydrological events in the last two decades to climate change (Pall *et al*., 2011) but this is a new research area and beyond what is practical for water resources planning.

Using the scaling equations above, the base year is 2012 and reductions in DO, or increases in demand, will increase steeply to 2030/31 and then join a trajectory that can be traced back to 1975 (the centre of the 1961-1990 period). This approach has the strange effect of steepening the initial curve and also showing less impact, for example in 2012/2013, than was assumed in the previous plan. This raises some concerns that the approach may be under-presenting the current risks of a significant drought. However, the differences between scaling the 2025 impact from 2009 and the 2035 impact from 2102 are likely to be within the range of uncertainties considered in Headroom, which would seem the appropriate place to deal with any concerns that exist of timing of impacts.

It is suggested that water companies need to decide how precautionary the plans should be and if this is a concern the additional uncertainty should be determined in a simple way as part of Target Headroom (using S8 or S6). Detailed work could be done to back up this argument but this additional modelling (for example by applying P and T changes expected for a 0.7°C rise in climate since the 1970s (Jenkins *et al*., 2010) to a 1961-1990 climate and running through models) is unlikely to be cost effective. Testing this approach was outside the scope of this project.

6.2.6 Proposed revised method for scaling DO and Headroom

Based on the use of different variations of the current Environment Agency scaling method to trajectories using a range of climate datasets indicates that the following approach to scaling future DO is proposed for the next water resource management plans:

- Apply the Environment Agency formula for scaling based on the 2030s period including interpolation from present and extrapolation to 2040.
- For time horizons beyond 2040, use scenarios for the 2050s to fix the end point and interpolate between the 2030s and 2050s.
- Use the results of all model runs for the headroom distribution and then scale the headroom trajectories of interest. Scaling of the full Headroom distribution may not be necessary using UKCP09 data as we found that the uncertainty range tends to remain constant over time.

Where results for different time slices are available, for example the 2020s and 2030s, interpolation could be considered between these points. The main issue with this approach and using UKCP09 data is that this can only be done robustly for average DO. Using RCM data, linear interpolation between time slices could potentially be done for individual projections although these are also not ‘temporally smooth’. Where individual climate change scenarios need to be used for developing supply-demand balances for testing different options, UKCP09 data for one time slice could be considered but due to the fact that the scenarios are independent, several time slices cannot be used together.

With regards to headroom, the uncertainty range obtained using UKCP09 data is generally very similar for all time slices (see Figure 4.5). This is due to the fact that for the earlier period natural variability introduces a lot of variation in the results, whereas later on natural variability decreases but more of the uncertainty is due to uncertainty in the climate projections. This feature suggests that the uncertainty range may be assumed to remain constant over time if UKCP09 data is used. Using RCM data this is not the case and the headroom trajectories should be scaled using the Environment Agency method.

6.2.7 Limitations and uncertainties

The main limitations and uncertainties in terms of the proposed approach and use of the UKCP09 and Future Flows/RCM data:

- Very different results may be obtained depending on which set of climate change scenarios is chosen for the analysis, regardless of scaling equation selected. This may have a greater impact than the choice of scaling equation.
- The main issues with UKCP09 are the number of scenarios required (between 20 and 100 as a minimum) and the fact that the scenarios for time slices are completely independent. This means that scenarios for one time slice can be scaled using the Environment Agency equation but interpolation can only be done based on more than one time slice for the average impact on DO.
- The RCM data is limited by the fact that not all the uncertainty is included in the 11 projections compared with UKCP09. Furthermore, natural variability within the projections produces a lot of noise looking at the trajectories, and for this reason it may be advisable to stick to one time slice for interpolation/extrapolation.
- The SCP data include more of the uncertainty but also include a lot of fluctuation over time. Furthermore, similarly to the UKCP09 data, they do not seem to incorporate variability from one time slice to the next and it would therefore be necessary to stick to one time period and use the Environment Agency equations for interpolation/extrapolation.
- Using rescaled RCM scenarios would avoid this problem, but some documentation would be required to justify the rescaled scenarios – which would be straying even further from UKCP09 territory and standard guidance.
- The selection of base year is important for future investment plans and there is currently no reliable information on how climate change may have already changed the potential risks of hydrological drought.

6.2.8 Conclusions and recommendations

The pilot study modelling work using UKCP09 data and Future Flows transient climate data has led to the following provisional recommendations for scaling climate change over a planning horizon:

- Apply the Environment Agency formula for scaling based on the 2030s period, including interpolation from present and extrapolation to 2040.
- For time horizons beyond 2040, use scenarios for the 2050s to fix the end point and interpolate between the 2030s and 2050s.
- Use the results of all model runs for the headroom distribution and then scale the headroom trajectories of interest. Scaling may not be necessary using UKCP09 data as the uncertainty range tends to remain constant over time.

7 Making decisions under climate change uncertainty

7.1 The current approach

The EBSD Framework and the Environment Agency's WRMP Guidelines are aimed at providing planners with a toolbox approach to water resource planning. The EBSD Framework was published in 2002 and provides a range of approaches to investment modelling from relatively simple approaches which do not take into account changes of levels of service, to more advanced approaches that combine stochastic modelling techniques. The WRMP Guidelines are updated prior to each AMP submission.

The EBSD report described three approaches (Current, Intermediate and Advanced) to options selection, and the flow diagrams in Figure 7.1 show the three approaches schematically.

The impacts of climate change on the planning process are not specifically addressed within the EBSD report, partly because climate change was dealt with in Target Headroom, but the EBSD Framework has been incorporated into the Environment Agency's guidelines which incorporate climate change in a number of ways:

- Supply and Demand forecasts now (i.e. PR09) include estimates of climate change, this means that baseline supply and demand estimates over the planning horizon incorporate an estimate of climate change impacts;
- Target Headroom incorporates the uncertainty of climate change on both supply and demand, and results in a planning allowance which companies add to their demand forecast.

From our review (refer to Stage 2 reports) we have identified three broad approaches to the modelling of options in PR09[16]. These are:

- ranking of options and selection of lowest cost schemes based on average incremental social costs (AISCs);
- using a spreadsheet tool (e.g. What's Best) or other modelling optimisation tool to develop the preferred list of options based on lowest net present value (NPV);
- using 'systems models' (e.g. Miser and Aquator) to replicate systems and select options.

In addition all companies have incorporated climate change in their Target Headroom analysis.

Companies use these tools to help them decide the best investment plan. These plans are typically based on financial costs (OPEX and CAPEX) and broader economic costs (carbon, social and environmental costs and benefits). Other policies (e.g. the Strategic Environmental Assessment (SEA) Directive or water efficiency targets) may also impact on the investment decision process.

[16] During our research we identified some companies who were looking to develop more advanced approaches for PR14, including what have been described as 'probabilistic or stochastic' approaches, but (to our knowledge) these have not yet been fully scoped.

Our review also highlighted that:

- Some companies undertook scenario modelling as part of their assessment of the potential impacts of uncertainty in their plans (for instance testing the impacts of different demand forecast assumptions).
- Consultation with stakeholders is also typically used also inform the plans, with some companies undertaking Willingness To Pay surveys to take into account customer preferences.
- Target Headroom is a buffer between supply and demand designed to cater for specific uncertainties, and it is often used to determine the impact of different investment strategies on levels of service by applying it as part of a probabilistic supply-demand balance. However, this approach may be flawed, as discussed in the UKWIR project WR-27.

7.1.1 Current approach to Target Headroom

The first step to assessing headroom is to consider each of the headroom components in turn and quantify the uncertainties inherent in each and represent this as a probability distribution.

In most cases simple statistical distributions are used, such as uniform, triangular and normal distributions based on maximum, minimum and/or most likely outcomes. Another style of distribution that is commonly used is known as a discrete distribution. A discrete distribution has a range of fixed values, each with a fixed probability.

Typically, 10,000 iterations are undertaken for each distribution and these are combined in the model, which should take account of any correlations between each Headroom component. For example, climate change uncertainties around demand and supply are likely to have some correlation. The model output values describe the combination of all uncertainties considered and this total distribution is known as headroom uncertainty.

From the reviewed WRMPs it is apparent that most (if not all) companies have incorporated climate change in their Target Headroom calculations and that the impacts of climate change on both supply and demand can be a significant driver in the overall headroom uncertainty. The latest Environment Agency guidance states that companies should use the Medium/Mid scenario for climate change as the baseline scenario, and that High and Low scenarios be incorporated into Target Headroom calculations to understand the uncertainty around that baseline estimate. In particular this applies to the S8 and D3 factors in the Headroom calculations, but some companies may have incorporated climate change into other elements (e.g. water quality).

From the reviews we have undertaken, companies have not clearly differentiated climate change uncertainty from other aspects of headroom calculation in their WRMPs. This makes it difficult to compare headroom calculations across companies and for stakeholders to understand the relative impacts of climate change compared to other planning uncertainties. In some cases this more detailed analysis has been completed, but is in technical notes and appendices that may not be published.

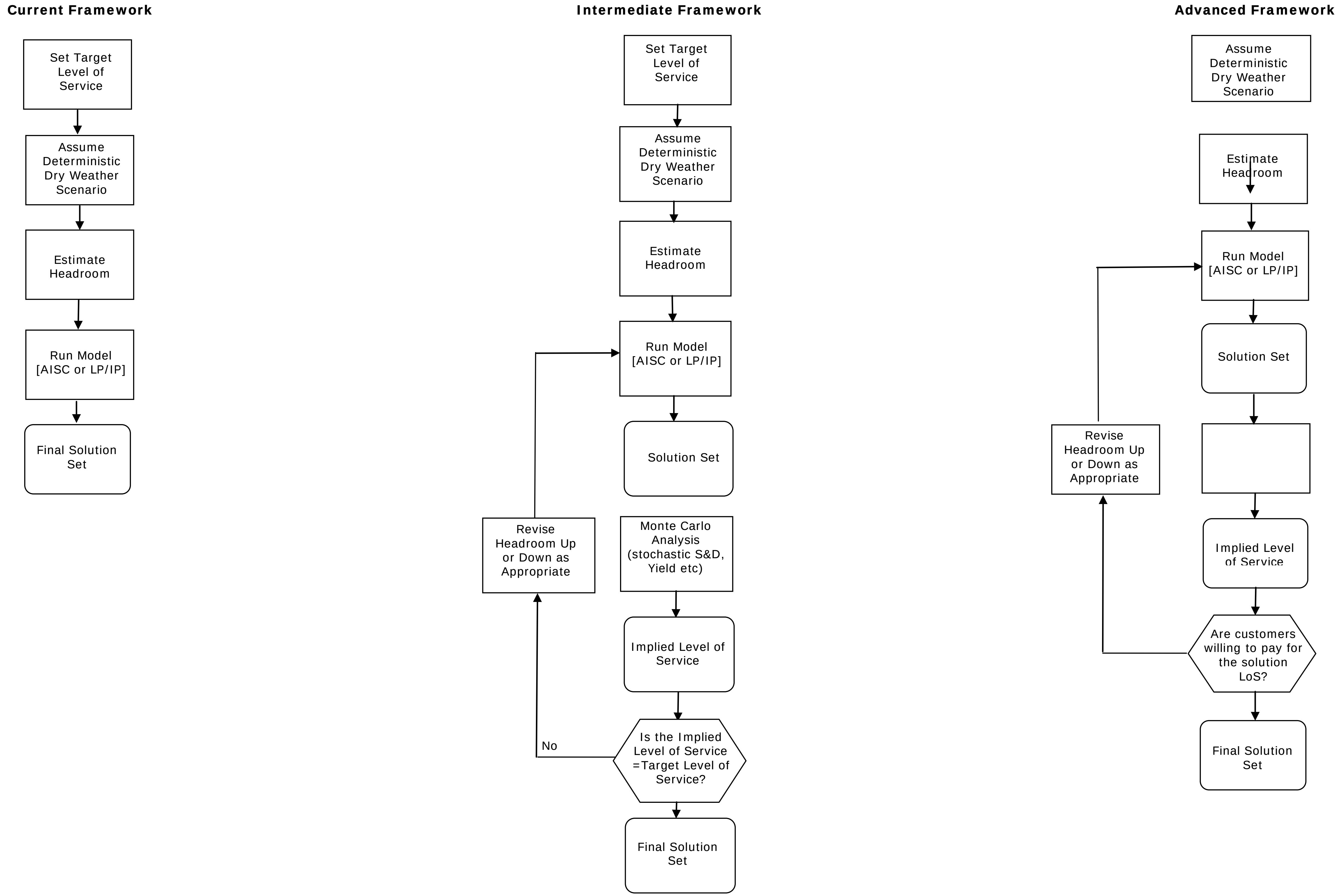


Figure 7.1 Current EBSD Guidelines.

7.2 Proposed Approach - the Adaptive Management Framework

There is uncertainty in all aspects of water resources planning, especially given the requirement to look at least 25 years into the future. The treatment of uncertainty in the selection of options has not been updated since EBSD, yet new guidance around climate change has been provided. Going forward we have tried to ensure that the proposals are consistent with a risk-based approach which is currently adopted by companies and regulators, whereby low-risk investment plans require less supporting work than high-risk investment plans. In the case where a company has sufficient supply to meet demand over a reasonable range of planning uncertainties, including UKCP09 scenarios, there is no benefit to customers or the environment in companies undertaking more detailed analysis of those risks. However, where a company takes a view on climate change which either puts levels of service at risk, or may result in unnecessary costs to customers through inefficient investment, or if there is a lot of investment driven by climate change, then we propose additional work to understand those risks and to develop 'low regrets' approaches to investment decisions. The main focus of the proposed new guidelines is 'how can better investment decisions be made given climate uncertainty?'

For Moderate and High risk investment plans, we have concluded that a broader approach to decision making is required. From the evidence base it appears that companies are already undertaking much of this analysis, so our approach is to provide some specific guidance to encourage consistency across the industry.

It should be noted that this guidance is written in the context of climate change uncertainty and how this potentially drives investment. It may be appropriate to incorporate some of the changes discussed where uncertainty other than climate change is driving investment, but that is beyond the scope of this project.

7.2.1 Assessing the Risk Profile

Clearly, the current EBSD Framework and Environment Agency's guidelines are well established and provide planners with a toolkit for the water resource planning process. We could not identify any consensus to move away from the current EBSD-based approach, though we noted that companies are looking for flexibility going forward.

The approach we have developed is risk-based so companies with low-risk investment plans will not be required to undertake any further analysis, whilst those investment plans considered more risky will need to show that the investment decisions they have made are robust to a range of future uncertainties.

To be consistent with other elements of this report, we have developed our approaches based on three levels of risk: - 'Low', 'Moderate' and 'High'. As a first step, companies will have to undertake an analysis of the amount of risk in their WRMPs and they should justify their ranking.

Figure 7.2 Risk Profile.

We propose that the risk assessments take into account two elements in relation to climate change: investment uncertainty and investment costs. (There are opportunities to link these investment criteria with the formal vulnerability assessment described in Section 3).

Investment Uncertainty could be defined as the estimated range of deficits a company calculates under a range of realistic planning (in the context of this study climate change) scenarios. If a plan has very little uncertainty in it (the range of deficits is low), then there is little risk to customers or the environment because there is a low likelihood the investment plans developed will be 'materially wrong'.

Investment Costs are defined as the total investment to meet a supply demand deficit. If the investment costs are low under a range of planning scenarios, including those with climate change, then there is little or no benefit from undertaking further analysis to try to mitigate the risk. However, where investment costs are large, including where these are driven by climate change, there is greater risk to customers' bills. Large projects tend to have long lead times and construction times, mitigating some of the risk, however we think companies should still use a broader range of tools to show that they have considered these risks in their investment appraisals.

In Figure 7.3 we have developed a simple risk matrix which will help companies describe the risk in their investment plans.

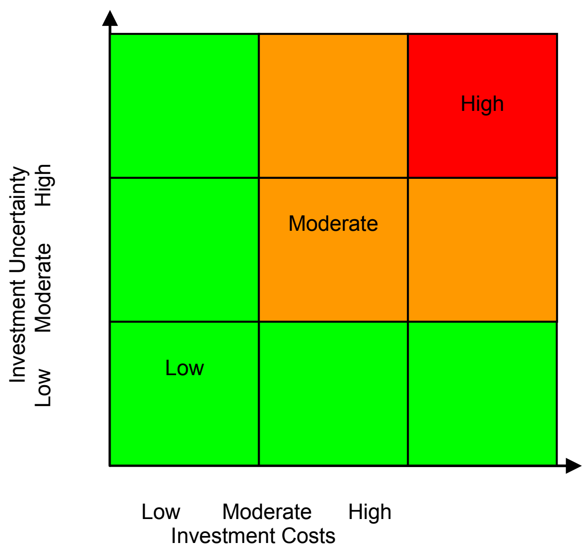


Figure 7.3 The Risk Matrix.

7.2.2 Estimating Climate Change Uncertainty

It is important to understand the amount of uncertainty in a Water Resource Management Plan (WRMP). Target Headroom provides an appropriate tool for this analysis, however there is no guidance as to which percentiles should be adopted in the calculation of Target Headroom. It is currently difficult for stakeholders to compare the uncertainty in different WRMPs because different companies choose to adopt different views as to an acceptable level of risk. Further to this, it is not currently a requirement to present the contribution attributable to climate change uncertainty separately from the overall Target Headroom.

We proposed that climate change should be distinguished from the other components of Target Headroom and reported separately. This involves calculating four aspects of headroom separately within the larger Target Headroom calculation:

- supply uncertainty excluding climate change (S1 – S7, S9);
- demand uncertainty excluding climate change (D1, D2, D4);
- impacts of climate change on supply (S8);
- impacts of climate change on demand (D3).

We also propose that all companies should report a specific reference level for all aspects of climate change uncertainty to ensure consistency across the industry. Within their WRMPs companies should still manage their own risk profiles and build their plans on levels of risk which they, and their customers, will accept.

Figure 7.4 shows the output from a Risk-based headroom model to indicate the relative uncertainty in each of the four aspects. Within the figure, the red and purple areas show the calculated uncertainty on supply and demand solely from climate change, whilst the green and blue area show other aspects of planning uncertainty.

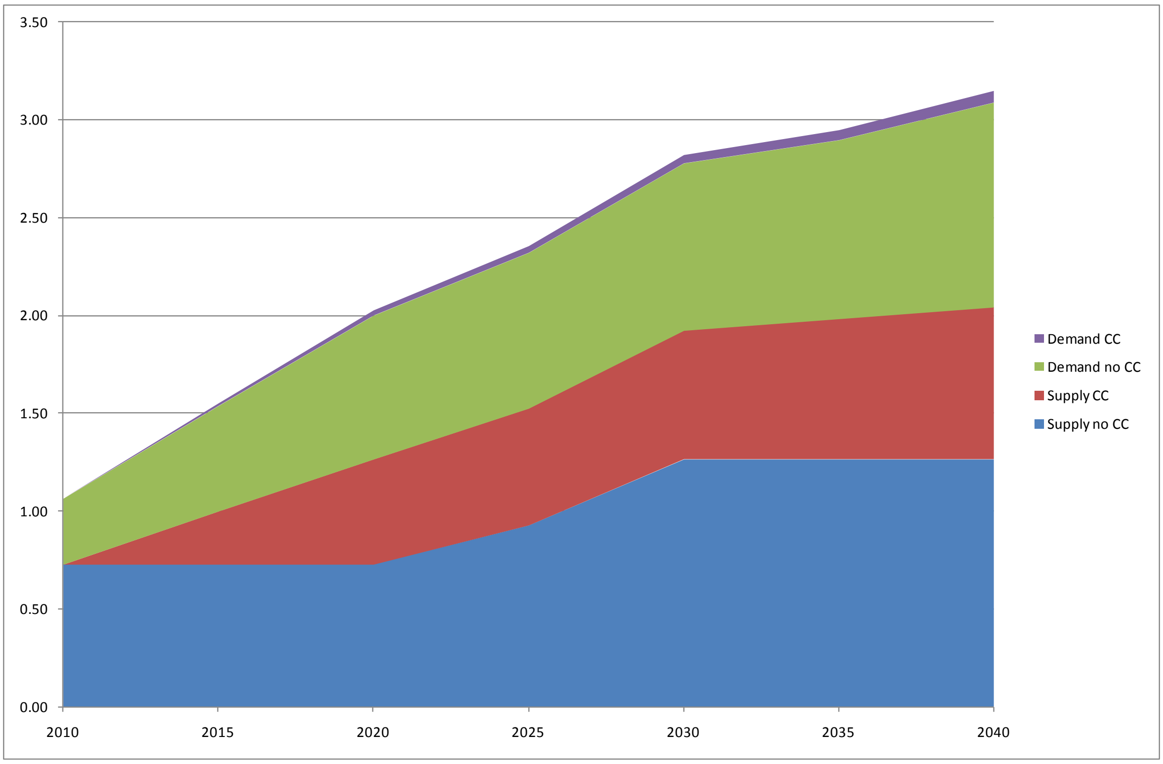


Figure 7.4 Presentation of climate change impacts in Target Headroom.

7.2.3 Adaptive Management

Figure 7.1 shows the three current approaches to scheme selection: these are called the Current, Intermediate and Advanced Approaches. It is proposed that this broad framework still applies, but where climate change uncertainty is great and has the potential to drive significant investment (Moderate to High Risk), then additional phases of work are required based on an Active Adaptive Management Approach to better understand and present that risk[17].

Adaptive Management is used in other countries for water resources planning (e.g. USA and Australia), and in the UK in other sectors (e.g. power generation and flood risk). The concept of Adaptive Management is considered to be a robust approach to investment modelling in situations where climate change uncertainty means there is a moderate or high level of risk in a WRMP. These changes should promote a 'no' or 'low-regrets' approaches to investment planning.

At this stage it is worth outlining with what we mean by Adaptive Management.

Definition

There are several definitions of Adaptive Management, but the key element is 'making sure that decisions made now about the future can be adapted in time as the future becomes more certain'.

The current AMP cycle can be considered a **Passive Adaptive Management** approach ('a review of decisions based on updated information') by requiring water companies to update plans. **Active Adaptive Management** involves a more effective approach to developing adaption measures to improve the robustness of decisions made. Several different approaches have been reviewed to inform our proposed approach that incorporates this concept.

Low Risk Approach (Do minimum)

A key element of this work has been to develop a risk-based approach so that companies with low risk water resource plans are not required to undertake unnecessary additional work.

As described in Section 7.2, we propose using Target Headroom to understand and present the impact climate change is having on supply and demand forecasts and to undertake an initial risk assessment to identify if a WRMP is has Low, Moderate or High levels of investment uncertainty and investment cost.

Companies will be expected to comment on whether they feel their investment plans are Low, Moderate or High Risk (as defined in Section 7.2). Where plans are Low Risk then they should follow the current EBSD approach and develop a least cost plan. This means relatively little further work is required for these companies, as investment plans are likely to be robust irrespective of climate change uncertainty.

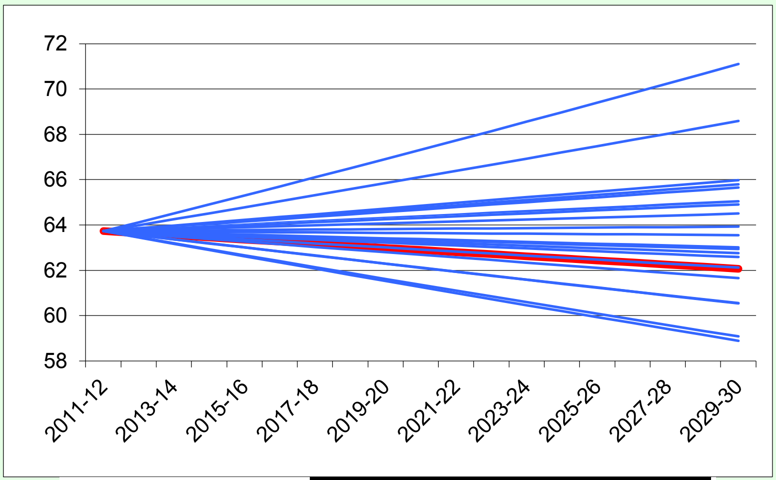
The Case Study in Box 7.1 is based on our South East case study and uses work described in Section 4 to estimate Deployable Output to understand the levels of risk in the WRMP. In this instance we used a low demand forecast that included savings predicted from the company's current metering programme.

[17] It may be appropriate to incorporate these changes where uncertainties other than climate change are driving investment, but that is beyond the scope of this project.

Box 7.1: Case study – South East zone with a low risk investment plan

Aim: The purpose of this study was to test the use of the proposed changes to Guidance for a Low Risk WRMP.

Approach: The approach involved using data from the resource zone using the results of earlier analysis on Deployable Output to determine the level of risk and the impacts of uncertainty on investment plans. One hundred different supply forecasts were produced by HR Wallingford, these are presented below as a graph (DO Ml/d versus Time) and summary table for the 2,035 results. In the summary table the likelihood of different forecasts are grouped as 24 scenarios, each with associated probabilities (the four most likely outcomes are shaded red).



		Temperature			
		T1	T2	T3	T4
Rainfall		-0.5 - 0.5	0.5 - 1.5	1.5 - 2.5	2.5 - 3.5
R0	<-10	0	1	0	0
R1	-10% - 5%	0	6	9	2
R2	-5 - 0%	1	12	21	8
R3	0 - 5%	1	11	16	3
R4	5 - 10%	0	3	4	2
R5	>10%	-	1	1	0

The range of DO forecasts is from 59 to 71Ml/d so the key question is what investment plan should the company adopt given there is a large range in DO uncertainty.

Results:
The level of risk in this zone depends upon estimates of supply and demand. If a low demand forecast is used then only limited investment is required and that is at the end of the planning horizon. The investment uncertainty is therefore 'Low'.

Conclusions:

- In this case study we used a Low demand forecast. In spite of the uncertainty in supply forecasts given in the graph, little investment is required even under the hottest, driest scenarios.
- In this case the 2002 EBSD Framework provides perfectly adequate tools for planning.

7.3 Moderate or High Risk Approach

If a company considers its WRMP to be ‘Moderate’ Risk, it should decide whether to use the EBSD approaches or the [Active] Adaptive Management Approach. Where a WRMP is High Risk then we would expect companies to use the [Active] Adaptive Management Framework.

Broadly, we have identified the following tools and broader considerations, which should be considered as part of an Adaptive Management approach:

- Undertaking sensitivity analysis and testing the response of projects to climate change to determine the most robust set of options given climate change uncertainty.
- Considering the use of stochastic modelling tools which may be appropriate where companies have a High Risk WRMP.
- Considering whether (given a background of uncertainty) a simple ‘least cost’ approach to investment modelling is appropriate.
- Where companies have a high Target Headroom estimate they will need to confirm that those decisions are not putting customers (and potentially the environment) at risk by investing in options which may not be used. Where companies have taken a low Target Headroom estimate they will need to show that they are not under-investing, resulting in risks to Levels of Service (LoS).
- Where investment is being made early for options which are providing security in the future, willingness-to-pay studies will be used to support those decisions. For instance, some options might incur costs in a current AMP period, but not provide a benefit for several AMP periods. Companies should show that such investment plans are not being influenced by the strict definitions of the planning timeframe.

The Adaptive Management Framework provides companies with a range of tools to help ensure their plans are robust. It is possible that a Least Cost plan developed under EBSD would not be consistent with Adaptive Management techniques, so Adaptive Management provides companies with an approach which will allow them to justify a plan which is not Least Cost under a simple deterministic approach.

Companies can use a range of techniques, including sensitivity analysis, stochastic modelling, robust decision making (RDM), optimisation and willingness to pay to support a preferred plan and show that risk and uncertainty has been fully addressed.

Some of the tools that companies may consider are described in more detail below.

7.3.1 Sensitivity Testing and Resilience

Demand forecasts and DO estimates will be different under different climate scenarios and many options will have different DOs depending upon the weather (for instance, a surface water scheme will (typically) have a lower DO during a 1:50 year event than a 1:20 year event).

If single deterministic estimates of supply and demand are used and LoS are set at (say) 1:20 years, then options to meet 1:20 years will be selected. But these options may not be the most suitable to ensure future demand is met under a wider range of return period events and future climate change scenarios.

In cases where companies' LoS are at risk from climate change, a two-staged approach is suggested to test the robustness of potential options across the range of probabilistic climate change scenarios. This will help ensure that options are selected which increase supply across a broad range of drought events and climate change scenarios.

Firstly, companies should determine the supply-demand balance over a range of planning scenarios, testing the combined DO of existing and proposed new options. This can be done using existing methodologies with behavioural analysis or other agreed approaches to show the effects of different critical drought events and levels of service.

7.3.2 Use of a Stochastic Model

We have undertaken a review of stochastic modelling approaches and suggest that it may be appropriate for complex supply-demand deficit where uncertainty is resulting in a High Risk WRMP.

Using this stochastic approach we have shown that the preferred investment plan is likely to be more robust than a solution developed from a deterministic model.

Companies that use fully stochastic models may negate the need for calculating Target Headroom in a separate modelling package.

7.3.3 Alternative Approaches to Least Cost

The third consideration we have made is how appropriate 'least cost' planning is as an appropriate investment driver. Are there alternatives which are likely to result in a better outcome?

By least cost we mean 'the set of options with the lowest NPV which can meet the supply demand deficit'. The NPV calculated by companies is often a broader economic cost of CAPEX, OPEX, environmental, social and carbon costs (and benefits).

We believe that companies should be developing plans which are robust against a range of future scenarios and that investment which is required now should be less risky (more certain) than investment required in the future.

A complementary approach to an assessment of this sort would be to undertake a series of scenarios to determine which options are most likely to be built given a range of possible future outcomes (we have called this likelihood testing).

For instance, if there are 3,11 (as in Future Flows) or 100s of climate scenarios then supply-demand balances could be created for each one and the results used to identify those options which are most often selected. Where possible and appropriate, this would take account of the probability of each scenario. Developing an investment plan based on those options which appear in the list of options most regularly selected would be a pragmatic approach, with more certainty in the early years of a plan. These approaches are already practised by some water companies in their current planning processes by considering different demand profiles and including/excluding certain option types.

7.3.4 Plans Requiring Investment Now for the Future

In some cases, investment decisions need to be made many years in advance of construction to ensure that approvals are obtained. However, there is a risk that as plans change, these options become less attractive and may never be fully utilised.

This means that customers may be required to pay some costs for options that are not subsequently built, or are not the most suitable option. For example, it is typically quoted that an impounding reservoir takes 15 to 20 years from feasibility studies to it providing Deployable Output. Over three or four AMP cycles customers may be paying increased charges for something that does not subsequently bring benefit.

We suggest that companies should test their models to ensure that modelling code or the way cost data is presented is not unduly influencing options assessment. We do not propose that demand forecasts or DO forecasts are modelled beyond 25 years other than by simple extrapolation (there is too much uncertainty in forecasting to warrant complex additional analysis).

In situations where large schemes are proposed which are required towards the end of the planning horizon, we propose that customers are asked to confirm their views on these schemes and confirm their willingness to pay (WTP) for such options. This is particularly important where customers' bills may increase in advance of an option supplying DO, and especially where such options may prove to be 'risky'.

Customers may express a preference to wait and see or develop different schemes which require less up-front capital risk.

Most (if not all) companies undertake willingness-to-pay studies as part of their Business Plans and WRMPs, so we do not anticipate that this additional requirement will be particularly onerous. The WTP should be incorporated as an additional cost (positive or negative depending on the responses), to each options costs.

7.3.5 Case Study

In the case study on the following page we have used the same Deployable Output and options data as the previous example; however we used a higher demand forecast (excluding the impacts of any metering programmes). This results in a requirement for investment under some climate scenarios. We used a range of techniques to determine the most appropriate investment plan.

7.4 Limitations and issues with the different approaches

We set out some limitations and issues under two separate headings below. Firstly we consider the impacts of changes to the presentation and reporting of Target Headroom and secondly we discuss the implications of the Adaptive Management Framework.

Overall we have tried to develop approaches which will help companies make decisions given that the new UKCP09 scenarios may provide a broad range of potential supply demand balances. Tying to model many supply and demand forecasts could become a complicated analysis. The approaches we have set out in Section 7 are designed to help companies develop investment plans against this uncertainty.

Case study – South East Zone, High Demand Forecast

Aim: The purpose of this study was to test the use of the proposed changes to Guidance for a Moderate or High Risk WRMP. The same supply data as presented in the previous case study was used; however a higher demand forecast (excluding a metering programme) was included.

In this case, six of the 24 scenarios show a deficit during the planning horizon (shaded red); the probability that a deficit will occur is around 38% for this specific emissions scenario.

		Change in Temp (deg)			
		-0.5-0.5	0.5-1.5	1.5-2.5	2.5-3.5
Change in Rainfall	<-10%				
	-10-5%				
	-5-0%				
	0-5%				
	5-10%				
	>10%				

Approach:
The key question is what investment plan the company should adopt given there is a large range in DO uncertainty. Investment costs to meet the deficit are considered relatively high, and the probability that a scheme will be required is ~38%. We undertook a range of Adaptive Management Techniques to test different possible investment plans:

- Likelihood Testing - Using an optimisation model we ran 6 scenarios to see which options are selected and built a plan around those options.
- Resilience Testing – We assessed the vulnerability of different options to climate change. We built a plan around those options considered least vulnerable.
- Stochastic Modelling – We tested if it was appropriate to use stochastic modelling techniques to select options.

Results:
Our analysis showed that two options were repeatedly selected in each of the approaches set out above. The approaches were relatively practical to use and provided confidence in the results.

Conclusions:
Under higher demand scenarios there is a risk that investment in the South East case study will be inefficient. Using Adaptive Management tools helps to identify a preferred set of options.
Use of stochastic approaches is common in other utility sectors and may be appropriate for complex supply-demand balances where there is uncertainty in the supply demand balance.

7.4.1 Target Headroom

We have proposed only minor changes to the Target Headroom analysis.

1. We propose that all companies should report climate change uncertainty separately from other aspects of planning uncertainty.
2. We propose that companies publish specific reference levels of Target Headroom uncertainty, e.g. using the 50th percentile or 75th percentile (noting the 50th would be zero if this was Headroom around the forecast lines so the 75th percentile, which equivalent to 50% of the residual risk would be more appropriate).

We do not expect that these changes will result in significant additional costs, but will provide greater clarity and understanding of the impact climate change uncertainty is having on investment plans.

Companies can choose and justify their own approach to Headroom following the Environment Agency WRPG, but it is important that for the climate change headroom components to be clearly reported. This will allow an auditor to understand how much climate change was included on the supply and demand lines, how much is included in Headroom and the magnitude of the residual risk. Company plans can then be compared using a specific reference level of headroom.

Some companies may wish to use a fully stochastic modelling approach in their investment modelling. If this is the case, they should consider how to ensure that they meet these two requirements.

7.4.2 Adaptive Management Framework

Companies which have 'High Risk' plans could be required to follow the adaptive management framework whilst companies which have a 'Moderate Risk' score can choose whether to follow the approach.

We have avoided being prescriptive in how companies should ensure their plans are robust given the uncertainty of climate change. This means that companies should be able to avoid requirements for investment in new modelling techniques unless they particularly wish to invest in new products. We have not suggested that companies move to fully stochastic methods, although our work has shown that this is possible.

We recognise that moving away from a deterministic least cost planning approach to one which involves judgement, expert opinion and testing may need to be explained more fully to stakeholders to ensure that they understand how a company has developed its plans. The WR-27 project was developed for this purpose but it may not completely cover some issues related to how climate change should be incorporated into future plans.

There is the possibility that companies may use different assumptions in their analyses; for instance one company may consider its plan to be Low Risk, while another may consider a similar plan Moderate or High Risk. Companies may need to understand these issues when, for instance, they are discussing bulk supply agreements or shared resources.

8 Conclusions

This study presents the following methodological improvements to dealing with climate change (and uncertainty) in the WRMP process, with respect to the principles for new methods introduced in Section 1:

- **Proportionate**: Adopting a proportionate approach to dealing with climate change, supported by a vulnerability assessment**,** to guide the level of analytical effort to evaluate the vulnerability of a particular Water Resource Zone to climate change and the potential value of climate change driven investment.
- **Risk-based**: Some of the methods promoted using UKCP09 allow for more risk-based approaches, including the intermediate vulnerability assessment and the use of probabilistic aspects of UKCP09 for DO or demand analysis. Future flows is arguably more suited to scenario modelling (with just 11 equally probable runs). However the most important aspect is for companies to consider a range of possibilities in order to develop robust plans.
- **Participatory**: The early work on vulnerability provides the evidence and basis for early discussion on the most appropriate approach for climate impact assessment.
- **Transparency:** Clarity and consistency in the treatment and presentation of climate change uncertainty by adopting a reference level for Target Headroom in the Supply-Demand Balance and clearly stating and presenting the contribution from climate change. Again the simple vulnerability assessments can make a complex topic easier for stakeholders to understand.
- **Robustness**: The tools described in Chapter 7 demonstrate appropriate approaches to investment planning that promote robust investment plans that value flexibility and adaptability considering over delivering an optimum least-cost solution to maintaining a single supply-demand balance. Further work on this was completed in UKWIR project WR-27.

The main changes proposed as a result of this research are as follows:

- The need for vulnerability assessments (basic or intermediate) to clearly describe each water resource zone's vulnerability to climate and future climate change.
- The use of the outcome of vulnerability assessment to determine the level of modelling required to assess the future impacts of climate change.
- In low vulnerability zones, a minimum amount of impacts assessment is required using UKCP09 or Future Flows. For the climate change and hydrological analysis, this would involve using 5, 11 or 20 different climate change scenarios for the 2030s.
- In medium and high vulnerability zones, a greater level of analysis is recommended using UKCP09 or transient Future Flows data. For the climate change and hydrological analysis, this would involve using 20 or more different climate change scenarios for the 2030s.
- There are alternative methods to scaling the impacts of climate change from the base year to the 2030s and beyond; the standard approach of applying a two stage interpolation (as per the Environment Agency WRPG guidance) has been shown to be effective until the 2030s using UKCP09, but other methods of scaling are also valid, such as modelling the 2080s and temperature scaling back to 2012.

- There may be practical limitations to the number of climate change scenarios that can be applied to detailed groundwater models and the most complex water resources systems models. In such cases sufficient climate and hydrological analyses should be completed to place a reduced number of runs in the full context of UKCP09 and Future Flows.
- UKCP09 products, including the Weather Generator, are appropriate for modelling the potential impacts of climate change on peak demand as well as average demand.
- Headroom assessment should clearly distinguish between climate and non-climate risks and report outputs for specific reference levels of Headroom, to enable easier comparison between zones and companies.
- More advanced decision making methods are recommended for zones with moderate or high levels of climate risks. These generally involve considering how options perform under a range of future scenarios, modelling a wider range of scenarios, and sensitivity testing.

There is still a lot to consider when scoping and implementing a climate change impacts assessment. The use of a simple audit checklist may be helpful to keep track of approaches for internal consistency and to record key decision points.

Potential checklist of decisions and actions related to climate change assessment.

	Task	**Outcome**	**Comment**	**Task**
1	Vulnerability Assessment	Vulnerability	Low / Moderate / High	Determines levels of vulnerability and need for simple of detailed modelling in later stages
		Drought Indicator		A simple indicator that links water availability to climate, which is useful for targeting samples of UKCP09
2	Identify climate change tools/products to use for supply – demand forecasts	UKCP09 projections	Yes / No	The use of small or large sub-samples of UKCP09 projections are recommended for DO assessment.
		UKCP09 Weather Generator	Yes / No	The WG is suitable for assessing impacts on Peak Demand and, under some circumstances DO.
		Future Flows climate time-series	Yes / No	Factors are appropriate for Level 1 DO assessment. Time series for Level 2 assessments.

		Future Flows River flow/ groundwater time-series	Yes / No	Factors are appropriate for Level 1 DO assessment. Time series for Level 2 assessments.
3	Regulatory engagement	Meetings / consultation		Maintain log of consultation and outcomes
4	Climate change impacts on Deployable Output	Proposed approach		Provide details of products and sampling strategy
5	Climate change impacts on demand	Proposed approach to Annual Average demand		Provide details of products and sampling strategy
		Proposed approach to Peak Period demand		Provide details of products and sampling strategy
6	Scaling impacts	Proposed approach	Environment Agency WRPG equation	Provide details if a different approach is used.
7	Target Headroom	Percentage used in SDB		75% recommended
		Percentage contribution to Target Headroom from climate change		
8	Investment Planning	Risk Profile	Low / Moderate / High	
		Proposed approach testing robustness of preferred options	Sensitivity testing / Likelihood testing / Stochastic modelling / Other	Provide details including number of ‘futures’ considered and the approach to ensuring consistency between supply and demand forecasts

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Appendix A
Use of UKCP09 for Peak demand

Introduction

The overview report presented a range of different approaches to assessing the effects of climate change on peak demands, based on the vulnerability of a particular zone to climate change impacts in the critical period planning scenario. The summary table included in section 4.4 of the overview report is presented here as Table 1.1.

Table 0.1 Examples of potential approaches to climate change and CRITICAL PERIOD demand analysis.

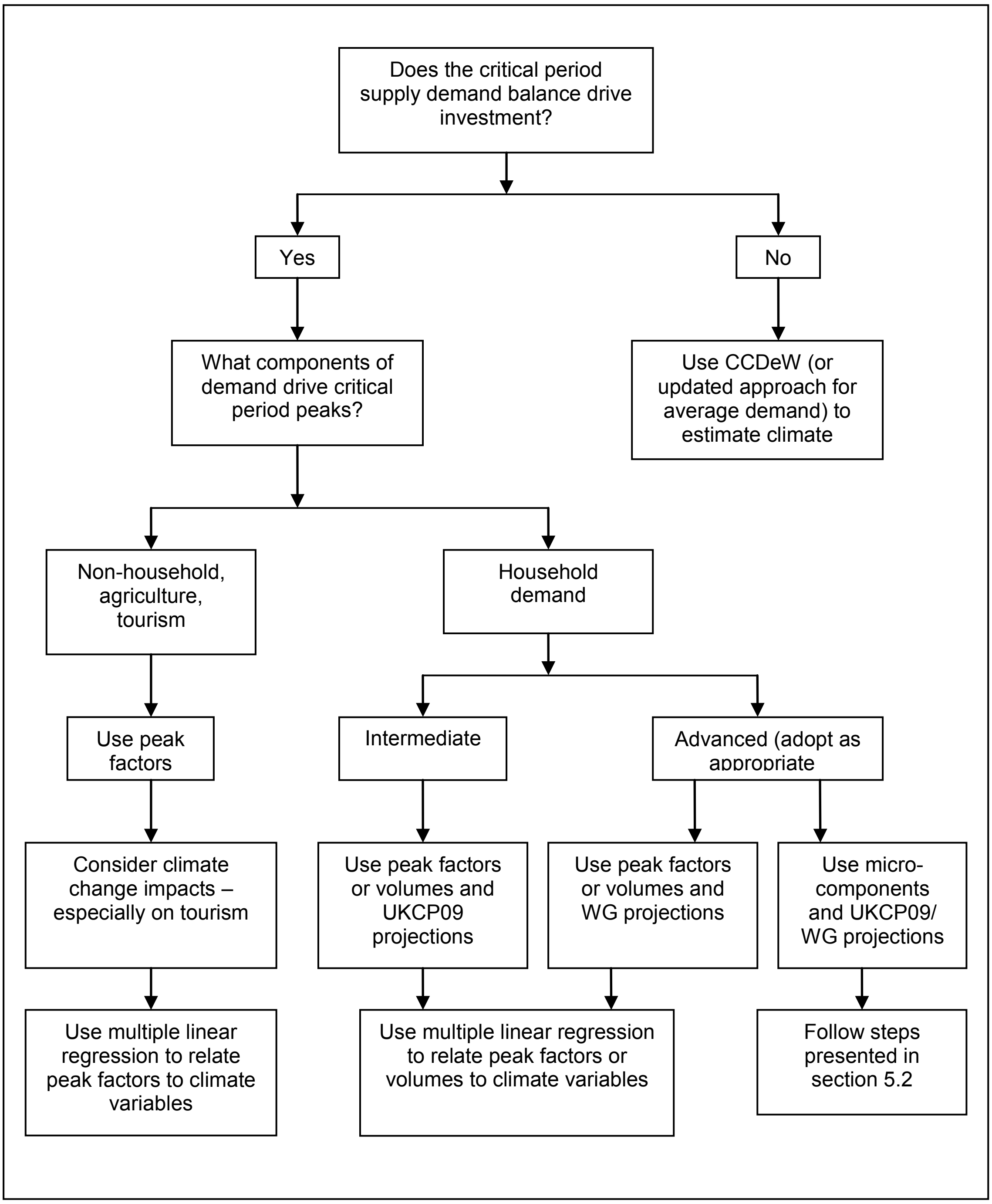
Context	Potential approaches	Comments
Critical period supply demand balance in water resource zone is not likely to be an issue, even under climate change scenarios.	No specific climate change analysis of critical period demand forecast is necessary.	
Climate change uncertainty on critical period demand is small and/or is unlikely to affect investment planning.	Explore drivers of peak demand. Consider their sensitivity to changes in climate variables under climate change. Refer to UKCP09 probabilistic outputs to identify uncertainty associated with these variables. Develop estimates of how peak demands may change in response to these drivers – using historic data from relevant years (e.g. drought years), if available.	If a company has done any work on climate-demand relationships, then a simple investigative approach could explore how predicted temperature changes (using UKCP09 probabilistic outputs) could affect these relationships – e.g. linear regression between daily maximum temperature and distribution input (DI). A micro-component-based approach could include consideration of how temperature change at different UKCP09 output probabilities is likely to affect frequency of use of the micro-component considered most sensitive to climate change – e.g. frequency of shower use. These behavioural changes are likely to have the greatest impacts on peak demand.
Climate change uncertainty on critical period demand is moderate and/or uncertain and/or may affect investment planning	Further work on climate and demand variables could be considered. This would utilise approaches currently used by companies (e.g. linear regression of distribution input and daily maximum temperature, or neural network analysis). Companies may wish to undertake studies to collect more/better data on climate sensitive micro-components. These studies would need to be maintained over several years to collect usage data under a range of climate sequences including a mix of dry winter and dry summer sequences.	Initial analysis could be based on probabilistic outputs from UKCP09, applied to DI or household demand. Further, more detailed investigation could utilise scenario outputs, making use of the approaches developed for the UKWIR 'rapid assessment' study[18] to identify a 'smart sample' set of scenarios. Outputs from investigations would be useful in defining relationships between principal climate variables and principal micro-component variables. Analysis could consider two or three components – e.g. shower frequency, garden watering volumes, outdoor pool sales (i.e. ownership)

[18] UKWIR (2009) Assessment of the Significance to Water Resource Management Plans of the UK Climate Projections 2009. Ref: 09/CL/04/11. London. UKWIR.

Climate change uncertainty on average household demand is predicted to be large and/or is likely to affect investment planning.	Detailed micro-component analysis could be considered, focused on changes in frequency of use, but also assessing how climate factors influence purchase (and therefore ownerships) of certain water-using devices. This would be based on UKCP09 scenario outputs, potentially making use of the methods and approaches developed for UKWIR in the 'rapid assessment' study[18]. Investigations could focus on key climate variables such as temperature, but also consider 'secondary' variables such as sunshine hours.	Weather Generator outputs could be used to provide detailed information on day-to-day weather patterns and to provide climate derived variables (such as sunshine hours) that are not available elsewhere from UKCP09. Consideration could be given to assessing how long-term climate change could affect structural aspects of demand – most likely through scenario analysis.

The outline approach developed previously is illustrated in more detail in the flow chart presented in Figure 1.1.

Figure 1.1 Flow chart illustrating options for climate change and demand analysis.



In this note we have selected a sample of water resource zones from across the country and have carried out a vulnerability assessment to determine what kind of analysis might be appropriate to assess the impacts of climate change on peak demands. This is presented in Section 2.

We then carry out some pilot studies on zones identified as most vulnerable to climate change impacts (or uncertainty) during the critical period. Two approaches are presented: the first used linear regression equations from the UKWIR Peak Water Demand Forecasting Methodology report to illustrate the analysis that might be used where there is a moderate degree of climate change vulnerability in the critical period scenario. This is presented in Section 3. The second approach undertakes analysis on micro-components of peak demand to illustrate the kind of approach that might be used where there is a significant degree of climate change vulnerability in the critical period scenario. This is presented in Section 4.

1.1 Using UKCP09 climate projections

The UK Climate Projections produced in 2009 (UKCP09) provide projections of climate variables (temperature, precipitation, air pressure, cloud and humidity) under three possible future greenhouse gas emissions scenarios, based on outputs from global climate models. The UKCP09 projections show a wide range of possible outcomes for these variables, which can be analysed and presented in many different ways. Practitioners should familiarise themselves with the basics of UKCP09, via the range of introductory pages available via the main UKCP09 website: http://ukclimateprojections.defra.gov.uk/.

The main UKCP09 website provides summary data on climate projections in the form of maps and graphs which are useful for high-level reporting and presentation of the predicted effects of climate change. The outputs from the main website are not in a form suitable for further analysis, as required for peak demand investigations. Such outputs need to be accessed via the UK Climate Projections User Interface, available at: http://ukclimateprojections-ui.defra.gov.uk. Registration and login is required.

Again, water resources practitioners who are new to UKCP09 should familiarise themselves with the principles of the approaches used and the various outputs available, in order to determine the approach (or approaches) most appropriate for them.

Two main sources of data are available: 'probabilistic projections of climate change', or the Weather Generator. Practitioners should consult the User Interface manual (http://ukcp09.defra.gov.uk/content/view/1145/537/) to determine which approach is most appropriate and the implications of the different approaches. Both these main approaches were used in this pilot study (by selecting data source at the start of the User Interface process): it is important to recognise that different methods, types of data and outputs (e.g. using spatially averaged outputs) may be appropriate in different situations, and that practitioners may need to trial a number of alternative approaches until a suitable methodology is finalised.

1.2 Using historic climate data

Water companies will often have access to meteorological data from key local stations. Practitioners may also wish to use published long term average data that are consistent with baseline data used in UKCP09. For the purpose of this study, a range of historic climate data for individual stations and for regions from the Met Office website has been used (available from: http://www.metoffice.gov.uk/climate/uk/averages).

The Met Office also provides data on weather extremes, available at: http://www.metoffice.gov.uk/climate/uk/extremes/monthly_temperature_country.html#highest_daily_maximum_england.

Data for the highest daily maximum temperature reported per month shows that the single highest peak in England was 38.5°C in Faversham (Kent) in August 2003, and the highest July temperature recorded was 36.5°C in Surrey in 2006.

2. Vulnerability analysis

Ten water resources zones have been selected to demonstrate how vulnerability analysis can be used to identify the different types of analysis that can be used, depending on how important peak demands are in a particular zone. The zones selected are presented and the baseline supply-demand balance situation described briefly in Table 2.1.

Table 2.1 Summary of zones selected for vulnerability analysis.

Zone name	Company	Zone characteristics
SWOX	Thames Water	Critical period deficit due to outdoor use.
Sussex North	Southern Water	Critical period deficit due to outdoor use.
~~Tywyn Aberdyfi~~	~~Welsh Water~~	~~No critical period.~~
Southern (RZ3)	Veolia Water Central	Critical period deficit late in planning period – driver not specified.
West Cumbria	United Utilities	Critical period deficit due to supply side issues.
West WRZ	Wessex Water	No peak deficit, peak driven by personal washing and outdoor use.
Fenland	Anglian Water	No peak deficit at zonal level (deficits in two planning zones). Peak driven by tourism and weekend domestic use.
Pembrokeshire	Welsh Water	Dry year and critical period deficits.
East Surface Water	Yorkshire Water	Critical period no deficit.
Colliford	South West Water	Critical period supply demand balance not assessed.

Zone characteristics taken from 'R067 v4 Climate change and peak demand note_test4.pdf', prepared as part of Stage 3 of this project.

Table 2.2 summarises the zones in terms of their potential vulnerability to climate change in the peak period, and the types of approach that water companies with these types of vulnerability should adopt. The vulnerabilities refer to the baseline scenario. The approaches are taken from an Environment Agency report in progress (*Climate change approaches in water resources planning – overview of new methods*).

Table 2.2 Vulnerability of water resource zones to peak demand impacts of climate change.

	Low vulnerability	Medium vulnerability	High vulnerability
8.1 Definition	Climate change uncertainty on household demand is small and unlikely to affect investment planning: *No critical peak period deficit*	Climate change uncertainty on household demand is moderate and/or uncertain and/or may affect investment planning: *A deficit in the peak period towards the later stages of the planning period.*	Climate change uncertainty on average household demand is predicted to be large and/or is likely to affect investment planning: *An existing deficit in the peak period, or a deficit forecast in the first half of the planning period (particularly in AMP6) driving investment options.*
Zones	DCWW: Tywyn Aberdyfi zone – no peak period in revised draft WRMP. **Climate change impacts based on the UKCIP02 scenarios.**	Pembrokeshire zone – no peak deficit until 2017/18. Most significant deficits (-13Ml/d) forecast after 2020. **Climate change impacts based on the UKCIP02 scenarios.**	TW: SWOX zone – an existing and significant peak deficit is forecast to become more severe. Climate related activities are the driving factor. **Has tested UKCP09 data in two other zones.**

	WW: West zone – surplus in peak period. **Climate change data not specified.** YW: East surface water zone – surplus in peak period. **Climate change impacts based on the UKCIP02 scenarios.**	SWW: Colliford zone – peaks are significant and driven by tourism. SWW does not plan for peak period due to availability of large strategic reservoir. However, supplies are vulnerable to long multi-season droughts which climate change could generate. **Climate change impacts based on the UKCIP02 scenarios.**	SWS: Sussex North zone – an existing deficit which continues across the planning period. **Applied CCDeW climate change data.**
	AWS: Fenland zone – surplus in peak period. **Climate change impacts based on the UKCIP02 scenarios**	VWC: Southern zone – small deficit in peak forecast from 2030. **Applied CCDeW climate change data.**	UU: West Cumbria zone – peak deficits forecast suddenly at 2014/15. Supply is limited by storage capacity. **Applied CCDeW climate change data.**
Recommended approach	Continue to use existing CCDeW results to estimate climate change uncertainty	Further work on climate and demand variables could be considered.	Detailed micro-component analyses could be considered.

2.1 SWOX zone – Thames Water

The SWOX zone has a dry year annual average deficit from 2016/17 increasing to 16.3Ml/d by 2024/25 then remaining mainly between 16 and 18Ml/d for the remainder of the planning period. SWOX also has a dry year critical period deficit throughout the PR09 planning period, starting at around 17Ml/d, increasing to around 50Ml/d by 2024/25 then remaining between 50 and 55Ml/d for the remainder of the planning period. Critical period deficits are therefore a significant issue in the WRZ.

Thames Water uses peaking factors to estimate peak demands. For all non-London WRZs the peaking factor used is 121.38 per cent. This factor is based on analysis using Thames Water's 'OMSPred' model and data from the company's domestic water use monitor. OMSPred uses 50 years of weather data to model peaks for households, stratified by property type and measured status.

The model uses a series of relationships between demand, sunshine hours, maximum temperature and rainfall, and models peak demands using a long time series of weather data. The peak week demands in the model outputs are then factored by long term annual average demand and plotted in a cumulative distribution. This enables the 1:10 critical period demand to be determined.

Given the importance of the critical period in the supply-demand balance for the SWOX WRZ, this would be considered to be a high vulnerability zone, where further detailed analysis on the influence of climate change on peak demands could be justified.

2.2 Sussex North zone – Southern Water

There is an existing deficit in the baseline dry year scenario until 2012/13 when the supply-demand balance reaches a zero balance forecast until the end of the planning period. In the critical period a rapidly emerging deficit is forecast in 2010/11 (-7Ml/d) improving to-1.6Ml/d by 2018/19 before dropping back to -5.8Ml/d by the end of the planning period.

Indoor consumption is relatively constant between dry year and peak period, but outdoor discretionary use during the summer period, due principally to garden watering, is considerably greater during the summer than the winter. There is no information in the WRMP main report on dry to peak scenario domestic peaking factors. Southern Water has rebased historic peak demand record to reflect the current level of meter installation. The company predicts that peak week dry year demand will fall rapidly in the short term but will subsequently increase year on year, although not exceeding 2010 levels.

Southern Water has applied the results from the *Climate Change and Demand for Water* (CCDeW) report to calculate the impact of climate change on demand. The company has used the medium-high emissions scenario because most information is provided on this within CCDeW. Mean domestic demand is calculated to increase by 1.45% in the 2020s, and 2.92% by the 2050s. A 15Ml/d resource side solution is the company's preferred option to restore a negligible surplus (less than 1Ml/d).

The significant peak in this zone suggests this would be considered as a high vulnerability zone, where further detailed analysis on the influence of climate change on peak demand could be justified.

2.3 Southern (RZ3) zone – Veolia Water Central (Three Valleys)

A surplus in the dry year scenario is forecast to decline steadily over the planning period, dropping to a deficit of -0.16Ml/d in 2033/34. The zone has a critical period and this too has a surplus which is forecast to decline, dropping to a deficit of 0.7Ml/d in 2030/31 and then further declining to a deficit of 5Ml/d by 2034/35.

Veolia Water Central applied the 2002 CCDeW factors to the demand forecast in order to derive a maximum effect by 2035. Factors have been applied according to the medium-high forecasts for the Alpha and Beta scenarios for the Thames Region for domestic demand. This is an increase in demand of 1.37% by 2020. A discrete distribution was applied with the probability of climate change effect rising over time to a probability of 1.0 by 2032. The company has reported that in 2022, climate change will generate an extra 1.75Ml/d of domestic demand in this zone (Southern - WRZ3). However, the company has not reported what the impact would be on domestic peak demand specifically. Dry to peak peaking factors have been calculated based on historical data records but are not reported in the WRMP main report.

Based on available information, this appears to be a zone with intermediate vulnerability.

2.4 West Cumbria zone – United Utilities

In a dry year the West Cumbria zone forecasts a dramatic shift from a surplus of 4.5Ml/d to a deficit of 4.8Ml/d in 2014/15. After this the deficit situation is forecast to improve slightly but the zone is forecast to remain in deficit throughout the rest of the planning period. The zone has a critical period in which the same sudden drop into a sustained deficit is forecast. However, the critical period deficit is more severe dropping to -8.3Ml/d in 2014/15 and not improving above -6.7Ml/d within the baseline planning period.

The West Cumbria resource zone is vulnerable to short period drought events because of the lower volumes of storage available. The critical period of the company's water sources is between two and three months. United Utilities has used the CCDeW data to estimate the impact on water demand for West Cumbria resulting in an increase of 0.4Ml/d by 2025 (central estimate).

Based on available information, this appears to be a zone with intermediate vulnerability.

2.5 Fenland zone – Anglian Water

The Fenland WRZ as a whole is forecast to have a surplus in the peak across the planning period. However two out of the five Planning Zones (Feltwell and Kings Lynn) are projected to have headroom deficits against dry year average and critical peak period forecasts by the end of the planning period (local production side improvements are expected to resolve this).
The north of Fenland zone includes seaside towns which have the potential for climate-related unpredictable peak demands due the influx of holidaymakers. Peak demand is normally associated with the increased domestic use of water over long weekends. Increased economic

activity through the promotion of links with Europe could result in higher than historical peak demands during the summer season.

Anglian Water has used the 2006 UKWIR Peak Demand Methodology which relates demand to the climatic factors of temperature and rainfall based on historical records of climate and the current behaviour of its customer base. Anglian Water calculates peak demands (measured, unmeasured, and combined households) by inputting household and weather data into a per capita consumption (PCC) micro-component model. This includes: maximum daily temperatures; daily rainfall; and sunshine hours per day. However, Anglian Water decided not to apply climate change to its PCC model (to forecast the impact of climate change on peak demand) because the uncertainty over future customer behaviour and the scale of extreme events was thought to be too large to produce a robust model.

The effect of peak demands varies between WRZs due to factors such as the location of holiday resorts and heavy industry and socio-economic factors reflected in the type and age of housing stock and customers' behaviour. Overall the company has recorded peaks in recent years that are lower than older historical peaks. This is attributed to more customers paying measured charges and customers' behaviour responding to the promotion of water efficiency. The company applies peaking factors to dry year data.

The company strategy is based on maintaining demand management through leakage control, household metering and the promotion of water efficiency. It may be interesting to examine how vulnerable this zone could be to climate induced changes in demand. Based on available information, this appears to be a zone with intermediate vulnerability.

2.6 East Surface Water – Yorkshire Water

The East (Surface Water) zone has a forecast surplus of between 4.2Ml/d to 4.7Ml/d across the planning period. The zone has a critical period that is also forecast to remain in surplus, between 2.8Ml/d and 3.3Ml/d.

Based on available information, this appears to be a zone with low vulnerability.

2.7 Colliford Zone – South West Water

In the baseline dry year scenario, Colliford zone drops into deficit in 2025/26 and then the deficit is forecast to increase to 9Ml/d by 2034/35. At a regional level, the company experiences a higher seasonal variation in the demand for water than any of the other nine Water and Sewerage Companies. Demand in the peak week can be up to almost 25 per cent higher than the average daily demand throughout out the year. In tourist 'hot spots', however, peak week demands of twice the winter average are not uncommon.

South West Water does not plan for a critical period despite the seasonal pressure driven by visitors to the area in the summer months. The company states that none of its three zones are dependent only on groundwater, run of river abstraction or limited storage nor are they particularly sensitive to peak demands. From the information that is available, it would appear that peak demands are not calculated and forecasted as historical records show that the company does not need to plan for this scenario.

Based on available information, this appears to be a zone with low vulnerability.

2.8 West zone – Wessex Water

The West zone is in surplus throughout the baseline dry year and critical period forecasts. The company has assumed that by 2035 behavioural trends in personal washing and outdoor water use will lead to a growth in the peak week demand so that it becomes 64 per cent greater than normal for metered households and 59 per cent greater than normal for unmetered households. Wessex Water expects average demand to fall while peak week demand will rise slightly. Based on available information, this appears to be a zone with low vulnerability.

2.9 Tywyn Aberdyfi zone – Welsh Water

In Dŵr Cymru's revised Draft Final Plan (April 2011), Tywyn Aberdyfi has a small baseline dry year surplus, and no critical peak period. Based on available information, this appears to be a zone with low vulnerability.

2.10 Pembrokeshire zone – Welsh Water

In a dry year Pembrokeshire zone is forecast to fall into deficit from 2015/16 and then plateau at -14.5Ml/d from 2020/21 across the remainder of the planning period. The zone also has a critical period in which the supply-demand balance is also forecast to drop rapidly from surplus to deficit. Deficits between 0.5Ml/d and 5Ml/d are forecast between 2017/18 and 2019/20, after which the deficit suddenly increases to -13Ml/d for the rest of the planning period. Based on available information, this appears to be a zone with medium vulnerability.

3. Literature review

3.1 Introduction

A fundamental element of this analysis is to understand the relationship between climate and demand for water. The drivers of peak demand are presented in Appendix G, identifying the typical types of domestic water use that are influenced by climate. A literature review has been undertaken to identify any research providing more insight or quantitative data on relevant relationships that could then be used to support an improved methodology. We have already identified that the key micro-components are typically garden watering (or other outdoor domestic use) and showering. We have also already identified that climatic influences are most likely to affect frequency of use and so the review has been orientated to seeking relevant information on this.

Other more structural changes in demand (e.g. substantial change in garden form, or ownership of new technology) is beyond the scope of this pilot study but where the literature includes useful contextual information this has been included for reference in the analysis. Other related factors which are out of scope include the influence of exposure to direct sun, high winds, and receiving heat from reflective surfaces.

Where the literature review provides examples of numerical relationships between frequency of use of showers or (e.g.) hosepipes, we will pilot the application of climate variables (derived as described in section 3.1) using these models. In the absence of existing relationships we will propose relationships based on known issues and the likely nature/form of functions linking frequency of use and weather variables, and test these.

3.2 Results of literature review

Downing *et al.* (2003). Climate Change and the Demand for Water
The 2003 report, *Climate Change and the Demand for Water* (Downing *et al*., 2003) commissioned by Defra was one of the first UK-based studies to address the issue that climate change will impact on demand as well as supply, moving on from basic assertions and attempting to quantify or at least define the relationship.

The focus of the 2003 study was overall rather than household demand, and it considered domestic demand components such as bathing to have a low/medium sensitivity to climate change, representing a minor component of overall demand. The study highlighted garden watering as component with high sensitivity to climate change. It also pointed out the risks of under- or overestimating climate impacts and highlighted that while peaks may be large, they typically only last for a few days (as opposed to a month).

At that time the report recognised that there was a correlation between peak demand and climate variables. The report refers to an unpublished study by Southern Water which investigated the correlation between peak domestic demand and a number of climate variables including rainfall and temperature, and the results were informed by knowledge of other company specific studies.

The report identified ‘bias uncertainties’ including how soil-water deficit drives garden watering; the relationship between demand and climatic variables other than temperature (e.g., humidity); and the idea that while metered use might encourage conservation (through awareness and pricing) it could also encourage peak use (as the heightened importance of using water may lead to an increased willingness to pay for it).

Information on the Thames and Lee Valley catchments suggested that by 2050 water supplies in the peak July period will need to increase by 7-8 per cent to meet the increased demand driven by garden watering. The study also stated that: ‘Concentrated in the two driest months, the peak demand may rise to 25% above the average level of water use’. Our pilot study aims to explore how climate change could affect peak demands, and to test how impacts on the micro-components may drive that demand. The 2003 study provides a basis from which to identify and prioritise types of peak domestic demand that are most likely to be affected by climate change. However, it is clear from that study that in 2003 there was limited published information on the relationship between weather and demand, and even less specifically on peak demand and micro-components of demand.

Loughborough University (2011)

Since 2003 there has been further work examining the potential impact of climate change on peak demand. In the UK, Loughborough University has recently announced a study that it is undertaking using Anglian Water’s *Survey of Domestic Water Consumption* (SODCON) data to examine the sensitivity of measured micro-components to climate variability and change (Parker, J. undated [2010/11]). The paper recognises that there are still very few studies that have examined this important relationship and its expectation that the UKCP09 projections could *ultimately* be applied to the relationships that it intends to determine between micro-components and climatic variables using multiple regression analysis.

As part of a feasibility study, the university has examined the SODCON data and initial findings from the model show that a metered household with four occupants consume a maximum of 6.5 litres water per 1°C rise in air temperature compared with single occupancy households which consume 1.5 litres per 1°C temperature rise (based on historical data). The UKCP09 climate data suggests that peak maximum daily temperatures could increase by 3-4°C. Assuming that all factors remain constant, peak period consumption in higher occupancy households could be much more responsive to temperature than single households. This level of detail is outside of the current scope of investigation, which is based on theoretical estimates of measured PCC without the context of occupancy rate. However, one factor that could explain this phenomena is the relationship between higher occupant households and the presence (and potential size) of gardens. Single occupant properties may be more likely to be flats or other properties with limited access to gardens or opportunities for other outdoor use. This is a further factor that has been used to assume that garden watering and other outdoor use is a key component to be considered under climate change.

Catchment Change Network Workshops

In 2010 and 2011, the Catchment Change Network delivered workshops on the theme of water resources management in a changing climate. The 2010 workshop focused on water supply issues, and resulted in the publication of a collective paper by the presenters at the workshop (Hall *et al.*, 2012). The paper focused on supply-side issues, but did recognise the relationships between supply and demand in terms of levels of service and the potential effects of climate change on demand in only very broad terms.

The 2011 event focused specifically on demand and included presentations on the CCDeW methodology as well as more recent research, e.g. by Chris Kilsby at Newcastle University on 'Water Demand Estimation using UKCP09'. His talk presented evidence from other studies on the relationship between household demand and climate variables (especially temperature, rainfall and sunshine hours), indicating that these variables could not fully explain demand variations, but that they may usefully explain some components of demand. An outline of the UKCP09 climate predictions, their basis and application was also included in the presentation.

Overall, the 2011 event focused more on general demand management and analysis issues than on climate change specifics.

Danielson (1979). Analysis of residential demand

Before climate change became a known issue, Danielson (1979) examined the basic relationships between climate and demand. The study, based in North Carolina (United States), used a series of meter readings from 261 households to conclude that household domestic demand is 'a function of temperature, rainfall, house value, water price, and household size'. Of all the household demands, the study found that the main factor driving overall demand was household occupancy. It also found that for garden watering, 'sprinkling demand' was 'highly responsive to changes in water price and the level of the climatic variables'. This suggests that models of measured peak demand should suppress sprinkler use slightly to account for cost concerns. The pilot model has suppressed potential sprinkler usage by limiting the ownership of sprinklers by measured customers.

Matthias *et al*. (undated). Impact of climate change on urban water demand – New Zealand

A research project in New Zealand (Matthias, *et al*., undated [post 2006]) has attempted to quantify changes in domestic household (urban) demand with climate change. The authors of this paper also point out that little attention has so far been given to the implications of climate change on water use. The 1979 Danielson study is highlighted as an exception and, as has already been noted, that study was limited to qualitative descriptions of relationships. Other more recent examples are limited to a study primarily focused on the impact of climate change on urban drainage (Burian, 2006), and the implications for metropolitan areas to secure supplies to meet demand (areas such as Boston, USA (Kirshen *et al*., 2004, 2006), New York (Rosenzweig, *et al*., 2000), and the global context (Arnell, 1999)). These latter studies are acknowledged as being supply rather than demand orientated.

The New Zealand study itself concentrates on the city of Hamilton, on the North Island. Water issues in this location may be comparable to the UK, with many parts of the country having sufficient water resources available, while others are likely to experience water shortages. As with the UK, New Zealand's climate is affected by the ocean and diverse topography. The country is already recording warmer winter temperatures, and elevated minimum temperatures. It is estimated that for every degree of global warming between 1990 and 2100, temperatures in New Zealand will increase by 0.7°C. During the next 70-100 years temperatures could increase by 3°C. No information is given on how summer maximum temperatures could increase under climate change.

The study identifies that during the eight year period of record, consumption was significantly higher during the summer months in 1998 to 2000 when temperatures were highest. Again this supports the concept of relating temperature to demand, but it does not provide sufficient data for robust quantification. A model of daily per capita consumption regressed against maximum temperature and other climatic variables showed, as expected, a significant and positive relationship between water use and temperature. The results indicate that 'for every one degree increase in temperature water consumption will increase by 1.4 per cent'.

It would be useful to understand the extent of this relationship; for example, does a linear relationship continue as temperatures continue to increase, and is there a threshold? However, the paper does not explore this issue. There is no temporal reference point in the study and so it is assumed that this relationship is applicable to annual daily average consumption. It is not clear if this relationship is applicable in peak periods. Another significant factor limiting how this data can be applied elsewhere is the fact that the New Zealand study was unable to disaggregate total daily demand into household and non-household use, even less so to individual household demand components. The reported data shows that Hamilton residents use between 330 and 500 litres per person per day. This is significantly higher than in the UK and so is another factor limiting transfer of information to our pilot model.

These papers demonstrate that while understanding of the relationship between weather and demand components is improving, there is still very little empirical evidence to help quantify that relationship. Further work, such as is planned at Loughborough University, is required to examine and quantify the relationship, and to consider the individual components and micro-components of demand.

Despite the lack of empirical evidence, it is still possible to test the potential impact of climate change on peak demand by applying assumptions to micro-components to test their sensitivity and significance. The pilot study has applied the general concepts arising from the literature review, identifying the key components and recognising the indicative relationships, and has used expert judgement to develop an illustrative relationship between maximum temperature and shower frequency.

4. Linear regression analysis

4.1 Introduction

The link between household demand for water and climate variables is well understood (at least at a conceptual level) and the relationships between climate and peak demand has been explored by the water industry. The UKWIR peak demand forecasting methodology proposed the use of linear regression for a range of purposes in demand forecasting, including the 'assessment of the impact of changes such as…climate change'[19]. The approaches developed in this study provide a useful starting point for assessing how climate and demand relationships could be used to assess the effects of climate change on peak demands. This section therefore begins with an outline of this study, before considering how the linear regression methods demonstrated in the UKWIR report may be used to estimate the effects of climate change on peak water demands.

4.2 UKWIR Peak Demand Forecasting Methodology background

The main purpose of this study was:

- to develop a consistent and robust methodology for preparing peak water demand forecasts;
- to identify the different types of peak demands and the differences in approach which are appropriate for their calculation, to determine the key factors that affect peak demand forecasts and how to assess their impact;
- to clarify what data records are required to enable reliable derivation of peak demand.

The study report is split into two: a methodology section and a section on practitioner guidance. Appendix 1 includes worked examples from pilot studies undertaken as part of the project. The methodology developed in this study takes the form of a framework supported by a 'toolkit' of different approaches, so that practitioners are able to select the most appropriate approach to their particular situation – similar to how the current project on climate change and water supply planning is being developed. The framework has three steps:

- rebasing – to allow historical peaks to be compared on a like-for-like basis;

[19] UKWIR (2006c) Executive Summary, page iii.

- return period analysis – to select a base year peak demand with an appropriate return period;
- forecasting – to take account of likely changes in customer characteristics and other factors that are likely to influence peak demand.

The report sets out a number of key issues that demand planners should consider. One of the most important is the choice of using either peak factors or peak volumes – each has advantages and disadvantages, and the choice will depend on particular circumstances in a water resources zone. For example, peak factors are a simple concept, but are sensitive to changes in average conditions, for example due to leakage reduction or changes in non-household demand. They may be most appropriate when peak demand is driven by micro-components that also affect average demand – such as personal washing. Peak volumes are independent of average conditions and are most appropriate for analysing peaks that are driven by factors that have a limited effect on average demand – such as garden watering – or where seasonal drivers such as tourism are important peak demand drivers.

Five pilot studies were carried out as part of the UKWIR project, on a range of water resource zones, using a range of analytical methods. This included the use of regression analysis (predictive modelling) to explain the historic variation in peak demands. This analysis demonstrated that peak demand is often strongly related to summer weather, particularly temperature, and also the characteristics of the customer base (e.g. meter penetration).

Where predictive modelling was undertaken, the analysis could be extended using historical climate data (with other influential variables such as meter penetration held constant). These equations may also be used to consider the effect of future climate on peak demands (see Table 5 in the UKWIR report). It should be recognised that this analysis assumed that demand is not affected by other drivers, and is otherwise static.

4.3 Assumptions

The following sections use predictive multiple linear regression equations from the UKWIR Peak Demands report to demonstrate how these kinds of models may be used to estimate the potential impacts of climate change on peak demand – particularly in terms of the effects of changes in summer temperature, sunshine hours and rainfall. In order to undertake this kind of assessment, water companies will need to have developed their own versions of these kinds of relationships. To do this, they will have implemented the method set out in the UKWIR report, with access to at least ten years of disaggregated distribution input data and historical local climate data.

The following sections have made some assumptions regarding the location used for historic and projected climate data, in the absence of any details on locations in the UKWIR report. Specific assumptions are summarised in the following section.
The analysis also uses UKCP09 probabilistic projections of climate change and Weather Generator outputs. For the probabilistic projections, the 'job details' used in this pilot are shown in Table 4.1.

Table 4.1 'Job Details' for the UKCP09 Probabilistic Projections.

Job Detail	Selection
Data source	UK Probabilistic Projections of Climate Change over Land.
Climate change type	Future Absolute Climate Values.
Variable(s)	Mean daily maximum temperature (°C), Precipitation (mm/day).
Emissions scenario(s)	Medium.
Time period(s)	2010-2039.

Temporal average(s)	July.
Location type	25km Grid Box.
Location(s)	1586 (Oxford/Didcot).

For the Weather Generator projections, the 'job details' used in this pilot are shown in Table 4.2.

Table 4.2 'Job Details' for the Weather Generator simulations.

Job Detail	Selection
Data source	Weather Generator Simulations.
Variable(s)	Standard Weather Generator Variables (mandatory).
Emissions scenario(s)	Medium.
Time period(s)	2010-2039.
Temporal average(s)	January to December (all months).
Location type	5km Grid Box.
Location(s)	4400195 (Didcot).
Sampling Method	Random.
Number of Random Samples	100 (to reduce file size and run time).
WG Temporal Frequency	Daily.
WG Run Duration	30 years.

4.4 Analysis and results

The case studies presented in the UKWIR peak water demand forecasting methodology include the development of linear regression relationships that may be used to predict the effect of projected changes in climate variables, as a result of climate change, on peak demand. It should be noted that the equations presented in the UKWIR report appendices were developed based on specific historic demand and climate data, and do not provide generic relationships between climate variables and demand that could be applied elsewhere. Also, it is important to remember that these equations were developed to try to understand the causes behind historic year-on-year-variation in peak demand (defined as either peak volumes or peak factors). Therefore these equations may not accurately predict the effect of climate change on peak volumes when projected climate variables are greater than or less than the historic range. In addition, the changes in climate in the Weather Generator are expressed as 30-year long-term averages.

However, these equations are useful as they set out the likely form of relationships between peak demand and climate variables, and highlight which climate variables in particular appear to predict peak demands most accurately. This means that we can test how the projected climate variables available from UKCP09 and related sources may be used and applied using a linear regression approach.

4.4.1 Peak factor model

The 'predictive peak factor model' in Case Study 1 was selected using the following relationship (based on the correlation coefficient R^2, and its ability to reproduce historical peak volumes):

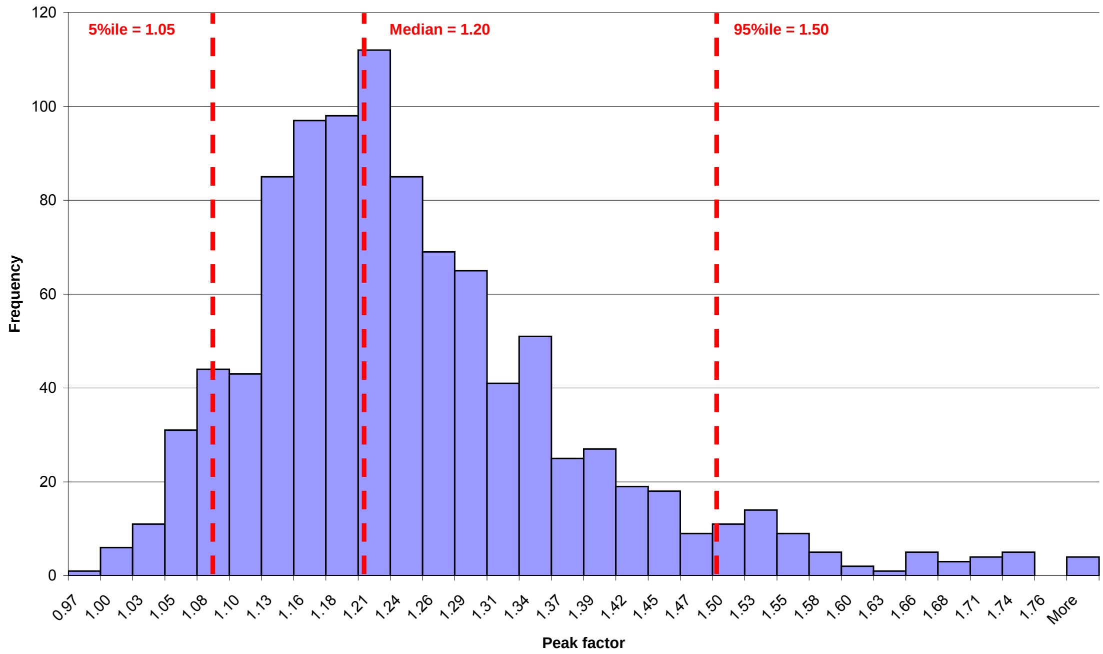
$$PF = 0.0015(Temp - 18)^{2.73} - 0.013(Rain)^{x} + 0.0012 * Year - 1.12$$

Where:
Temp = maximum monthly temperature in July (°C)
Rain = total rainfall in July (mm);
x = exponent applied to rain variable[20]
Year = calendar year

The equation was applied to the UKCP09 probabilistic projections of climate change over land (described in Table 4.1 above), which are 1,000 projections of possible future climate for 2020s. The results of the analysis are shown in Figure 4.1, showing a median peak factor of 1.2 and 5th and 95th percentiles of 1.05 and 1.50 respectively.

Analysis of the results showed that of the 1,000 scenarios, the maximum peaking factor returned was 1.78. This is driven by a combination of low July rainfall (21mm) and high maximum monthly temperature (27°C). Only one combination of rainfall and temperature data returned a peak factor of less than one (20.5°C, 71mm of rain), while six scenarios returned factors of one. In these seven scenarios, the specific combination of rainfall and temperature data from the probabilistic projections results in no peak demand.

Figure 4.1 Application of peak factor equation to 1,000 projections of future climate.



4.4.2 Peak volume model

The 'predictive peak volume model' in Case Study 1 selected the following relationship (based on the correlation coefficient R^2, and its ability to reproduce historical peak volumes):

$$PV(Ml/d) = 0.18(Temp-18)^{2.3} - 462(Sun-130)^{-1.67} + 15.9$$

Where:
Temp = maximum monthly temperature in July (°C)
Sun = total sunshine hours in July

Maximum monthly temperatures are available from the UKCP09 probabilistic projections, however sunshine hours projections are only available from the Weather Generator. Therefore in this example, Weather Generator projections will be used for both variables. The Weather

[20] The UKWIR report includes a typographic error in this equation, which omits the exponent to be applied to the 'Rain' variable. For illustrative purposes, using a step-wise approach to estimating this exponent, a value of 0.776 has been used for this pilot study.

Generator produces a user-defined number of random samples from possible future climates, and provides a baseline equivalent for each of these results. Therefore the baseline situation should be derived from these scenarios, rather than from long-term average historical climate, to ensure comparison with like-for-like data.

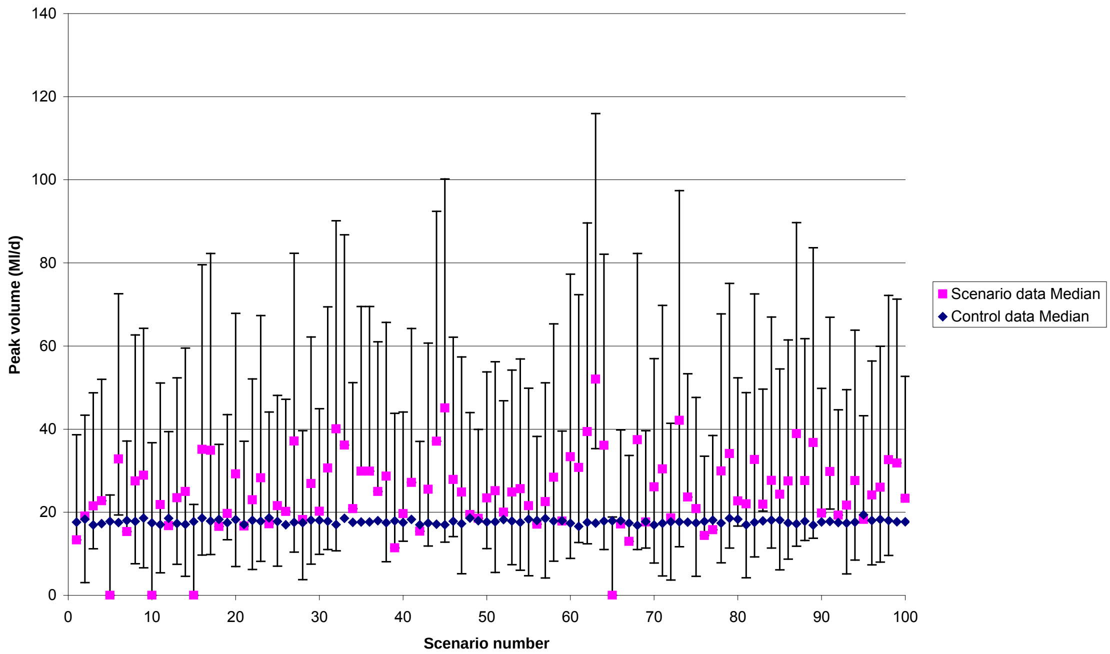
The Weather Generator job created in this pilot study (described in Table 4.2) produced 100 sample baseline and projected climate scenarios of 30-years duration. A sample of 100 was selected in order to minimise run time and file size – it is likely that larger samples would be needed in a 'real life' situation. The UKCP09 User Interface produces a zip file containing 100 paired baseline and projected climate files, each containing daily climate values for 30 years. In order to use these data it was necessary to pull out the appropriate 'Temp' and Sun' data from these 200 files, and then derive percentile values to enable the risks associated with climate change and peak demand to be estimated. This can be completed manually in Microsoft Excel in around 5-6 hours, or automated using Microsoft Visual Basic for Applications.

Figure 4.2 shows the output of the assessment, comparing the median values of the control data with the scenario data for each of 100 scenarios. The error bars shown in Figure 4.2 indicate the range between the 5th and 95th percentiles in the scenario data. The analysis shows that for the control set of data, the median peak volume is calculated at 16.6 to 19.4Ml/d, with an average of 17.7Ml/d. Using the scenario data set, the median peak volume ranges from 0 to 44.9Ml/d, with an average of 24.6Ml/d. Under this analysis, the average peak volume increases by 6.9Ml/d from 17.7Ml/d to 24.6Ml/d.

Applying the peak volume equation results in zero values for those years within a scenario where the total sunshine hours in July are less than 136.53. There are two reasons for this. Firstly, where a scenario has between 130 and 136.53 hours of sunshine in July, application of the peak volume equation will return a negative value. Secondly, where the number of hours of sunshine in July is less than 130, an error value is returned. It was therefore necessary to zero these values. The equation therefore determines that in these years, sunshine hours are low enough to result in no peak volume being generated.

The number of years in a scenario with less than 136.53 hours of sunshine in July can have a significant impact on the median and percentile values. For example, Figure 4.2 shows that four scenarios contained a sufficient number of years of less than 136.53 hours of sunshine to return a median value of zero. In the case of scenario five, only five of the 30 years had more than 136.53 hours of sunshine in July.

Figure 4.2 Application of peak volume equation to Weather Generator output.



4.4.3 Comparison of peak factors using probabilistic and weather generator

To enable comparison between using the Probabilistic Projection and Weather Generator climate data sets, the Weather Generator data has been analysed using the peak factor model previously described. This is shown in Table 4.3. It is not possible to compare the two data sets by assessing them with the peak volume equation because the equation requires sunshine hours, a parameter only available using the Weather Generator.

Table 4.3 Comparison of peak factors assessed using Probabilistic Data and Weather Generator data.

	Weather generator	Probabilistic Projections	Difference
5th Percentile	0.93	1.05	+0.08
25th Percentile	1.13	1.14	+0.01
Median	1.26	1.20	-0.06
75th Percentile	1.43	1.29	-0.14
95th Percentile	1.75	1.50	-0.25

The assessment shows that when the median values are considered, the Probabilistic Projections produce a peaking factor that is 0.06 lower than that derived from the Weather Generator data. To illustrate the impact of this, in a water resource zone with a dry year annual average demand of 50Ml/d, peak demand assessed with the Probabilistic Projections would be 3Ml/d lower than that assessed using the Weather Generator (63Ml/d).

The range in peaking factors produced by the Probabilistic Projections, indicated by the 95th and 5th percentiles, is smaller than that produced by the Weather Generator. Using the Probabilistic

Projections, a smaller peaking factor is derived at the 95th percentile. Taking the example of a resource zone with a 50Ml/d dry year annual average demand and using the 95th percentile peaking factors, peak demand assessed using the Probabilistic Projections would be 12.5Ml/d lower than that assessed using the Weather Generator data.

When the 5th percentile values are considered, application of the Probabilistic Projections would produce a higher peak demand. Based on the example of a water resource zone with a 50Ml/d dry year annual average demand, peak demand would be 2.5Ml/d greater than dry year annual average. There would be no peak factor using the Weather Generator data at the 5th percentile. In the example presented here, using the Weather Generator data to derive peak factors would drive additional investment earlier in the planning period in a peak deficit zone than using a peaking factor based on the Probabilistic Projections. This may not always be the case, since the Weather Generator data used in this case study is based on only 100 simulations of possible future climate realisations, compared to 1,000 UKCP09 probabilistic scenarios. The difference in the range of results may also be a consequence of the linear regression equation used and the data used in this example.

4.5 Summary

This section has described approaches for obtaining relevant climate projections from UKCP09 that may be used in linear regressions that relate peak demand (in terms of peak factors or peak volumes) to climate variables. The example presented here shows that using the Weather Generator data results in a peak factor of 1.26, compared to a factor of 1.20 derived using the Probabilistic Projections. This indicates that water companies should consider undertaking analyses using both sources of climate predictions, when undertaking climate change analysis of peak demand in the most vulnerable water resource zones.

The equations used in this section are taken from the UKWIR peak demand forecasting methodology. They have been developed based on specific company data and should not be used generically. Companies wishing to pursue this approach should develop their own relationships and test them under a range of historic and climate change scenarios.

5. Micro-component analysis

5.1 Introduction

This section of the report considers how climate change may manifest in changes in domestic water-using behaviours, and how this may be analysed using micro-components. It does not include examination of how long-term climate change may influence wider behaviours such as tourist numbers or changes in garden plant species. Assumptions are made that climate change does not change meter penetration forecasts, or ownership of ‘climate mitigating technologies’. Modelling for the CCDeW project revealed that an increased frequency of droughts could provide the catalyst for increased uptake of water efficiency technologies. However, the scope of this study is focused on exploring the direct relationship between climate variables (temperature) and frequency of use. Longer-term changes in climate could create a shift in the market for more water efficient water-using products (including garden plants) but this is not considered within the scope of this pilot micro-component analysis.

5.2 Proposed approach

The following process has been developed and piloted to test an approach that applies climate change to micro-component modelling of per capita consumption in a water resources zone.

- Present the base year dry year and critical period per capita consumption (PCC) and micro-components.
- Consider the factors driving dry year and critical period PCC and define the micro-components where the frequency of use may be affected by climate variables.

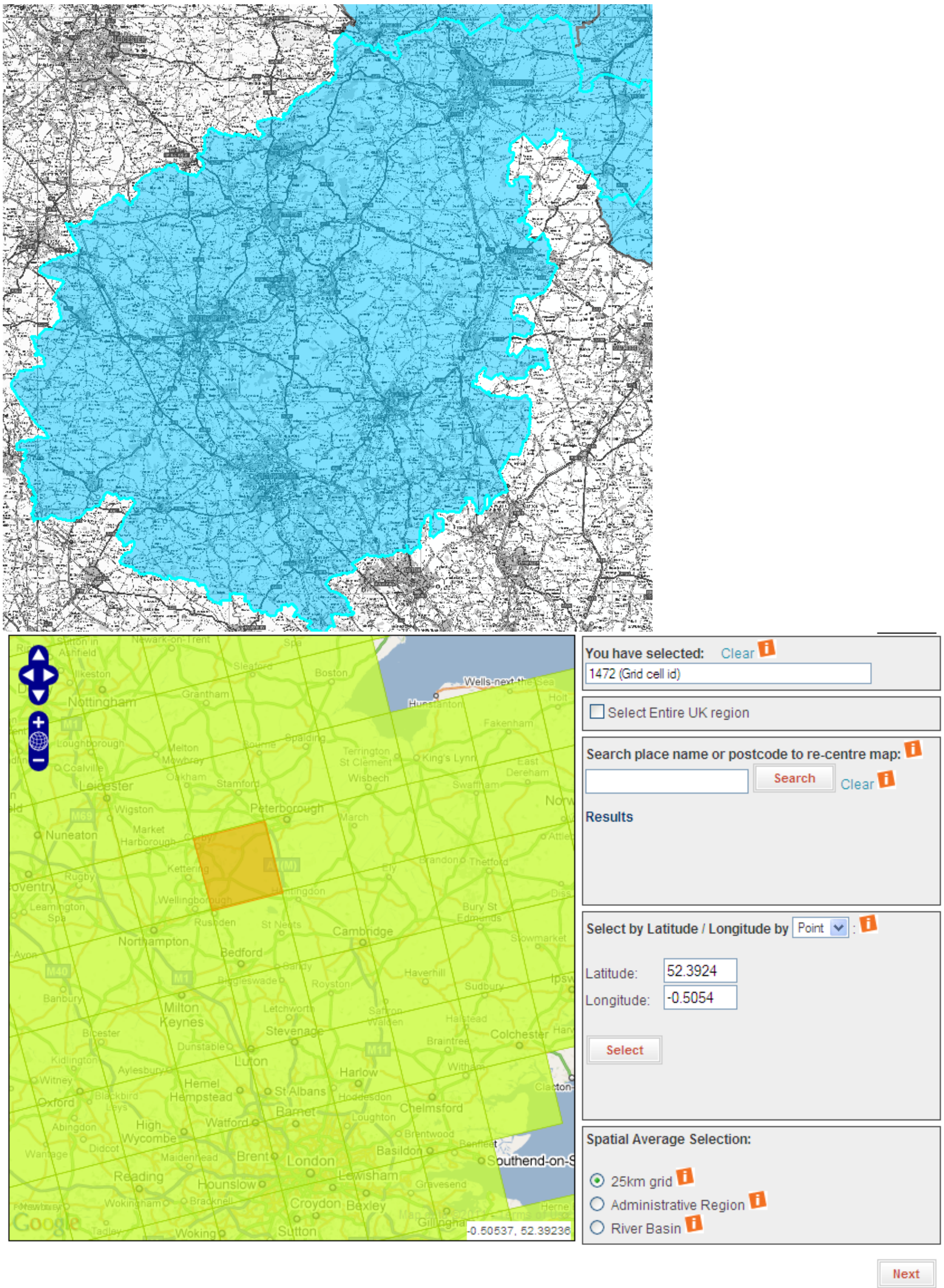
- Identify the relevant climate variables that affect critical period demands, such as maximum daily temperature and/or sunshine hours.
- Determine the climate data that will be used to estimate base year demand (e.g. Met Office long term average (1961-90) station data or regionally averaged data).
- Determine the specific climate projections that will be taken from UKCP09, taking account of water companies' preferred approaches and the limitations and availability of data based on the method used.
- Use the UKCP09 User Interface to generate relevant climate change data for the demand area in question (see example below).
- Define how the micro-components will respond in relation to the climatic changes presented in the UKCP09 data. This study has assumed that the changes would be observed in frequency of use rather than ownership or volume, based on the assumptions set out in section 5.1.
- Substitute the 'climate change' frequency of use values for a relevant year (e.g. 2025) in the peak micro-component model and compare the overall PCC with the original critical period PCC forecast for that year (with no climate change).

One option may be to use climate projections from a 25km grid cell central to the water resources zone in question. Figure 5.1 provides an example identifying a suitable 25km grid cell for the Anglian Water Ruthamford zone.

Water resources practitioners may also:

- Interpolate the results from the climate change modified peak model backwards to the base year. This step has not been undertaken in the pilot test.
- Consider the extent to which the climatic factors affect the components in relation to one another, for example would water for drinking increase at the same rate as for personal washing.
- Consider more complex relationships, such as an increase in temperature increasing personal washing, but while the overall frequency may increase, use of baths may remain constant with the additional personal washing being achieved by showering.
- Assess how increasing peak demands driven by climate change affect long term dry year annual average demands, the effect of climate change on the return period of future peak demands, and the implications for levels of service.

Figure 5.1 Example of Anglian Water Ruthamford Zone and UKCP09 25km Grid Selection.



5.3 Pilot Study

PCC model

A model disaggregates dry year annual average measured PCC disaggregated into micro-components including ownership (O), frequency of use (F), and volume per use (V) factors. This has been based on the measured PCC forecast in the Water Resource Management Plan of a water company in England. The disaggregation does not necessarily reflect that company's micro-component model (which has not been made available to this study).

Present the base year dry year and peak period PCC and micro-components

The base year is 2007/08 and the UKCP09 projected climate variables used to modify peak demand are applied to 2024/25.

Examine the factors driving peak micro-components

Increases in temperature are likely to affect discretionary water uses such as:

- drinking water;
- personal washing;
- clothes washing;
- car washing;
- garden watering.

Practitioners will need to explore climate and demand relationships between these types of micro-components. Existing models that explain this relationship may be used, as described in Section 4.4. For the purposes of this study we have developed an illustrative relationship between temperature and shower frequency.

The climate variable to be explored is therefore **Maximum Temperature.**

Climate change data - Determine the UKCP09 modelling variables

Average climate data are available for the period 1961-2000 (the baseline period for UKCP09) from the Met Office website. Stations with available data within the resource zone in question include Cambridge and Marham (King's Lynn). Average July maxima for these stations are 21.5°C and 21.0°C respectively, suggesting an indicative long term average for this zone of 21.3°C.

This study has trialled climate data for the East of England as climate projections generally show elevated temperatures in this area. Regional mapped data for the East of England is presented in Table 5.1.

Table 5.1 Climate data for Peterborough.

Job Detail	Selection
Data source	UK Probabilistic Projections of Climate Change over Land
Climate change type	Future Absolute Climate Values
Variable(s)	Mean daily maximum temperature (°C)
Emissions scenario(s)	Medium
Time period(s)	2010-2039
Temporal average(s)	July
Location type	25km Grid Box
Location(s)	1473 (Peterborough)

Summary results	Absolute projection (°C)	Change relative to baseline (°C)
5th Percentile	20.88	-0.42
25th Percentile	21.98	+0.68
50th Percentile	22.80	+1.50
75th Percentile	23.87	+2.57
95th Percentile	25.25	+3.95

The UKCP09 projections show that for this area, there is a small probability that the future maximum July temperature will be equal to or less than the historic baseline, but that it is more likely that July maximum temperatures will increase, with the most likely increase around 1.5°C. These statistics are for the monthly mean of daily maximum temperatures in July. This variable may explain some or part of the variation in micro-component frequency of use, however, the literature review has not identified any explicit relationships between the micro-components of demand and climate variables. Practitioners who wish to develop more advanced methods by considering micro-components should assess whether mean maximum temperatures, as derived here, and/or other monthly averages of climate variables such as sunshine hours or rainfall influence micro-component frequency of use. This would need to be undertaken using analytical methods to evaluate the 'quality' of such relationships, which are outside the scope of this study.

It is recognised that micro-component variables may respond to short term changes in climate that are not captured in monthly averages. For this reason, practitioners may wish to consider the use of Weather Generator outputs to predict how the micro-components that drive peak demands may vary as a result of short-term (i.e. day to day) variations in climate.

Weather Generator

Section 3.3 summarises how Weather Generator outputs have been derived from the UKCP09 User Interface website. The outputs indicate that mean monthly maximum temperatures are in a similar range to those derived from the probabilistic projections, but that daily maxima are much higher, as one would expect in both the baseline and future projections.

A number of water companies use models to make short term predictions of demand during peak periods. These models often include climatic variables. It is recommended that companies who wish to undertake advanced analysis of climate change projections on peak demand should run the Weather Generator as required (i.e. for appropriate locations, time-slices and durations); and extract a range of projected climate data that can be used in their short-term demand models.

Define how the micro-components will respond to the UKCP09 climate forecast

The literature review did not reveal any published information describing specific relationships between the micro-components of household demand and climate variables. Also, it was not possible to obtain water company demand models that could be used as part of this pilot study. The following assessment illustrates how the data from the Probabilistic Scenarios (described in Table 4.1) could be used to model changes in the frequency of shower usage under a changing climate. The assessment assumes that the relationship between shower frequency and temperature is S-shaped; that is, as temperature increases shower frequency will increase until a maximum shower frequency is reached. Beyond this temperature, it is assumed that increases in temperature will not increase frequency of use further.

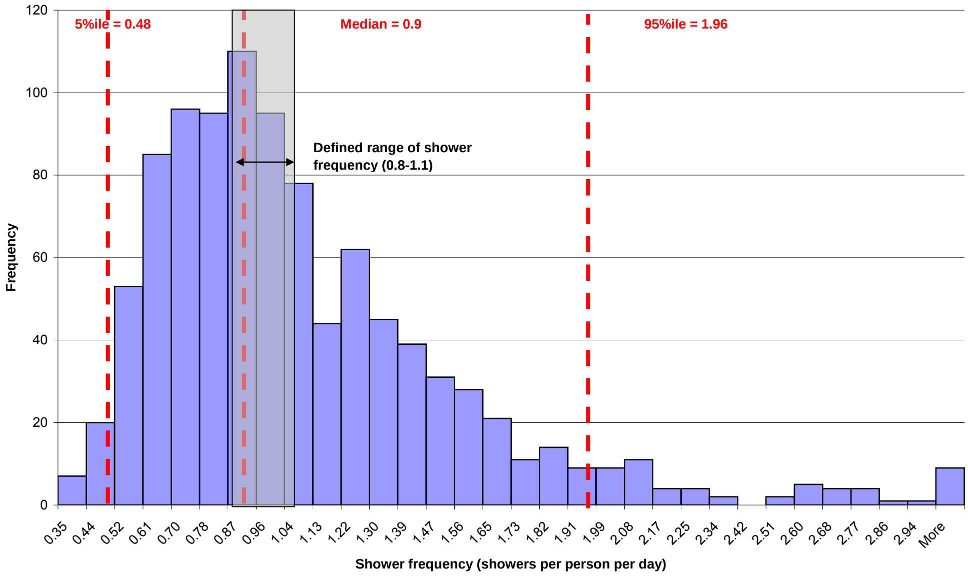
For the purpose of this assessment, the relationship is assumed to be described by the formula:

$$SF = \frac{34.5}{(1 + EXP)^{(-0.315*(Temp-34.5))}}$$

Where:
Temp = Maximum air temperature in July (°C)

Figure 5.2 shows distribution of 1,000 values calculated by the above formula. For the purpose of this assessment, a minimum and maximum frequency of use for showering has been set at 0.8 and 1.1 showers per person per day respectively. This is illustrated by the shaded area on Figure 5.2.

Figure 5.2 Modelling the impact of Probabilistic Projections on shower frequency.



From the 1,000 scenarios, the temperature data of 227 scenarios produces results that lie within the range of frequency set (0.8-1.1 uses per person per day). The effect of changes in shower frequency on shower use is shown in Table 5.2. In the example presented here, relatively small changes in temperature (<1°C) result in an increase in shower frequency. The changes in frequency from 0.8 to 1.1 showers per person per day result in an increase of 13.5 litres/head/day for showering.

The assessment presented here is intended to illustrate the type of approach that may be possible using the UKCP09 Probabilistic Projections. The formula used to illustrate this example means that a relatively small temperature change results in a significant increase in frequency of use.

Table 5.2 Changes in air temperature: impact on shower frequency.

Average maximum air temperature for July (°C)	Shower frequency (showers per person per day)	Shower duration (minutes)	Per capita consumption, shower use (litres per head per day)*	Average maximum air temperature for July (°C)
22.61	0.8	5.00	36.00	22.61
23.00	0.9	5.00	40.50	23.00
23.65	1.1	5.00	49.50	23.65

*where a shower is fitted, assuming flow rate of 9 litres per minute

6. Conclusions

The study has illustrated a range of analytical approaches to climate change and peak demand analysis, from the relatively straightforward use of probabilistic projections of climate variables from the UKCP09 data, to more advanced techniques using Weather Generator outputs and micro-component models. This has demonstrated that UKCP09 outputs are appropriate for modelling potential climate change outputs on peak demand. The UKCP09 projections are easier to extract from the UKCP09 User Interface and do not require as much post-processing as Weather Generator outputs. UKCP09 projections can be readily analysed in terms of probabilistic impacts on peak factors or peak volumes. However, UKCP09 projections are not available for some of the climate variables that may affect peak demand, including sunshine hours and soil moisture deficit. This means that the use of UKCP09 and/or Weather Generator outputs will depend on the parameters that demand forecasters consider most influential in affecting peak demand in their water resources zones.

It has been difficult to compare outputs from these two approaches given the basis of the analysis and the scope of this study. However, practitioners who need to undertake more advanced analysis of climate change impacts on peak demands may need to compare the effects of using UKCP09 and Weather Generator outputs, using comparable 'job definitions' in the User Interface – especially in terms of the number of samples/simulations and spatial coverage.

The study has demonstrated that the range of climate change impacts on peak demand when using UKCP09 or Weather Generator data is significantly greater than the effects of climate change on average demand estimated in the CCDeW study.

This work represents the beginning of detailed assessment into the relationship between climate and climate sensitive water demands. It is theoretical and is based on a range of assumptions. Very little study has been completed and reported into the relationship, and so it is unrealistic to expect this study to provide detailed robust analysis of the relationship between climate and customers' measured status and so on. What this study does do is propose a methodological framework, the details of which will require more investigation.

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