Water resources long term planning framework

(2015-2065)

Technical Report

WATER UK

Acknowledgements

The authors would like to thank the members of the Steering Group for their input and guidance throughout the duration of the project

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1. Introduction

1.1. Context of water resource planning

1.1.1. WRMPs and drought plans

In accordance with the Water Industry Act 1991, each water company must produce a Water Resources Management Plan (WRMP). These plans are updated every five years with the aim of ensuring that there is a sufficient supply of water to meet the anticipated demands of its customers over a minimum 25-year planning period, even under conditions where water supplies are stressed, that is, under dry conditions where supplies are stretched and demand for water tends to be higher than normal.

Each plan builds on the last, updating and reviewing the proposed investment strategy to reflect the latest information, technology and the views of customers and communities. This means that while options selected for the first five years of this plan will be implemented, it is possible that options for later years may change or the timing of their implementation be amended, as detailed investigations are carried out in future, and as each company revises and updates its plans in future years.

Water companies are also required to produce Drought Plans. These demonstrate how each water company would manage the security of supplies in the event of impending or actual drought events, which are normally of short duration (typically affecting water supplies over a period of one to two years). The Drought Plan describes the company's tactical and operational responses during a drought event, whereas the WRMP is a strategic plan setting out the planned investments required over a 25 year planning horizon to maintain the balance between water supplies and customer demand for water.

In a succession of dry years (drought), and / or when the risks of a shortfall become significant, measures to reduce demand (e.g. Temporary Use Bans (TUBs, which were formerly known as hosepipe bans), non-essential use bans, and in extreme droughts potentially standpipes) or to allow increased abstraction, outside that permitted by an abstraction licence, may be required. Such measures are known as drought interventions.

Drought interventions either have a direct effect on customers (e.g. TUBs) or the environment (e.g. drought permits for temporary changes to abstraction licences) and the companies need to strike an acceptable balance between the frequency with which such interventions are likely to occur and the costs of having additional supply and/or demand measures in place to reduce the frequency of interventions. Water companies are therefore required to specify targets in their WRMPs, Drought Plans and Business Plans regarding the frequency with which such interventions will be permitted. These targets, which are known as "Levels of Service" (LoS) are agreed through a process of consultation with customers, the Environment Agency, Natural Resources Wales and Ofwat, and the Secretary of State and/or Welsh Minister must sign off companies' WRMPs. These are the "benchmarks" against which the company must plan its future (25 year) investment in schemes that increase the water available for supply or that reduce customer demand for water in dry years.

The aim of the WRMP is thus to ensure that companies will be able to meet customer demands for water in the dry years without the need for drought interventions at a frequency that exceeds the stated LoS. The entire focus of a WRMP is therefore on the balance between supply and demand in dry or very dry years where the stress on the supply/demand balance falls just short of that required to trigger one or more drought interventions.

A further component of the water resources planning process is the business plan. The WRMP identifies the demand management requirements and the investment needs in new resource and supply infrastructure, including third party and cross-company supplies and strategic, cross-catchment / company schemes to manage supply and demand over the 25 year planning period. By contrast, the focus on investment needs identified in companies' business plans typically tends to be more on the short to medium term (the next 5 years or so) reflecting more immediate and certain impacts on customer bills.

The Environment Agency, Defra, Natural Resources Wales, Welsh Government and Ofwat publishes guidance on how companies should plan to manage their water resources, and this includes consideration of resilience, including climate change. It also encourages companies to consider a longer planning period than the statutory 25 year minimum planning period. Defra provides strategic directions on priorities and desired outcomes. It may also issue directions on minimum levels of resilience.

1.1.2. Regional planning groups

In addition to water company specific WRMPs and Drought Plans, companies in some of the more water-stressed areas of the country have established regional water resources groups to try to consider how to optimise the sharing of water resources. Two groups exist, both of which undertake regional modelling exercises to help inform their members' WRMPs, and to assist the companies in identifying potentially beneficial water trading options. These are:

- Water Resources in East (WRE); and
- Water Resources in the South East (WRSE).

1.2. Drivers behind project

Through the Water Resources Management Planning process described previously, water companies in England and Wales have made significant strides in understanding future uncertainties and risks in planning and managing their supply/demand balance in the face of greater expectations from stakeholders, regulatory requirements, and the longer term impacts of population growth and climate change.

Traditionally, supply systems have been designed to cope with the worst historic drought each region has experienced, and this can differ across the country. But the future will be different and needs a different approach to planning in the face of drivers such as:

- A changing climate,
- A growing population and economy,
- Increasing pressure to reduce abstraction to protect the aquatic environment, and
- The risk that future droughts may be worse than the historic droughts against which companies plan, resulting in greater risk of supply shortfalls and more severe consequences for the economy and customers.

In addition, because companies plan to differing levels of service and drought severity, agreed with their customers, there is no consistent view of resilience either in terms of the current availability of resources or the future reliability of water resource options, even for neighbouring companies, against which levels of service to customers can be assessed and compared.

There is limited consistency between companies in terms of explicit consideration of the potential benefits of drought measures (drought permits and orders) within the WRMP – for many companies the drought plan and WRMP are not considered in an integrated way. The exceptions are those companies who have developed behavioural simulation models to assess deployable output for their supply systems. However, as we consider increasingly severe drought events, we need to consider how recourse to permits and orders contributes to the resilience of the supply system as a whole, under an increasingly uncertain future.

> *"Resilience is the ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future."*
>
> Ofwat Resilience Independent Task and Finish group

This leads to a number of questions around resilience in regard to water resources across England and Wales, such as:

- What could resilience look like over the next 50 years? What trade-offs will there be in terms of the costs and benefits involved in adopting particular levels of resilience?

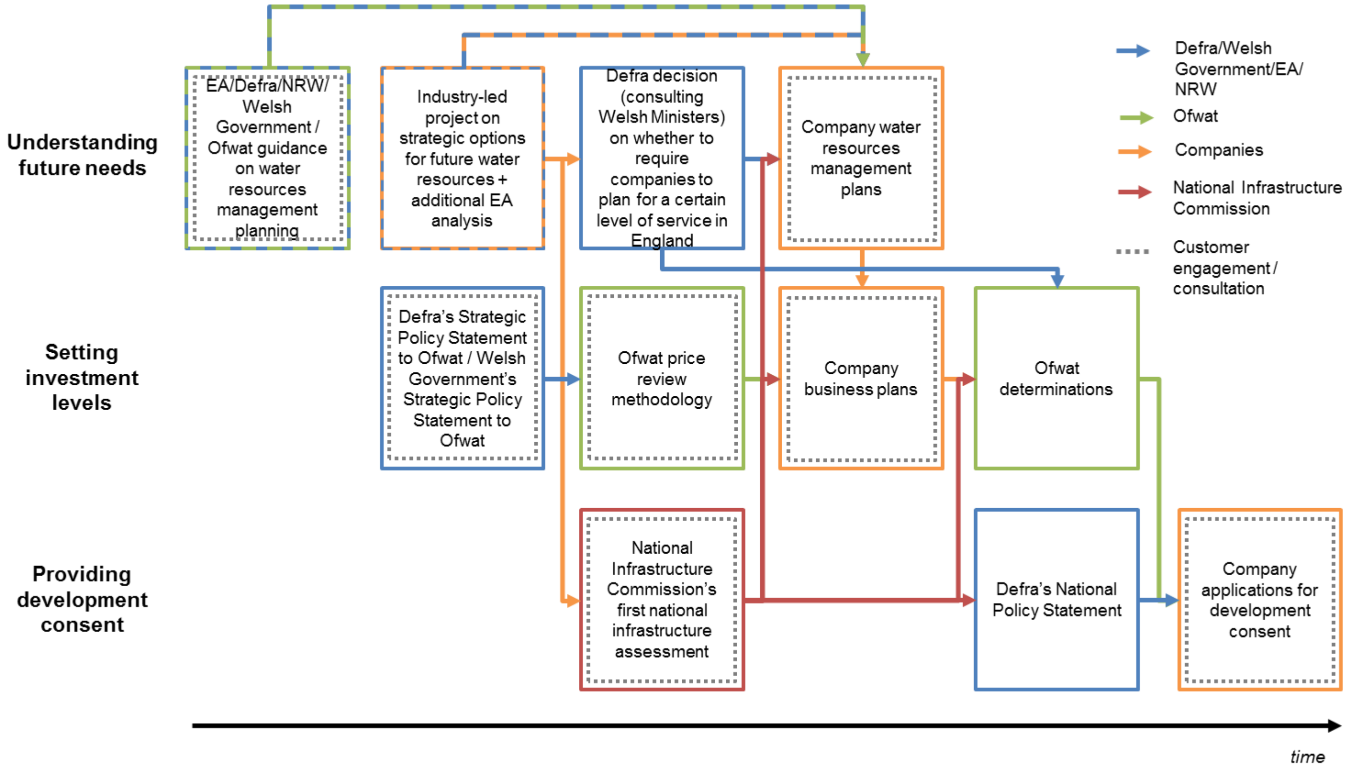
- What are England and Wales' long term water needs? What are the costs, impacts and benefits associated with achieving the desired level of resilience? What choices need to be made regarding infrastructure options that are best suited to meeting that resilience, given future risks and uncertainties?

- What are the practical steps required to meet these needs? Where do regulatory or procedural barriers impact on the planning, promotion and delivery of new resource schemes and what changes will be required to deliver resilience in water resources and supply planning?

This project was established to provide analysis to support a national, strategic and long term view of these issues and the potential consequences for the industry, its customers and stakeholders. The project examines supply/demand vulnerability to more extreme drought events than have been considered under the current water resource planning framework, which has typically focussed on the worst historic drought experienced and which is limited by the period of observed records (up to 100 years, and therefore broadly equivalent to droughts of return period of around 1 in 100 years).

There are a wide range of activities and processes currently underway to try to improve the understanding of future needs, define and set investment levels in the short to medium term, and to inform longer term development priorities. Figure 1-1 provides a summary of these current activities and processes, and the organisations responsible for each of the various tasks.

Figure 1-1 How it all fits together: summary of water resources planning processes and activities (Defra)



1.3. Project objectives

The primary aim of the project is to develop a high **level strategy and framework for the long term planning of water resources** for Public Water Supply in England and Wales.

This includes consideration of the following:

- A sector-wide view of future resilience and options for improving that resilience.
- Assessment of variation in levels of service and potential minimum levels of service for customers and the environment, accounting for costs and benefits at a national, regional and sub-regional level, which includes the wider social impacts of drought and drought resilience.
- Exploration of opportunities to integrate investment (WRMPs) & operational management (Drought Plans).
- Qualitative identification of potential implications of drought failure on other sectors.
- Identification of the potential barriers that are represented by current and future arrangements that might exist between water companies, including potential trading arrangements, the implications of competition etc.
- Identification of the likely nature of resilience infrastructure and preferred levels of service to inform discussions relating to national infrastructure planning and the development of a national policy statement on water resources.

1.3.1. Project outcomes

The project provides an assessment of **drought resilience** of existing and future national water resources systems, based on **climate change perturbations** of the historic climate, and **under 'alternative' more severe drought scenarios**, which have been generated through stochastically based modelling.

The project provides a number of outputs, including:

- Assessment of the impacts of the drivers of differing future scenarios (drought resilience, environmentally-driven abstraction changes, climate change, growth).
- Identification of the scale of deficits in 2040 and 2065 across the range of future scenarios and different drought regions in England & Wales.
- High-level portfolios of options that could be used to address the range of future scenarios.
- The relative resilience and costs of the high-level portfolios.
- Improved understanding of trade-offs such as resilience versus cost, the balance between demand management and supply side development, appropriate level(s) of resilience, improving our understanding of emerging environmental pressures and the constraints of water resources, etc.
- High-level strategy identifying the types of portfolios (investments) or option types needing further investigation.
- Identification of policy and regulatory constraints on implementation of the portfolios of options identified, the risks that these may impose on planning for resilience and opportunities / recommendations where these may need attention and change to ensure the timely implementation of schemes to improve resilience.

1.3.2. What the project won't do

There are a number of key considerations that are outside of the scope of this project. As a result, **the project will not**:

- Provide a single plan for the country up to 2065. Instead, the focus of this project is to provide a high level strategy identifying promising option types for further investigation;
- Provide an instruction to companies to develop specific schemes. Instead, companies may choose to review the options from this project and consider the needs for further feasibility investigations to identify options for implementation in greater detail in the company WRMPs;
- Provide detailed technical feasibility or engineering designs for options. The options assessed in this project are, out of necessity, considered at a strategic level relevant to a national assessment. They are based on readily available information from previous WRMPs or from discussions with water companies and other bodies;
- Consider future sector or scheme financing mechanisms, or commercial trading arrangements for transfers that may be identified through this project's analysis. No consideration or indication of ownership and operations, nor of industry structure has been taken into account or considered, although potential risks and barriers caused by particular institutional arrangements are referred to where appropriate;
- Consider emergency responses and recovery from very extreme events or catastrophic outages. The objective is to help to identify longer term plans for water resources that may mitigate the need for emergency responses.

1.4. Structure of report

This Technical Report is aimed at water industry practitioners and policy makers who require more detailed information than that provided in the Executive Summary of this Project. This Technical Report is supported by the Technical Appendices, which provide a more detailed description of the methods and assumptions used in the analysis.

This Technical Report is structured as follows:

- **Section 1**: Provides the introduction and context behind this project.
- **Section 2**: Sets out some key questions that the project is aiming to address.
- **Section 3**: Explores the challenges faced in balancing future supplies against future demands.
- **Section 4**: Sets out the long term planning framework developed for this project, and a summary of the evaluation techniques that were used. Technical details are provided within the relevant technical appendices, and referenced as appropriate within this section.
- **Section 5**: Provides analysis around drought resilience to answer the question "is there a problem?"
- **Section 6**: Sets out the analysis to identify how big the problem is in terms of the resources available under different drought conditions, and in the face of the challenges explored in Section 3, and provides a summary of the scale and spatial distribution of potential future deficits.
- **Section 7**: Provides a summary of the analysis to support the valuation of the consequences of failures to supply customers.
- **Section 8**: Sets out what options and portfolios are available to avoid or mitigate the problems identified, including analysis of the resilience of potential portfolios of options and the key outputs from the modelling work.

- **Section 9**: Identifies a range of potential enabling actions that would support the portfolios of options required to mitigate future challenges.

- **Section 10**: Provides a summary of the key headline messages and conclusions that can be drawn from the analysis undertaken for this project.

- **Section 11**: Provides the commentary and findings of the independent External Review Panel.

- **Technical appendices**: A series of brief standalone reports providing greater detail on the technical approaches and analysis undertaken.

2. What questions is the project aiming to address?

The project seeks to answer a number of key questions. These are examined in the following sections of the report.

1. Do we have a supply/demand resilience problem?

The report provides an assessment of the key challenges facing public water supplies in England and Wales up to 50 years in future, in terms of the current planning process (water resource management plans and drought plans) and approaches used, and in particular, in terms of the levels of drought resilience that are planned, and how these differ across the country.

This is informed by an examination of more extreme drought events than have been considered before in the current water resource planning processes. Whereas previous analysis generally considered the worst historic drought experienced over a period of up to 100 years of observed records, this report uses stochastic weather generation to examine a wider range of plausible but more severe droughts.

The challenges for planning water resources into the future are outlined further in Section 3, while the issues around drought resilience across England and Wales are explored in Section 5.

2. How big is the problem?

What scale of deficits may be faced in future, under a range of scenarios focused on differing levels of drought resilience, climate change impacts, growth, environmentally-driven abstraction changes and demand management strategies and policies? Hence, what are the potential long term water needs for public water supplies, and how do these differ across different parts of England and Wales? This report also considers how potential risks of failure may be evaluated to allow trade-offs to be explored.

Quantifying the size of the problem is discussed further in Section 6. This is supplemented by Section 7, which examines how the potential failure can be evaluated in economic terms.

3. What do we need to do to avoid or mitigate the problem?

The report provides a high level assessment of the options required to meet the wide range of potential future deficits, considering both demand management strategies and new supply side sources and strategic transfers. An assessment of how the portfolios of options might perform against a wide range of drought conditions and planning scenarios has been undertaken to understand the extent of level of service failures.

The report considers different option types, in terms of:

a. Policies and regulations: To support or drive options, such as to facilitate customer water-using behaviour changes or to support engineering solutions.

b. Engineering solutions: Understanding the typical infrastructure that may be needed, to understand and assist in planning for implementation, and to allow more detailed investigations to be carried out under the existing water resources planning processes.

Section 8 describes the options available to address the problem, how portfolios of options can improve resilience, and what residual consequences remain.

4. What enabling actions are needed to support the intervention measures?

Following on from the above question, the report provides an assessment of whether there are particular enabling actions that might support the development or implementation of key options or types of options, and consideration of which stakeholders may be best placed to drive specific enabling actions.

The range of enabling actions are discussed in Section 9.

5. When do enabling actions need to be enacted?

Linked closely to the answers to the above question, there is a need to provide an indication of when such enabling actions may be needed by to mitigate the risk of potential future supply shortfalls.

The considerations of when enabling actions may be required are discussed in Section 9.

3. Challenges

This section explores the challenges faced in balancing future supplies against future demands. The outcomes of the analysis are presented in Section 6.

3.1. Environmental drivers behind abstraction changes

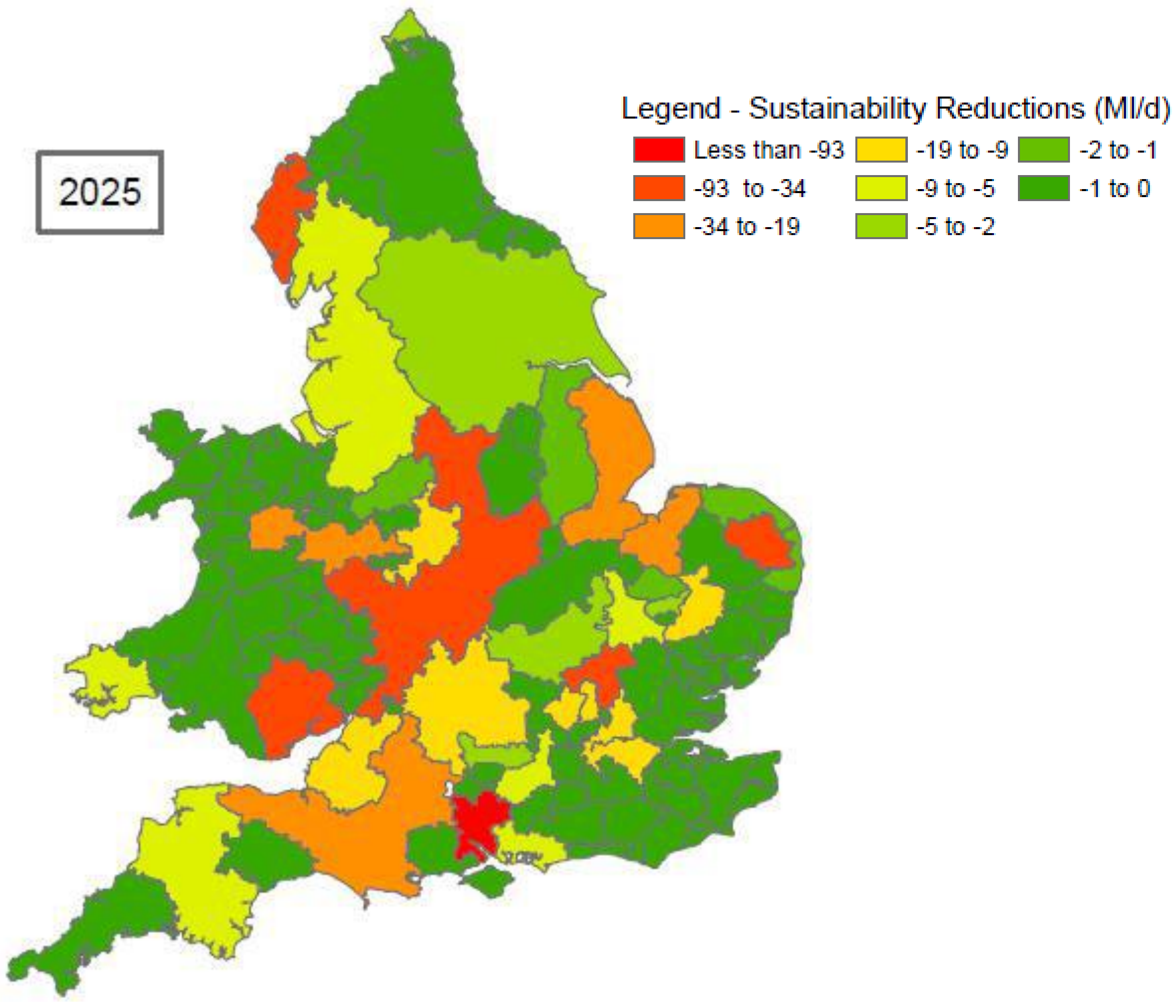
The UK is home to globally important wetlands, rivers and chalk streams. Customers value a resilient environment that is able to respond to future challenges. Our natural capital is valuable in its own right.

Changes to abstraction and management of water are required to manage our natural environment in a sustainable manner. There are likely to be increasing pressures in future on agriculture, power, and industry as well as on public water supplies.

Actions to protect and sustainably manage these water bodies have, to date, been managed through the National Environment Programme (NEP), with reductions in abstraction licences applied to reduce the impacts of damaging abstraction on the environment. Changes in abstraction over the last 20 years have been carefully evaluated and mitigated in order to maintain the security of public water supplies at affordable cost. There remain a number of confirmed or very likely licence changes, which will further decrease deployable output significantly by 2025, and water companies have planned alternative resources to mitigate these in their 2014 WRMPs. However, beyond that there are still other abstractions that are potentially resulting in damaging impacts to the environment, but at present there is insufficient information to determine if this is the case, so further investigation by the water sector will be required to confirm the scale of the impact. In particular, the broader question of how best to ensure longer term sustainability, possibly through initiatives such as reducing licences at sources that are not currently fully utilised, means that there are large amounts of Deployable Output that may need to be replaced in order to balance the needs of the environment and public water supplies.

The magnitude of these changes is not distributed evenly. The fifth phase of the National Environment Programme, known as NEP5, confirmed and likely impacts for each water company by 2025 are presented in Figure 3-1. There is considerable uncertainty over the magnitude of impacts on deployable output that will arise from changing abstraction licences in order to meet and preserve good ecological status of water bodies and the habitats they support.

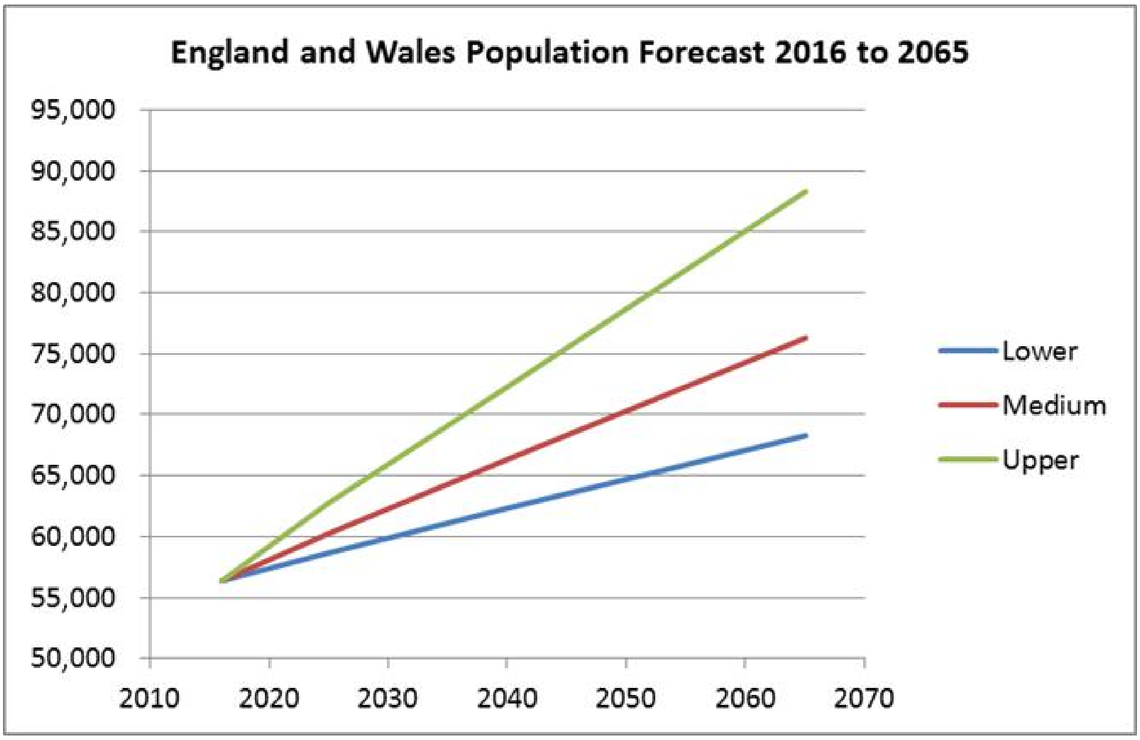
Figure 3-1 NEP5 confirmed/likely impacts by water resource zone (negative denotes a decrease in deployable output)



3.2. Demand growth

The Office for National Statistics (ONS) forecasts population growth for England and Wales of between 6 and 16 million by 2040, and between 12 and 32 million by 2065 (WRMP14 assumed a mid-range of 8.6 million by 2040). This range of population growth is presented for a number of scenarios in Figure 3-2 below.

Figure 3-2 Population growth scenarios



It should be noted that population growth is highly variable between different regions.

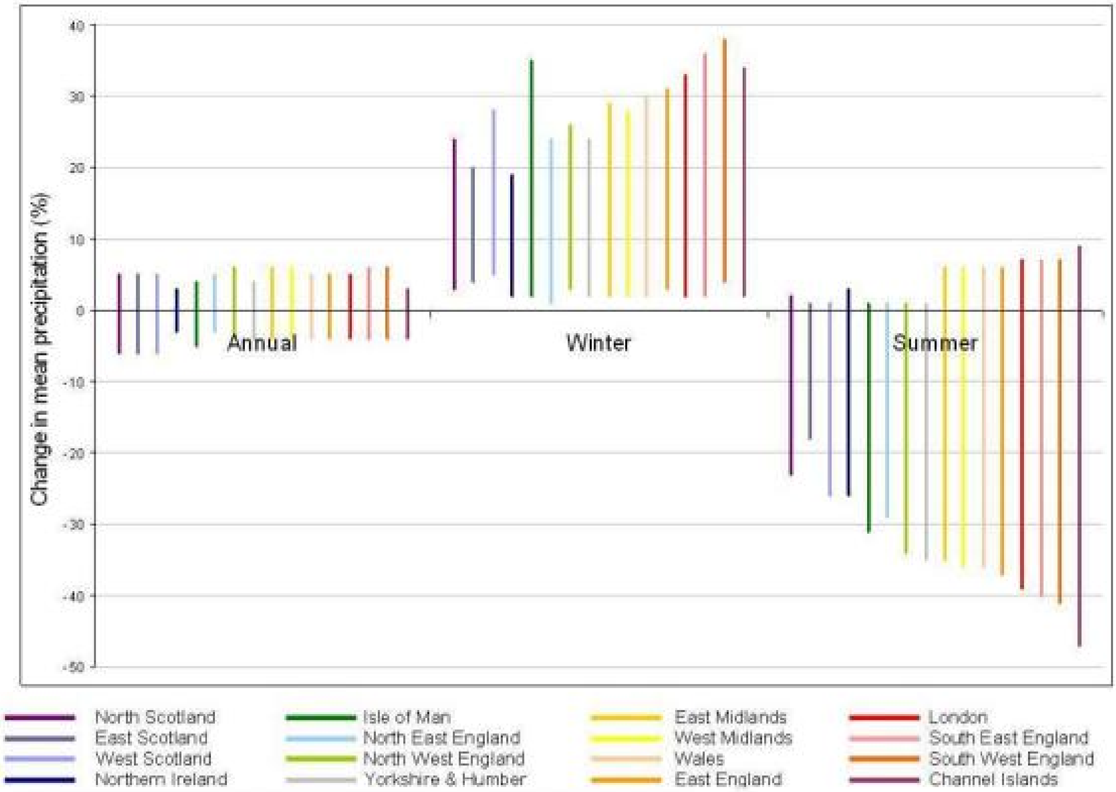
In addition to population growth driving household demand, economic growth is likely to increase water use by businesses. This presents a key challenge during periods of water stress as provision of water to a larger population could mean less water available for business use.

3.3. Climate change

Climate change studies indicate that increasing future temperatures are likely to be associated with a range of changes in future precipitation. As shown in Figure 3-3, the general expected trend is one of wetter winters but drier summers.

The Future Flows study (2012) indicated that, overall, the balance between higher temperatures and the change in precipitation means it is more likely that flows during medium to low flow periods will tend to reduce compared with the current situation. With a few exceptions, water company WRMPs show that this results in a general reduction in available resource for the ‘median’ climate change situation for surface water sources, and hence an increasing level of stress on the supply/demand balance, The WRMPs also indicate that this pressure could be exacerbated in higher emissions scenarios or warmer climate futures.

Figure 3-3 CCRA Assessment of the range of changes in precipitation for the 2050s



This figure shows the range of changes in 30-year mean annual, winter and summer mean precipitation considered in the CCRA, averaged over administrative regions, by the 2050s under the Medium emissions scenario (Source: Met Office from CCRA1 2012).

3.4. Resilience to droughts

The drought in 2011 to 2012 in South East England was one of the most significant 'near-miss' events in recent times. Large water resources systems in the south and east were well below normal operating curves following the winter of 2011/12 and if the summer had been even moderately dry there would have been large scale restrictions across much of the region. By chance the late spring and summer went on to be one of the wettest on record, which alleviated the risk. However, significant droughts occur on a regular basis[1] across England and Wales, with 1995/96 being the most severe of the recently recorded events. As a direct result of that event Yorkshire Water invested heavily in its water resource system and now plans to a much higher level of drought resilience than any other part of the country (see Section 6.1.3 for the evidence base on this). Similarly, the widely known drought of 1976, which led to standpipes in a few isolated parts of the country, resulted in significant research and investment in water supply resilience.

Following the 1995/96 drought, the majority of water companies now plan to be resilient to the worst drought recorded for their area. This generally covers the period back to the 1920s or start of the 20th Century and includes very significant events such as the multiple dry winters of the 1932-34 drought, or the extended drought of 1921 that lasted through to January of 1922. Currently only two companies, Yorkshire Water and Southern Water, plan for resilience to droughts that are worse than those seen in the historic record. It is notable that they are the two companies that have been most affected by drought events in recent times.

[1] See Section 5.1.1 for further analysis of historic drought events.

What happens in a drought?

Water company operational management interventions are based on ‘drought triggers’ (rainfall, reservoir storage, groundwater levels etc.) in accordance with their Drought Plans. The derivation of drought triggers is consulted on in the Drought Plan. Interventions include:

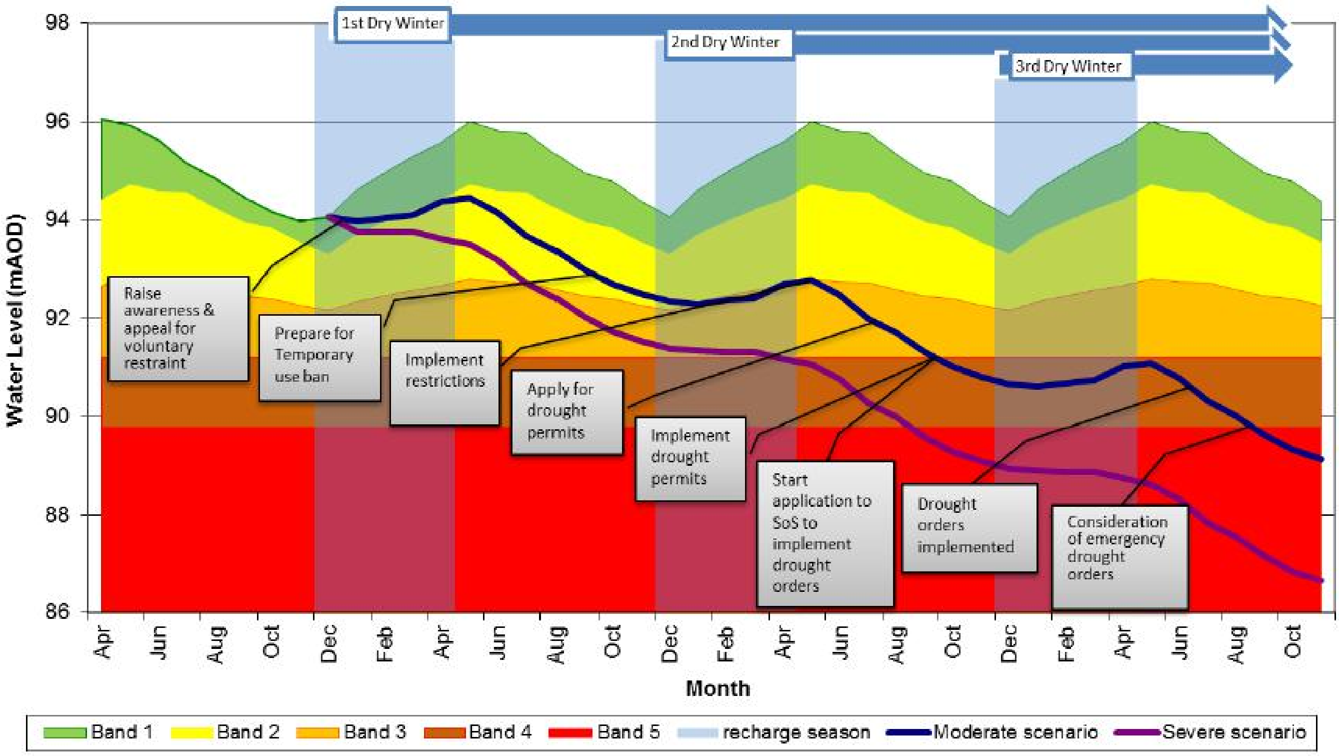
- Media messages, voluntary water conservation campaigns and supply-side measures (e.g. measures to enhance abstraction at existing sources or standby sources without recourse to a Drought Permit / Order);
- Temporary use bans (TUBs, or as they were formerly known, ‘hosepipe’ bans);
- Non-essential use bans (NEUBs – affecting industrial/commercial water users as well as households);
- Supply side Drought Permits and Orders (e.g. reducing river flows or allowing water companies to take additional water); and
- Emergency Drought Orders (e.g. standpipes, emergency abstractions).

For the purposes of this report, when ‘**Drought Resilience’** is referred to, it is generally defined as the severity of a drought event that a water company could experience without having to rely on Emergency Drought Orders (EDOs). EDOs therefore represent the ‘point of failure’ of resilience for the purposes of this analysis.

It is notable that, whilst drought planning is carried out using backwards looking time series of data, companies do not have the luxury of knowing what is going to happen when they face a drought. **As a drought unfolds, water companies inevitably must plan for the worst perceivable outcome (they do not have the benefit of hindsight)**, which often results in the introduction of drought measures such as TUBs and NEUBs at a frequency that is greater than that predicted by a theoretical analysis of the historic record. In order to better understand and control the risk and response process, water companies operate a system of ‘drought triggers’, which are designed to inform the water company of the ongoing severity of a drought and help them to plan interventions that can act to preserve resources in the event of a continuation or worsening of the drought.

A typical system of ‘drought triggers’ is illustrated conceptually in Figure 3-4. In reality most companies do not have the ‘luxury’ of the long timescales and build-up to a drought as shown in Figure 3-4. Large systems across much of the central and west of England are most vulnerable to severe single year events (a dry winter followed by a dry spring, summer and possibly autumn), and some are vulnerable to events lasting as little as 8 months. Even the larger storage systems across the east and south east are often vulnerable to a 12 to 18 month event (e.g. 1921 is the most significant drought in the historic record for Thames Water), and nearly all would be severely tested by 2 dry winters followed by a dry spring to autumn period.

Figure 3-4 Illustration of typical sequence of drought interventions (taken from the Affinity Water Drought Plan)



Example diagram of a drought trigger-response system. The purple and blue lines represent theoretical monitored groundwater levels during a two or three year event respectively. The green, yellow, orange and red bands represent 'thresholds' that are based on an analysis of historic records, and are used to help inform the company when it is making decisions on the level of demand restrictions and supply side interventions to take.

The y-axis in this indicative diagram, presents the groundwater level (in metres above ordnance datum, mAOD).

The operational management of drought and associated drought triggers are described within a water Company's Drought Plan. Typically the 'point of failure' for most companies is when they have to resort to 'emergency drought orders', which are required to allow emergency activities such as the implementation of standpipe restrictions on customers, or potentially highly environmentally damaging emergency abstraction measures.

As well as examining the challenges faced by future changes to the water resources system, this project seeks to understand the implications and costs of drought events that could occur that are worse than those in the historic record. This is entirely plausible, and, for example, could have happened in the south east if there had been a dry summer and autumn in 2012. The *probability* of such an event happening is relatively low (less than 1% chance per year), but the *consequences* of such an event are potentially very high, and the probability of encountering such an event tend to build over time. For example, over the course of a typical 25 year water company plan, the chance of encountering an event that was worse than the historic record is in the order of 15% to 20% (depending on the severity of the worst historic event in their area).

Levels of service

'Levels of Service' for water companies' water resource systems generally describe the frequency at which they plan to introduce different types of drought interventions. As illustrated in Figure 3-4 these cover a range of interventions, from media messages surrounding the need for conservation of water, through to Emergency Drought Orders. Each Company currently has its own set of commitments in relation to the frequency of these interventions, which tend to be developed as a result of a company's experience of drought, liaison with environmental regulators and dialogue with customers and other stakeholders. This has resulted in a high degree of variability in those Levels of Service, in the range of:

- Temporary Use Bans (TUBs) planned for 1 in 10 years to 1 in 100 years*.
- Drought Permits and Non-Essential Use Bans (NEUBs) at 1 in 20 years* to never**.
- Emergency Drought Orders at 1 in 50 years* to never**.

Notes:
** 'Return periods' are usually defined through analysis of the historic record.*
*** In practice 'never' actually relates to the worst historic drought on record – the main exception to this is Yorkshire Water, who state a 1 in 500 year return period for their resilience.*

The actual Level of Service commitments for TUBs and NEUBs (which generally coincide with the introduction of supply side Permits) are shown in Figure 3-5 and Figure 3-6 below. Although the full range is quite large, most companies generally have Level of Service commitments in the range:

- TUBs at 1 in 10 to 1 in 33 years;
- NEUBs & Permits/Orders at 1 in 20 to 1 in 100 years.

Most companies state that standpipes/emergency orders are 'not acceptable', but in practice this means that they could just manage the worst drought in the 1920-2016 historic record without them – they are still 'expected' for more severe droughts. This is complicated by the presence of 'emergency storage' within reservoir systems, which could theoretically be used to further delay the introduction of standpipes for some companies. However, the provision and use of such emergency storage is variable and many of the large systems in the south and east are managed so that standpipe type restrictions would be implemented at the point emergency storage starts to be used.

Figure 3-5 Current levels of service for drought restrictions on Temporary Use Bans (formerly known as hosepipe bans)

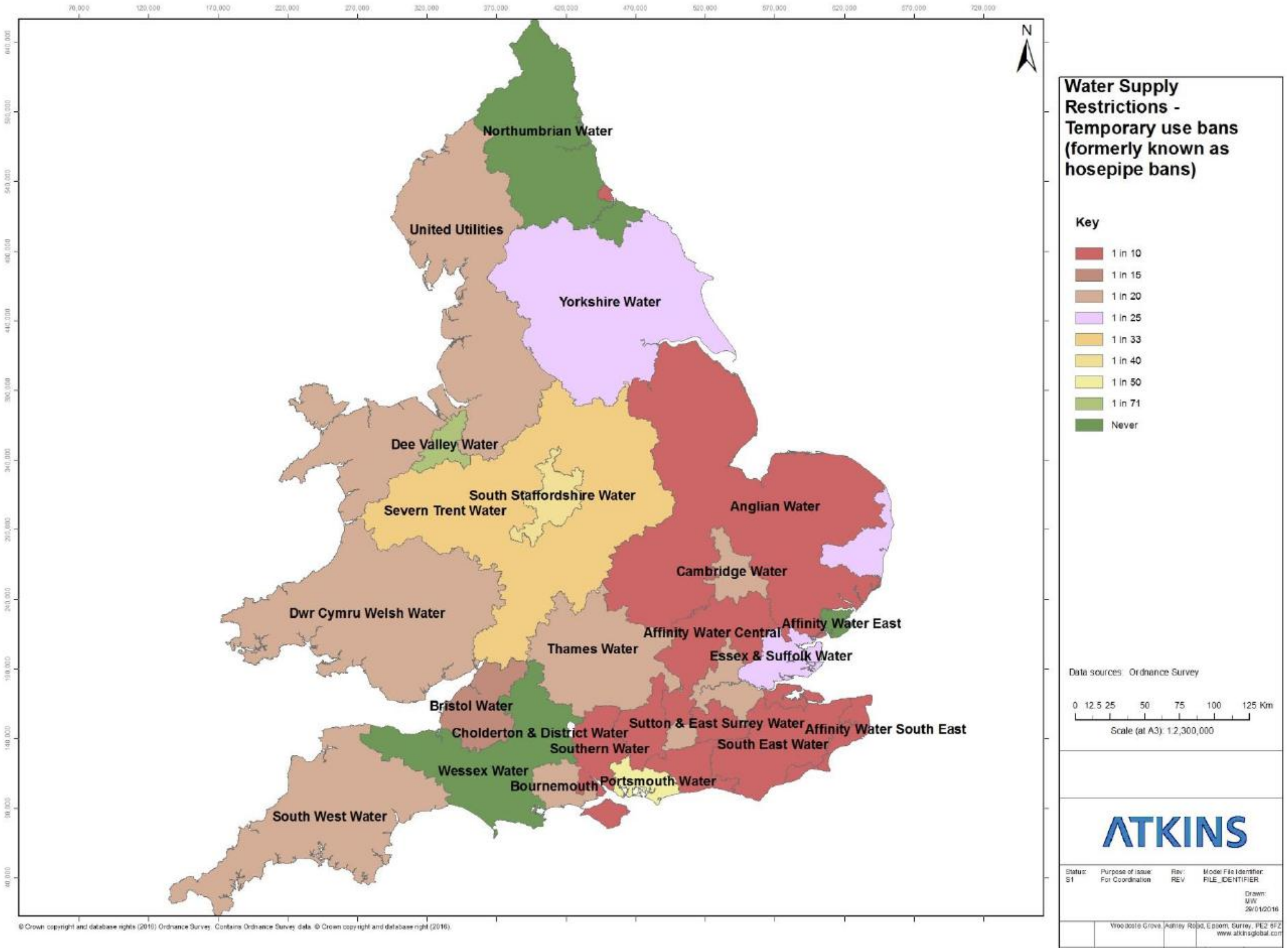
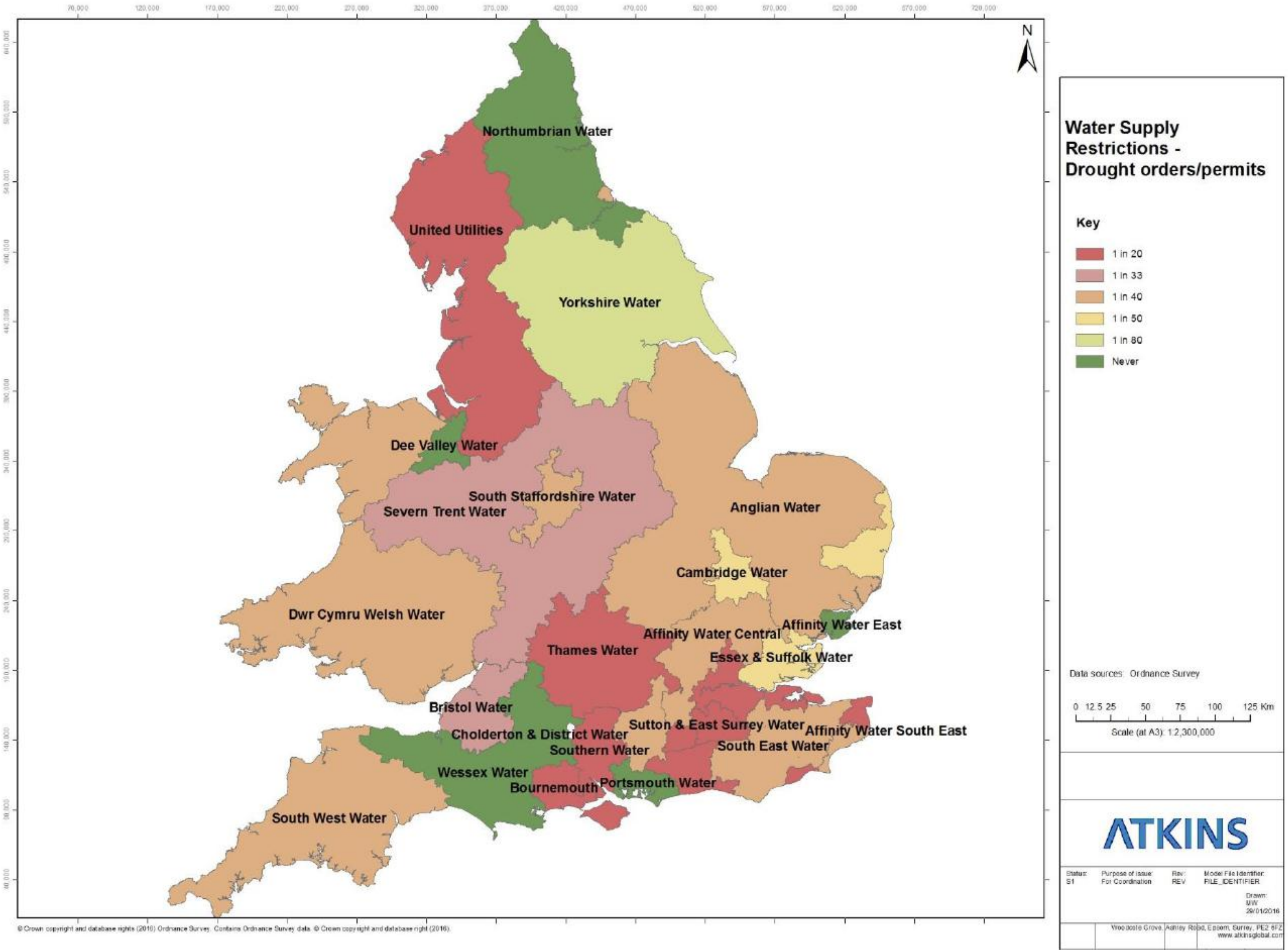


Figure 3-6 Current levels of service for drought permits and orders



4. Key concepts and definitions used in the evidence base

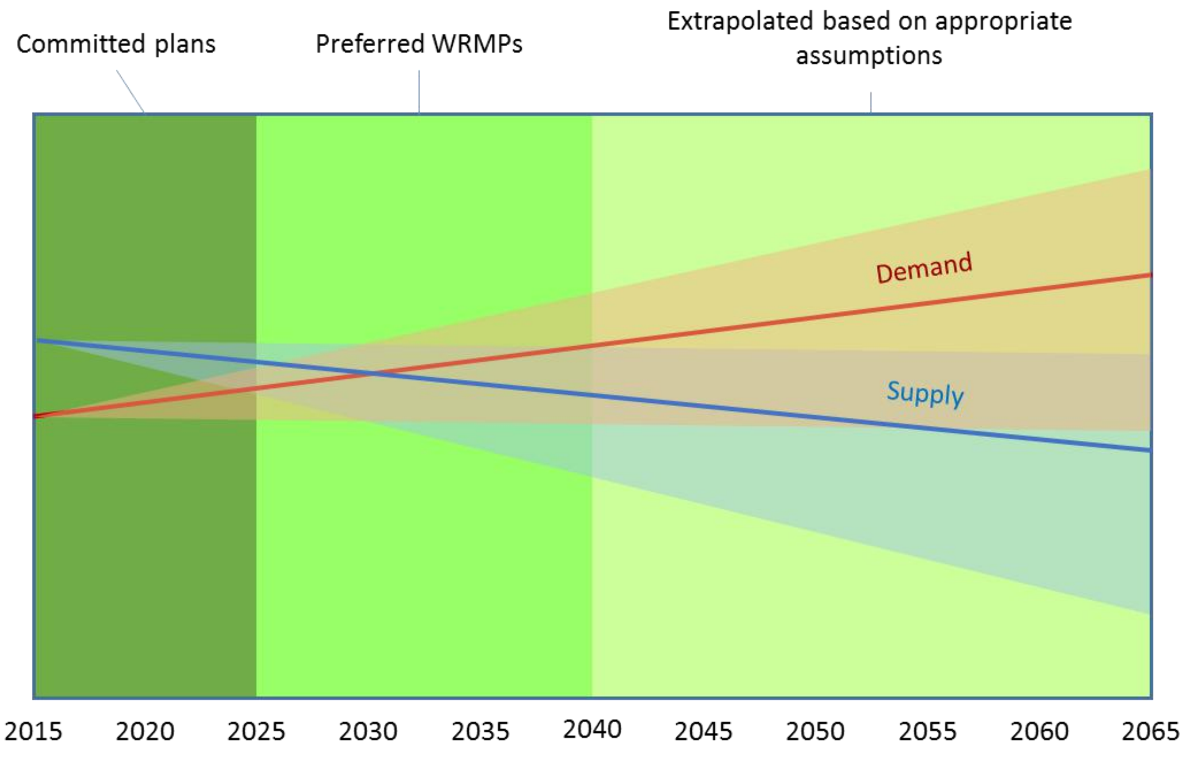
This section sets out the long term planning framework developed for this project, and applied to public water supplies for England and Wales. It is intended to provide a summary of all the evaluation techniques that were used. Technical details are provided within the relevant technical appendices, and referenced as appropriate within this section.

4.1. Outline of framework

The project looks at two future points in time – effectively providing a snapshot assessment of the future at 2040 and 2065. Figure 4-1 illustrates how this project relates to existing planning frameworks, indicating:

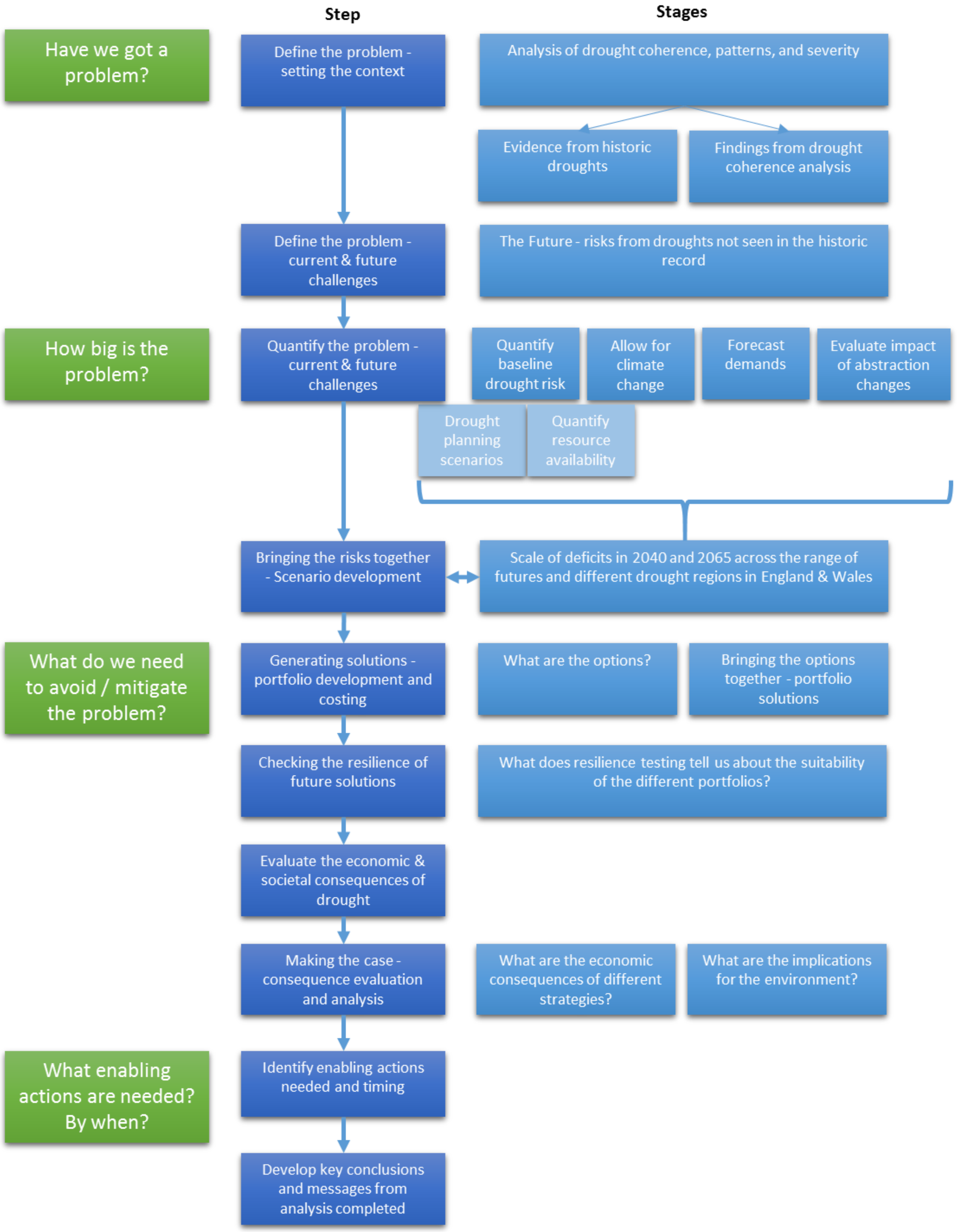
- The illustrative "envelope" of possible future demands and supplies – due to uncertainties with how the future may unfold and the inherent uncertainty associated with trying to forecast 25 to 50 years into the future.
- The relationship to the most recent set of Water Resource Management Plans (WRMPs) that were published in 2014 and provided forecasts through to 2040.
- The "committed plans" comprising a number of options identified in each company's WRMP. This is really the key focus of the WRMPs; to identify the schemes required in the next 10 years or the investigations needing to be undertaken to support strategic schemes identified later in time.

Figure 4-1 Illustrative overview of timeframe assessed in project



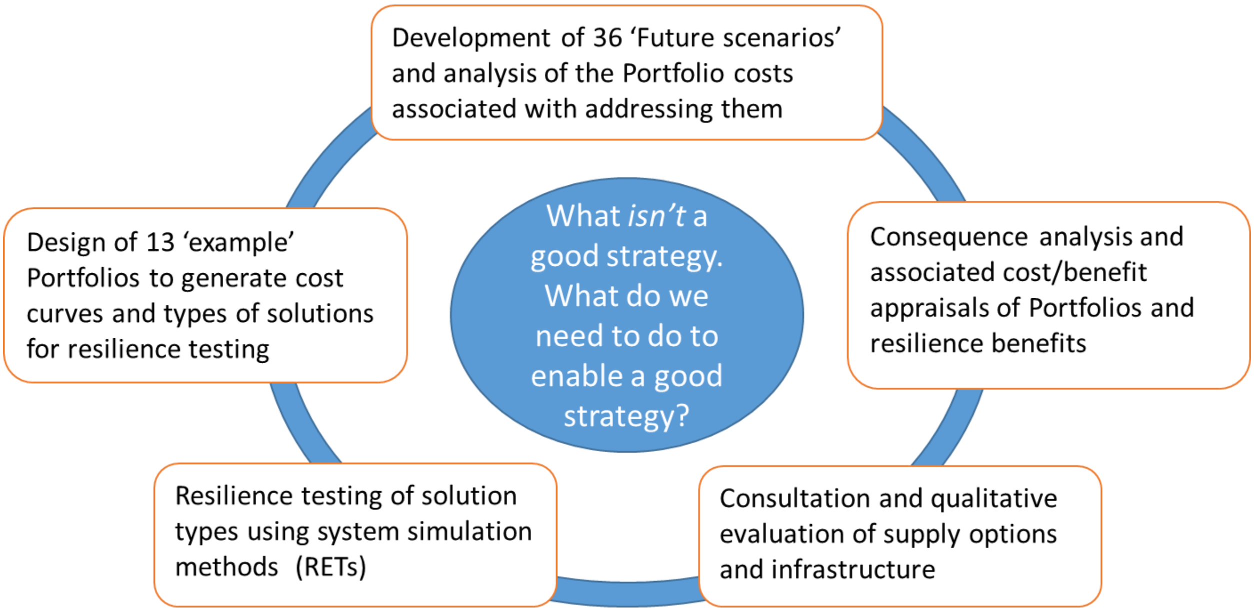
The framework approach adopted to long term water resource planning in this project is presented in Figure 4-2. Each step is discussed in more detail in the sections and sub-sections below. The framework is structured around the key questions that this project is seeking to address.

Figure 4-2 High level strategy and framework for the long term planning of water resources for Public Water Supply in England and Wales



It is important to note that the evaluation of options and potential solutions contained within this report goes beyond the 'conventinonal' least cost approaches that have been used for such studies in the past. Least cost analysis is used, but it is only one of five elements of analysis that have been applied to draw conclusions for the study, which incoporates current 'good practice' elements such as scenario analysis, costs/benefit evaluation, best value considerations and system simulation (see UKWIR 2016 for further information). It is intended that all of the outputs from the study should be viewed using this holistic approach, based on the five elements shown in Figure 4-3.

Figure 4-3 Five interlinking aspects of options appraisal and strategy development



4.2. Defining the problem – setting the context

Drought can be spatially unpredictable and affect different parts of the country's water supply system in different ways. This means the scope of any assessment is potentially enormous. However, it is possible to focus the problem so that it concentrates on the risks and consequences of drought ***as they affect those areas that are most likely to experience water resources deficits in the future.*** By doing this it is possible to examine how other areas of the country may be able to help with mitigating actions (investment and transfer of water), and whether such actions might, in turn, place those supporting areas at risk if the analysis indicated that transfers are a potential solution for the identified deficit regions.

The analysis carried out for this project made use of a significant body of evidence currently available, primarily from the water company Water Resources Management Plans, but also information such as the Climate Change Risk Assessment (CCRA) reports (HM Government 2012).

Although deficits could occur under the right set of circumstances in many parts of England and Wales, the largest drought risks and the future challenges that will be experienced most strongly are generally located across the central, east and south of the country. In order to define the planning problem the country was therefore separated into anticipated **'Deficit**' and **'Supplier' Drought Regions**. These were defined based on:

- The nature of the existing water resources systems and possible major transfer routes; and
- An analysis of drought coherence (see section 5.1).

An overview of these regions is provided in Figure 4-4 below. In terms of meteorology the south and east of England was found to demonstrate a high degree of *expected* coherence[2] during severe drought events, so these were classified as a single region for this study. However, understanding potential opportunities for sharing water within the South-East region was an important part of the study, so this region was separated into the 'sub-regions' shown in Figure 4-4, namely:

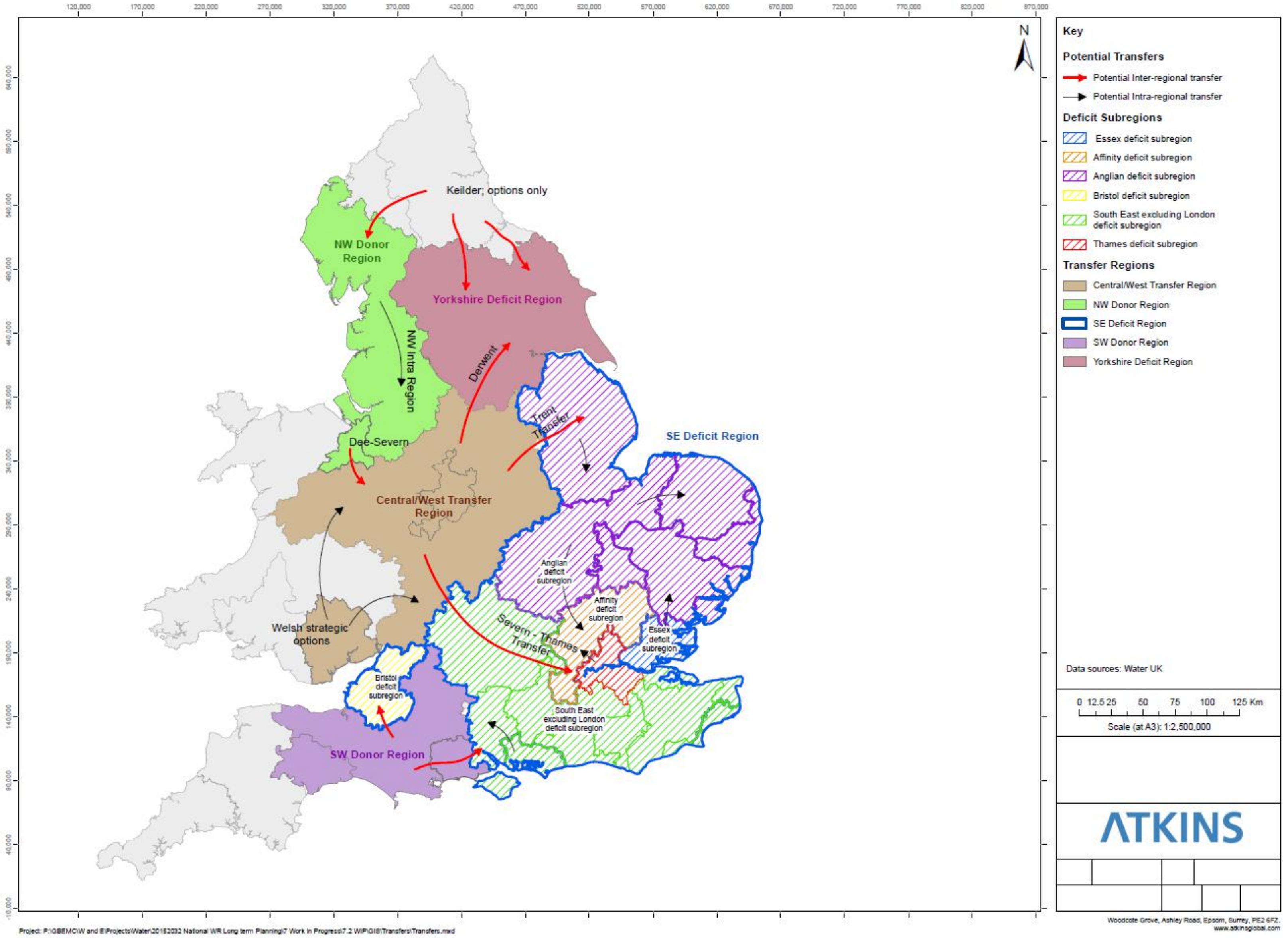
- The Anglian sub-region (including Cambridge Water);
- The Affinity-London sub-region;
- The Thames-London sub-region (including the SWOX water resource zone);
- The Essex sub-region (the Essex & Suffolk Water Essex WRZ);
- The South-East excluding London (SEEL) sub-region.

The Bristol Water sub-region was also separated for study purposes from the South West region.

The **Central-West** region was classified separately to all the others. Although it has some surplus and is not generally one of the first Regions to experience deficits under median climate change and baseline sustainability reductions, it is vulnerable to both of these challenges and can experience very large deficits under some scenarios. However, it also has a large number of indigenous resources and could potentially act as a 'hub' for transferring additional resources from Wales and the North-West to the Thames and Anglian sub-Regions. It has was therefore classified as a **'Transfer' Region**. Its potential role in transferring water meant that it could not be analysed for consequence impacts in the same way as the Deficit Regions, but it was the focus of much of the resilience testing that was carried out (See Sections 6.1.3 and 8.3).

[2] The 'expected' drought coherences refers to the conditions that would be expected to occur, 'on average' in a given region when drought conditions of a given severity are experienced in a different region e.g. if one company in the south east is experiencing a drought of 1 in 100 years severity, then you would expect the neighbouring company to experience a drought of similar severity; however, if a drought of 1 in 100 is being experienced.in Kent then you might only expect an event of, say, 1 in 10 (or even less) to be experienced in Cumbria at the same time. This understanding is based on an analysis of *conditional probability* – every event will be different and the degree of variability will be different. However, *on average* there will be an expectation of coherence that can be estimated through statistical analysis.

Figure 4-4 Overview of drought sub-regions (deficit, donor and transfer regions) and potential strategic transfers



4.3. Defining the problem – current and future challenges

The analysis focused on a specific aspect of overall water supply system resilience, namely **Drought Resilience.** This is defined here as the risk that available water resources will fail to be sufficient to meet demands for public water supplies, resulting in emergency restrictions on demand and potential detriment to the environment through the use of high risk Drought Orders**.**

Four key risks affecting the resilience of water supplies to future droughts have been examined:

1. **Baseline** (current) **drought risks.** This is an immediate issue that is already faced under current Levels of Service. The project focused on the 'High Impact, Low Likelihood' (HILL) consequences of drought, and was primarily geared towards understanding the risk that water supply customers might experience emergency restrictions such as the need for standpipes or rota cuts, although implications on 'lesser' restrictions such as Temporary Use Bans (TUBs) and non-essential use bans (NEUBs) were considered. In reality the response of water supply systems to drought is a continuum, with a likelihood and duration of restrictions that increases as drought severity increases. However, in order to allow a practical, solvable representation of this challenge, droughts were separated into four 'bands', which were representative of the following levels of drought severity (quantitative descriptions are provided in the next section):

    - 'Typical' significant droughts that have been experienced in relatively recent times, and which might be expected to require intervention measures beyond simple Temporary Use Bans (TUBs).

    - Droughts with a severity similar to that demonstrated by the worst droughts within the reliable historic record (**'worst historic' droughts**). Effectively this means drought events that have been recorded between the current day and the start of the 20th Century.

    - Droughts that are more severe than those contained in the 20th & 21st Century record, but that have a reasonable likelihood of occurring during the next 50 years (**'severe' droughts**)[3].

    - Extreme droughts that are plausible, but would only occur very rarely (**'extreme' droughts**)[4].

2. The impact of **Climate Change effects** on drought severity and resource availability. Although droughts have occurred in the 21st Century, these have all been 'near-miss', rather than severe, events. The 'worst historic', 'severe' and 'extreme' droughts referred to above therefore represent the risks that might be expected under a 20th Century climate, and are not reflective of the potential climate in 2040 or 2065. The 'baseline' droughts have therefore been *perturbed* to account for the impacts of climate change on drought. This effect was examined at two levels:

    - 'Median' climate change - i.e. the current 'central estimate' of how climate change might affect drought risk and resource availability in the future.

    - 'Dry' climate change – i.e. the risk that the future climate will tend towards drier conditions. For the purposes of this report a relatively conservative view was taken (i.e. the more detrimental future climate change projections have not been considered), and 'dry' represents the climate that might be expected under a medium emissions scenario, with a 25% or so chance of materialising.

    Wetter climate futures have not been analysed in detail, but have been taken into account when the consequences of future risks are calculated.

3. **Growth in demand** placed on water supply systems by population and economic growth. This presents a longer term risk associated with the uncertainties in forecasting how the population may grow across

[3] To put these in context, these are droughts that would only be expected to occur around half as often as the worst droughts seen in the 20th Century.
[4] To put these in context, these are events that would only be expected to occur twice or so in each millennium – there is evidence of such droughts occurring in Northern Europe in the longer historic record, but they are very infrequent.

different regions of the country, and also how customers' water using behaviour may change from current levels.

4. **Reductions in abstraction to protect the aquatic environment** – this factor is a current or short-term risk, as a range of potential abstraction changes have been signalled by the Environment Agency and Natural Resources Wales for implementation by the 2020s; however, there remains significant uncertainty around the number and scale of these environmentally-driven abstraction changes, which will affect the baseline forecast moving forward to 2040 and 2065. In addition, it is conceivable that further environmentally-driven changes could be required in order to protect the aquatic environment and ensure sustainable abstraction in the longer term.

The methods that were used to quantify and formulate the challenge in relation to each of these four aspects are described in the sections below.

4.3.1. Quantifying 'Baseline' Drought Risks

4.3.1.1. Definition of Drought Severity

The concept of 'return period' is often used within natural event analysis, but has been avoided as far as possible within this report for two main reasons:

1. It can be misleading for policy makers and members of the general public.

2. It can provide a false sense of accuracy of the probabilities involved, and may not be conceptually appropriate for a non-stationary climate (i.e. under climate change).

However, on a pragmatic basis it is important to be able to provide some understanding of the level of likelihood that design droughts might occur in order to make meaningful policy decisions. The general approach used in this study has therefore been to broadly define drought categories in comparison to the current 'standard' assumptions (i.e. the type of drought that is similar to the worst event seen in the historic record), and evaluate other droughts in comparison to that standard. **To support this, the definitions of drought likelihood presented in Table 4-1 have therefore been used throughout this report**.

Table 4-1 Definition of Drought Severity Classifications used in this report

Drought Severity Level	Description	Probability (relative - nominal) that a drought at or worse than that level of severity would be experienced in a 25 year planning period	Average expected number of events of that severity or greater occurring between 2015 and 2065
Significant	Droughts that might be expected to require intervention measures beyond simple temporary use bans.	70%	2 or 3
Worst Historic	Significant events with a severity equal to the worst events seen in the 20th Century record.	22%	0.5*
Severe	Rare events beyond those seen in the 20th Century – might only be expected to occur once every couple of centuries.	12%	0.25*
Extreme	Very rare events of a type only observed a few times in even the longest reconstructed records (using tree ring analysis or similar).	5%	0.1*

*where the *expected* number of events is less than 1, this means that there is a good chance that the event will not be seen during the 50 year period, so it is more meaningful to consider it as a probability risk rather than an expectation.

Return periods have also been used where necessary, but it is noted that these are pragmatic, approximate categorisations that are intended primarily to provide a comparison against current, standard planning assumptions.

4.3.1.2. Definition of Drought Coherence and Planning Assumptions

Conventionally, Water Resources Management Plans in England and Wales have only considered the historic record, generally back to the 1920s or 1900s. This means that the analysis of drought risk is therefore both constrained to the severities and patterns shown within the droughts experienced in that time period, and contain a very limited number of significant events from which conclusions about drought coherence can be drawn. A key element of this project was therefore the creation and use of a **stochastic drought weather generator**, which is technically described within Appendix B. This weather generator was entirely statistically based and worked by generating 'what if' analyses of rainfall timeseries, which were then matched against potential evapotranspiration (PET) using a persistence-corrected resampling method. This generator was developed to provide two key pieces of evidence for the report:

1. The analysis of the statistical coherence of droughts between the different Drought Regions (as described in Section 4.2 and presented in Figure 4-4), with a view to understanding the potential resilience benefits that might be gained by sharing resources across those regions.

2. The creation of droughts that are more severe than those seen in the 20th Century in order to understand the resilience of current and future resource systems during such events.

The weather generator did not inherently include climate change – this was added to the generated droughts using perturbation techniques that are standard to the UK water industry. It is recognised that adopting such a perturbation method carries two potential issues:

1. 'Return periods' based on historic data become somewhat meaningless under climate change.

2. Drought patterns that are generated and ranked under the 20th Century climate will change with the climate, so the relative severity of a given drought pattern will change in relation to other patterns as climate change progresses.

These issues were recognised and conceptually accounted for in the approach that was used for resilience testing under the 2040 and 2065 futures, as described in Section 4.6.

'Drought severity' is a combination of both the intensity of rainfall deficits that occur, and the duration of the deficit, and varies according to meteorological, hydrological and water resource system factors. Ideally this would be explored through the interaction between many multiple (hundreds or even thousands) of generated drought events and the water supply systems involved, but this was simply not practical due to the scale of the modelling and the 'granularity' with which river basins and water company supply systems had to be represented. The analysis therefore focused on a **Drought Configuration** based approach, using both historic records and artificially generated drought events to examine water resources risks. The Drought Configurations were specifically constructed to allow the options appraisal and resilience testing elements of the study to answer the following two key questions, without incurring impractical levels of complexity and computer processing:

1. If you have a drought of severity *x* in a recipient Drought Deficit Region, what should we plan for in the potential 'supplier' Drought Regions?

2. What do droughts beyond those seen in the 20th Century record look like, and how does that affect resilience?

In order to identify the appropriate Drought Configurations, it was first necessary to evaluate the nature of drought coherence. This process relied on both historic data and the weather generator, and is described within Appendix B.

The analysis of drought coherence and the process used for selecting Drought Configurations relied on the generation of ***aridity indices*** that describe the duration, intensity and timing of drought events. Such methods are widely used across the world and seek to define a drought by how far the weather patterns that form the drought deviate from a set average (in this case the 20th Century average). An example plot of a 12 month aridity index for the 1976 drought, as calculated from 22 representative meteorological locations, is provided in Figure 4-5 below. This form of index has two key advantages:

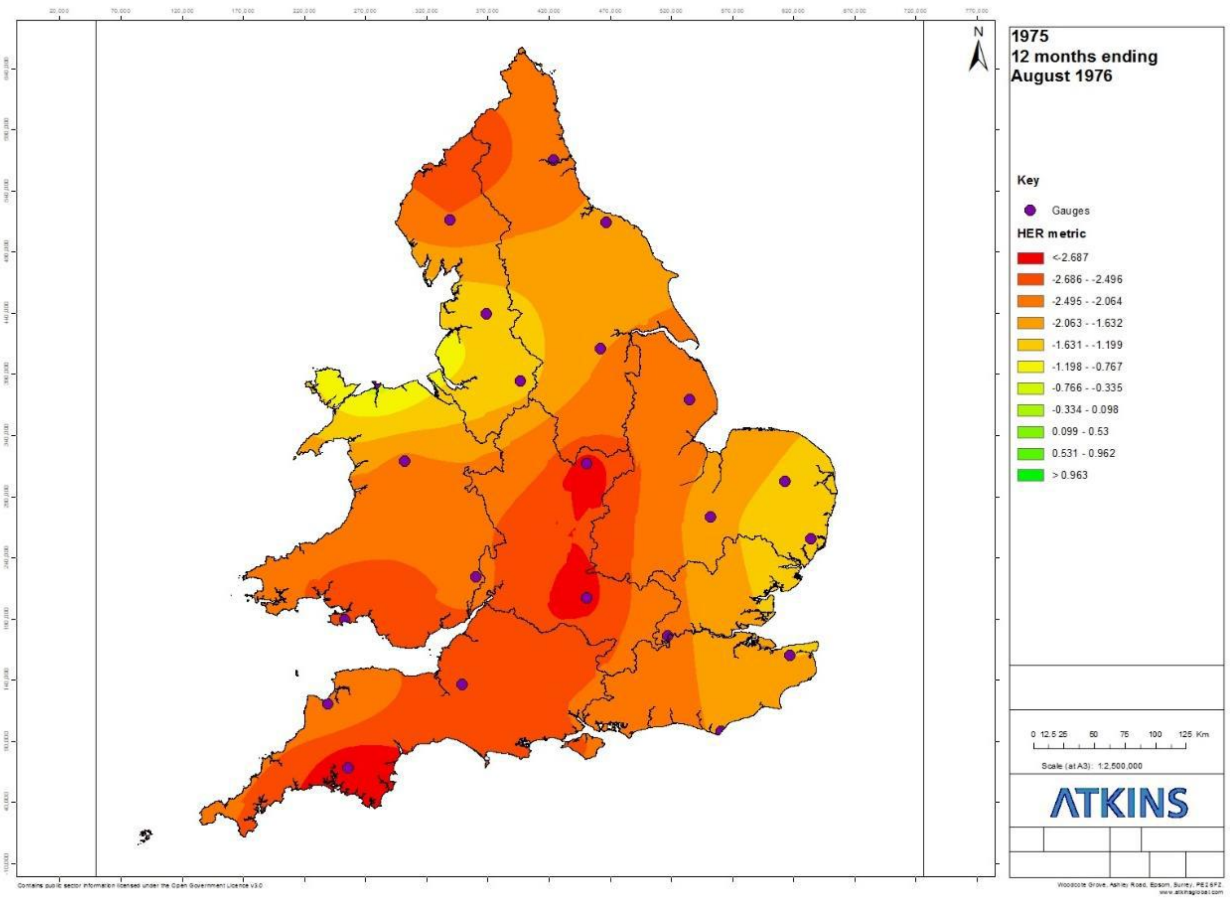
1. It inherently accounts for the fact that evaporation is lower in winter, so winter rainfall is more ‘valuable’ in water resource terms, but does not under-estimate the value of rainfall/recharge that can occur during the spring to autumn period, even during drought events.

2. It inherently allows for the natural meteorological variability that occurs at a site, which is important because droughts are caused by a *deficit* from the norm, rather than just by absolute quantities of rainfall and evaporation (e.g. the rainfall associated with a severe drought in Cumbria is much higher than the rainfall that occurs during a drought in East Anglia).

It should be noted that all of the maps of this type have been generated from the 22 sites selected, so tend to be ‘smoothed’ and will not reflect localised influences such as orographic (mountainous) influences. The analyses are also deliberately provided on a *relative* basis, as water resource systems tend to be developed around the local ‘norm’ and it is the deviation from that which results in the drought risk.

The ***drought coherence*** was based on statistical *expectations* of relationships between sub-Regions. In effect this represents the ‘average’ difference in expected drought conditions for surrounding Regions when a drought is centred over one particular Region. For example, the analysis showed that, if a drought of around a 1 in 200 year Return Period occurs across the Thames sub-Region, then it is *expected* that the Central-West (Severn Trent) Region would experience a 1 in 150 year Return Period event at the same time. Obviously there is a very large amount of variability involved in any given drought, so it is only the *on average* ‘expectation’ that was quantified by the drought coherence analysis. This ‘expectation’ is meaningful in water resources planning terms, as, for example, it means that it should be reasonable for Severn Trent to plan for a slightly less severe drought if they are considering transfers to Thames, but wish to maintain the same level of resilience as Thames. The results of the coherence analysis are presented within Section 6.1.1 of this report.

Figure 4-5 Example Aridity Index; calculated for the 12 months ending August 1976



4.3.1.3. Drought Configurations

Both the resource evaluation that was used to evaluate the yield capability of water company systems under different droughts, and the resilience testing of the Portfolio options that were developed to address future supply/demand risks relied on the creation of **Drought Configurations.** These Drought Configurations were developed to show how different regions of the country would be expected to behave under different severities and durations of drought events. The Drought Configurations were designed to be spatially coherent – i.e. they were designed to reflect the *expected* severity of drought that would occur within a 'supply' or 'transfer' region during a drought of a given severity that was focused on the Drought Deficit Regions. For example, the 'severe' 12 month drought event contained drought sequences with an aridity index return period of approximately 1 in 200 for the Thames, Anglian, South-East excluding London and Bristol sub-Regions, which was matched by a 12 month drought with an aridity index return period of around 1 in 150 for the Central-West (Severn Trent) Region. Each configuration consisted of 15 drought scenarios, each of which contained either an historic event, or an artificially generated event of a specified duration and severity. Seven separate configurations were developed:

1. The 'Scenario 0' Drought Configuration, which represents drought risks across the country prior to the application of climate change.

2. Three Drought Configurations that were based on Scenario 0, but perturbed for climate change impacts through to 2040.

3. Three Drought Configurations that were based on Scenario 0, but perturbed for climate change impacts through to 2065.

The exact method used to construct these Drought Configurations is provided in Appendix B. Full details of the final construction of each Drought Configuration are provided in Section 6.1.1.

4.3.1.4. Evaluation of resources and resource impacts

The evaluation of resource availability under the different Drought Configurations was carried out using two broad approaches (technical details of the approaches are provided in Appendix B2):

- 'Tier 1' analyses for smaller surface water sources (generally less than 30Ml/d yield), and all groundwater sources. These relied on technical data from the WRMP14 submissions, along with the aridity indices for each Drought Configuration and expert judgement to estimate the percentage impact that each historic drought (including the 'worst historic') and the 12, 24 (and 36) month 'severe' and 'extreme' droughts would have on the Deployable Output quoted in each water company's WRMP14 submission.

- For all larger, strategic surface water sources, a 'Tier 3' analysis based on full timeseries analysis of each Drought Configuration using rainfall-runoff modelling and water resource system modelling was carried out to determine the resource capability (comparative yield) under each drought duration and severity.

- 'Tier 2' analyses only applied to those resources that needed to be represented as a timeseries within the Wathnet water resource model, but were too small to warrant full rainfall-runoff modelling. These were derived by generating the timeseries from the 'Tier 3' resources based on regression algorithms developed from the historic records.

The outputs of this resource evaluation process are provided in Section 6.1.2 of this report, and comprise a table of expected losses or gains in yield (Deployable Output) that would be expected under the 'worst historic', 'severe' and 'extreme' drought conditions in both the Deficit and Supplier Drought (sub)Regions. The timeseries analysis developed for the Tier 3 resources was also used to underpin the resilience testing described in Section 8.3.

Discussions were held with all water companies to ensure that the best data were available for this process, and, where companies had carried out their own analysis of resource impacts under drought severities beyond the historic record, these were used to inform the outputs.

4.3.1.5. Accounting for supply side operational interventions; Drought Orders and Permits

When considering droughts that might be beyond the severity of those seen in the historic record it is important to acknowledge that the water company Drought Plans contain 'supply side' drought interventions to allow abstraction beyond normal licences in the case of significant drought. However, including these within an investment planning context is problematic, as the benefits of such interventions are not necessarily *reliable* to the extent that they can be used as a basis for deferring investment. This is as a result of issues over the 'lead time' required to investigate, apply for and implement the Permit/Order, the potential for objections and associated public hearings, and the need to ensure that adequate environmental safeguards are in place *before* the Order or Permit is implemented.

For the purpose of this project all Permits and Orders that are contained within water company Drought Plans were therefore reviewed and categorised into three types:

- **High reliability** – these are interventions with a low environmental impact that are simple to implement. In most cases companies also have some prior experience of that implementation under drought conditions.

- **Medium reliability** – these are interventions that generally would be expected to have a moderate level of environmental impact, and there is some uncertainty over the risks involved in implementation (e.g. likelihood of objection, conditions on use that would limit its value).

- **Low reliability** – these interventions are included within the Drought Plans as they could be called upon in certain circumstances, particularly more severe drought events, but are also more likely to be challenged or objected to, or be applied for when the environment is already under stress and, therefore, may attract restrictive conditions on their use.

A full summary of the classification of all Permits and Orders, along with the methods used for quantifying the benefits for the resource evaluation, is provided in Appendix E. For the resilience testing (which used water resource simulation models) the same overall classification was used, but the Permits and Orders were generally triggered once reservoir storage in the relevant sub-Region had passed the 'Level 3' control curve. A small number of the larger Permits and Orders that relied on the filling of reservoirs during the winter were explicitly modelled using the relevant control rules and changes in licence conditions.

4.3.2. Allowing for Climate Change

The process used for the incorporation of climate change was relatively simple. The Future Flows (2012) data set was analysed and representative rainfall, PET and flow factors were extracted for the 2065 time horizon for the following Future Flow scenarios:

- One 'median' future climate: (AFIXL).

- Two 'dry' future climates:

  - One with worse summer conditions, but wetter winters, which is more significant to northern & western resources (AFIXJ).

  - One with less winter rainfall, but also lower PET and higher rainfall (in relative terms) over the summer, which is more significant to eastern and southern resources (AFIXO).

These were applied as *perturbations* to avoid any double counting of the natural variability that occurs within the Future Flows scenarios. It is noted that, because Future Flows works on the basis of single timeseries runs, there is a risk that the factors reflect and element of natural variability, rather than just climate change impacts. Therefore, in order to reduce the risk that the factors associated with a single Future Flows scenario might significantly affect the results of the study, the two 'dry' climate change scenarios were applied to the different parts of the analysis in two different ways:

1. The simpler resource assessment that was used to underpin the scenario and portfolio analysis was based on absolute supply/demand balances (see Section 4.4), and was therefore potentially more

sensitive to this risk. To mitigate this, an average of the two impacts was taken and translated into a single 'dry' climate impact for the resource impact assessment.

2. For the more complex resilience testing, both dry climate scenarios were maintained and formed the basis of two different sets of scenario testing. However, the results of these outputs were used in an evidence based, *qualitative* assessment of the risks involved in developing a given portfolio, so any potential impacts from the 'natural variability' element of Future Flows were inherently mitigated because the resilience of each portfolio was evaluated 'in the round' against all future risks, rather than just for a specific future scenario.

This climate change assessment was deliberately conservative, and did not account for higher emissions scenarios or climate futures that might be drier than the Future Flows scenarios shown above. Because this project accounted for the full range of future risks, and was already concerned with 'High Impact, Low Likelihood' (HILL) events, it would not have significantly added to the overall findings if drier climates had been considered. However, it is acknowledged that there remains a risk from such climate futures, and this has been included within the narrative of the findings where appropriate.

The impacts were applied using one of two methods, depending on which 'Tier' of water resource evaluation had been used to estimate the baseline drought impacts:

1. For 'Tier 1' resources, water companies' own WRMP14 estimates were used, with the 'dry' climate set at around the 75th percentile[5] of the range evaluated for WRMP14. This set the 2040 value; the 2065 impact was set at 166% of the 2040 value (this figure was based on extrapolation of trends identified in some companies' WRMPs (Bristol Water 2013, United Utilities 2013)). The 166% was also considered to be a logical simplification; if the effects of climate change are considered to start at around 1990 (1961-1990 is conventionally used as the standard Long Term Average baseline), then there are 50 years from there to 2040, compared to another 25 years from 2040 to 2065.

2. For the 'Tier 2' and 'Tier 3' resources, impacts were calculated according to either rainfall-runoff model assessment using the monthly rainfall & PET change factors within the Drought Configuration input data sets, or (in a few cases) direct adjustment of flows based on the relevant monthly flow factors, depending on the nature of the baseline resource assessment.

4.3.3. Forecasting Demand

'Demand' for water is made up of three components:

1. Household demand, which can be calculated based on population and the *per capita consumption* of that population.

2. Non-household (commercial) demand.

3. Leakage losses from the distribution system.

The three **levels of growth** (low, medium and high) that were used in the development of future scenarios only reflected growth in household *population*. The methods and assumptions used to define each growth level are provided in Appendix C. Future variability in *Per capita consumption* was handled entirely through the assumptions associated with each of the four **demand management strategies** that were incorporated into the options appraisal. Effectively this meant that each demand management strategy incorporated both water company specific interventions to reduce demand, and wider societal policies and attitudes. The strategies also contained definitions of distribution system leakage reductions. The following four demand management strategy definitions were used in the options appraisal process:

[5] Although on a simple basis it would appear that using the 11th out of 11 Future Flows scenarios implies a 'dry' climate probability that represents the 91st percentiles, the actual estimate of risk was set at the 75th percentile based on three key factors. The first was that Future Flows are spatially coherent, so tend to be less severe on an equivalent basis than the UKCP09 approach used by most water companies, which were locally specific – i.e. the 90th percentile in the WRMPs tended to be more severe than the worst Future Flows scenario in the majority of cases. The second was that the two 'dry' Future Flows scenarios were averaged to a national level, so represent somewhere between the 10th and 11th rank (out of 11). Finally Future Flows ignores the high climate change scenarios, so again will tend to be lower than the equivalent probability values assessed using UKCP09.

1. **'Business as Usual' (BAU) – Upper**: this represents the situation that would occur if water companies continue with their current policies and methods for reducing demand, but the societal and policy support for demand management is low.

2. **'Business as Usual' (BAU) – Base:** as above, but with a greater degree of societal and policy support.

3. **Extended:** this represents an ambitious extension to demand management, incorporating initiatives such as the use of differential tariffs to help reduce demand.

4. **Enhanced:** this represents a 'stepped change' in demand management, incorporating initiatives such as grey water re-use and much tighter controls on water efficient design for new households.

The full definition and rationale for each demand management strategy is provided in Appendix C.

Non-household (commercial) demand is forecast to remain relatively constant over time from 2025, as any local and regional shifts in demand approximately balance out at a national level, so growth in non-household demand was simply extrapolated from water company WRMPs.

4.3.4. Evaluating the Impacts of Changes in Abstraction to Protect the Aquatic Environment

As described in section 3.1, one of the key aims of strategic water resource planning will be to maintain and improve ecosystem resilience, alongside a resilient public water supply system. Under the Water Framework Directive regulations, abstraction licence changes may be needed to achieve good ecological potential in heavily modified and artificial water bodies, and good status in groundwater bodies. To date, the focus has been to reduce licences where damage to the environment has already occurred. This is an ongoing programme, with confirmed and likely changes included in WRMPs where possible. However, there remain a number of unknown changes that are yet to be fully quantified and confirmed.

The other risk to deployable output comes from the need to avoid any deterioration in ecological status across water bodies from now on, or to achieve protected area objectives. There are at present a number of abstraction licences granted historically, which are not yet fully utilised but are included in deployable output assessments in order to meet forecast future increases in demand or loss of supply from elsewhere. It may be necessary to reduce a large portion of this 'spare' licence capacity in order to prevent environmental deterioration in the future.

The full scale of these impacts is yet to be quantified and companies have started an engagement process with the Environment Agency to do so. For this project, it was considered important to attempt to include the potential magnitude of these losses in an "extended" abstraction licence changes scenario. A number of companies have already identified the risks as potentially significant, and others have investigations underway.

This uncertainty required that the incorporation of changes in abstraction to protect the aquatic environment be based on two scenarios: a **'baseline'** and an **'extended'** scenario. These were intended to reflect, in a pragmatic way, the general principles described within the DEFRA document 'UK Government response to consultation on reforming the Water Abstraction Management System (15th January 2016), although it should be noted that the analyses and core assumptions presented here have been made entirely on behalf of this study and do not reflect any quantified analysis provided by the government.

Both scenarios included all abstraction licence changes which are confirmed or likely to go ahead by 2025 under the National Environment Programme (NEP) programme. These are outweighed by the potential scale of unknown and "no deterioration" impacts, so it was necessary to carry out a high level consultation with regulators and water companies to develop a pragmatic approach to the incorporation of such uncertainties. The following process was adopted to support this analysis:

1. Identify water bodies at high or medium risk of deterioration due to increasing abstraction up to current licensed quantities.

2. Identify the abstraction points which could cause this deterioration.

3. Determine the likely impact on DO of capping these abstraction licences at “Recent Actual” abstraction rates.

This allowed the full potential abstraction changes to be identified for each company, as summarised in Figure 4-6. It is clear that a portion of these ‘unknown’ changes are likely to occur, but that full ‘capping’ at recent actual abstraction rates is likely only to be needed where growth is forecast to cause deterioration in the aquatic environment. Because there was insufficient technical evidence to determine how much of the potential changes might need to be implemented, the following definitions were used for the two possibilities:

- **Baseline**: DO losses determined in response to confirmed/likely sustainability reductions at NEP5, plus 25% of unknown/unconfirmed NEP5 impacts plus 25% of “no deterioration” impacts.

- **Extended**: DO losses determined in response to confirmed/likely sustainability reductions at NEP5, plus 75% of unknown/unconfirmed NEP5 impacts plus 75% of “no deterioration” impacts.

The impact of these two scenarios, by drought region, are summarised in Figure 4-7.

Figure 4-6 Potential losses in DO due to environmentally-driven abstraction changes (by company)

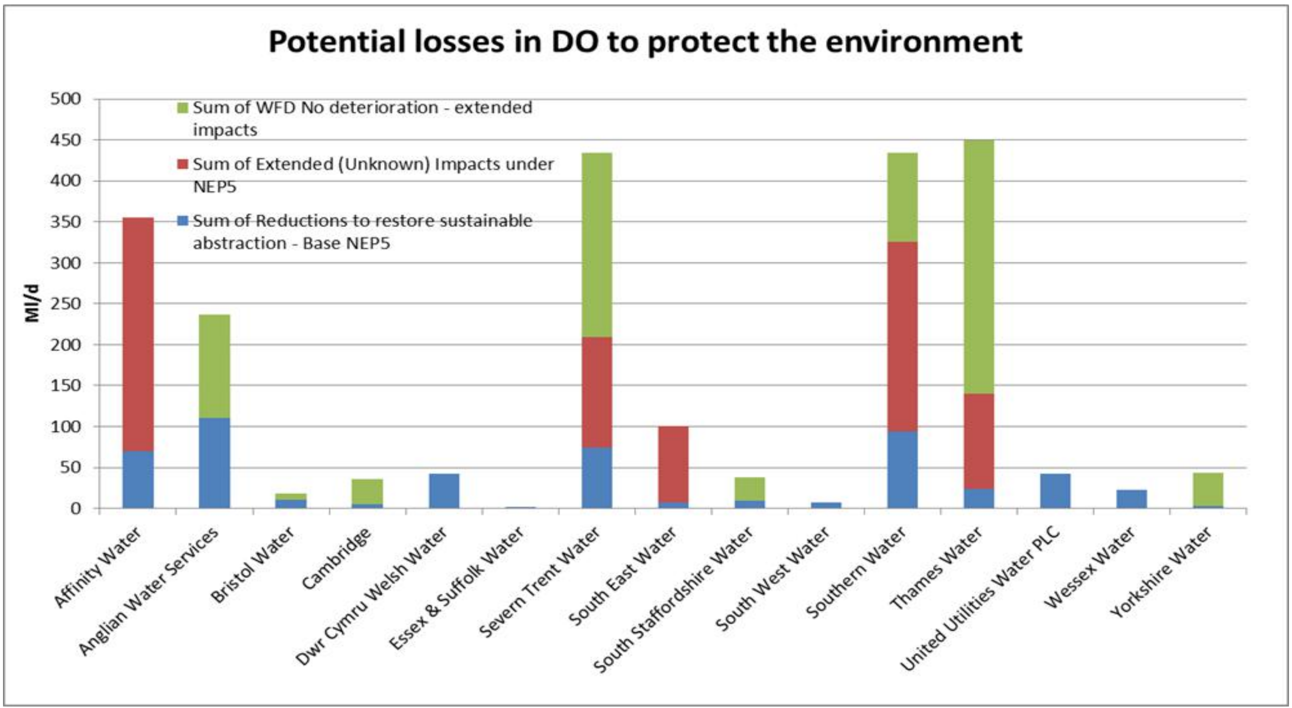
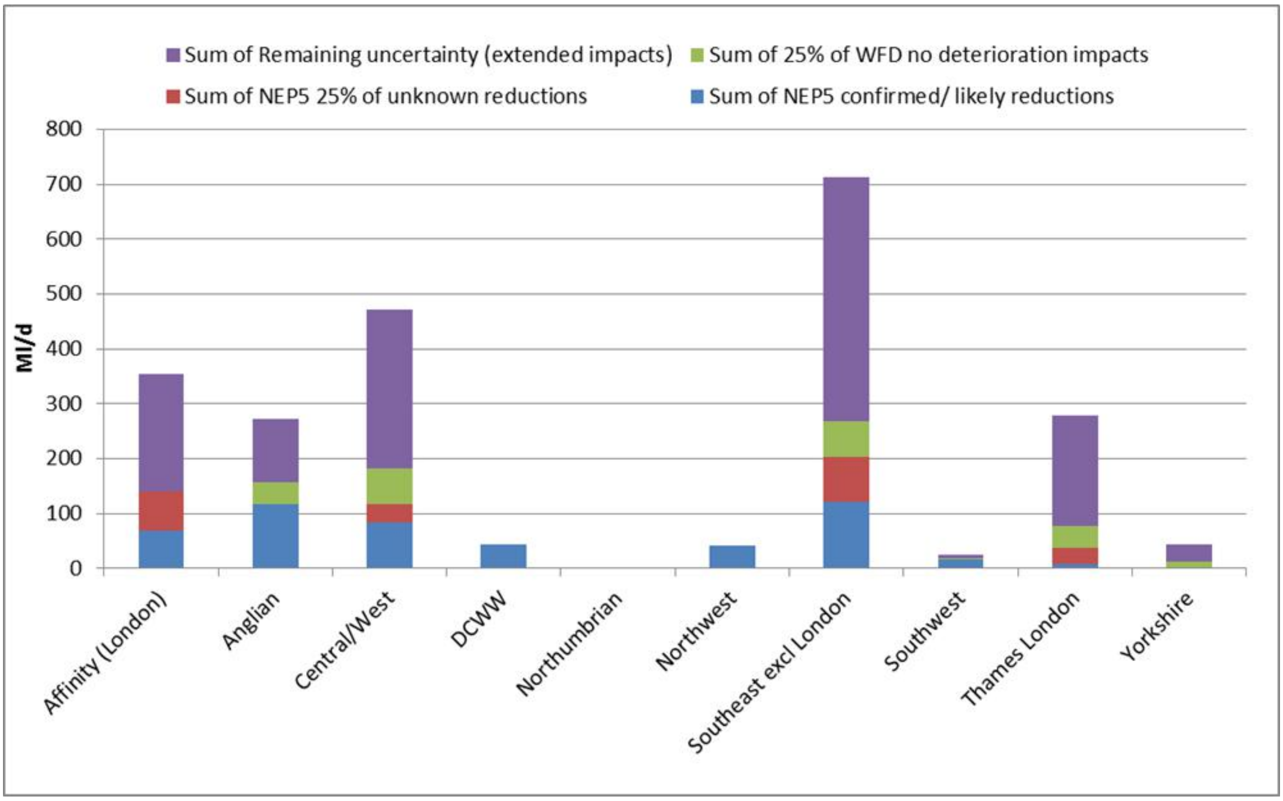


Figure 4-7 Components of potential losses in DO due to Changes in Abstraction Required to Protect the Aquatic Environment (by Drought Region)



4.4. Bringing the risks together: scenario development

As presented in Figure 4-2 a key part of the framework approach employed for this project was to develop a wide range of representative 'futures' built up from scenarios that try to account for the uncertainties in future supplies and demands.

A representative sample of possible futures with a range of potential deficits was developed from combinations of scenarios related to the current and future challenges described in Section 4.3. This resulted in 12 different possible futures, based on:

- 2 possibilities for environmentally-driven abstraction changes (see Section 4.3.4);
- 3 possibilities for demand growth (see Section 4.3.3);
- 2 possibilities for climate change (see Section 4.3.2)

Each of these 12 futures was further separated into three categories of drought severity type ('worst historic', 'severe' and 'extreme'), as described in Section 4.3.1.1. This resulted in 36 future scenarios.

The process used to build up these future scenarios is shown in Figure 4-9. Table 4-2 then presents a summary of the construction of the 36 scenarios for reference.

As noted previously, the three levels of demand growth were only reflective of changes in *population*. Changes in the per capita consumption were handled through the use of four different demand management strategies in the options appraisal. This approach was taken because it was recognised that it would politically and environmentally unacceptable to pursue supply without first considering demand management. The concept used was therefore that the demand management strategy would be set and then the remaining supply/demand imbalances would be addressed through supply side options. This approach meant that the different combinations of demand management strategies and supply side portfolios could then be compared for resilience and cost effectiveness, whilst maintaining a simple approach that allowed for large scale innovation in demand management (e.g. large scale smart metering) and policy / societally-driven changes in behaviour and attitudes. This approach also allowed for a more adaptive interpretation of potential future strategic options, as it provided an understanding of how well supply side options could fill the supply/demand deficit under different future scenarios if the more ambitious demand management strategies failed to achieve their assumed benefits.

Each of these demand management strategies was applied to the 36 futures built up from the current and future challenges, to give a total of 144 plausible futures. The construction of the final 144 futures is presented in Figure 4-10.

Figure 4-8 Bringing the risks together: Development of the 12 'Futures'

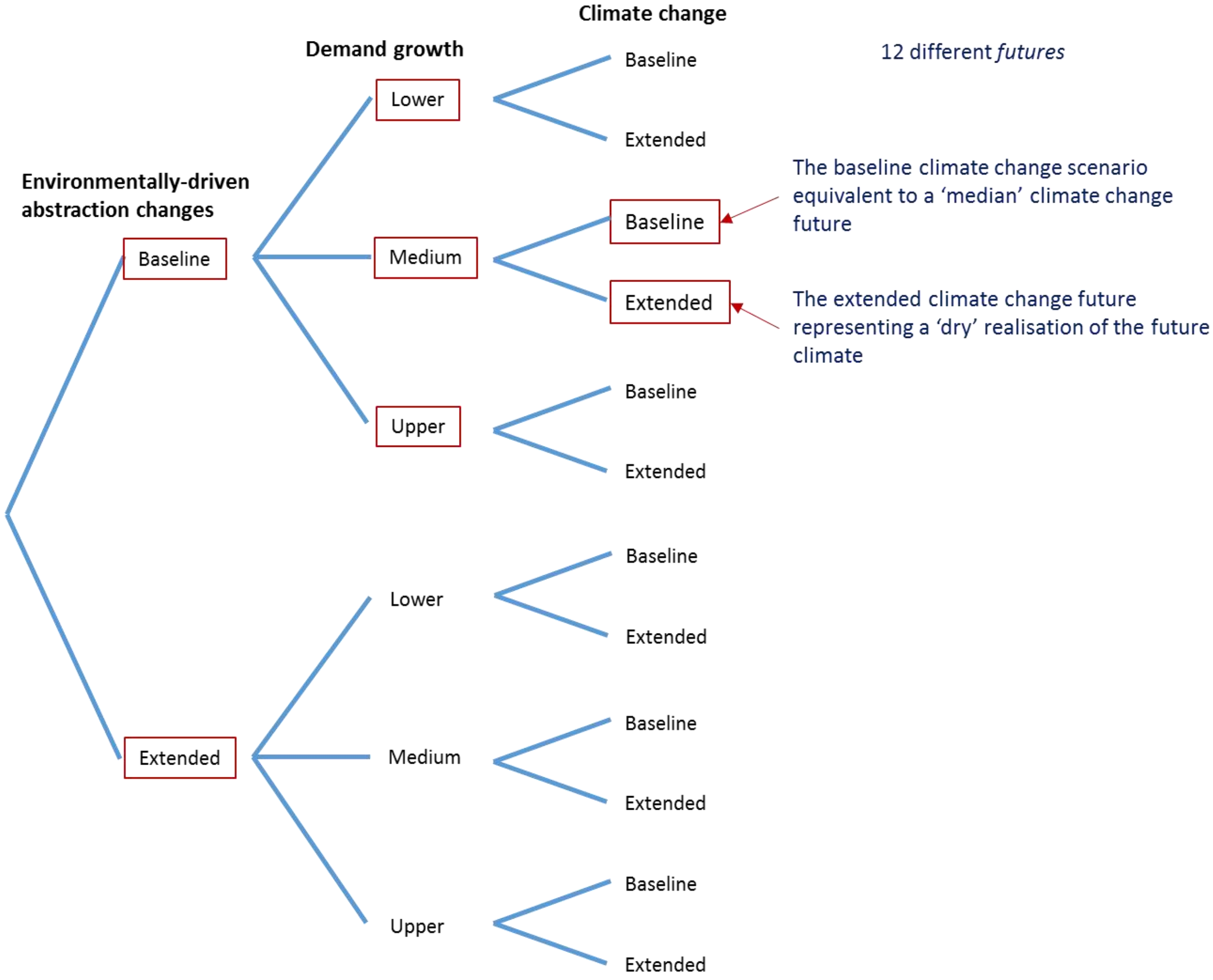


Figure 4-9 Bringing the risks together: Development of the 36 Future Scenarios

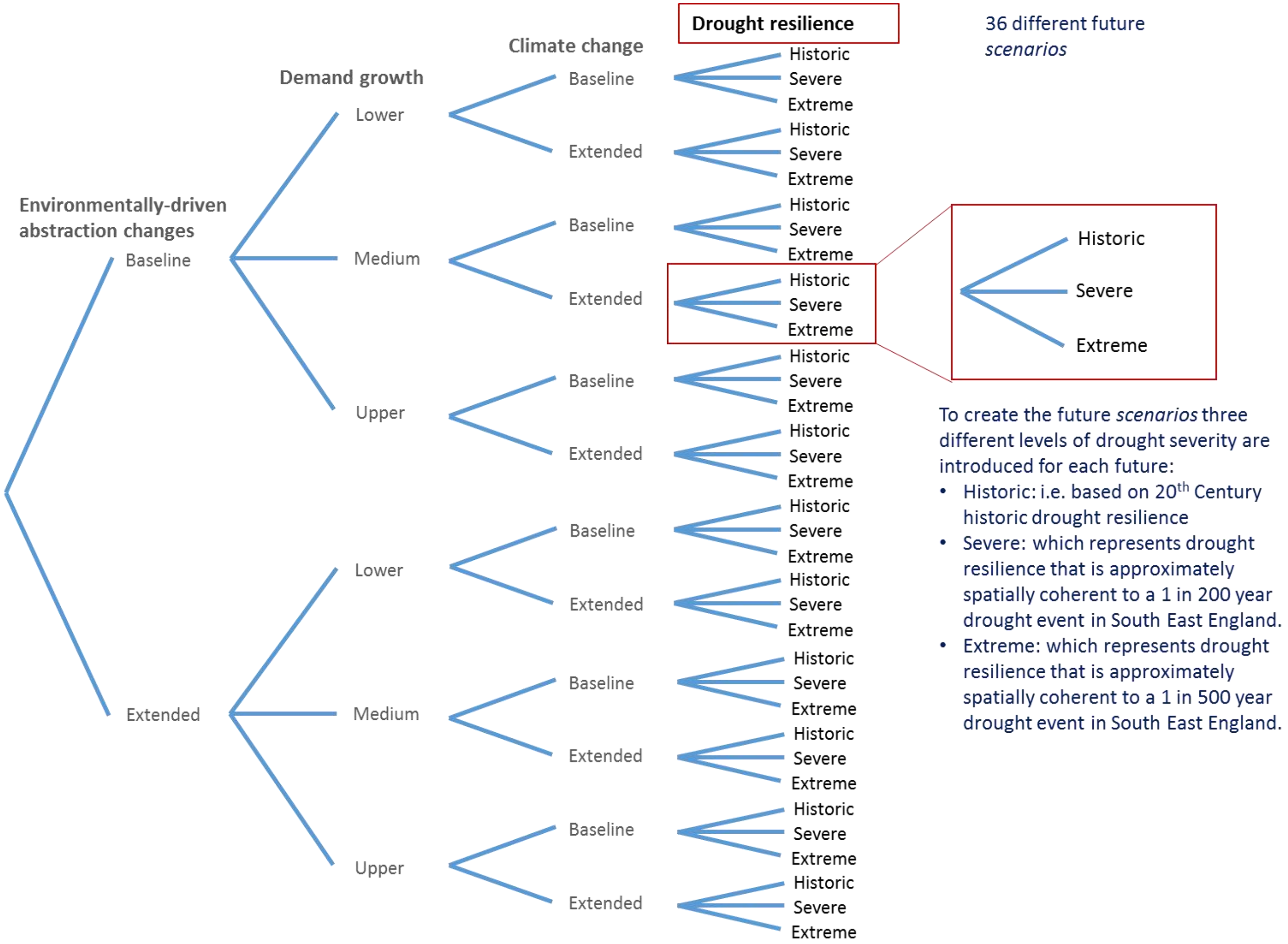
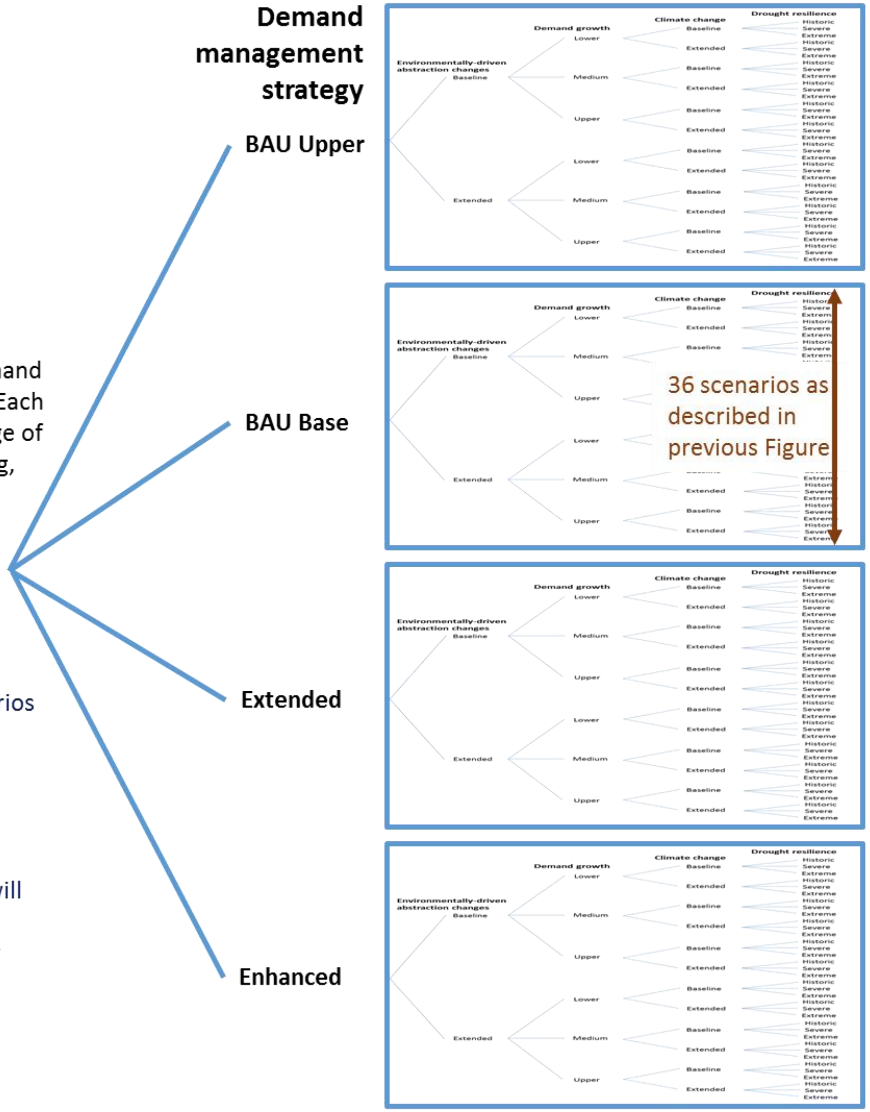


Table 4-2 Summary of the 36 Future Scenarios used for Portfolio Development

Drought resilience	Population Growth	Sustainability	Climate Change	Scenario
Historic	Lower	Baseline	Median	1
			Dry	2
		Extended	Median	3
			Dry	4
	Medium	Baseline	Median	5
			Dry	6
		Extended	Median	7
			Dry	8
	Upper	Baseline	Median	9
			Dry	10
		Extended	Median	11
			Dry	12
Severe	Lower	Baseline	Median	13
			Dry	14
		Extended	Median	15
			Dry	16
	Medium	Baseline	Median	17
			Dry	18
		Extended	Median	19
			Dry	20
	Upper	Baseline	Median	21
			Dry	22
		Extended	Median	23
			Dry	24
Extreme	Lower	Baseline	Median	25
			Dry	26
		Extended	Median	27
			Dry	28
	Medium	Baseline	Median	29
			Dry	30
		Extended	Median	31
			Dry	32
	Upper	Baseline	Median	33
			Dry	34
		Extended	Median	35
			Dry	36

Figure 4-10 Combining the future scenarios with potential demand management strategies to identify potential development Portfolios



There are 4 different demand management strategies. Each strategy comprises a range of measures across metering, efficiency and leakage reduction

Each of the 36 *future* scenarios is applied to each of the 4 potential demand management strategies.
This results in **144 different potential "Portfolios"**.
Each of these "Portfolios" will be designed to meet a different potential deficit or surplus

The **BAU Upper strategy** provides an alternative case where WRMP14 savings are not achieved – i.e. the WRMP measures to reduce PCC and leakage are largely ineffective or impossible to fully implement &/or do not achieve the savings envisaged. This does include an assumption that there will be background improvements in device efficiency and therefore a slight reduction in PCC over time.

The **BAU Base strategy** assumes that savings proposed under WRMP14 are achieved through water efficiency schemes, more sustainable new homes and reducing leakage per property.

The **extended strategy** provides more ambitious savings that are expected to be cost effective but culturally challenging. For example, the savings might require retrofitting and/or smart metering 65% of existing properties to achieve 40 l/property/day saving; or 50% new builds achieving 105 l/h/d and retrofitting/smart metering 50% of existing homes; requires significant behavioural change. Leakage reduced through extended pressure control and active leakage control.

The **enhanced strategy** provides the most ambitious savings that should be feasible technically and economically over the time period, but would come at considerably more expensive than other strategies. For example, it might involve all new homes achieving at least 105 l/h/d, 50% with greywater reuse (80 l/h/d); major behavioural campaigns; and substantial mains renewal

4.5. Generating solutions: portfolio development and costing

Having developed the 144 plausible futures described above, a selection of representative futures were selected so that a portfolio of options could be developed to solve whatever deficit there may be in each region under each of the representative futures. As noted previously, the point of the Portfolio development was to determine the cost of supply side options that might be required to make up the shortfall (i.e. demand management benefits were incorporated first).

Figure 4-11 shows an illustration of how the futures were considered and assessed in terms of the expected deficit or shortfall in supplies compared to demand. Thirteen different futures were selected to provide 13 separate ‘example’ portfolios of options (with a demand management strategy assigned to each future scenario, and a blend of supply and transfer options to solve the remaining deficit). The selection of 13 ‘example’ portfolios was considered to provide a representative number of potential development strategies to develop cost curves that could be applied to the remaining 131 Portfolios (i.e. 144 Portfolios in total less the 13 ‘example’ Portfolios selected for more detailed investigation), and also to help to understand the relationship between cost of portfolio and size of the deficit and key scenario issues.

A conventional *Economics of Balancing Supply and Demand* (EBSD) least-cost approach was used to identify which options would be included in each of the 13 ‘example’ Portfolios to meet the deficits in each drought region, taking into account options identified in companies’ WRMPs, wider options considered in other studies and the most realistic cascades of inter-regional transfers.

It is noted that documents such as the UKWIR Decision Making Process report (UKWIR 2016), which was written to provide technical support to WRMP19, highlight the risks of using approaches such as EBSD least cost planning for ‘deeply’ uncertain futures. This was an important consideration for this analysis. As previously described in Figure 4-3, the overall approach that was taken was one where:

- Individual schemes were incorporated into 13 ‘example’ Portfolios – *these were used to generate cost curves for costing the supply side needs of the other Portfolios and allow resilience testing of the types of schemes contained in the Portfolios*.
- The demand side costs were combined with the supply side costs to derive the overall costs for all 144 potential Portfolios.
- These costs were then combined with the resilience testing, plus high level evaluations of the likely constraints and issues associated with environmental quality, drinking water quality and infrastructure to determine which demand management strategies and types of Portfolio development should be considered on a long term strategic basis.

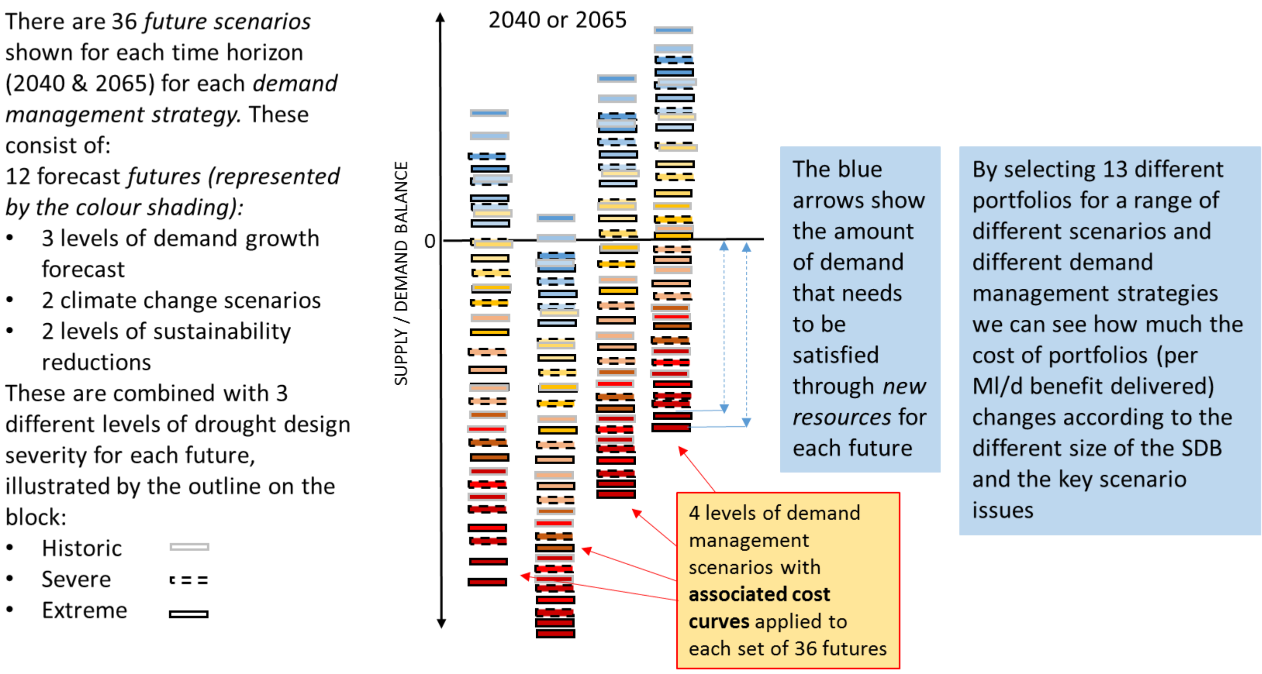
The use of 144 different portfolios across the 36 future scenarios mean that conclusions could be drawn for a large range of future uncertainty. The 13 ‘detailed’ portfolios, along with the resilience testing and constraints analysis were then used to derive more specific findings about the potential nature and timing of the supply side options that might be needed within each of the regions contained in this analysis.

Details of the scheme selection process used in developing the 13 ‘example’ Portfolios are provided in Appendix C.

The mix of options making up each of the ‘example’ Portfolios included various demand management options and policies, depending on which of the four demand management strategies was used for a given future. The ‘typical’ mix of demand management options under the different demand management strategies is described in Section 8.1.1.

Although the 13 Portfolios were only used to develop cost curves and check resilience, it was still important to ensure that they provided a reasonable representation of the variability that exists across *all* 144 potential Portfolios. Obviously this representation was geared towards checking different total supply side developments to provide a good range on the cost curves, but some ‘extended’ and ‘enhanced’ demand management Portfolios were also included to allow for the associated resilience testing. The final selection of the 13 ‘example’ Portfolios is detailed in Section 8.2.1.

Figure 4-11 Illustration of portfolio selection



4.6. Checking the resilience of future solutions

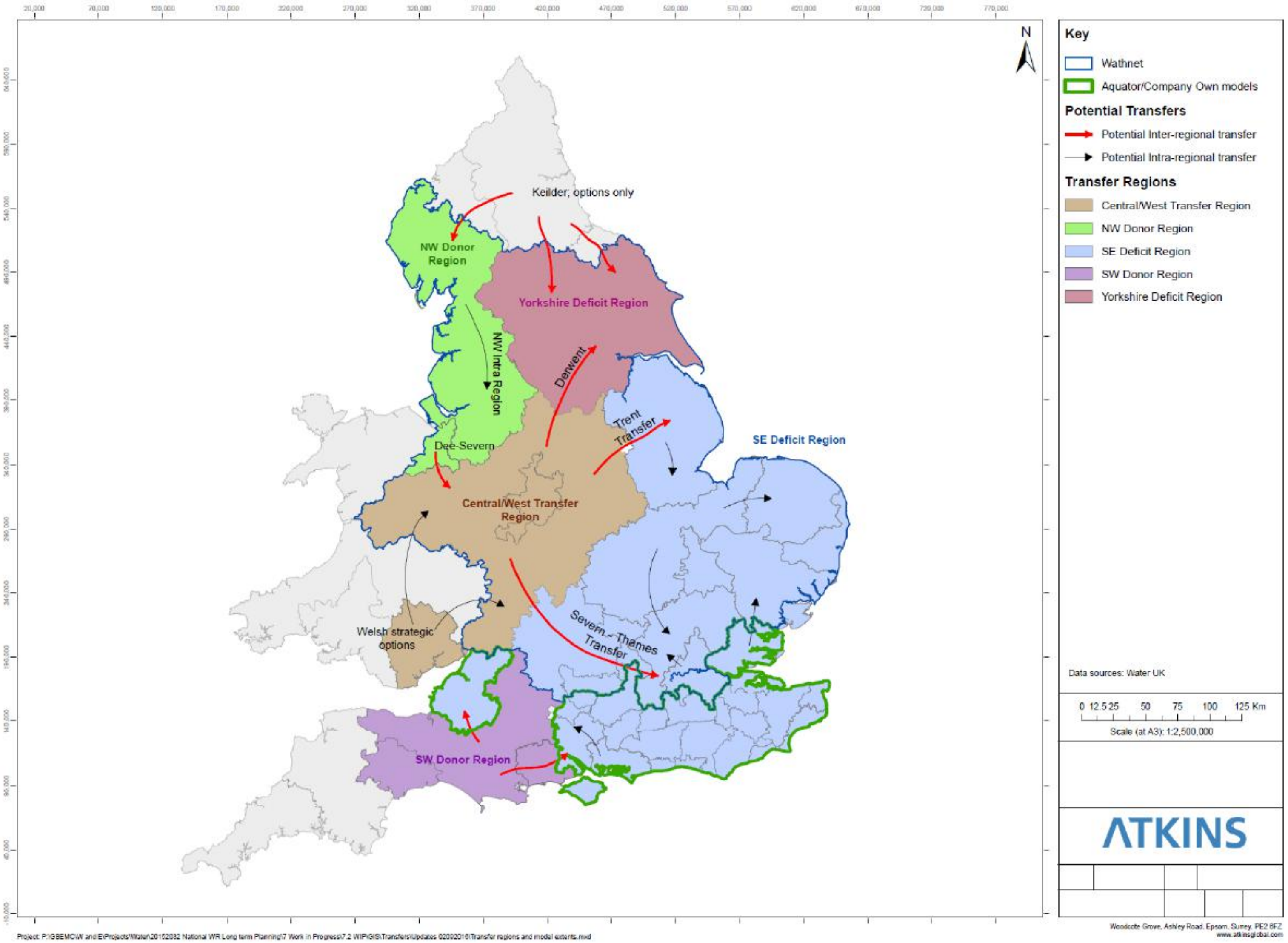
A number of different Resilience Evaluation Tools (RETs) were used to support the analysis of resource capability under different drought severities, and test the resilience of the 13 ‘example’ Portfolios generated by the options appraisal process. A graphical overview of the coverage of the different RETs is provided in Figure 4-12.

A ‘national’ water resource simulator was developed using Wathnet, an academic research software platform which is simple, fast and highly programmable. Developed for similar applications in Australia, Wathnet relies purely on cost/penalty functions to reflect preferences for abstraction and supply of water. This means it does not have the same degree of functionality as more advanced platforms such as Aquator or Miser, but this is less relevant when future strategic development portfolios are being examined, as the actual operating and trading arrangements are largely unknown. As described in Section 6.1.3, it was perfectly feasible to achieve a good validation of storage behaviour against water companies’ own models when historic data sets were run through the Wathnet system-simulator, which demonstrates that the simplifications involved do not affect the strategic validity of the resilience testing.

Although it was a ‘national’ level simulator, Wathnet only covered those areas where there is a reasonable likelihood that large volumes of raw water resource might be transferred and stored between different hydrological systems in different sub-Regions in future. The Wathnet model covers the following sub-Regions and sources:

- United Utilities Integrated Zone (plus West Cumbria).
- Severn Trent Strategic Grid, including Nottinghamshire and some of Shelton, plus South Staffordshire Water.
- The Yorkshire Water ‘Grid’.
- Anglian Water, including Cambridge Water.
- Affinity Water – London WRZs.
- Thames Water London and Swindon & Oxfordshire (SWOX) WRZs.
- Supply options from Dwr Cymru Welsh Water (DCWW) and Northumbrian Water (Kielder WRZ).

Figure 4-12 Overview of RET modelling approaches by sub-Region



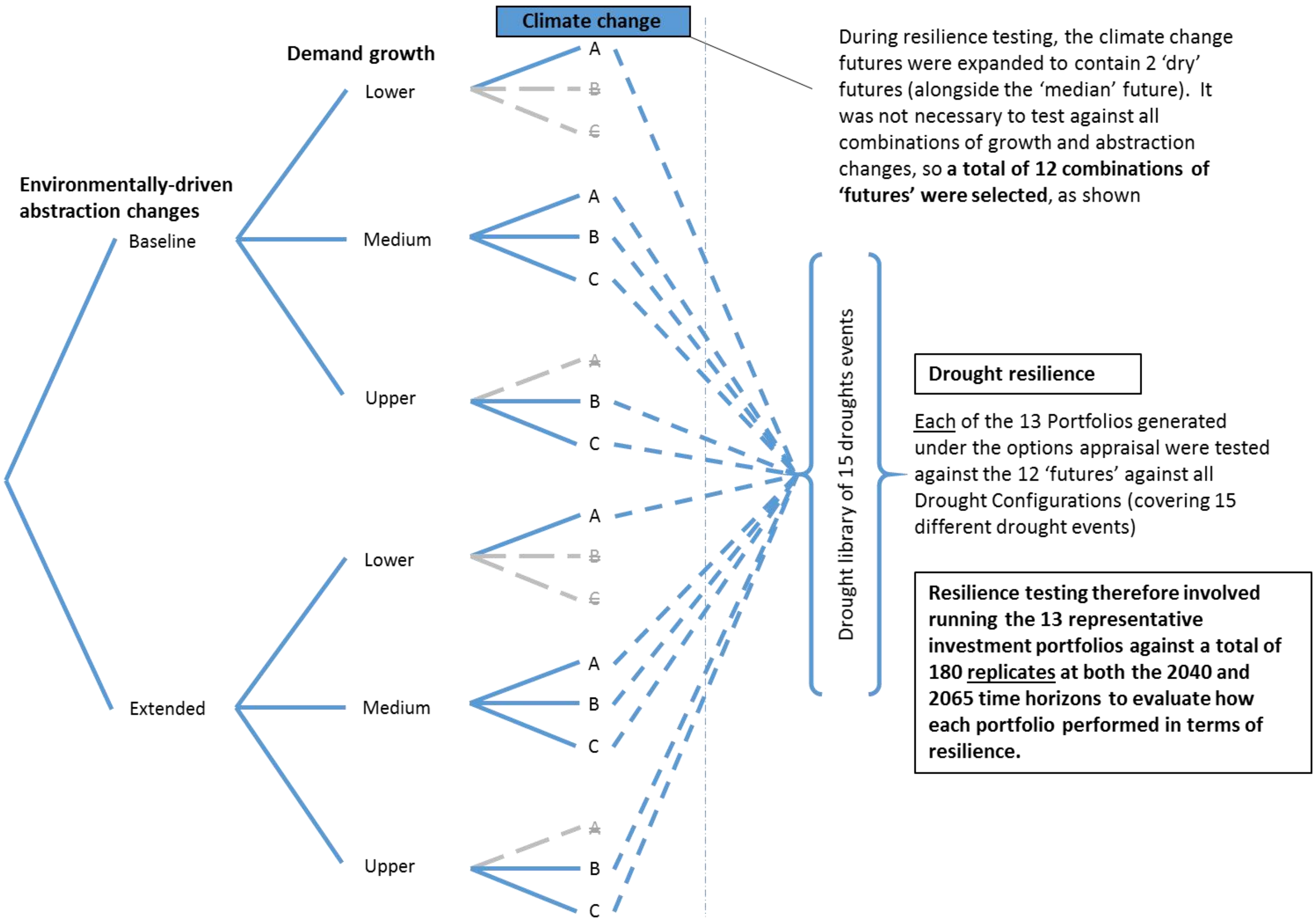
This meant that more complex, but 'isolated' strategic systems in the south and east were not included in Wathnet, and resilience was evaluated through a matrix type assessment of storage failure against incremental demand using the companies' own models, with inputs generated for each of the 15 Drought Configurations in the baseline year and 2065. This was done using the following models:

- Southern Water's West, Central and Eastern Aquator models.
- South-East Water's Ardingly/Barcombe Aquator model.
- Essex & Suffolk's Essex System Aquator model.
- Bristol Water's flow/storage spreadsheet model (this has been previously checked by Bristol Water and is adequately compatible with their more complex Aquator model).

The **Resilience Evaluation Tools (RETs) were used to support the project assessment in three ways**:

1. To provide more accurate estimates of ***yield*** ('Tier 3') for the large integrated systems under 'severe' and 'extreme' drought circumstances.
2. To provide an understanding of the ***consequence*** of future supply/demand deficits that might be faced under future conditions for 'worst historic', 'severe' and 'extreme' drought types. This was done by analysing the typical duration of Level 3 and Level 4 failure that is faced under those drought types at different levels of supply versus demand.
3. To test the ***resilience*** of the 13 'example' future strategic investment Portfolios. This was only done for those schemes contained within the Wathnet area. Each of the 13 'example' Portfolios developed during the options appraisal were tested within Wathnet by running each one against 180 'replicates' of the future at the 2040 and 2065 time horizon. In this case each 'replicate' represented one of the events contained within the Drought Configurations (i.e. an 8 year sequence containing a specific drought), with a given climate future, level of demand and level of abstraction reduction required to protect the aquatic environment. The derivation of these 180 'replicates' is illustrated in Figure 4-13. Portfolios were modelled by representing the strategic schemes according to their physical nature – i.e. simple expected yield, storage, abstraction, transfer capacity, etc. Conclusions were drawn based on the behaviours of the key storage systems within the water resources system under each Drought Configuration, alongside the amount of water transferred between the sub-Regions. It should be noted that **the purpose of this resilience testing was not to alter the expected yield of individual strategic options, but rather to test whether the storage and transfer behaviour suggested by those options was as expected when different sub-Regions became linked together under the future conditions described by the scenario that the Portfolio had been designed to address**.

Figure 4-13 Conceptual Illustration of the Approach to Resilience Testing of the 13 'Example' Portfolios



4.7. Making the case: consequence evaluation and analysis

As well as the potential costs and resilience of the strategies that could be used to deal with future risks, there are a number of important issues that need to be considered in relation to the consequences of the risks that *are not dealt with by a given Portfolio.* This is important to the final conclusions and recommendations, as it helps to understand the potential consequences of adopting different planning assumptions (particularly in relation to drought resilience) and evaluate the relative importance and timing of the potential enabling activities that might be required to support the development of future strategies. The consequences and economic aspects of the project were therefore addressed through the development of a **consequence model** for each of the Drought Deficit sub-Regions (excluding Yorkshire, as explained in Section 8.5). Technical details of the functioning of these consequence models are provided in Appendix H. In order to generate economic costs and benefits from these consequence models, it was first necessary to identify and value the economic 'currency' of drought failure. This valuation process is detailed in Section 7, and relied on assessing the consequences of three different categories of 'failure':

1. The economic costs that occur when customers experience each day of 'Level 4' (severe) restrictions on demand (brought about through actions such as standpipes/emergency drought orders), plus the associated economic consequences that might affect users of non-public water supply sources, which could be restricted to a similar level to preserve water resources.

2. The economic costs associated with each day of 'Level 3' restrictions on demand (bans on non-essential use), plus potential 'knock on' implications to non-public water supply users through the imposition of measures such as Section 57 restraints on irrigation use. At this level a qualitative assessment is also made as a result of anticipated impacts on the environment caused by the application and imposition of Drought Orders and Permits to alter abstraction licences.

3. The economic costs associated with 'Level 2' restrictions on demand (Temporary Use Bans on 'discretionary' uses such as hosepipes).

'Level 1' restrictions on demand were not considered, as these relate to activities such as media campaigns to reduce water use. It was assumed that these do not have significant economic consequences due to the fact that the reduction is discretionary; that is, it is a reduction rather than cessation in use. Time spent at 'hands off flow' (HoF) conditions in certain rivers was also used as part of the overall consequence analysis, but was not included within the economic consequences models. However, HoF impacts are relevant where new abstractions are proposed as the result of strategic schemes, or where demand management measures can be used to offset those environmental consequences, and were therefore incorporated into the findings in Section 8.5 of this report.

Three different types of output were used from these models to help inform the constraints and enabling actions described in Sections 9 and 10 of this report. The methodologies used to generate each of these outputs are described within Appendix H. The general concept and use of each output can be summarised as follows:

1. **Probability-consequence charts**. These provide a summary of the risk consequences (in terms of the number of days failure against 'Level 4' restrictions) that are expected to be faced by a given sub-Region at the 2040 time horizon *if current planning assumptions are maintained* – i.e. by continuing to plan for worst historic droughts perturbed by median climate change expectations with medium growth and baseline sustainability reductions. They are similar in nature to the 'Target Headroom' type output that is commonly used by the water industry, but takes it a step further so that it shows the *consequences* that would be expected if droughts and futures that are 'worse' than the baseline planning assumptions occur, set against the probability that those conditions might be realised in 2040. The main reason for this form of analysis is that it provides an understanding of the relative importance of those risks that can be monitored and progressively adapted to through the WRMP process (i.e. growth and environmentally driven abstraction changes), compared with those risks that are either inherent or cannot be adequately monitored at this stage (i.e. risks of droughts that are more severe than planned for, and drier climate futures). An annotated example of this type of output is shown in Section 8.5.1.
2. **Portfolio cost/benefit comparison**. These provide a comparison of the Net Present Value (NPV) cost of a given portfolio (over 25 years to 2040) compared with the *probability weighted* NPV of the consequence costs that are expected if that portfolio is developed – i.e. they are a conventional form of cost/benefit analysis (described below and Section 7). They indicate how much risk a given sub-Region

might seek to 'plan out' given the economic consequences that are prevented by adopting a higher level of resilience and hence cost.

3. **Resilience cost/benefit comparison.** These provide a comparison of the NPV of the net costs compared with the NPV of the net benefits (reduction in consequences) that are expected over the 2015-2040 period if deficit sub-Regions change from their current policy of planning to meet 'worst historic' drought risks, to one where they plan to meet either 'severe' or 'extreme' drought risks without incurring Level 4 failures (i.e. no standpipes under those types of drought events).

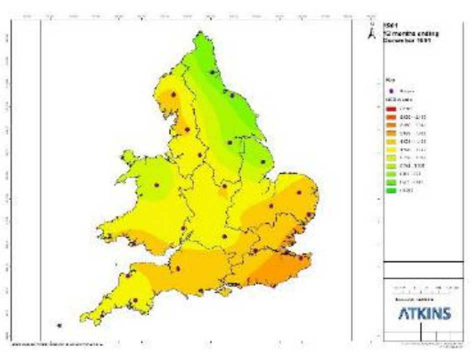
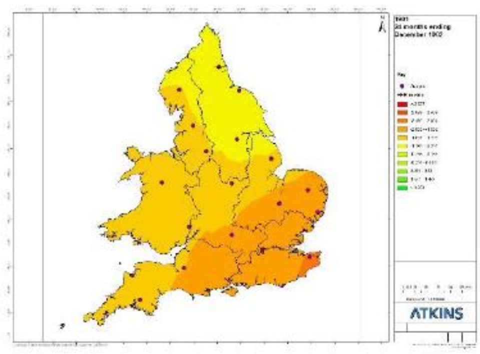
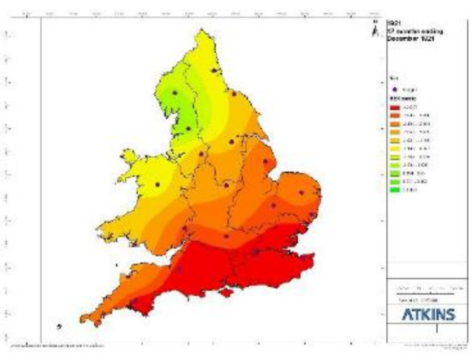
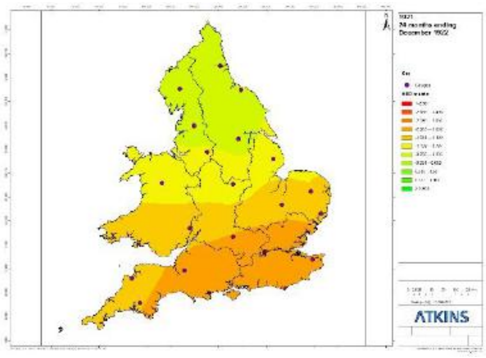
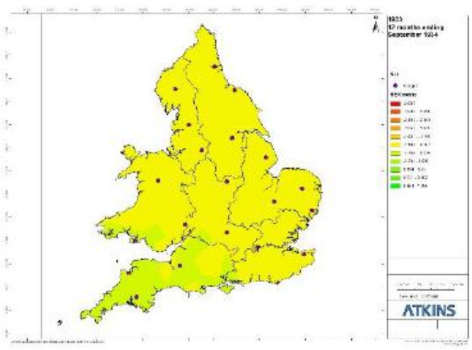
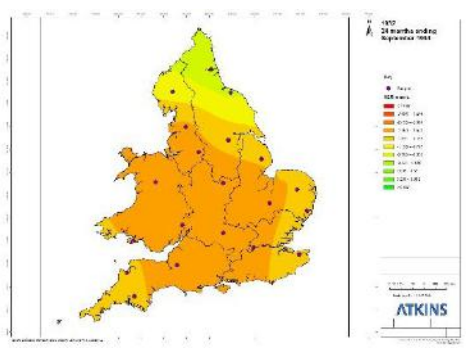
All of the above analyses were carried out for the 2040 horizon due to the large uncertainties associated with climate change and growth beyond that horizon. This can be used to advise on the general policy and planning implications of the consequences that are faced under different futures. The risks that then occur and the implications of adopting different balances between demand management and strategic supply schemes between 2040 and 2065 are then more appropriately evaluated through the analysis of cost and resilience, as described in Section 8.3.

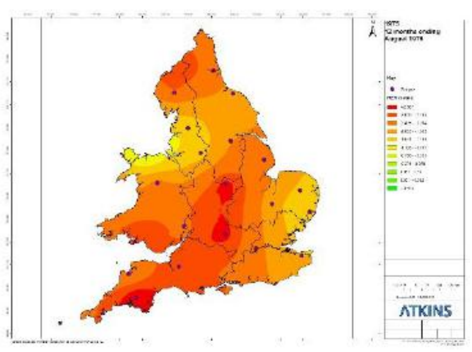
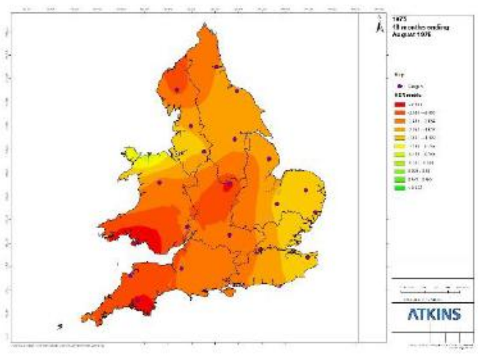
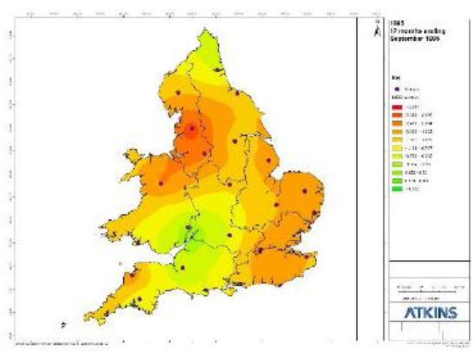
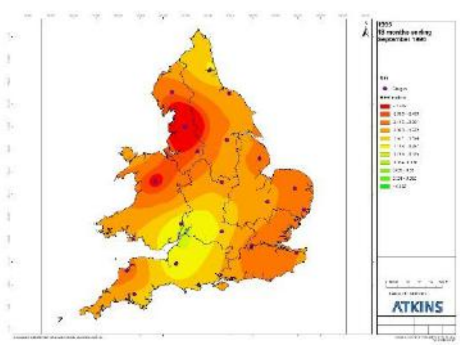
5. Is there a problem?

5.1. Analysis of Drought Coherence, patterns and severity

5.1.1. Evidence from Historic Droughts

By using the aridity indices described in Section 4.3.1.2, it was possible to examine the spatial nature of the significant droughts that occurred within the 20th Century. Nearly all water companies now plan their resources to be able to meet these events, with a 'median' allowance for expected climate change impacts. However, it is important to understand the nature and patterns of the droughts within the historic record in order to create 'plausible' Drought Configurations for the portfolio evaluation and resilience testing. A summary of some of the most informative findings from the analysis of historic droughts is provided below. It should be noted that these representations sometimes contain different years in the same plot – e.g. the 1932-34 and 1995/96 'worst' point in time varied across the country. This is commented upon where appropriate in the figures.

Drought Event: Short Duration Aridity Index (12 months ending summer or late autumn)	**Drought Event:** Longer Duration Aridity Index (24 months)	**Notes/Comments**
		**1901-03:** worst point for short duration was December 1901; worst point for long duration was December 1902. *Short duration not severe enough to challenge resources.*
		**1921-22:** worst point for short duration was December 1921, worst point for long duration was December 1922. *Long duration not sufficient to challenge resources – drought stress was exacerbated by the 'extension' of the 1921 event into early 1922.*
		**1932-34:** Multi-dry winter event; worst short duration occurred at different points spatially (hence apparent coherence). *Short duration not sufficient to cause stress – 2 year event in all areas, but varying between 1932/33 in some areas versus 1933/34 in others.*

Drought Event: Short Duration Aridity Index (12 months ending summer or late autumn)	**Drought Event:** Medium Duration Aridity Index (18 months)	**Notes/Comments**
		**1976:** short (<18 months) drought – very intense but stopped abruptly in September 1976. *Very severe for sources with less storage, but, unlike 1921, the recession after winter 1975/76 was not long enough to challenge larger storage systems.*
		**1995/96:** two different drought loci – north west most severe in 1995, versus south east most severe in 1996. *Spatial coherence less than it appears due to different timing. Note the lack of coherence across the Pennines.*
Other events: **1929** focused on east Yorkshire & parts of Severn Trent. Much lesser effect west of the Pennines. **1938, 1949** lesser droughts, but partly significant in central England. **1959** focused on east Yorkshire & parts of Severn Trent. Much lesser effect west of the Pennines. **1984** very short (8 months), but comparatively very intense, localised event affecting Cumbria and North Wales. 'Worst historic' for those resources.	*Other events* **1941-44** long, but less intense lead in with a severe event in 1944; locally significant for some areas in central/south east. **1989-1991** long drought, but interspersed with sufficient spring/summer/autumn rainfall to prevent more series levels of failure. **2010-12** long drought with severe resource deficits developing in early spring 2012, but these were ameliorated by record levels of rainfall over the late spring and early summer.	These were all either 'patchier', more localised events that affected certain resources but only tended to be the 'worst historic' due to specific combinations of source storage and location, or represented 'near miss' events.

As well as demonstrating that droughts are regularly experienced, this analysis provided a critical understanding of some key features of drought that were then used to inform the coherence analysis described in the next section:

- 24 month droughts tend to be less intense, but have a similar coherence to the medium-short (12 or 18 month) events. The coherence tends to be at, or greater than, the size of the Drought Regions described in Section 4.2. Very short events can be more localised.
- Although the longer events are less intense, their effect on larger storage systems is much more significant than shorter events such as 1976 or 1995/96.
- Many of the events suggest that the Pennines act as a dividing line between the parts of the country to the west and north-west that are dominated by the large Atlantic regional climate drivers (the North Atlantic Oscillation and sea surface temperatures), and the regions to the east and south-east of the country. This has an important bearing on drought coherence, as discussed in the next section.

5.1.2. Findings of the Coherence Analysis

As demonstrated in the previous section, although droughts do affect large areas, they are still variable in their nature and extent. In order to support the resource analysis for this study it was therefore necessary to examine the likely spatial consistency of droughts that are focused on the main Drought Deficit Regions.

The analysis of drought coherence was carried out based on three 'focus' areas:

1. Droughts focused in the Thames basin, which was representative of the 'mid-point' in the South & East Drought Region (focusing the analysis on the Thames basin this allowed differences with sub-Regions such as Anglian and the South-East Excluding London to be evaluated, as well as the more significant differences that occur in comparison with Regions to the north and west). It was also adjacent to the key 'Central-West' Transfer Region.

2. Droughts focused on east Yorkshire. This was used to examine the significance of the east/west Pennines split, and how coherent such droughts might be with the Anglian region.

3. Droughts focused across the whole of the Yorkshire Water resource base, primarily to determine the level of severity that should be planned for when droughts that cover the whole area are considered.

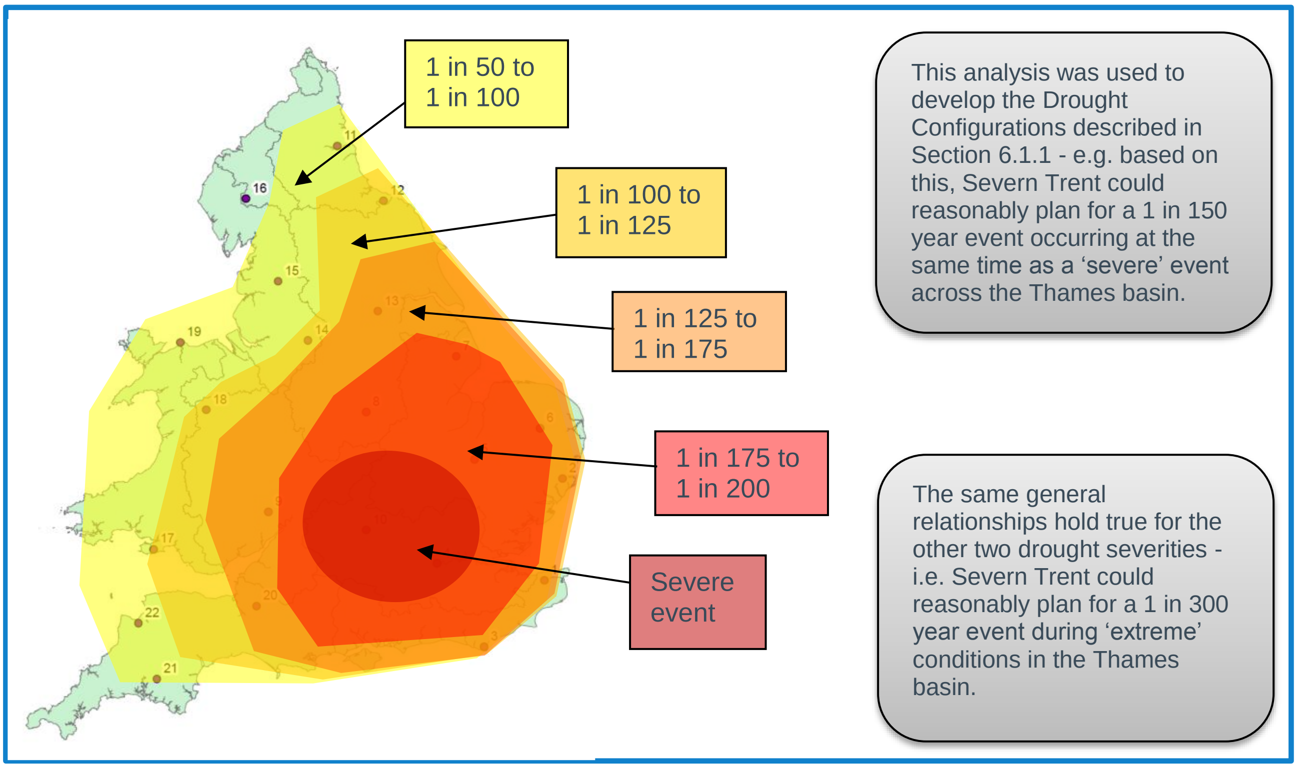
As noted, the conditional probability analysis showed that the relationships demonstrate a high degree of variability, which is entirely in line with the historical evidence base. For example, on average the North West is expected to experience moderate drought at the same time as a severe drought in the South East, but there are a very wide range of possibilities from wetter than average to extreme drought. Taking an average view allowed for the development a small set of realistic Drought Configurations for regional assessment.

There was a clear trend in the *expected* (average) coherence in drought severity, which is dictated by a combination of distance and the more significant orographic (mountainous) influences that exist in England & Wales. The analysis also showed that coherence, on a relative basis, was similar for droughts with varying durations (the correlations were similar regardless of whether 12, 24 or 36 month droughts were being considered). Based on the analysis of historic droughts presented above this seems to be logical – although there will be greater variability in weather patterns over longer periods, and hence less intensity of drought, there is also a longer time period over which that variability is being accumulated. The two effects therefore cancel each other out to a large extent, resulting in droughts that are less intense than shorter duration events, but have a similar coherence on a relative basis. It should be noted that very short duration events (6-8 months) were not specifically examined as part of this study, as, with a few exceptions, they are not relevant to the bulk of the national water supply system.

Coherence was tested at the **worst historic, severe and extreme levels** (see Table 4-1 for definitions of these levels of drought severity) for the focus area. There was some evidence that coherence might increase slightly with severity, but this was limited and should be viewed with caution given the uncertainties involved. For the purposes of this project it was therefore assumed that all of the Drought Configurations had the same relative level of coherence.

The outputs of the coherence analysis for the severe event, as shown in Figure 5-1 and Figure 5-2, is therefore considered to be reasonably representative of the relative coherence for all of the Drought Configurations. For the South East Drought Region, there is some variability in coherence between sub-Regions, but this was less than 20% (e.g. if a worst historic event is being experienced within the Thames basin, then it is expected that the South East Excluding London sub-Region would experience a drought of around a 1 in 80 or 90 year return period). This level of difference is too small to be separated from general statistical 'noise' around events.

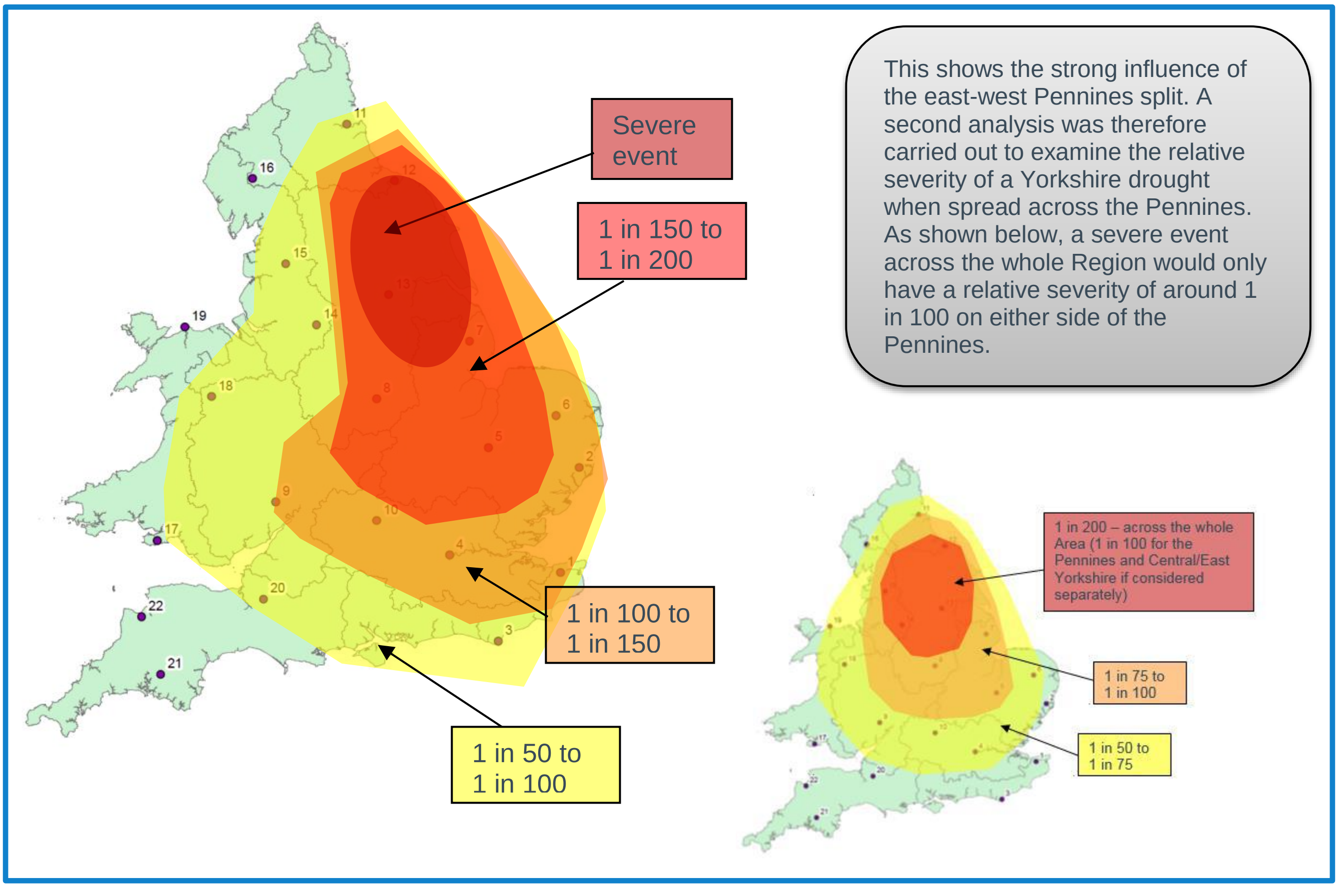
Figure 5-1 Illustration of the *expected* Drought Severity in surrounding Regions during a severe drought centred on the Thames Basin



This diagram shows expected differences in drought severity when a 'standardised' severe drought event is centred on the Thames basin. The patterns are effectively an average of all the drought severities for the other droughts that might occur in the other Regions during such an event, so the pattern is much smoother than shown for the individual events described in Section 5.1.1. The general relationships can be applied to other significant droughts – e.g. we would expect that an extreme event across the Thames basin would be co-incident with a 1 in 300 year event across Severn-Trent.

As noted previously, for the purposes of this analysis 'severe' droughts are those that would be expected approximately half as often as the worst droughts in the 20th Century record

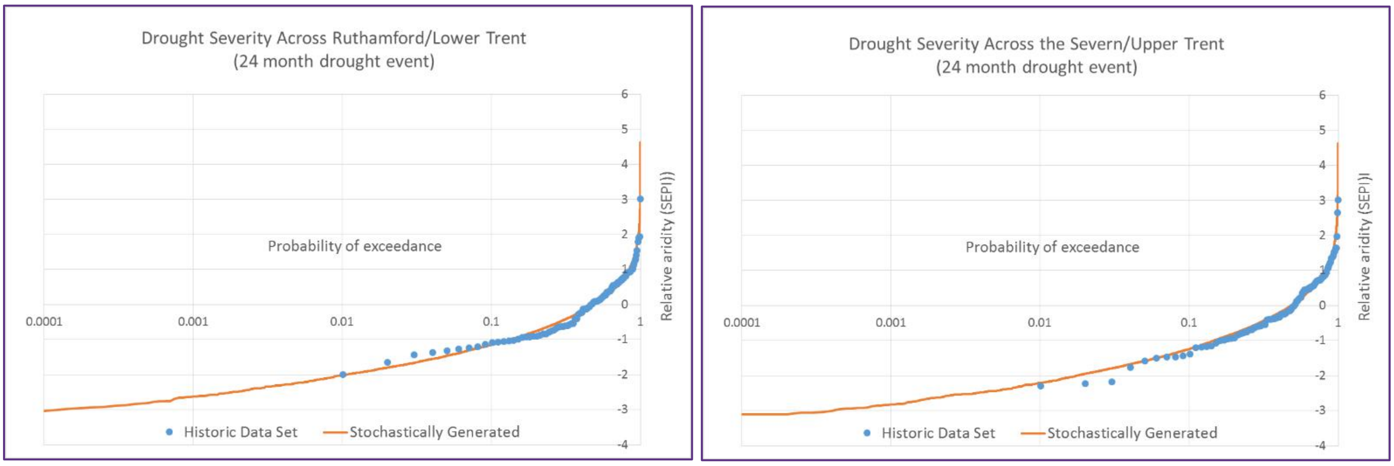
Figure 5-2 Illustration of the expected Drought Severity in surrounding Regions during a severe drought centred on Yorkshire



5.2. The future – risks from droughts not seen in the historic record

The rate at which drought aridity indices change follows a typical ‘extreme value’ type plot, whereby the increasing severity of drought events tend to tail off as the likelihood diminishes. A simple extreme value analysis plot of aridity indices therefore provides a good illustration the severity of droughts that might be observed in the future, where the probability (return period) is beyond that represented by the historic record. Two such examples are provided in Figure 5-3.

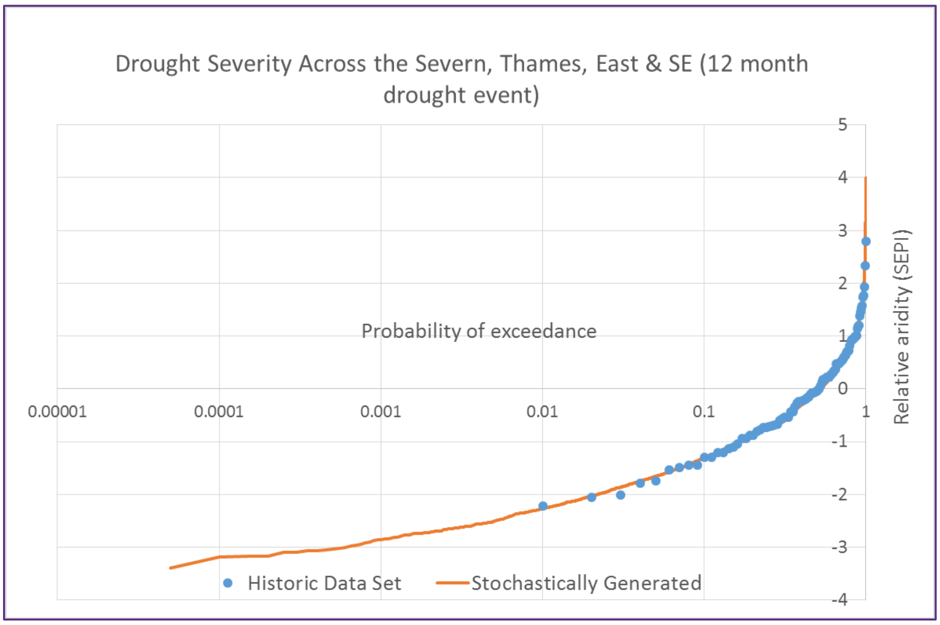
Figure 5-3 Example outputs of aridity indices (severity) versus probability (return period) plots



SEPI aridity index outputs for historic data (blue dots) versus the stochastically modelled (orange line) data sets for two strategic resource areas. These are plotted as the index value against the probability of an event occurring: 0.1 represents a 1 in 10 year event; 0.01 a 1 in 100 year event; 0.001 a 1 in 1000 year event. This shows the quality of the stochastic:historic data validation, and provides an indication of drought severity risks. The expected change in the index is around 5% to 10% for a ‘worst historic’ to ‘severe’ event, and around 10% to 15% for a ‘worst historic’ to ‘extreme’ event.

The availability of the stochastic data set meant that the relationship between drought severity and return period could be explored for various durations and at various scales. An example of a plot across a much larger spatial scale is provided in Figure 5-4, and shows that the larger spatial patterns follow the same general trend.

Figure 5-4 Example output of an aridity index (severity) versus probability (return period) plot for Central & SE England



Note – this is a shorter duration, which is why the rate of change is higher.

In most cases, the above relationships were reasonably similar, irrespective of the duration of the drought, although it was noted that the severity/likelihood relationship tended to be steeper for the very short duration (<8 month) events. Overall, the analysis showed that the drought aridity index tended to be between 5% and 15% lower (i.e. worse) during a ‘severe’ drought in comparison to a ‘worst historic’ event, with the range depending on the location and spatial coverage of the index.

Obviously aridity is not a direct representation of resource risk, and depends on the nature of the resource involved. For example, even where groundwater sources are at risk of loss of resource as a result of drought severity, the rate of change in yield against aridity index is much lower than the rates of change observed in surface water abstraction and storage systems. This relationship is explored in Section 6.1.2.

The analysis above only accounts for the ‘baseline’ environment. Climate change represents a further risk to future droughts. Analysis of water companies’ WRMPs indicates that the ‘median’ expectation of climate change impact is similar in magnitude to the difference that is seen between a ‘worst historic’ event and a ‘severe’ event – i.e. an *additional* increase of between 5% and 15% in drought severity (as measured by the aridity index) at 2040. The influence of a ‘dry’ climate future, even one that is as relatively conservative as that used for this report, adds a similar amount on top of the median expectation.

Overall, this analysis indicates that a ‘severe’ drought under a ‘median’ climate future in 2040 is likely to have an aridity index that is 20% to 30% worse than the worst historic event under the baseline year. Extreme droughts under a dry climate future in 2065 could be over 50% worse (in terms of aridity) than the droughts that companies’ systems are currently resilient to. These percentages are, in themselves, not particularly useful for water resources planning, and the effect that these changes can have on available water resources are explored in the next section. However, they are useful in assessing the relative impacts of different levels of drought severity compared with different levels of climate change.

It is important to note that droughts >3 years duration were not considered within this analysis. Such drought were not considered because there is a strongly decreasing relationship between intensity and drought duration, which was demonstrated by both the historic record and the stochastically generated analysis. This meant that the trade-off between overall severity and duration tended to decrease after 24 to 26 months. Beyond 36 months it was clear from the resilience testing that droughts would need to be worse than the ‘extreme’ (i.e. have very, very low probabilities) before they would have the same impact as the shorter duration ‘severe’ drought events (even in the larger south and east storage systems).

6. How big is the problem?

This section sets out the analysis to identify how big the problem is in terms of the resources available under different drought conditions, and in the face of the challenges explored in Section 3, and provides a summary of the scale and spatial distribution of potential future deficits.

6.1. Drought risk

This section provides the basis and quantification of the impacts on resource system yield that might be expected under droughts of different severities and different climate futures. This is based on the use of **Drought Configurations**, as described in Section 4.3.1.3. These were constructed based on the drought coherence analysis described in Section 5.1.2, and the 'tiered' evaluation of the anticipated resource impacts that would occur under each Drought Configuration and climate change future, as described in Section 4.3.1.4.

6.1.1. Drought Configurations

As noted previously, the Drought Configurations have been designed to provide a wide range of drought severities and durations against which the impacts on existing sources can be assessed, and which can be used to test the resilience of major strategic schemes within the Wathnet Resilience Evaluation Tool. For the Portfolio assessment these can be relatively easily defined, as described in Table 6-1 below. Effectively this table shows the expected severities that were planned to in the key potential 'Supplier' regions, which ensures that transfers and indigenous resources were treated on an equitable basis.

Table 6-1 Drought regions for portfolio development

	Relative drought severity planned for under each Drought Configuration		
Drought Region	Worst Historic	Severe	Extreme
South & East	Most severe in the historic record	c. 1 in 200	c. 1 in 500
Yorkshire	Most severe in the historic record	c. 1 in 200	c. 1 in 500
Central & West	2nd most severe in the historic record	c. 1 in 150	c. 1 in 300
South West (Bristol & Wessex)	Most severe in the historic record	c. 1 in 200	c. 1 in 500
North West	2nd most severe historic; Dee Valley 3rd most severe historic; Pennines & Cumbria	Most severe historic; Dee Valley 2nd most severe historic; Pennines & Cumbria	c. 1 in 200; Dee Valley Most severe historic; Pennines & Cumbria

South West Water, Dwr Cymru Welsh Water (DCWW) and Northumbrian Water have been treated differently to the above Regions, for the following reasons:

- South West Water has very low drought or climate change vulnerability, but currently relatively little spare resource (particularly following future growth in demand), and few strategic options. It is noted that the lack of identified strategic options is partly a reflection of the lack of need for new resources in the area, and it could be worth investigating the potential for new resource options as a support to Bristol Water in the longer term.

- DCWW potentially has water available under medium or low growth scenarios, but this is relatively limited, reflecting the constraints of the high quality and designated status of the majority of Welsh rivers. However, some large potential strategic resource developments have been identified, either through reservoir options, or by building schemes that can reduce its take from the River Wye and hence allow trading with other water companies. DCWW has therefore been treated primarily as an ‘option’ for supply under both the portfolio analysis and the resilience testing (see below).

- Northumbrian Water does not experience significant drought risk (at least in terms of resource availability) in the foreseeable future and is therefore regarded as a potential supplier. The availability of this supply tends to be limited by the capability to transfer water from Kielder down to the River Tees (and hence to either Yorkshire through transfer arrangements, or to United Utilities by reducing its take from Cow Green reservoir and transferring from there). This potential resource has therefore been represented as various ‘schemes’, rather than by a full analysis of the supply/demand balance within the Kielder WRZ.

The design of the Drought Configurations for the Resource Evaluation Tool analysis is similar to that shown for the portfolio analysis, but slightly more complex as this requires the design of 15 individual scenarios as 8-year timeseries that are both reflective of the drought coherence described in Section 5.1.2, and test a range of severities and drought durations. The exact makeup of the Drought Configurations used in the RETs was therefore as described in Table 6-2.

Table 6-2 Definition of the Drought Configurations used in the Resilience Evaluation Tools

Drought Configuration type and number		Historic Droughts (Scenarios 1 to 5)					Southern and Eastern focused					Yorkshire Focused				
							6	7	8	9	10	11	12	13	14	15
(Critical Duration - months)		*24*	*12*	*12*	*36*	*12 to 18*	*12*	*24*	*36*	*12*	*24+*	*12*	*24*	*36*	*12*	*24+*
Drought sub-Region	SEEL	1904	1921	1976	1991	1996	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 500	Stochastic - 1 in 500	**1921**	**1921**	**1902**	N/A	N/A
	London (Thames & Affinity)	1934	1921	1976	1991	1944	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 500	Stochastic - 1 in 500	**1934**	**1921**	**1945**	**1921**	Stochastic - 1 in 150
	Anglian & Essex	1934	1921	1904	1991	1996	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 500	Stochastic - 1 in 500	**1921**	**1934**	**1903**	Stochastic - 1 in 150	Stochastic - 1 in 150
	Central-West (Severn Trent)	1934	1921	1976	1991	1944	Stochastic - 1 in 150	Stochastic - 1 in 150	Stochastic - 1 in 150	Stochastic - 1 in 300	Stochastic - 1 in 300	**1959**	**1964**	**1964**	**1976**	**1934**
	Bristol & Wessex	1934	1921	1976	1944	1959	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 200	Stochastic - 1 in 500	Stochastic - 1 in 500	N/A	N/A	N/A	N/A	N/A
	Yorkshire - East/Central	1934	1929	1959	1991	1996	Stochastic - 1 in 150	Stochastic - 1 in 150	Stochastic - 1 in 150	Stochastic - 1 in 300	Stochastic - 1 in 300	**1929**	**1959**	**1991**	Stochastic - 1 in 200	Stochastic - 1 in 200
	Yorkshire & UU - W Pennines& Lancs	1934	1929	1959	1991	1996	**1959**	**1938**	**1934**	Stochastic - 1 in 150	Stochastic - 1 in 150	**1934**	**1996**	**1996**	Stochastic - 1 in 200	Stochastic - 1 in 200
	UU - Dee Valley	1934	1929	1976	1991	1996	**1976**	**1933**	**1996**	Stochastic - 1 in 200	Stochastic - 1 in 200	**1933**	**1996**	**1996**	Stochastic - 1 in 150	Stochastic - 1 in 150
	UU Cumbria	1934	1984	1976	1991	1996	**1976**	**1934**	**1934**	**1984**	**1996**	**1959**	**1934**	**1934**	Stochastic - 1 in 150	Stochastic - 1 in 150

Notes:

- *Where a year is shown, then this is the year, from the historic record, that forms year 5 of the 8 year sequence.*
- *Where a stochastically generated event is shown, then this event was selected through inverse ranking to extract a drought of the relevant severity from the full stochastic data set. It should be noted that this severity relates to aridity rather than actual water resource impact, as discussed in Section 8.3.*
- *As noted previously, DCWW SEWCUS and Northumbrian Kielder WRZs were incorporated into the analysis based on the potential supply options that they could provide. In the case of DCWW, the availability of options was checked through a simple supply/demand analysis based on the worst historic event. Because of its location relative to the Drought Deficit Regions, this was sufficient to account for availability under all but the ‘extreme’ Drought Configurations. For the ‘extreme’ configuration, an estimated DO reduction was applied to confirm that additional resource development would still be available for export once any deficits within the SECUS WRZ had been satisfied.*

6.1.2. Resource availability (source yields and deployable output)

Based on the Tier 1, 2 and 3 analyses described in Section 4.3.1.4, plus the assumptions relating to the inclusion of Drought Orders and Permits described in Section 4.3.1.5, an evaluation was carried out of the impact that different drought severities would have on the capabilities of water supply systems under different climate change futures. The results of this analysis are provided in Table 6-3.

The following should be noted in relation to the assessment:

1. In some cases there is a positive adjustment to resource capability for the ‘worst historic’ Drought Configuration. This relates to either:
    - Companies such as United Utilities, where the drought coherence analysis has shown that they could expect to experience a lower level of drought severity when a ‘worst historic’ drought is being experienced in the Drought Deficit Regions. Because the WRMP14 Deployable Output is based on the worst historic drought, United Utilities could expect to be able to deploy a surplus beyond this value when it is experiencing droughts of a lesser severity, which would be expected to be the case in those situations when the Central-West and Thames regions are in deficit so would benefit from transfers.
    - Companies such as Yorkshire and Southern Water plan to a higher level of resilience than the worst historic event, so their quoted DO is either constrained by the frequency of ‘lesser’ service failures, or is the quoted yield from events that are more severe than the worst historic drought. Either way this means that they would be able to output more than their WRMP quoted DO under a worst historic event.
    - Companies such as Severn Trent, whose DO is not constrained by ‘Level 4’ type failures, but rather by the frequency at which temporary use bans (TUBs) are imposed. Under a resilience testing scenario that means they would, potentially, be able to make use of the storage that is not taken up under significant drought conditions (although at the cost of losing some of their drought ‘headroom’, as discussed later).
2. In some cases there is a negative adjustment to get to the ‘worst historic’ Drought Configuration. In all cases where this occurs, it is because those companies do not currently plan to be resilient to the worst historic (or 1 in 100 year) event, so would not be able to achieve their WRMP14 stated DO under those circumstances.

3. In some cases there is a discrepancy between the WRMP14 stated DOs and the yields quoted in the table. This is because either there is updated information where stated DOs have changed since WRMP14 (e.g. the Thames Water figure relates to its Annual Return 2016 figure), or a sub-set of resources was included within the analysis, or (in the case of Portsmouth Water) it was logical to use values relating to the minimum deployable output (MDO) resource capability, rather than the normal annual average DO (ADO).

Overall, the impact of severe drought on DO is less than that described for drought aridity in the previous section, and is only around 3%. However, this is partly because a number of areas contain licence constrained sources (that are not affected by drought severity). Similarly the impact of ‘extreme’ drought is only around 6% compared with the worst historic event, for the same reasons. Local impacts are much higher (e.g. 5% for Thames-London, 10% for Hampshire). If the main Drought Deficit and Transfer Regions are considered, and sub-Regions such as Affinity Water (who have a high resilience to drought because the vast majority of their sources are licenced or treatment/infrastructure constrained), then the impact of severe droughts is equivalent to around **4%** of baseline DO, and the impact from extreme droughts is around **8%** of baseline DO.

These analyses are based on the weather generator, which was constructed around the 20th Century record. As part of the validation of that weather generator, a variety of literature on reconstructed droughts in the 19th century and beyond (some Europe-wide studies provided broad analysis back to the 1st Century AD) were reviewed. These indicated that the 20th Century was broadly indicative of a typical century pre-climate change, and that simple hindcasting of records beyond the start of the 20th Century would not have contributed to the understanding of ‘severe’ and ‘extreme’ droughts in any meaningful way.

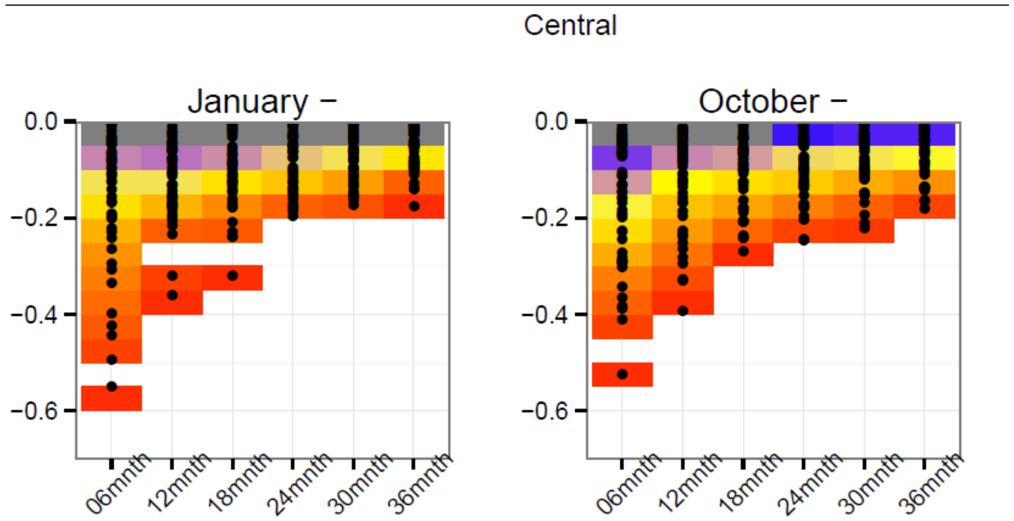
It is noted that, by assuming the benefits of Permits and Orders, even on the precautionary basis assumed in this Project (see 4.3.1.5), a significant amount of investment need has been deferred according to this analysis. However, as noted previously these are not abstraction licences and hence there is no actual guarantee that such interventions could be relied upon to provide the quoted benefits during a drought. Discussions with water companies show that potential issues with achieving a reliable benefit from Permits and Orders include:

- Reliance on winter permits during droughts where the severity only becomes apparent late in the winter (i.e. relevant trigger curves are not crossed), so the actual benefit to storage is limited.

- Rapid onset of droughts, combined with application/implementation delays such as third party objections meaning that Permits/Orders are not in place until after the critical point of the drought.
- Environmental monitoring and mitigation requirements that serve to limit the reliability and benefits that can actually be gained from the Permit/Order once it is implemented.

One key finding from the analysis of historic and stochastically generated droughts, is that the common assumption that more severe droughts tend to be longer (e.g. 3 dry winters) is not particularly valid. This can be readily seen within the Wathnet 'Scenario 0' validation plots shown in Section 6.1.3, where Drought Configuration number 11 relates to the selected 'severe' 36 month event. This is clearly less stressful than the shorter 'severe' events (and is generally less stressful than the worst historic event). Although this was just one drought, this pattern was seen generally across the historic record and results from the relationship between rainfall deficit and drought length. A typical plot of rainfall deficit versus drought duration is shown (for Central England) in Figure 6-1.

Figure 6-1 Example of a rainfall deficit-duration plot (Central England)



This figure shows how the deficit in rainfall (y-axis), expressed as a proportion of the long term average (i.e. -0.6 = 60% reduction compared with the long term average), reduces as the length of the deficit period (drought) increases (x-axis).

The colours represent increasing severity (return period) of deficits under each duration, whilst the black dots represent actual points calculated from the historic data set.

The analysis of historic drought events and the resource evaluation described above clearly shows that all drought events need to have a single full year of deficit before they become significant in water resources terms; wetter spring, summer and early autumn periods tend to result in 'near misses' rather than significant droughts. The above figure then shows that the relative deficit that occurs during this critical point is proportionally much larger than the longer term drought metrics – in other words, all droughts need this short, sharp, shock element before multiple dry winters or long term dry periods can become a serious water resource stress, and that will tend to be both rapid and unexpected in its intensity.

Most 'severe' events will therefore tend to have similar durations to those seen in the historic record, but with slightly higher deficits at key points during the development of the drought. This means that the level of warning and ability to respond to emerging droughts may not be enough to allow companies to *rely* on the potential benefits from Permits and Orders. For example, a typical 'severe' drought might be:

1. Similar to 1976, but continue through to the end of October; or
2. Similar to 1932-34, but with a drier spring/summer period, resulting in a more severe recession following the driest winter in that sequence; or

3. Similar to 1995/96, but with a drier winter period and longer summer/autumn recession.

The nature of these historic events is described further within Section 5.1.1, but clearly there is a wide range of possible droughts that could place severe stress on resource systems in the future, and the benefits of Drought Permits and Orders will vary considerably depending on the actual drought pattern that occurs. Crucially, it appears that there is little extra warning that could be relied on in the build-up to ‘severe’ and ‘extreme’ events than has been seen within the ‘near misses’ of recent history.

The estimates that are contained within Table 6-3 have therefore been added as a reasonable estimate of the benefits that might be expected, but a much greater understanding of the links between the WRMP and the Drought Plan, and the *reliability* of Permits and Orders for planning purposes is needed before the level of benefit could be applied within companies’ WRMPs.

The impact of climate change perturbation on the ‘baseline’ droughts is also shown within Table 6-3. These are largely based on company WRMPs, with some adjustments on the groundwater side to account for the different aridity index outputs contained within the different Drought Configurations. **Once these climate change allowances are factored in then the total anticipated reduction in resource capability from the WRMP14 baseline (as described by DO) in the Deficit and Transfer Regions becomes larger and more variable, ranging from around an 7% loss for a ‘severe’ drought under ‘median’ climate change, through to a 17% loss for an ‘extreme’ drought under ‘dry’ climate change. By 2065 this increases to a range of between 9% and 22% loss in DO.**

Table 6-3 Summary output of the resource availability analysis

Company	Area	Deployable Output Included in the **baseline**	Initial Adjustment to get to Drought Design Scenario 1 (without climate change)	Estimated Impact on DO at 2040 (change from 2015 baseline)									Estimated Impact on DO at 2065 (change from 2015 baseline)								
				Drought Design Scenario 1 - Worst Historic			Drought Design Scenario 2 - Severe Drought			Drought Design Scenario 3 - Extreme Drought			Drought Design Scenario 1 - Worst Historic			Drought Design Scenario 2 - Severe Drought			Drought Design Scenario 3 - Extreme Drought		
				Median Climate	Dry Climate	Assumed Permit/ Order benefits	Median Climate	Dry Climate	Assumed Permit/ Order benefits	Median Climate	Dry Climate	Assumed Permit/ Order benefits	Median Climate	Dry Climate	Assumed Permit/ Order benefits	Median Climate	Dry Climate	Assumed Permit/ Order benefits	Median Climate	Dry Climate	Assumed Permit/ Order benefits
Southern Water	Eastern	238	11	4	-6	0	-7	-17	5	-21	-31	5	1	-14	0	-10	-25	5	-23	-38	5
	Central (MDO)	209	7	5	2	0	-3	-6	0	-11	-14	5	5	1	0	-2	-7	0	-10	-15	5
	Western (MDO)	209	10	9	0	0	-10	-10	7	-11	-11	7	9	-1	0	-10	-11	7	-11	-12	7
South East	Kent	302	-13	-19	-22	0	-45	-48	13	-74	-77	13	-29	-33	0	-55	-59	13	-84	-88	13
	Guildford/West	250	-9	-9	-10	0	-22	-22	0	-35	-36	0	-14	-16	0	-26	-28	0	-39	-41	0
Sutton & East Surrey	All	245	-10	-10	-12	0	-11	-12	2	-13	-14	3	-16	-18	0	-16	-18	2	-18	-20	3
Affinity	London - N	172	-9	-8	-9	0	-9	-9	0	-9	-10	0	-13	-14	0	-13	-14	0	-14	-15	0
	London - S	804	-12	-11	-11	0	-11	-12	6	-12	-12	12	-16	-17	0	-16	-18	6	-17	-18	12
	Folkestone/Dover	52	-4	-4	-4	0	-4	-5	1	-7	-8	2	-6	-6	0	-6	-7	1	-9	-10	2
	TH		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Portsmouth (MDO)	All	242	-42	-44	-46	0	-59	-61	2	-74	-76	6	-45	-48	0	-60	-63	2	-75	-78	6
SC Bournemouth	All	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wessex	All	426	0	-4	-5	0	-6	-5	0	-5	-5	0	-6	-8	0	-8	-8	0	-8	-8	0
Bristol	All	367	-10	-22	-35	0	-37	-50	0	-47	-60	0	-28	-48	0	-43	-63	0	-53	-73	0
Thames	London	2300	-5	-81	-157	0	-230	-334	25	-385	-483	75	-123	-239	0	-272	-415	25	-426	-564	75
	Provinces	730	-1	-15	-23	0	-17	-30	0	-25	-34	19	-23	-35	0	-25	-42	0	-33	-45	19
Anglian	Lincs	428	0	0	-1	0	-2	-3	0	-3	-5	0	0	-2	0	-2	-4	0	-3	-5	0
	Ruthamford & Fenland	689	46	21	-53	0	-28	-103	24	-100	-174	27	33	-80	0	-17	-130	24	-89	-201	27
	ESE	253	-2	-4	-15	0	-13	-24	5	-17	-28	9	-6	-22	0	-15	-32	5	-19	-36	9
	Norfolk	150	0	-5	-25	0	-5	-25	6	-5	-25	18	-8	-38	0	-8	-38	6	-8	-38	18
Essex & Suffolk	Essex	369	0	-12	-17	0	-52	-57	0	-86	-90	1	-18	-25	0	-59	-66	0	-92	-99	1
Severn Trent	Strategic Grid	1615	32	-30	-325	0	-79	-374	14	-111	-406	43	-46	-493	0	-94	-541	14	-126	-573	43
	Nottinghamshire	270	0	-34	-40	0	-34	-40	0	-42	-48	0	-52	-60	0	-52	-60	0	-60	-68	0
	West	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
South Staffs	Group licence	370	8	0	-11	0	-7	-18	0	-15	-26	0	0	-17	0	-7	-24	0	-15	-32	0
Dee Valley	All	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
UU	Integrated Zone (Incl. Cumbria)	2136	128	-34	-74	0	-77	-117	10	-269	-309	72	-52	-112	0	-95	-155	10	-287	-347	72
Yorkshire	Grid	1486	103	-127	-229	0	-230	-332	35	-379	-482	85	-192	-347	0	-295	-450	35	-445	-600	85
Total		14612	229	-436	-1129	0	-997	-1713	156	-1753	-2461	401	-644	-1691	0	-1206	-2276	156	-1962	-3023	401

This table shows an assessment of the impact of different Drought Configurations and climate futures on WRMP14 stated Deployable Outputs. All values represent an absolute change from the WRMP14 figure (i.e. they are not cumulative), except for the benefits of Permits and Orders, which should be added to the relevant resource capability figure. The 'initial adjustment to get to Drought Configuration A is for information only and does not need to be added to or subtracted from the main table figures. As previously, DCWW and Northumbrian Water have been considered in relation to the potential for providing new resources for transfer, rather than through a full supply/demand balance.

6.1.3. Outputs and Validation for Resilience Testing

In order to provide the 'Tier 3' estimates of system yield (DO) under more severe droughts than those experienced in the historic record, and to check that the process involved in developing the hydrology for the Drought Configurations had not introduced unacceptable uncertainties into the historic record, all of the Drought Configuration timeseries that were generated according to Table 6-2 were run through each RET, at a level of demand that was set to equal the quoted baseline Deployable Output shown in Table 6-3. This is referred to as the 'scenario 0' analysis, and was done for three reasons:

1. In Wathnet, to check that the level of storage that resulted from the worst historic droughts reconciled with the storage volumes obtained in the validation runs, and carry out scaling adjustments if required.

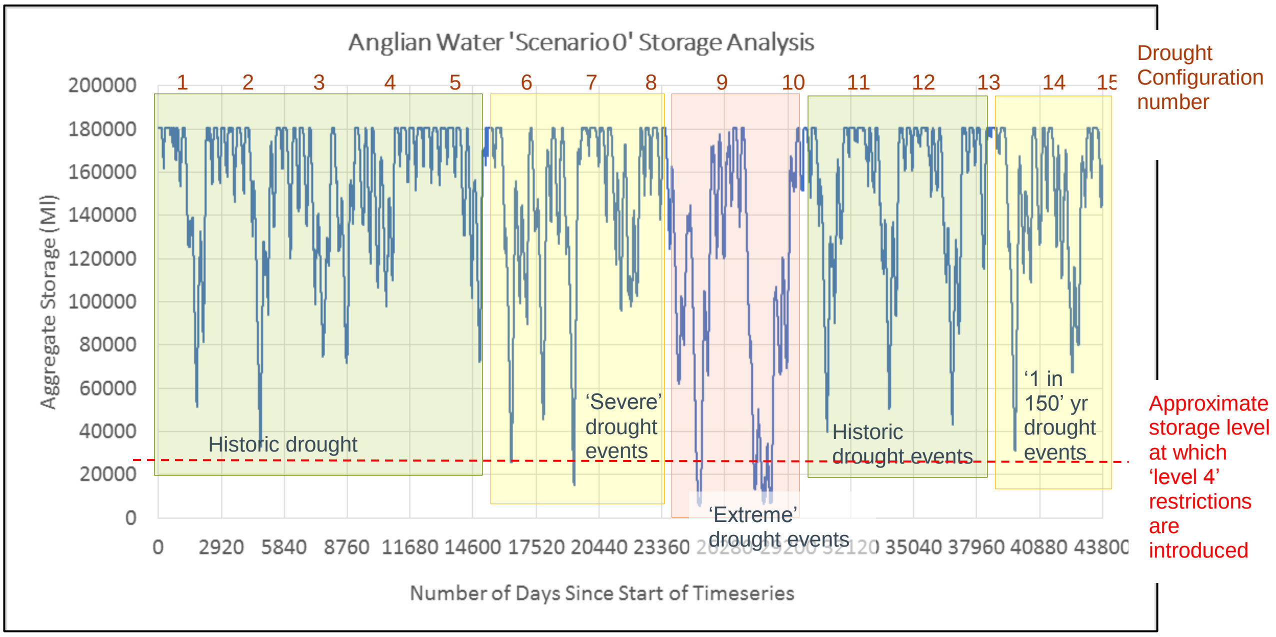
2. To allow the 'Tier 3' assessment of system DO to be carried out for those systems covered by the Wathnet model.

3. Within the Aquator models, to obtain outputs of the storage-severity behaviour of the reservoir systems to use in the consequence modelling (see Section 8.4).

In all cases the Wathnet Scenario 0 outputs reconciled well with the validation runs, and only three 'scaling adjustments', all at less than 5% of demand, had to be applied.

The Wathnet model outputs from Scenario 0 for Anglian Water (Ruthamford system storage) are provided in Figure 6-2 below.

Figure 6-2 Example output of the 'Scenario 0' Wathnet drought impact assessment

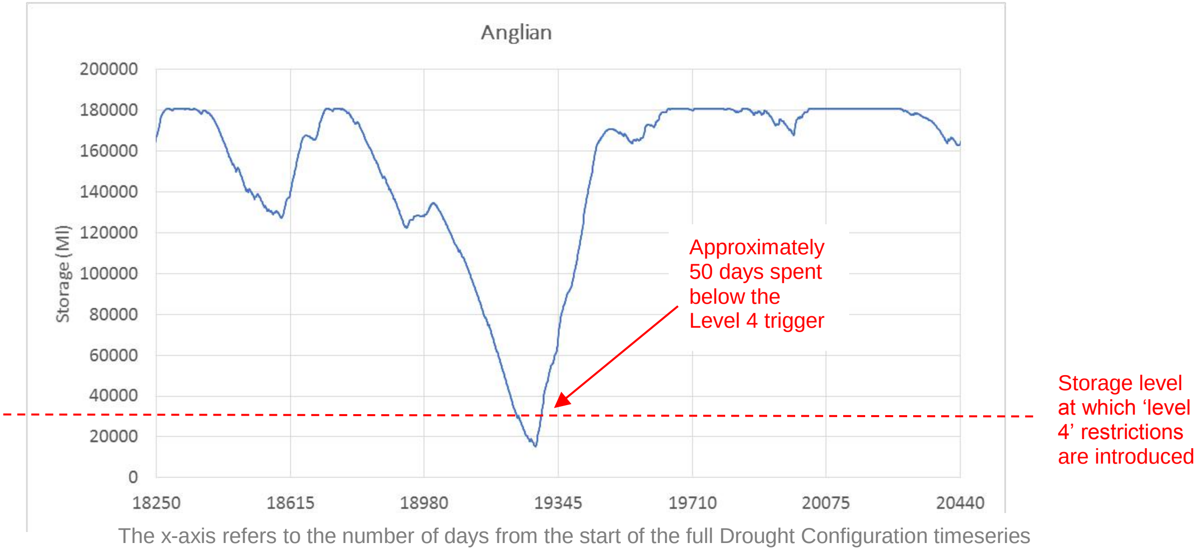


This figure shows the storage levels reached during each year of the Drought Configuration timeseries for the Anglian Water reservoirs (blue line). Each drought sequence contains a drought ranging from low severity for this particular system (e.g. 1996 in the green area), to 'extreme' droughts (contained in the red area). Each separate Drought Configuration timeseries lasts for 8 years, which is represented by a single gridline box width in the diagram.

This shows that the use of aridity indices to select drought events was reasonably successful as a proxy for resource stress, although it is clear that the match is by no means exact (i.e. a 1 in 200 year aridity index value does not necessarily translate through to a 1 in 200 year system yield event). The use of droughts of different durations was also not intended to provide a definitive answer to the nature of vulnerability within an area, but rather to make sure that the 'severe' and 'extreme' events that were used would test the resilience of the system against a number of different drought durations. It is noted that, although the difference between 'worst historic' droughts and the 'severe' and 'extreme' events does not appear that large in the

Scenario 0 output, much of that is due to the format of the chart and the fact that severe demand restrictions are imposed that result in a significant slowing of the reservoir recession once the 'Level 4' control curve is breached. This can be clearly seen if a single drought is focused upon from the above chart, as shown in Figure 6-3. (Note that the x-axis in the following figures down to Figure 6-8 refer to the number of days from the start of the full Drought Configuration timeseries)

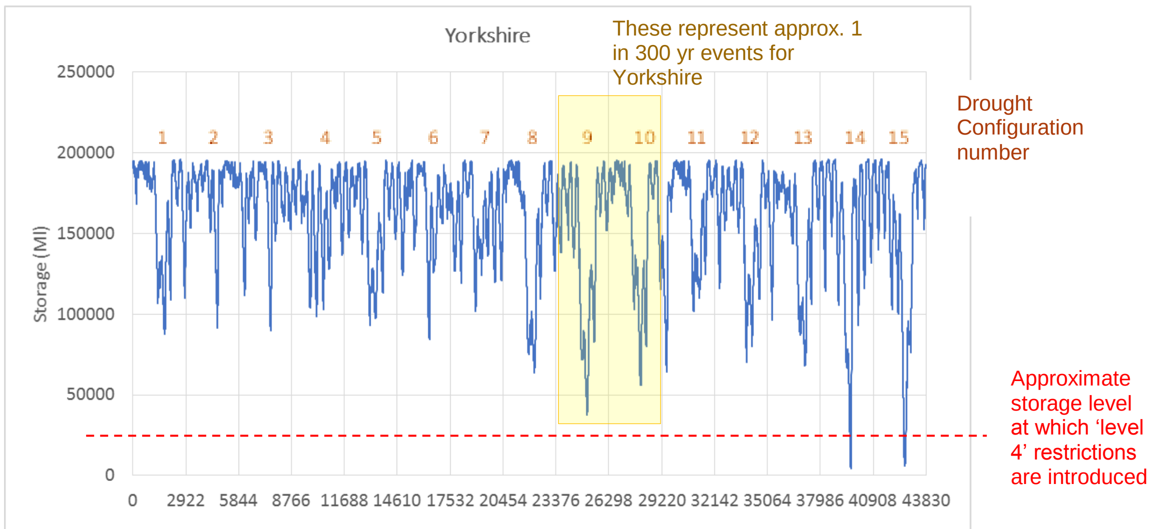
Figure 6-3 Details of the storage recession under Drought Configuration number 7 for Anglian Water (24 month severe drought)



As well as providing validation of the plausibility of the Drought Configurations and allowing 'Tier 3' estimates of resource system yield, the Scenario 0 analyses provided some useful indicators about the nature of risk and resilience under current day conditions for the other modelled sub-Regions.

For the Yorkshire Drought Region, the Wathnet outputs (Figure 6-4) confirmed that it is resilient to droughts that are less than 'extreme' (i.e. approx. 1 in 500 year return period), as declared in its WRMP14 Levels of Service.

Figure 6-4 Wathnet Scenario 0 output for Yorkshire



For the Thames-London Drought Region, the Scenario 0 outputs (Figure 6-5) showed that Drought Configuration 7 was probably a much higher severity of event in terms of yield than was indicated by the aridity index (closer to 'extreme' than 'severe'). It is also noted that the balance between available resource under the Lower Thames Operating Agreement and the demand that results once Level 4 restrictions are imposed means that most of droughts appear to 'stop' at the Level 4 trigger threshold if they exceed the system capabilities. This is purely a theoretical modelling output, and in any case the resilience analysis is only concerned with the occurrence and duration of any Level 4 failures. As shown in Figure 6-6, that length of time could be significant for droughts such as Drought Configuration 7, and could actually last for much longer than suggested by theoretical modelled outputs, as recharge would not be sufficient to allow the lifting of such restrictions (events lasting up to a year are feasible).

Figure 6-5 Wathnet Scenario 0 output for Thames-London

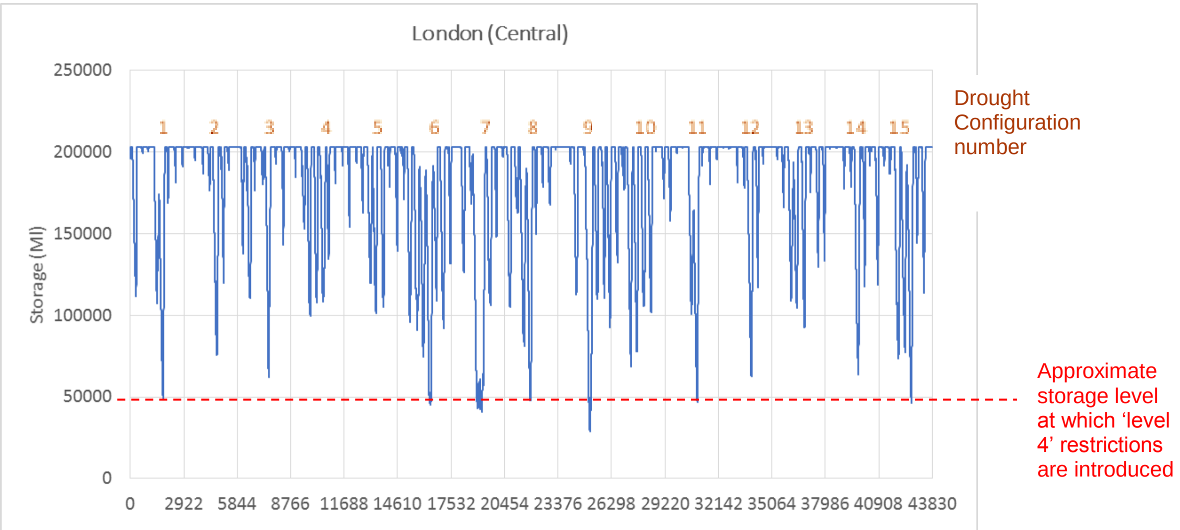
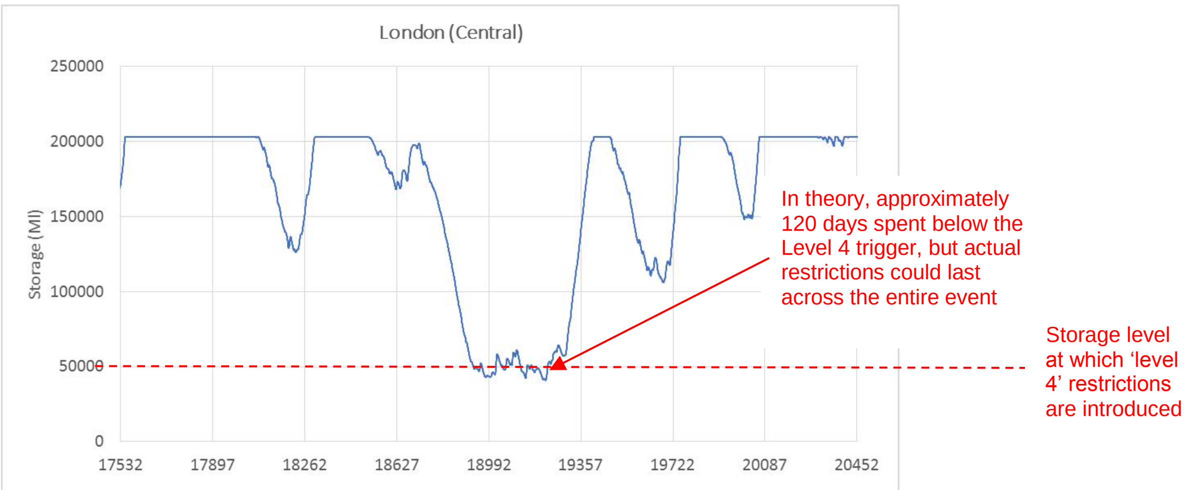


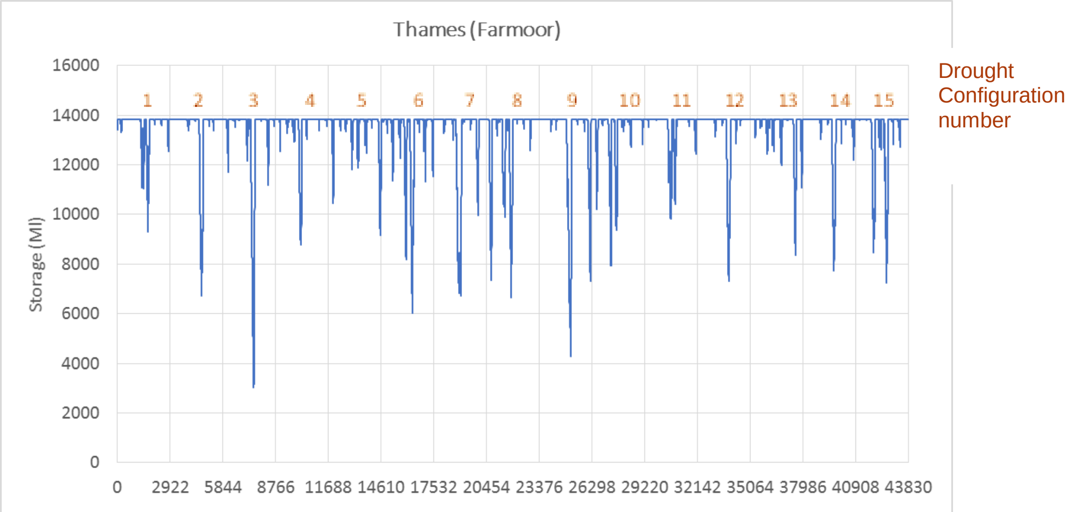
Figure 6-6 Details of the storage recession under Drought Configuration number 7 for Thames Water (24 month 'severe' to 'extreme' drought)



Analysis of the Thames-Farmoor system (SWOX WRZ) indicates that this is not always sensitive to the same type of drought as the main London reservoirs (Figure 6-7). Although this finding is based on a relatively limited number of Drought Configurations, it is consistent with Thames' own work into stochastically generated resource risk. For the purposes of the consequence assessment in Section 8.4, the household population and GVA of SWOX has not therefore been included when calculating consequence. This conclusion may be overly conservative for some of the Portfolios, as the nature of system risk between the

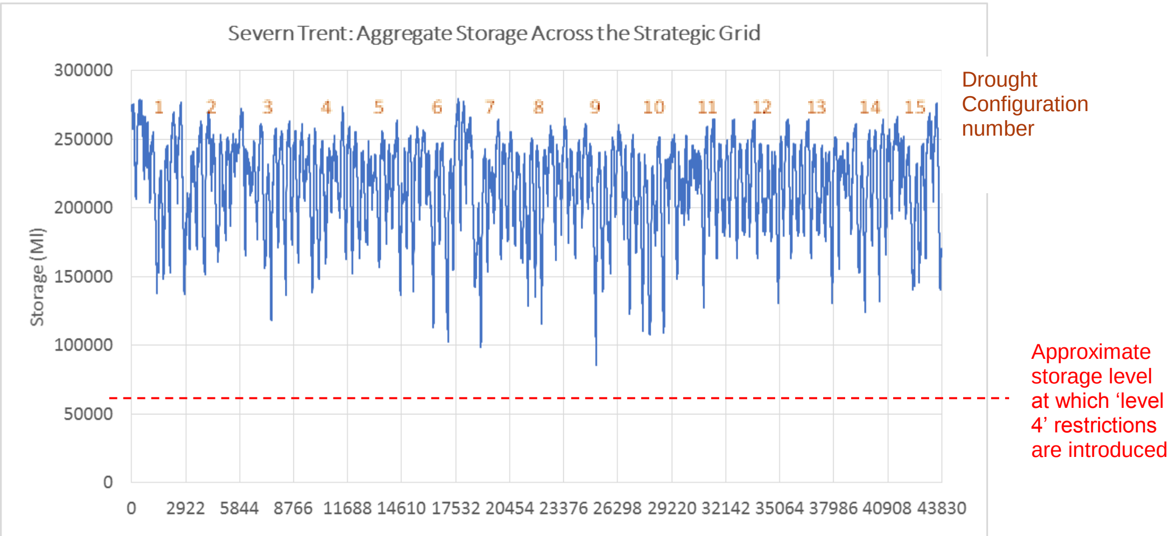
London and SWOX storages tend to become more coherent under climate change (Farmoor is vulnerable to long, hot summers, which tend to be more significant in the London droughts under climate change futures).This issue is noted as part of the consequence analysis in Section 8.4.

Figure 6-7 Wathnet Scenario 0 output for Thames-Farmoor



Finally, for Severn Trent, although the Drought Configurations only incorporated events down to the 1 in 300 Return Period level (according to aridity index), the Scenario 0 outputs clearly showed that this system currently has a high resilience to significant drought events. As shown in Figure 6-8, the disparate nature of its resources (which include the Welsh mountains, as well as the Peak District) mean that it would take a very extreme drought to completely exhaust the available storage in the system under design demand conditions (i.e. Deployable Output, which is constrained by the frequency of TUBs interventions). Of course this does not mean that localised failures are not possible (for instance, shorter droughts such as 1976 can create problems with storage on the western side of the system), but it does indicate that, under current day conditions, there is spare transfer capacity to help with resilience in other companies.

Figure 6-8 Wathnet Scenario 0 output for Severn Trent



Scenario 0 outputs for United Utilities and South Staffs were only used to confirm that they were responding appropriately under the Drought Configurations. In the case of United Utilities the droughts were not of sufficient severity to draw any conclusions beyond those that are obvious from the historic record, and in the case of South Staffs the drought types (which were geared toward the larger scale systems) were not sufficient to draw any conclusions beyond those that are obvious from the historic record. However, in both cases it was confirmed that they were abstracting the appropriate volumes of water from the relevant rivers and storage systems, which meant that they would be affecting resource availability appropriately when the Portfolio resilience testing was carried out (see Section 8.3).

6.2. Environmentally-driven changes to abstraction

There is considerable uncertainty over the magnitude of impacts on deployable output that will arise from changing abstraction licences in order to meet and preserve good ecological status of water bodies and the habitats they support. The methodology developed and described in Section 4.3 allows quantification of the range of possible impacts at a high level, as shown below. The impacts vary significantly between companies and regions, reflecting the differing nature of abstraction and historic licensing regimes, which are continuously under review, and subject to change further as part of abstraction reform.

Environmentally-driven abstraction changes have the potential to substantially impact the supply/demand balance across England and Wales, especially under higher growth scenarios. Considerable investment may be required, as discussed further in section 8. The breakdown of confirmed/likely impacts is shown in Figure 6-9 below. Figure 6-10 and Figure 6-11 shows maps of the potential losses in DO by 2025 under base and extended abstraction licence change scenarios, aggregated by supply area and by region respectively.

Figure 6-9 Breakdown of potential losses in DO

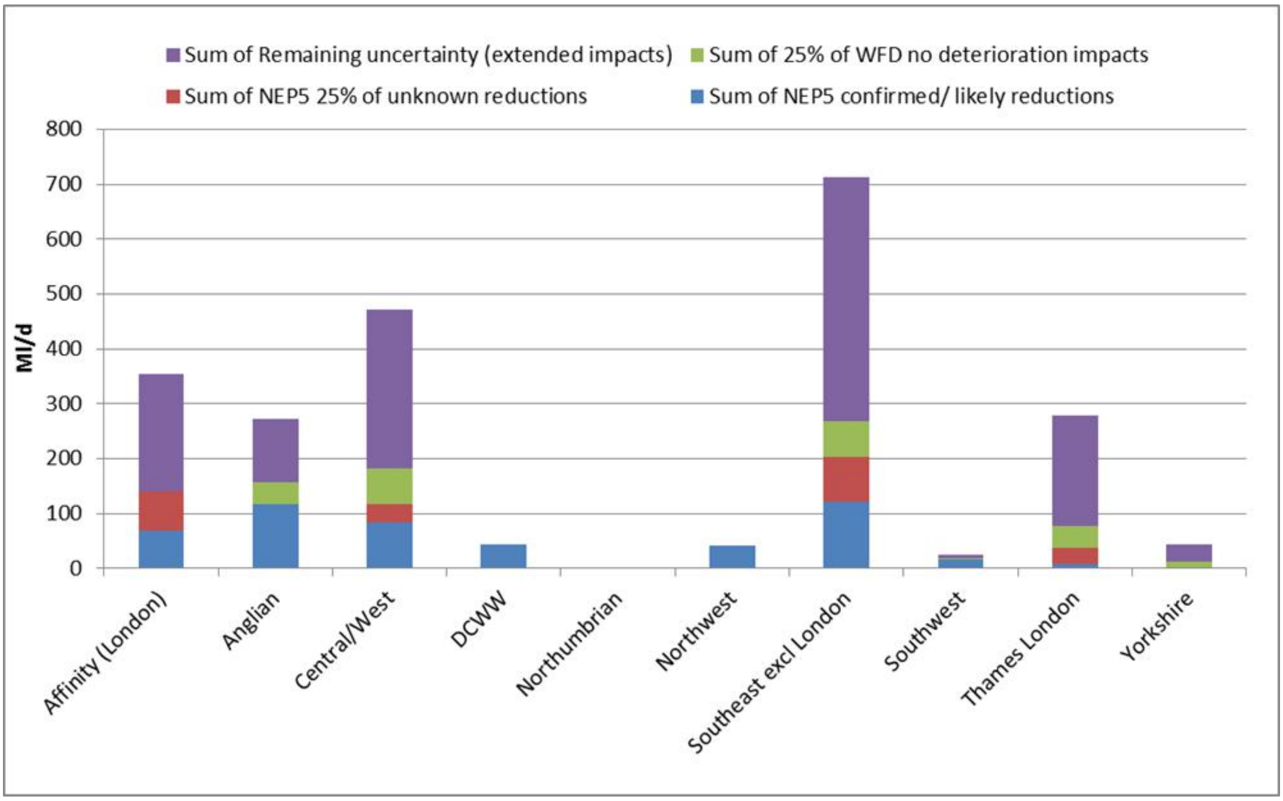


Figure 6-10 Map of potential losses in DO by 2025 under baseline (left) and extended (right) abstraction licence change scenarios – by supply area

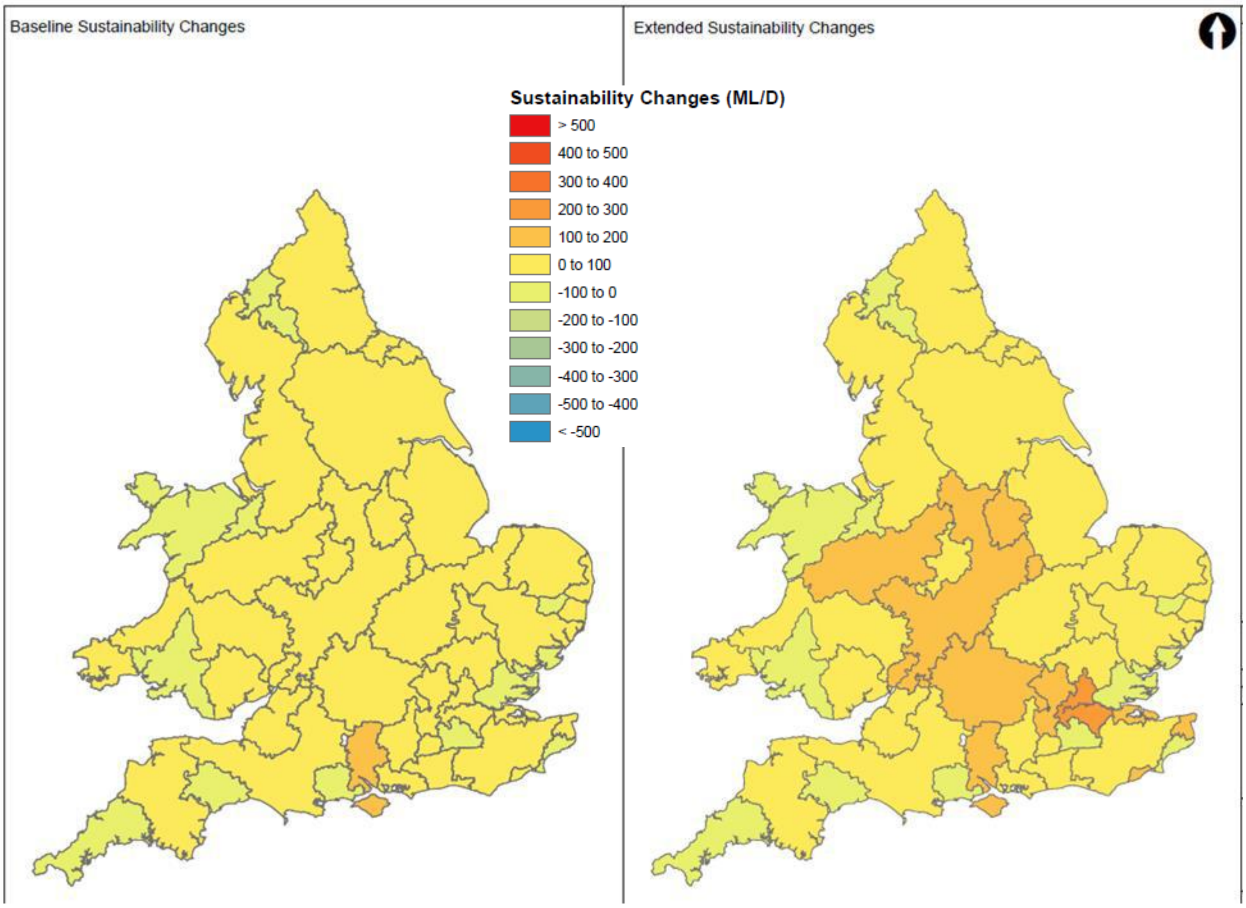
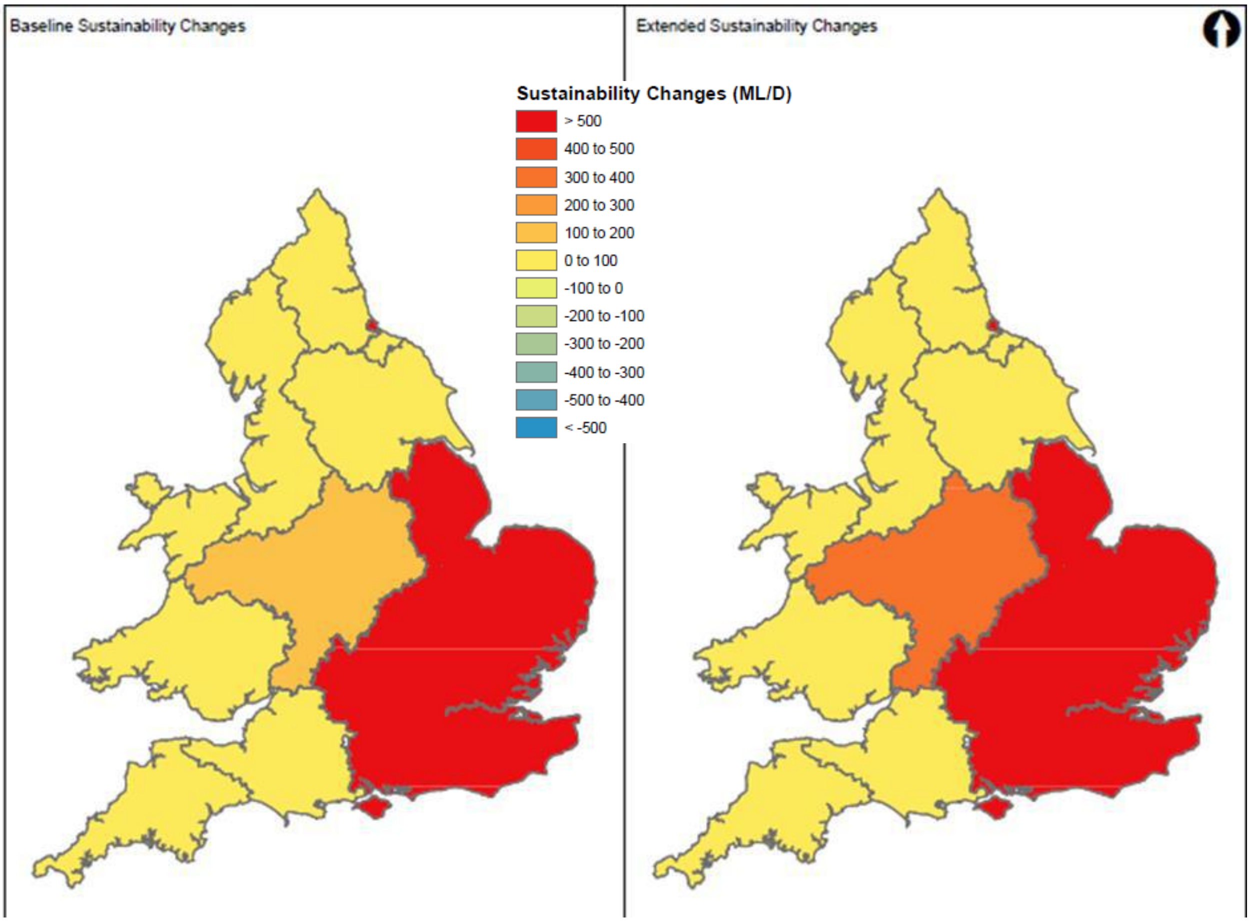


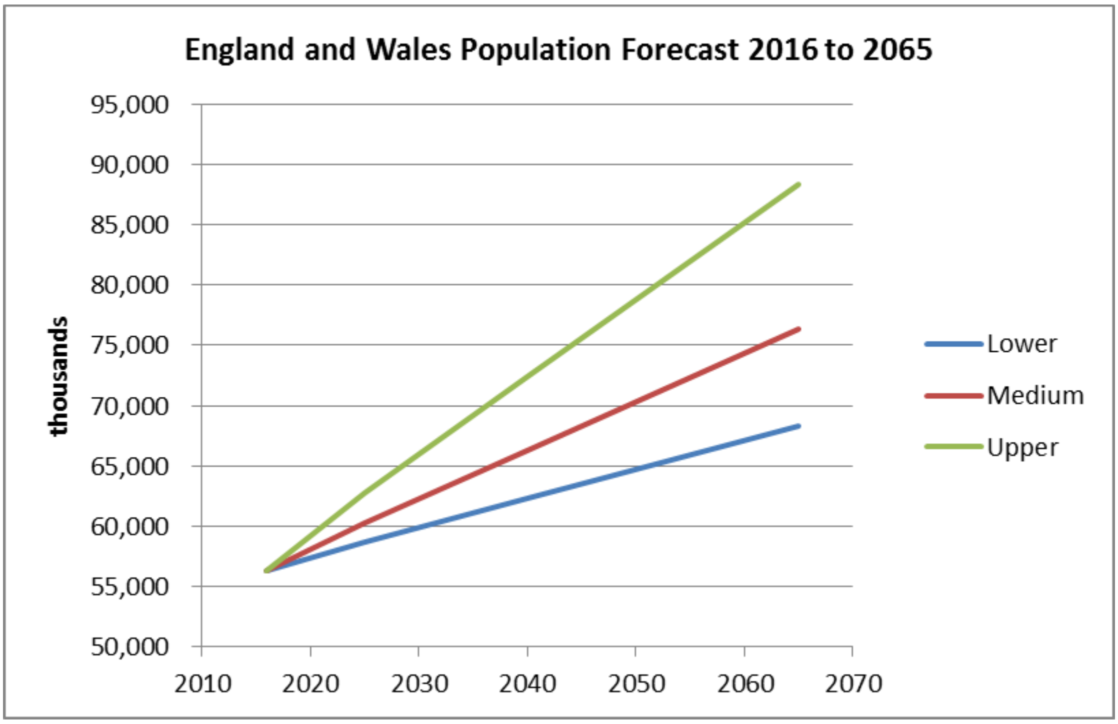
Figure 6-11 Map of potential losses in DO by 2025 under baseline (left) and extended (right) abstraction licence change scenarios – by drought region



6.3. Population growth

The ONS population forecast (2014) estimates population growth for England and Wales of between 6 and 16 million by 2040, and between 12 and 32 million by 2065 (WRMP14 assumes 8.6 million by 2040). The range of forecast changes used for this analysis is shown in Figure 6-12.

Figure 6-12 Population growth scenarios



This growth is not evenly distributed across England and Wales, but varies considerably by region as shown in Figure 6-13 and Figure 6-14 for 2040 and 2065 respectively.

Figure 6-13 Population growth scenarios by region for 2040

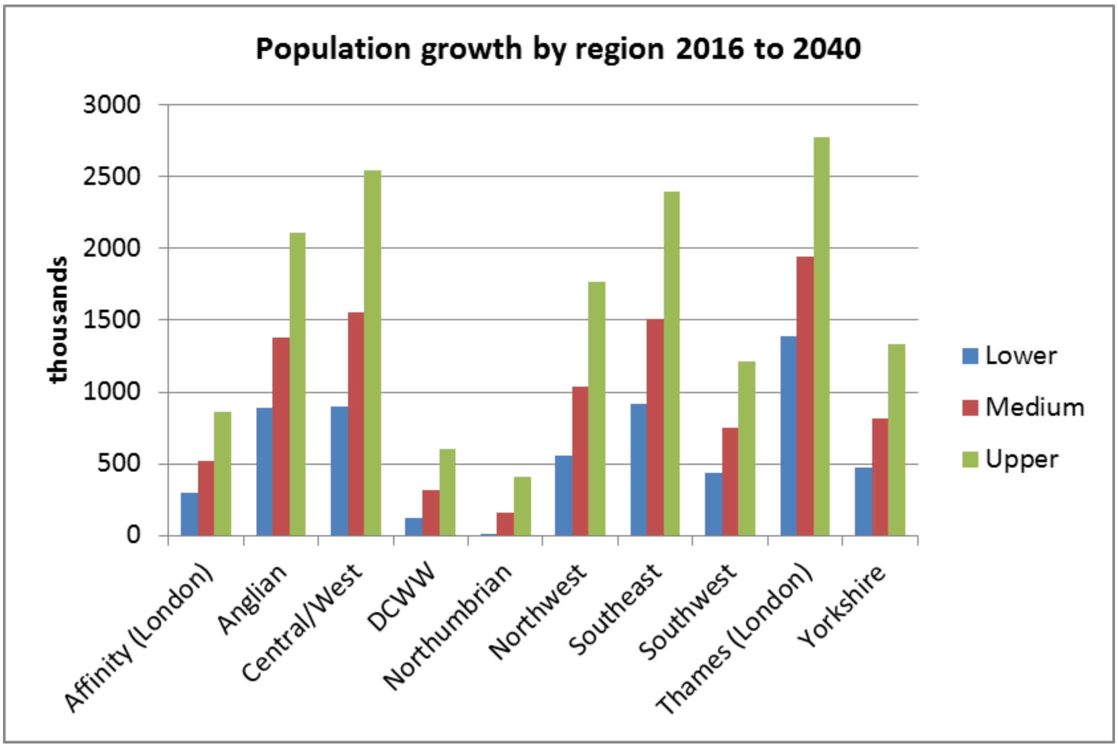
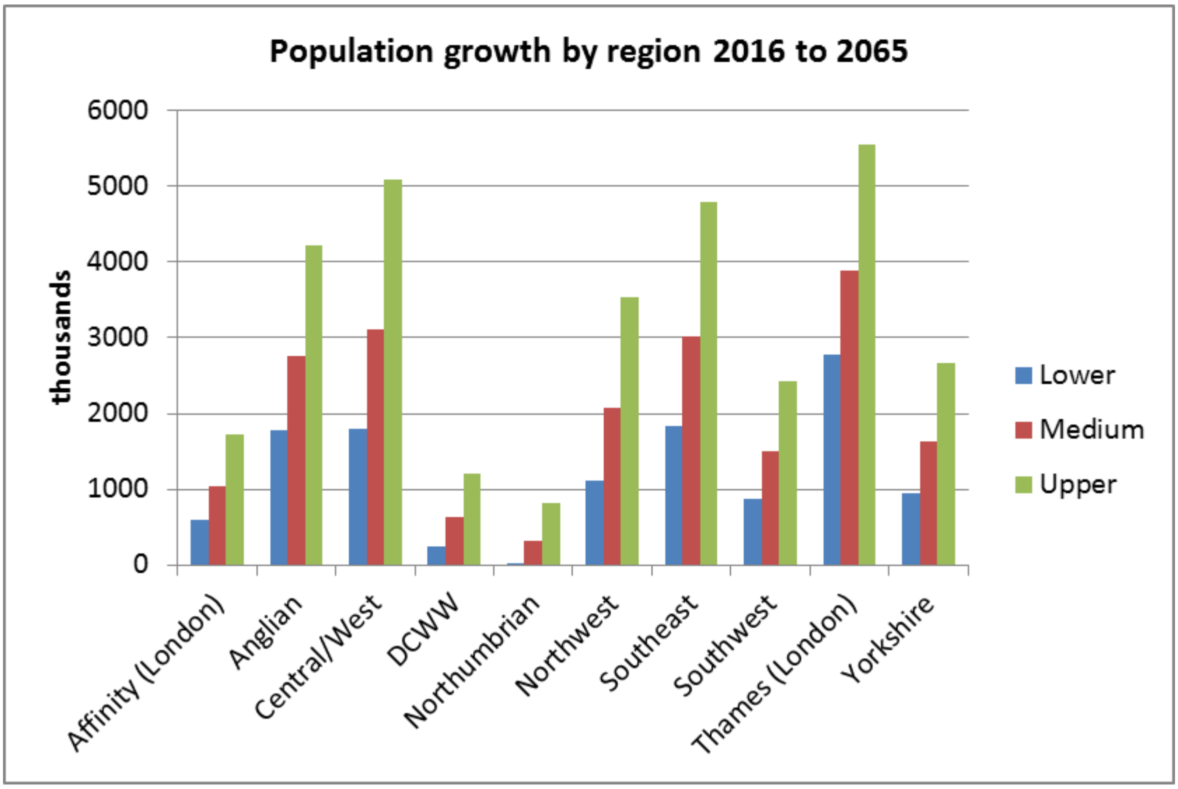
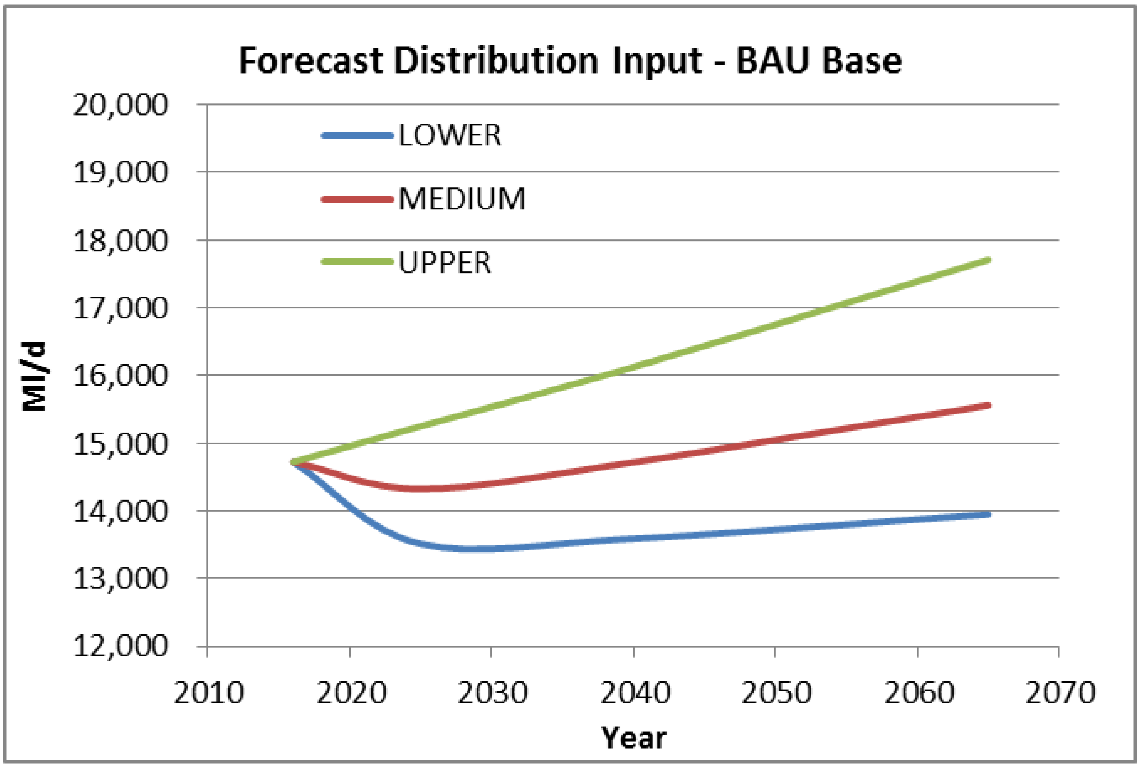


Figure 6-14 Population growth scenarios by region for 2065



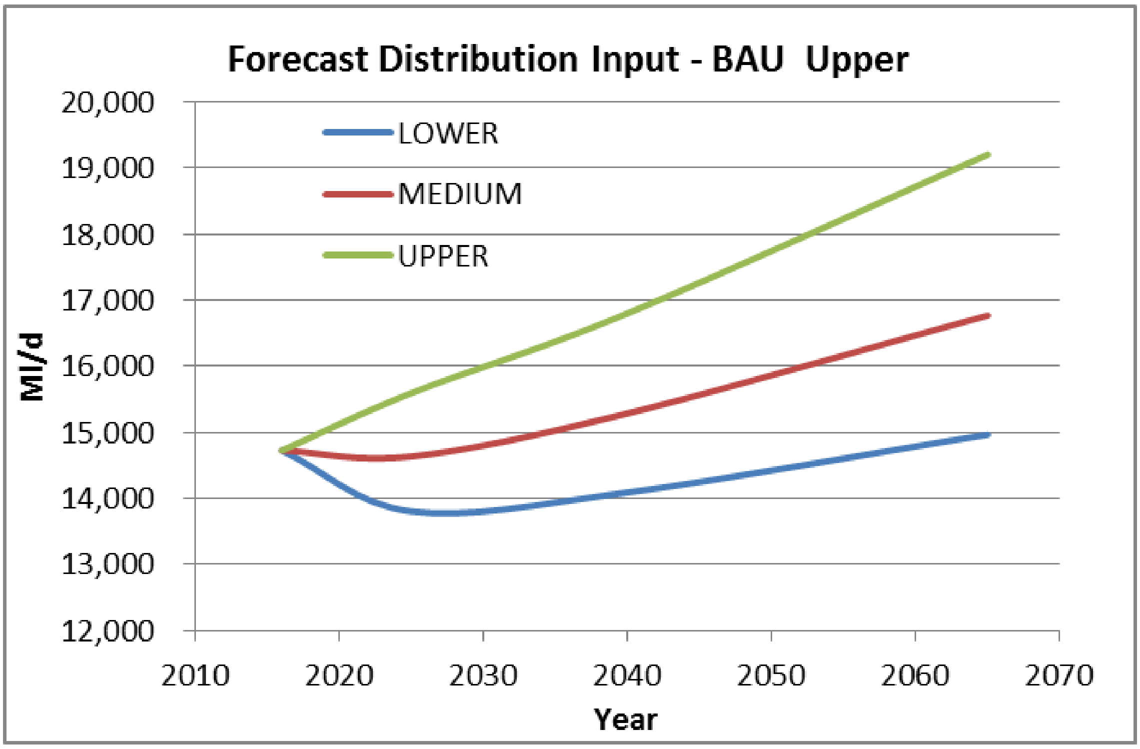
As noted in Section 4.3.3, population is just one component of total demand, which depends also on levels of per capita consumption (PCC). Leakage, either from distribution network or underground supply pipes, also contributes significantly to total distribution input. A notable part of the population growth is offset by declining consumption, due to ongoing metering programmes, efficiency improvements to appliances in homes, particularly in newly built properties, reduced non-household consumption, and reduced leakage through investment in the network and repair programmes. These were handled in the analysis through the different demand management strategies outlined in Section 4.3.3. The impacts that the different levels of household growth would have *net* of the 'Business as Usual' demand management strategy are shown in Figure 6-15 and Figure 6-16 below.

Figure 6-15 Forecast distribution input for BAU Base scenario



This assumes relatively ambitious demand management (PCC and leakage) is achieved as per WRMP14.

Figure 6-16 Forecast distribution input for BAU Upper scenario



This strategy assumes that part of the ambitious savings that are forecast under the 'BAU-baseline' demand management strategy are not achieved. It should be noted that it is assumed that considerable metering is achieved even within the BAU upper scenario; it is mainly the water efficiency measures and societal responses that are assumed to be less effective under this formulation of the strategy.

As with population, demand growth is not uniformly distributed as a result of the spatial variation of all components of the forecast. Maps showing forecast growth by supply area under the medium growth scenario (2040 and 2065) are below, again under a BAU demand management strategy.

Demand growth under lower, medium and upper population growth scenarios are illustrated in Figure 6-17, Figure 6-18, and Figure 6-19 respectively. These take into account PCC and leakage as well as population growth. London dominates demand growth under all scenarios, and there is considerable uncertainty elsewhere. Note that these maps show absolute changes in growth, rather than relative changes, such that supply areas containing major conurbations tend to dominate the results.

Figure 6-17 Demand growth under lower population scenario, BAU Base strategy, 2040 (left) and 2065 (right) – by Supply Area (top) and Region (bottom)

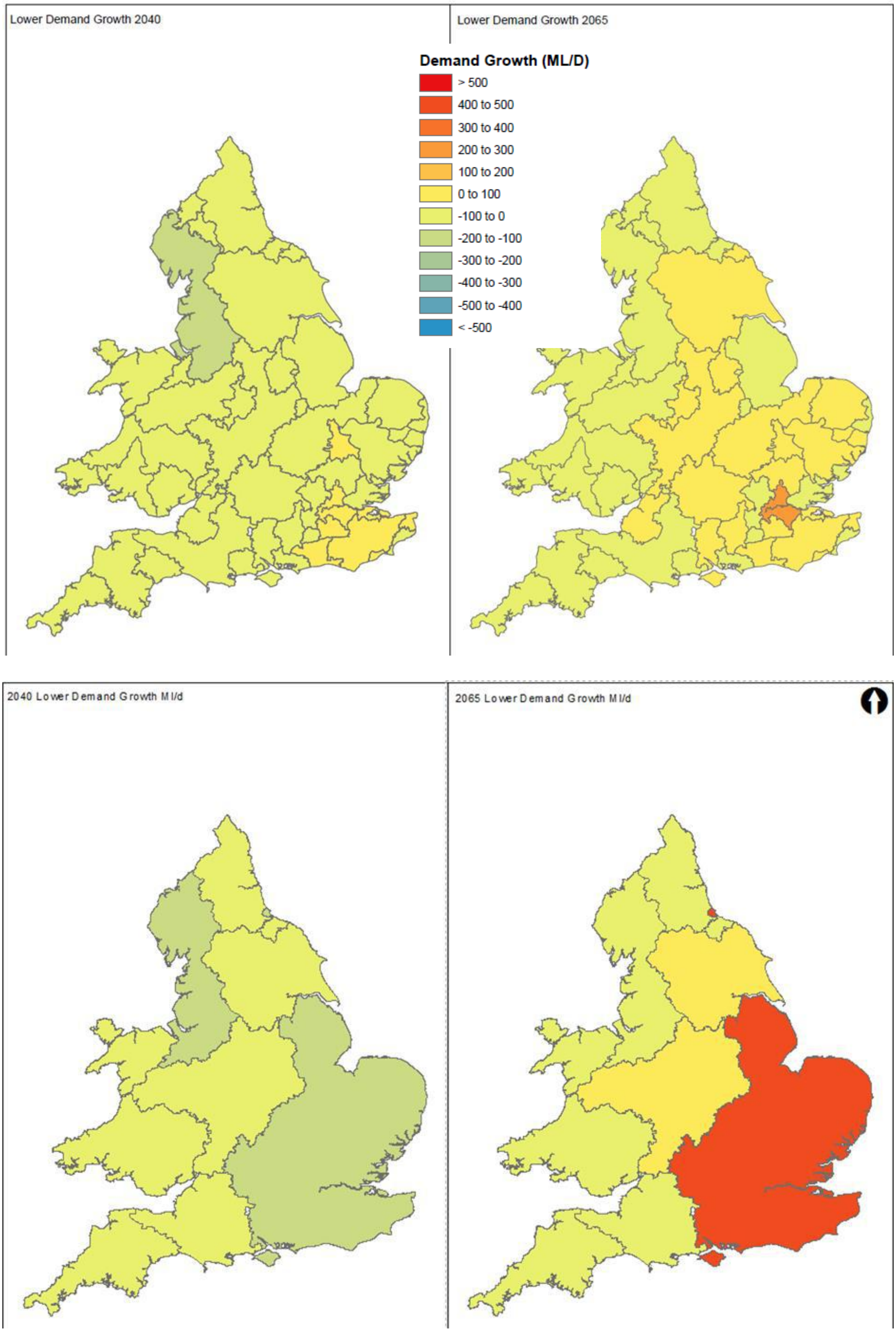


Figure 6-18 Demand growth under medium population scenario, BAU Base strategy, 2040 (left) and 2065 (right) – by Supply Area (top) and Region (bottom)

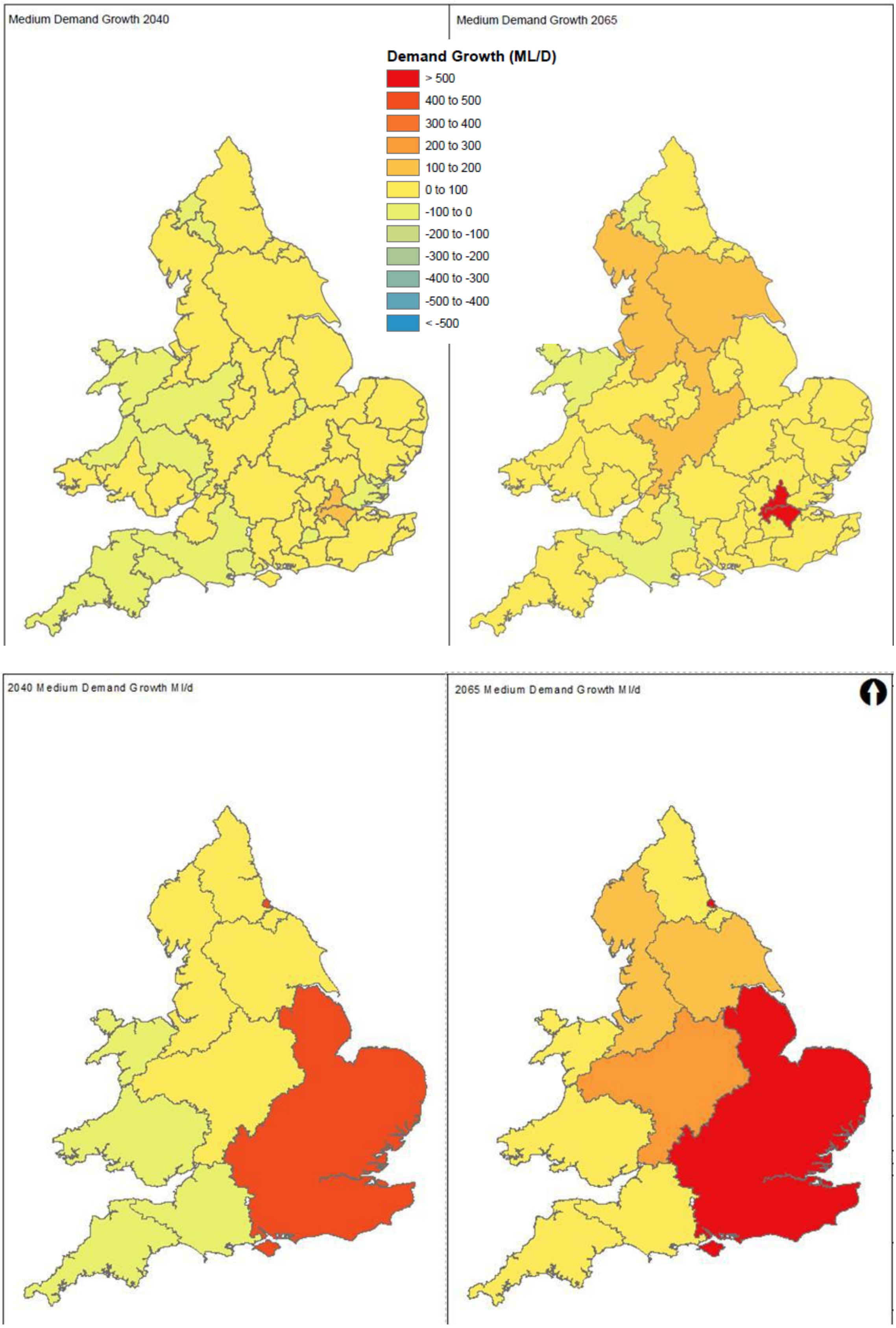
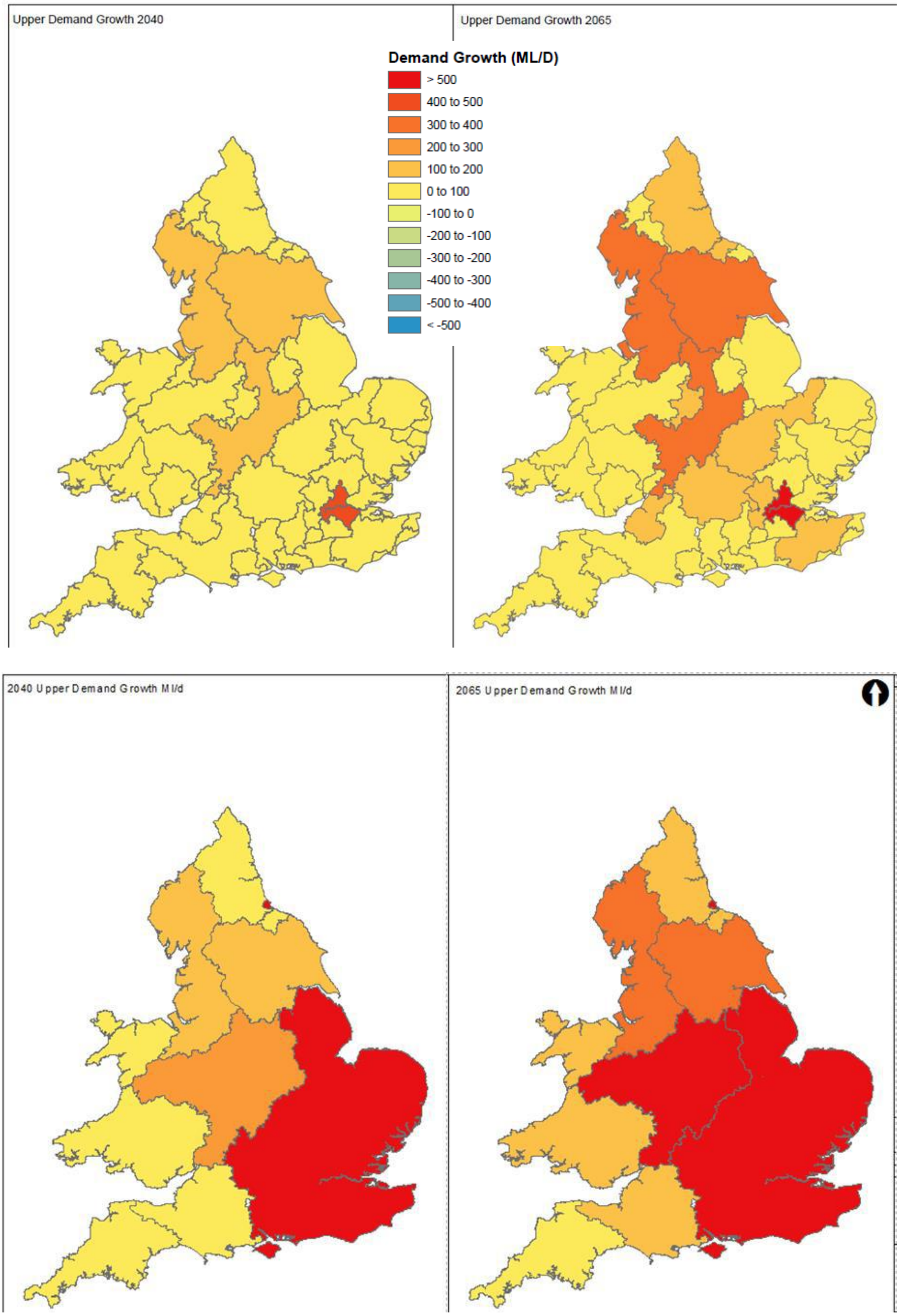


Figure 6-19 Demand growth under upper population scenario, BAU Base strategy, 2040 (left) and 2065 (right) – by Supply Area (top) and Region (bottom)



6.4. Climate change impacts

The values of DO reduction associated with 'median' and 'dry' climate futures have already been presented in Table 6-3 (note – these are nominal, single point estimates of the continuous probability space represented by 'median' and 'dry' futures). The impacts are highly variable between regions, depending primarily on resource type. Resources in the south east are typically more resilient to climate change because of a drier starting climate, with more significant existing storage already in place, and greater reliance on groundwater, which also has a higher effective level of storage. The Central/West is particularly sensitive to climate change, but with considerable uncertainty. Bar charts showing climate impacts by region – base and extended, for 2040 and 2065 are shown in Figure 6-20 and Figure 6-21.

Figure 6-20 Baseline and extended climate change impacts on DO by 2040

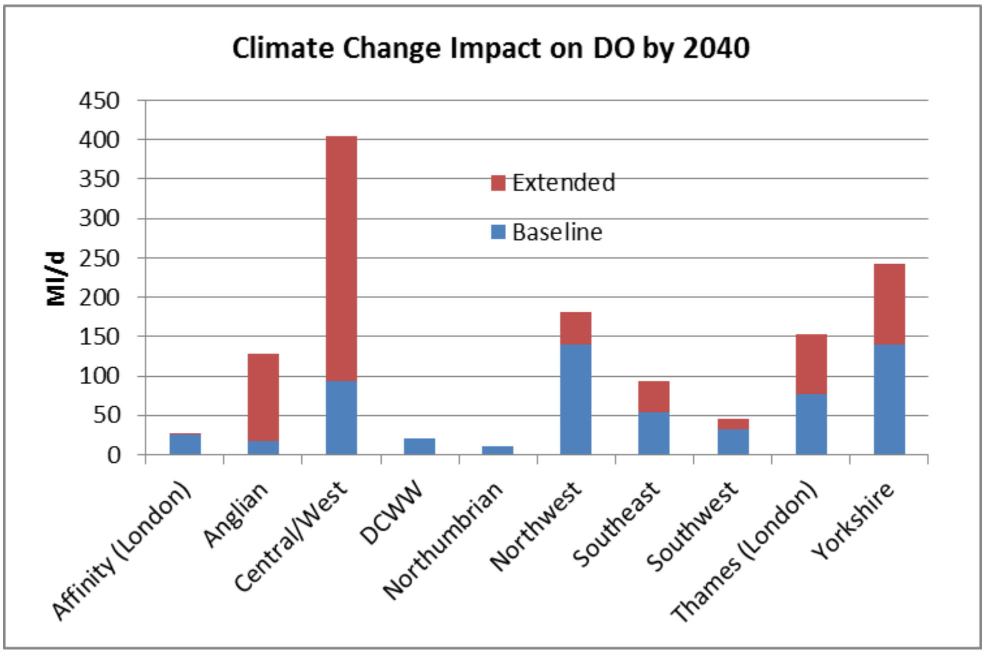
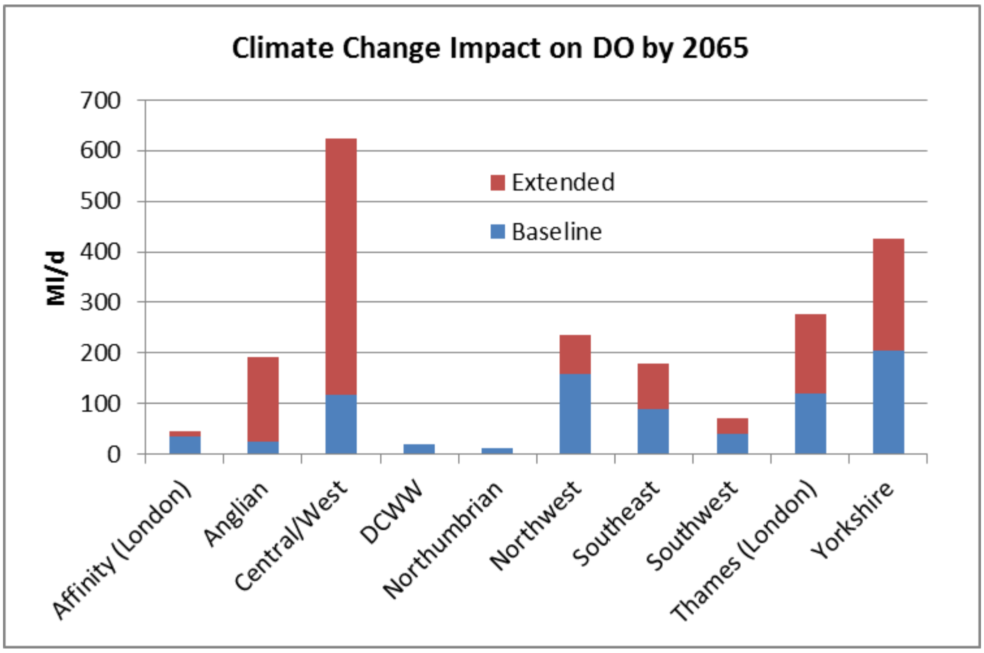


Figure 6-21 Baseline and extended climate change impacts on DO by 2065



These distributions are indicative of the nature of the supply systems involved. Although they are drought vulnerable in the baseline, the resources in the south and east have a strong groundwater component, which is predicted to be less vulnerable than surface water. Spatial impacts of climate change therefore tend to be dominated by the vulnerability of the associated surface water systems. The anticipated spatial variability is as shown in Figure 6-22 (by supply area) and Figure 6-23 (by Drought Region).

Figure 6-22 Baseline climate change impact on DO by supply area – 2040 (top) and 2065 (bottom) under base (left) and extended (right) scenarios

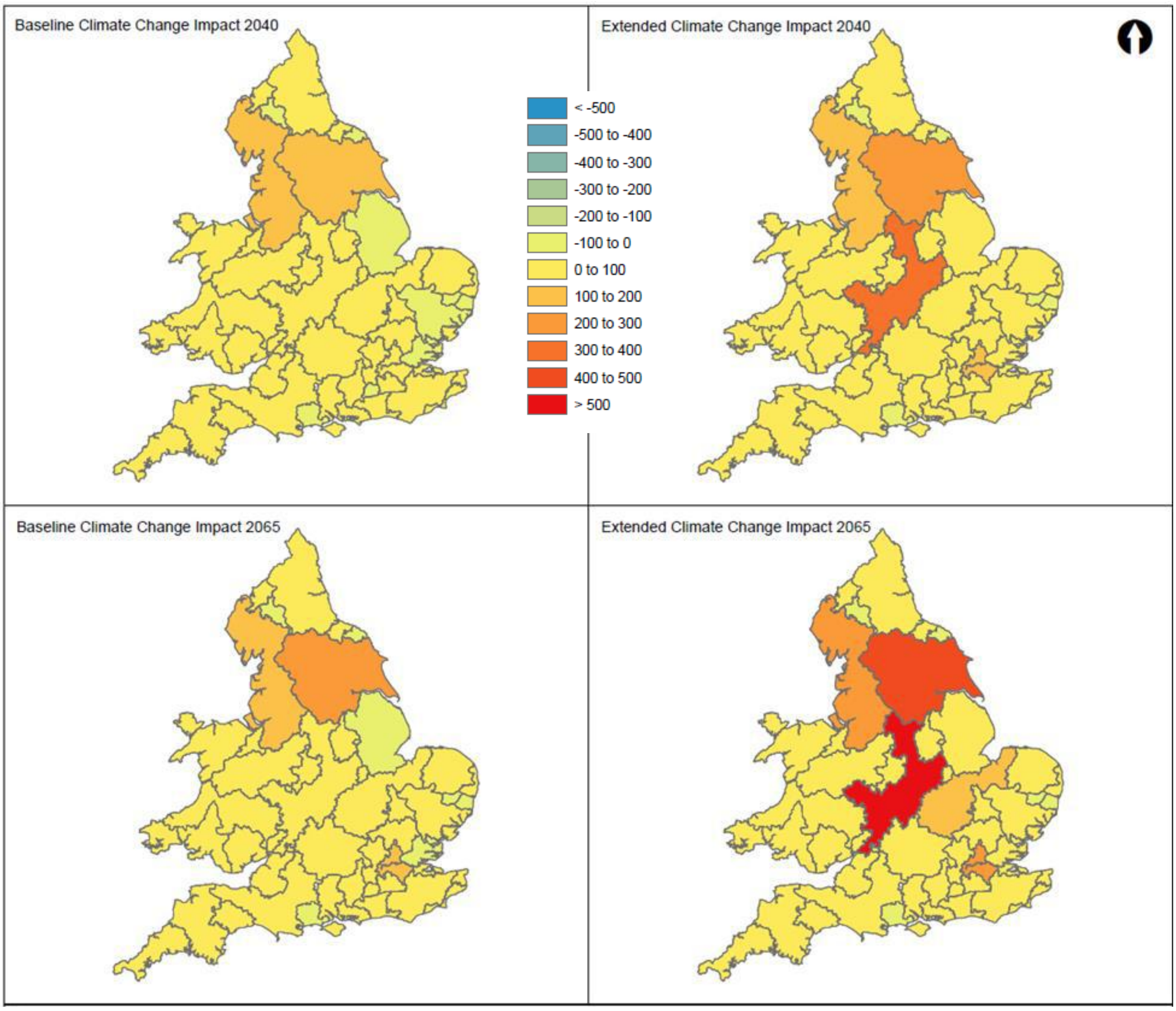
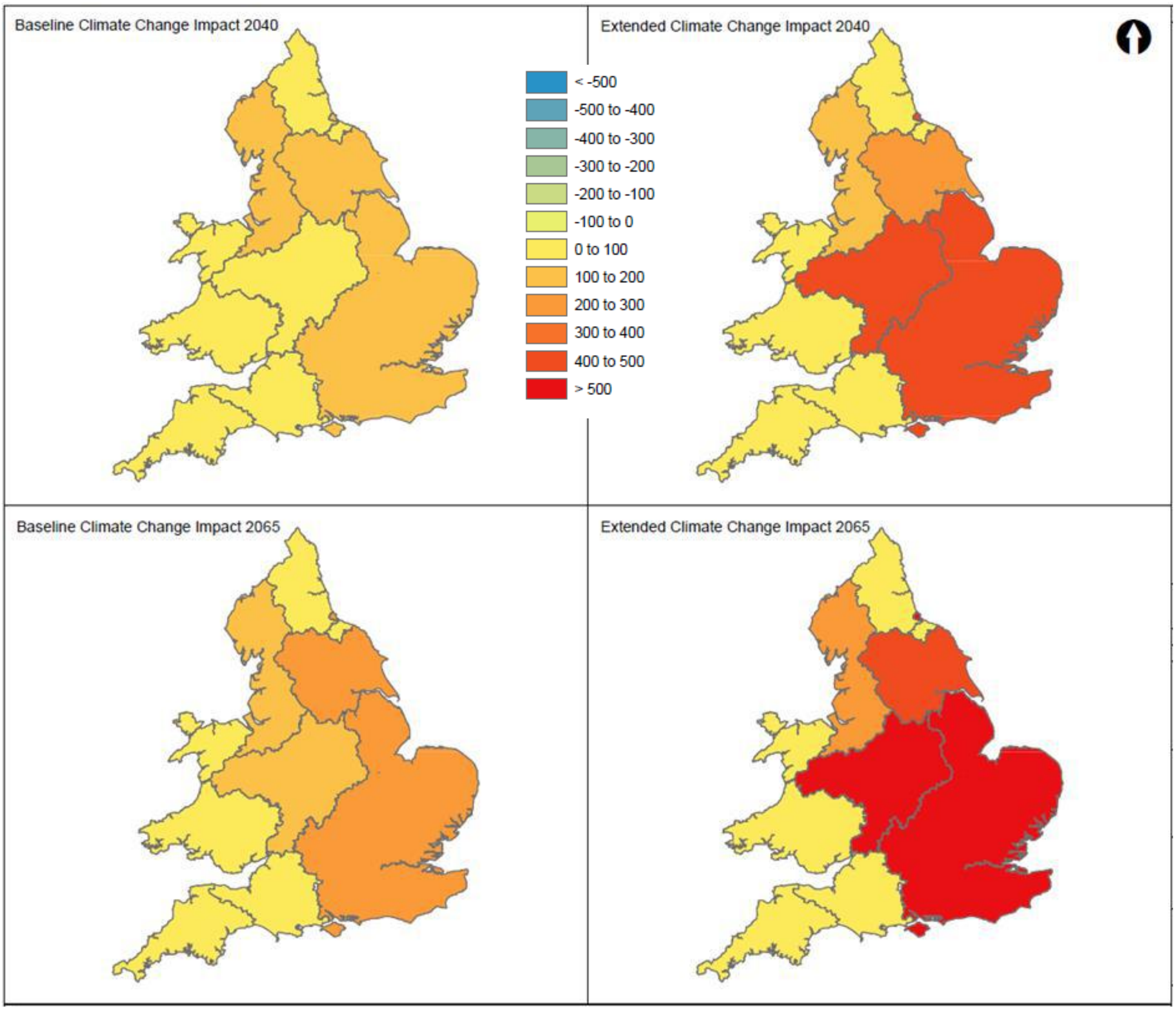


Figure 6-23 Baseline climate change impact on DO by Drought Region – 2040 (top) and 2065 (bottom) under base (left) and extended (right) scenarios



6.5. Scale of deficit faced

The potential impacts defined above for population growth, climate change, environmentally-driven changes to abstraction and drought return period were summed at water resource zone resolution in order to generate supply/demand balances for the 36 future scenarios. Initially this was undertaken assuming WRMP14 levels of demand management. Alternative demand management strategies were defined subsequently as described in section 8.

The water resource zone supply/demand balance values were up-scaled to calculate the supply/demand balance for each supply area, in order to simplify the situation sufficiently for generating option portfolios and modelling within Wathnet. For the purposes of all further modelling and cost-curve analysis, deficits at supply area resolution were used.

6.5.1. Deficits in 2040

Deficits in 2040 were calculated for every sub-Region and future scenario, as described above. The total of the deficits was then added to present results for each region, excluding surplus. This ensured deficits were recognised at regional level, even where a neighbouring supply area may have been able to provide sufficient surplus to mitigate the deficit. The results, broken down by region and scenario, are shown in Figure 6-24 and Figure 6-25 below, for baseline and extended environmentally-driven changes to abstraction.

Total deficits by 2040 vary considerably, between 300 and 3000 Ml/d under baseline abstraction changes and between 800 and 3800 Ml/d for extended abstraction changes.

Figure 6-24 Sum of Supply Area deficits under baseline abstraction changes, 2040

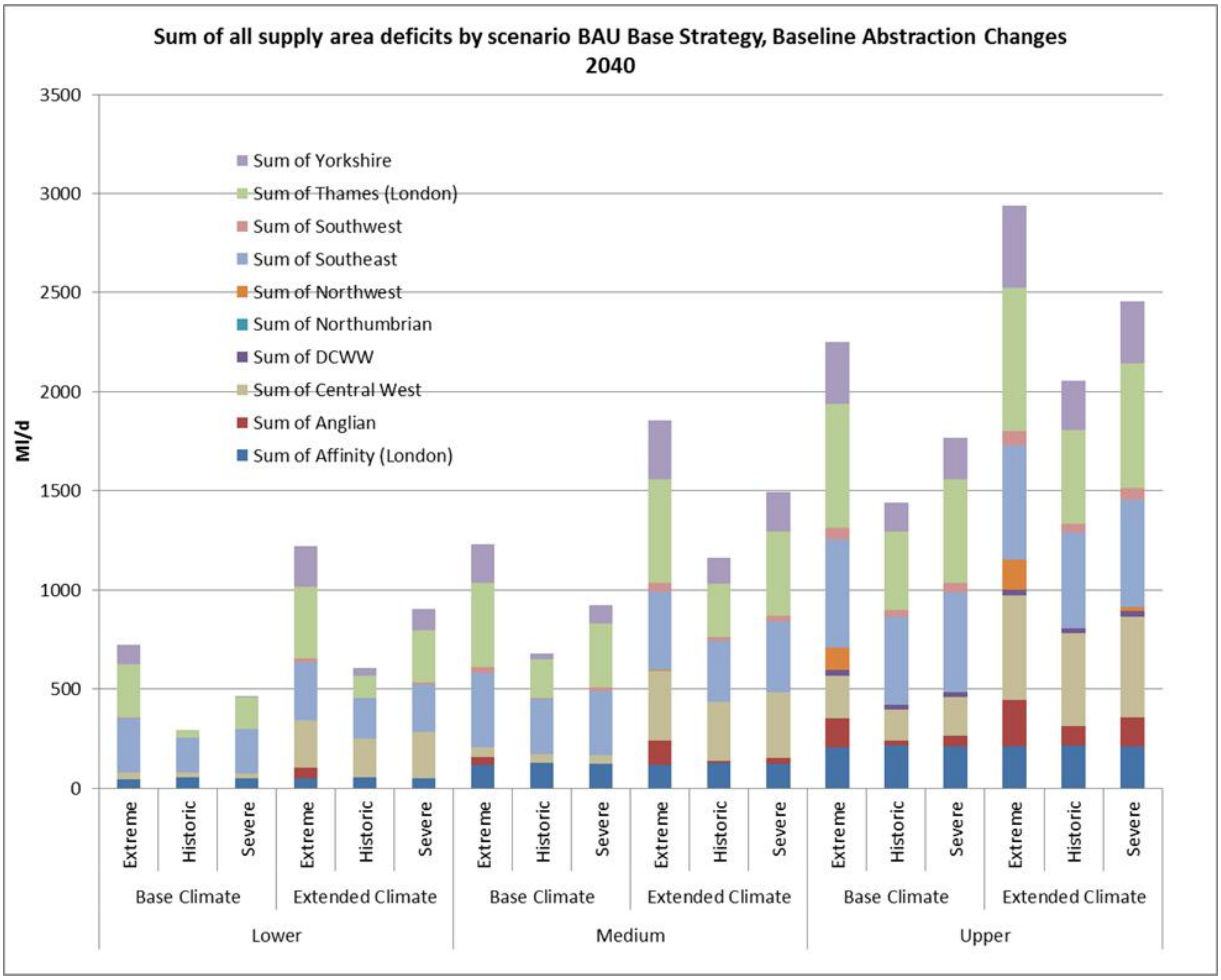
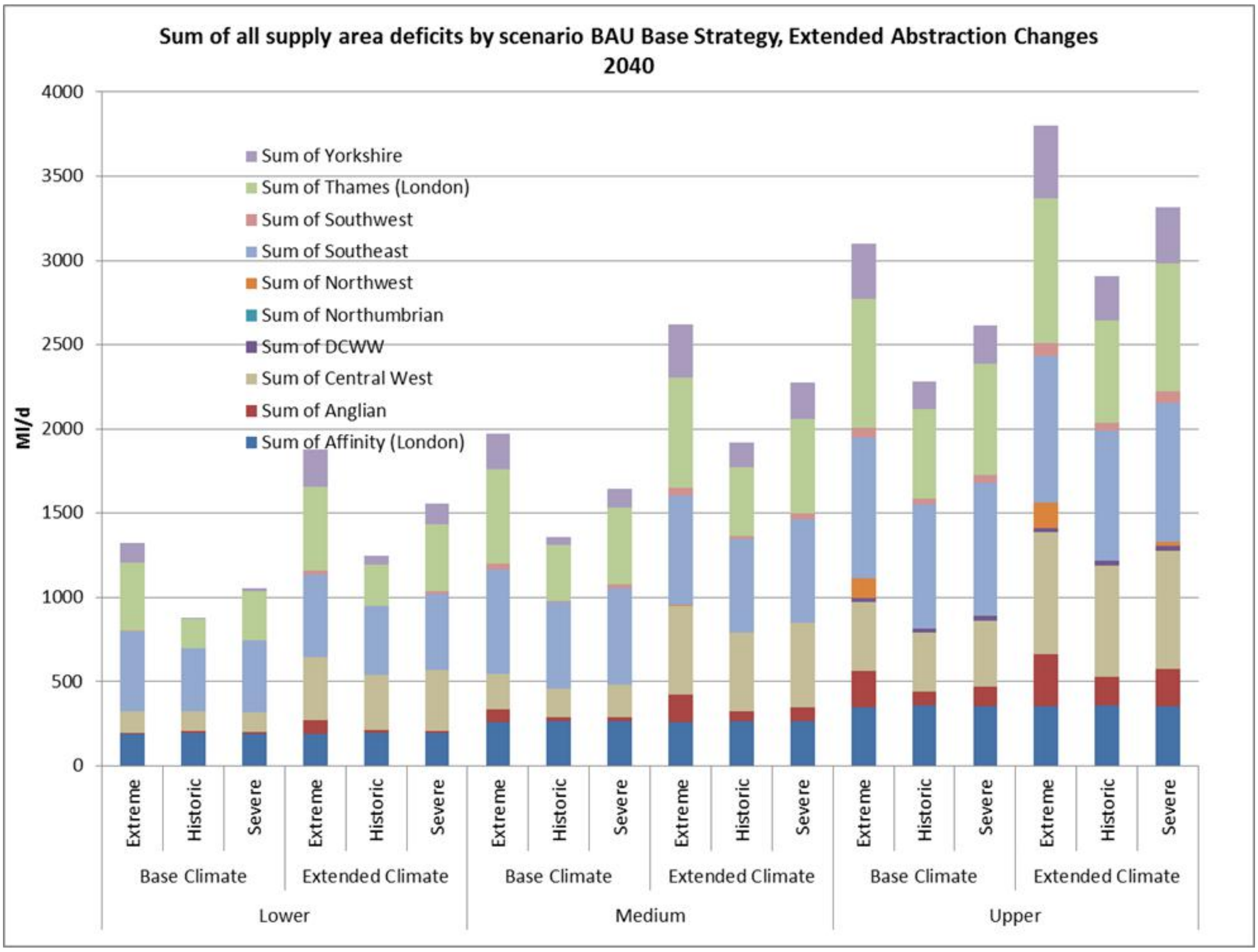
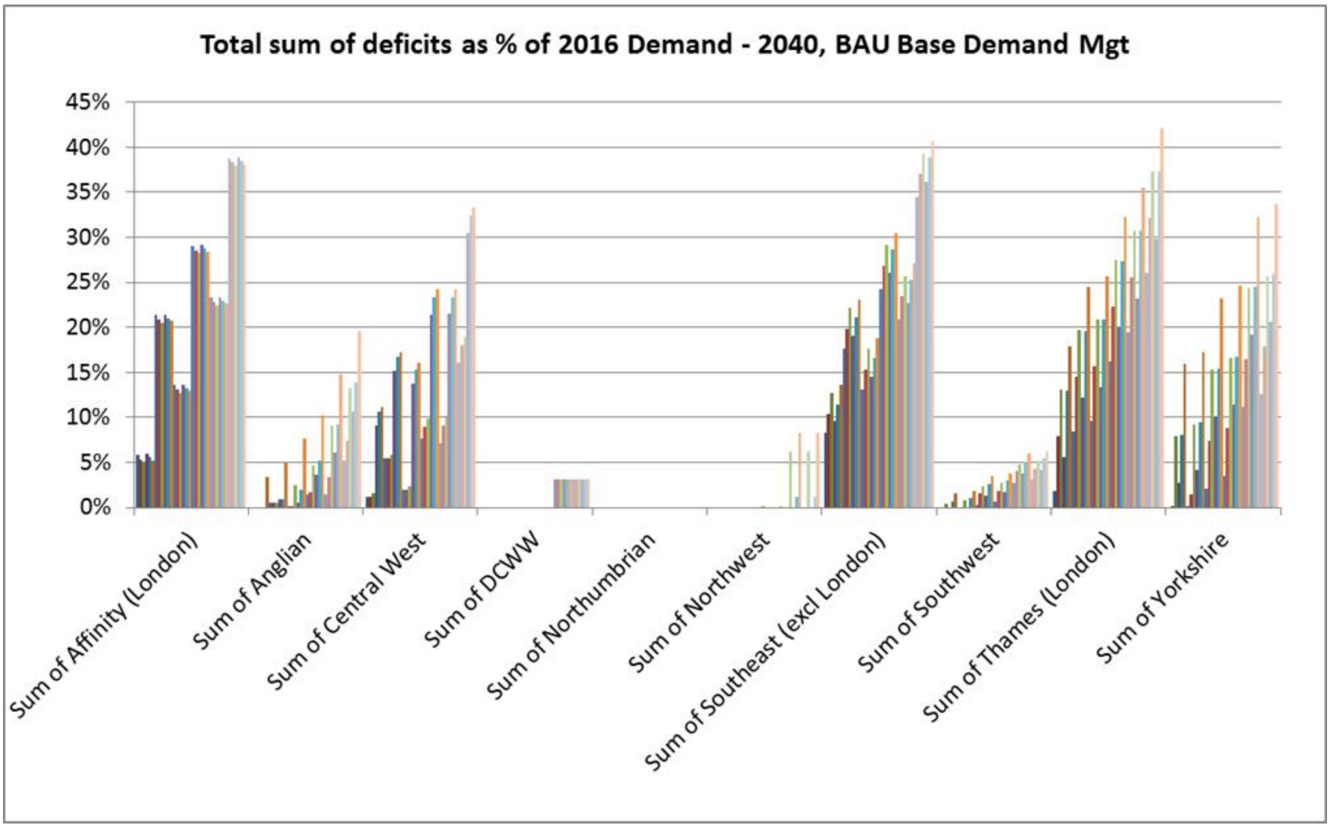


Figure 6-25 Sum of Supply Area deficits under extended abstraction changes 2040



Based on this information, Figure 6-26 below shows the additional supply-side resources that were anticipated to be required by sub-Region in 2040, expressed as a percentage of existing demand. Each bar represents a different scenario, all under BAU base demand management. This shows that there is a wide variability in deficit risk across all regions, but supports the initial assumption that the biggest percentage deficits are expected across London and the South East, which require an increase in supply side resources of between 5% and 40% by 2040 under the BAU Base demand management strategy. The Central West and Yorkshire Regions were found to be the next most vulnerable, requiring between 2% and 35% increase, with Anglian between 1% and 20%, and the Southwest up to 5%. Welsh Water is vulnerable under upper demand growth only, with a 3% resource gap, and the Northwest only under upper demand growth alongside extreme drought – by up to 8%. Northumbrian is drought resilient under all scenarios in 2040.

Figure 6-26 Sum of 2040 Supply Area deficits as % of 2016 demand, BAU Base demand management strategy (for the 36 future scenarios)



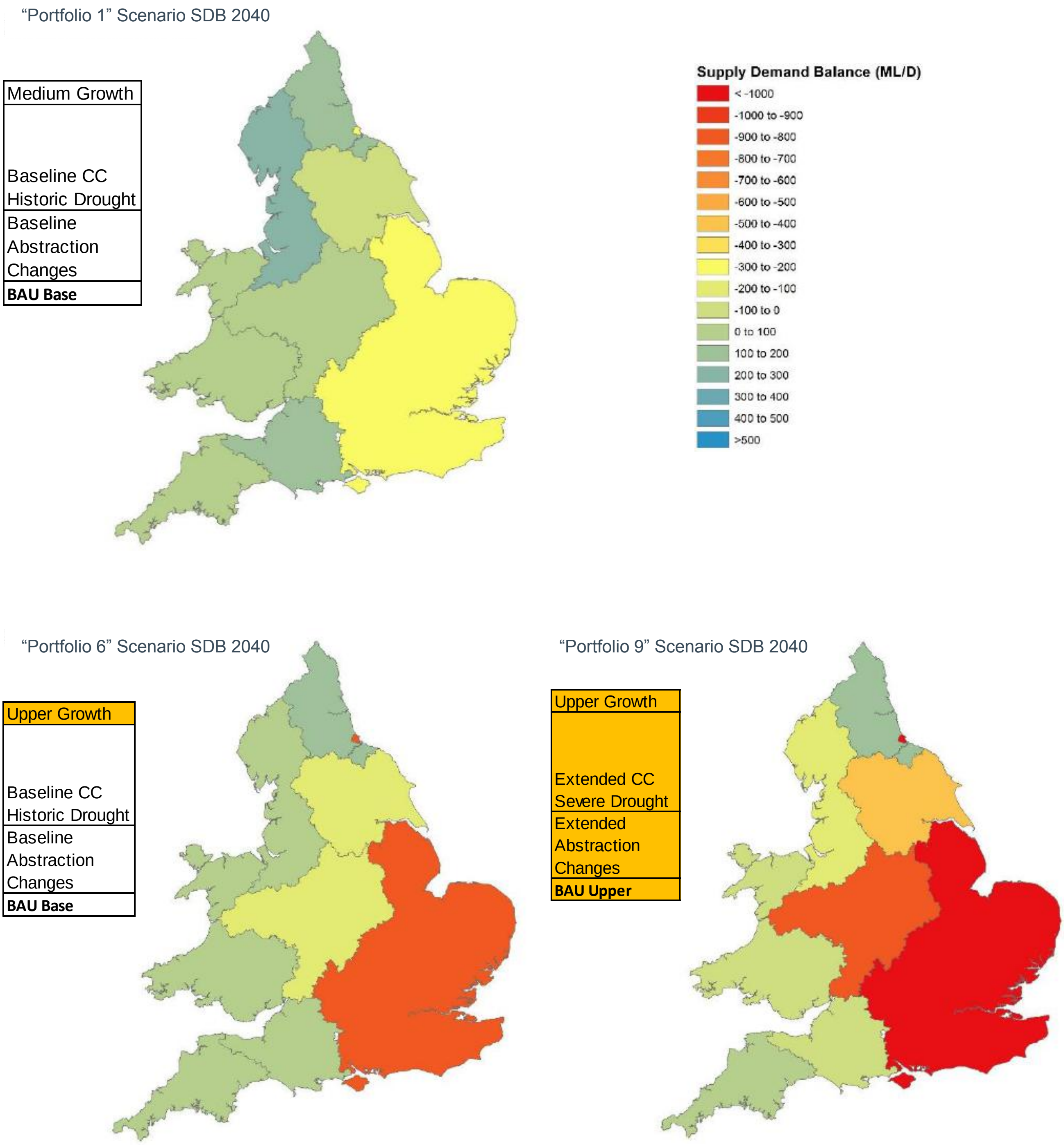
A graphical summary of the deficits according to Regions is provided in Figure 6-27 (note: this only contains BAU demand management and no supply side options beyond those committed for delivery within AMP6 & 7).

This wide variation in potential need, even at the 2040 time horizon, highlights the need for adaptive approaches to strategic water resources planning in England and Wales. There is unlikely to be an 'optimal' solution that could be predicted with any degree of confidence, which is why the approach set out within this report concentrated on evaluating:

1. **The range of need for supply side options, *given* different demand management strategies.**
2. **The broad cost effectiveness of the different demand management strategies when combined with the associated supply side developments.**
3. **The trade-off between costs and resilience for different types of Portfolios.**

Whilst the above analyses shows the situation at a regional level, it is noted that there is significant variation in deficits when viewed at the water resource zone resolution. This was accounted for when the 13 'example' Portfolios were being put together, as described in Section 8.2.

Figure 6-27 Maps of forecast Regional deficits by 2040 (accounting for committed supply side options planned to 2025) under three key example future scenarios



6.5.2. Deficits in 2065

Deficits in 2065 were calculated for every supply area and scenario, as for 2040. The total of the deficits was then calculated to present results for each region, excluding the surplus. The results, broken down by region and scenario, are shown in Figure 6-28 and Figure 6-29 below, for baseline and extended environmentally-driven changes to abstraction.

Total deficits by 2065 are almost twice as large as in 2040, as demand growth trends continue and climate change impacts worsen. Once again, there is considerable variation between scenarios, with total deficits ranging between 600 and 5200 Ml/d under baseline abstraction changes and between 1300 and 6000 Ml/d for extended abstraction changes.

Figure 6-28 Breakdown of SDB 2065, baseline abstraction changes

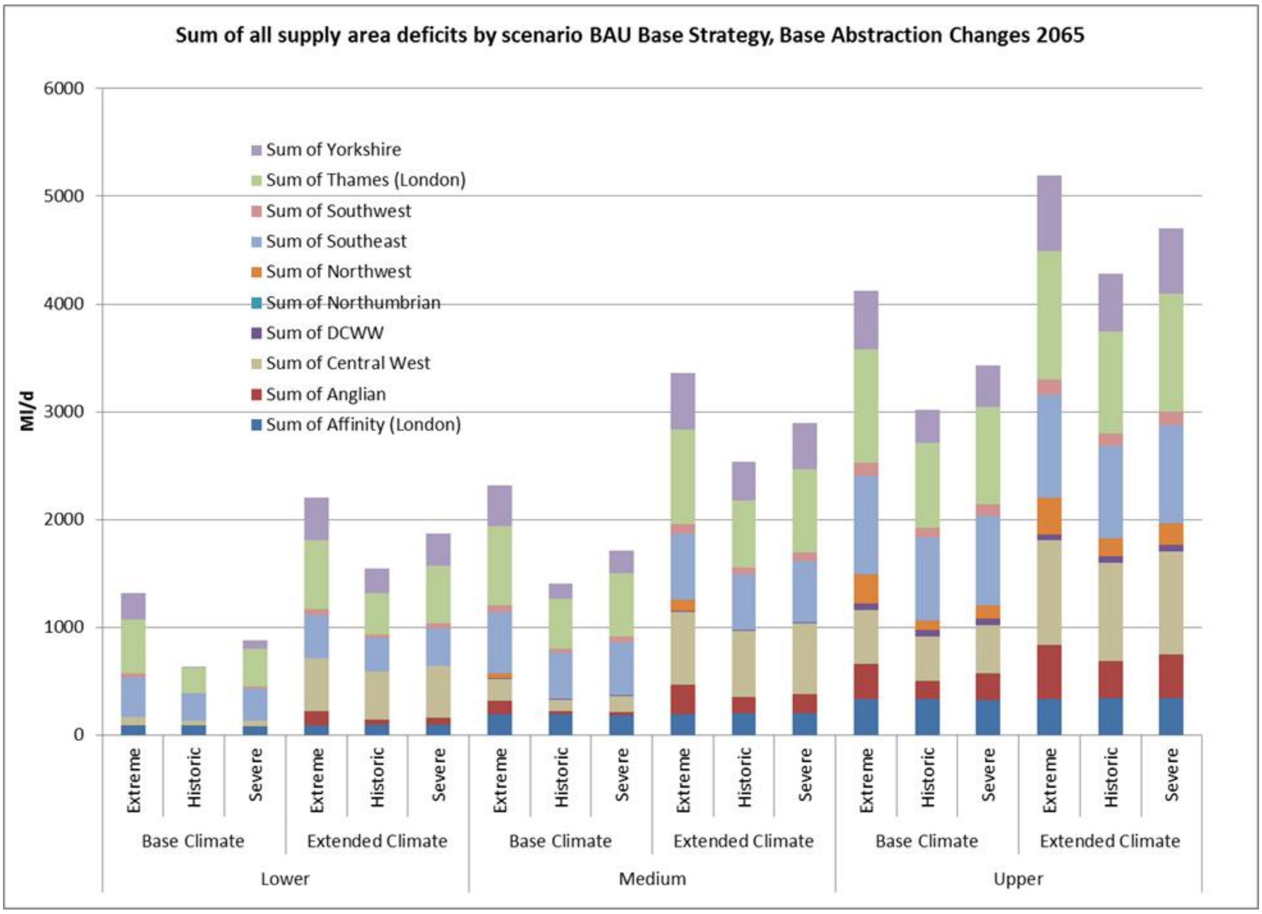
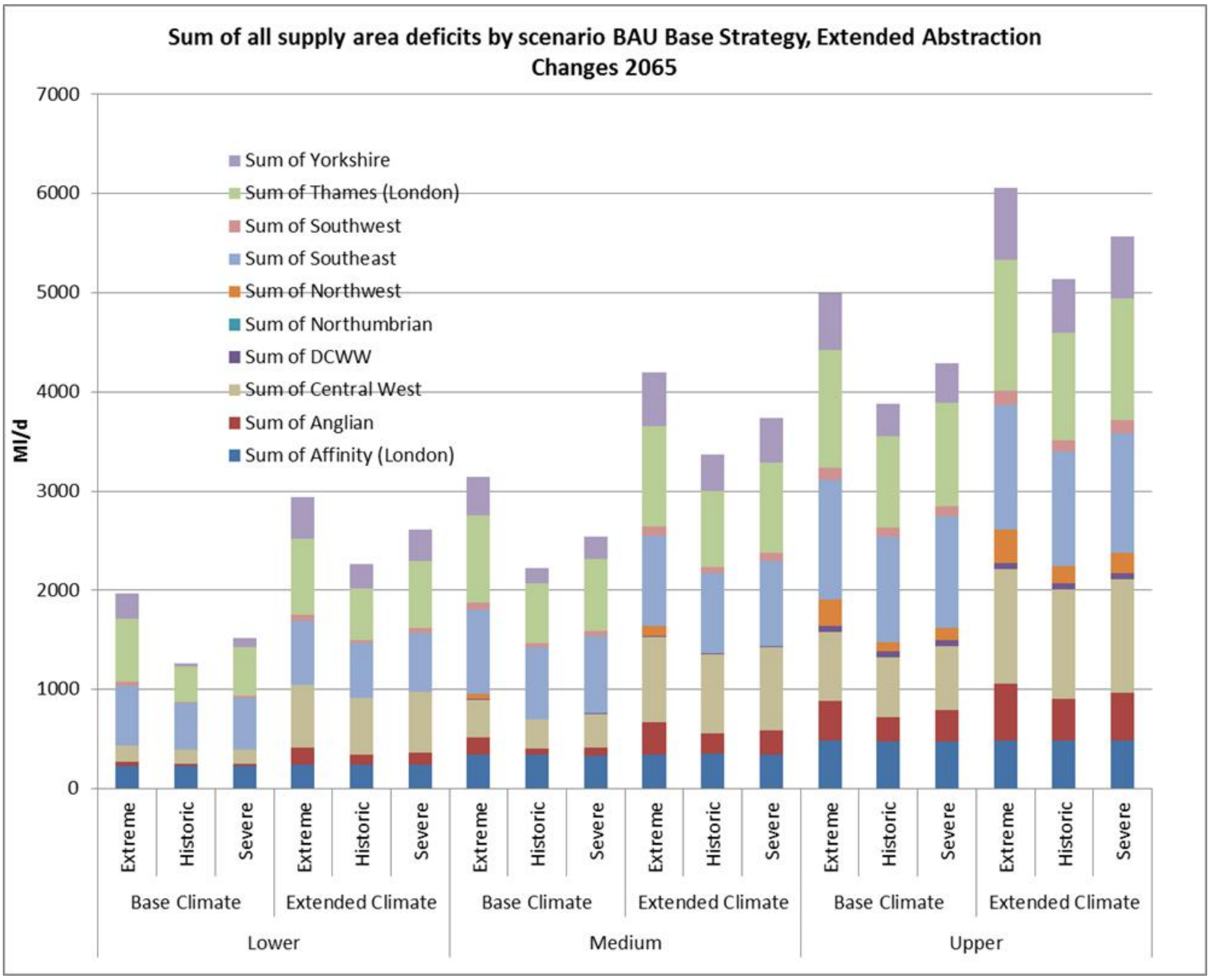
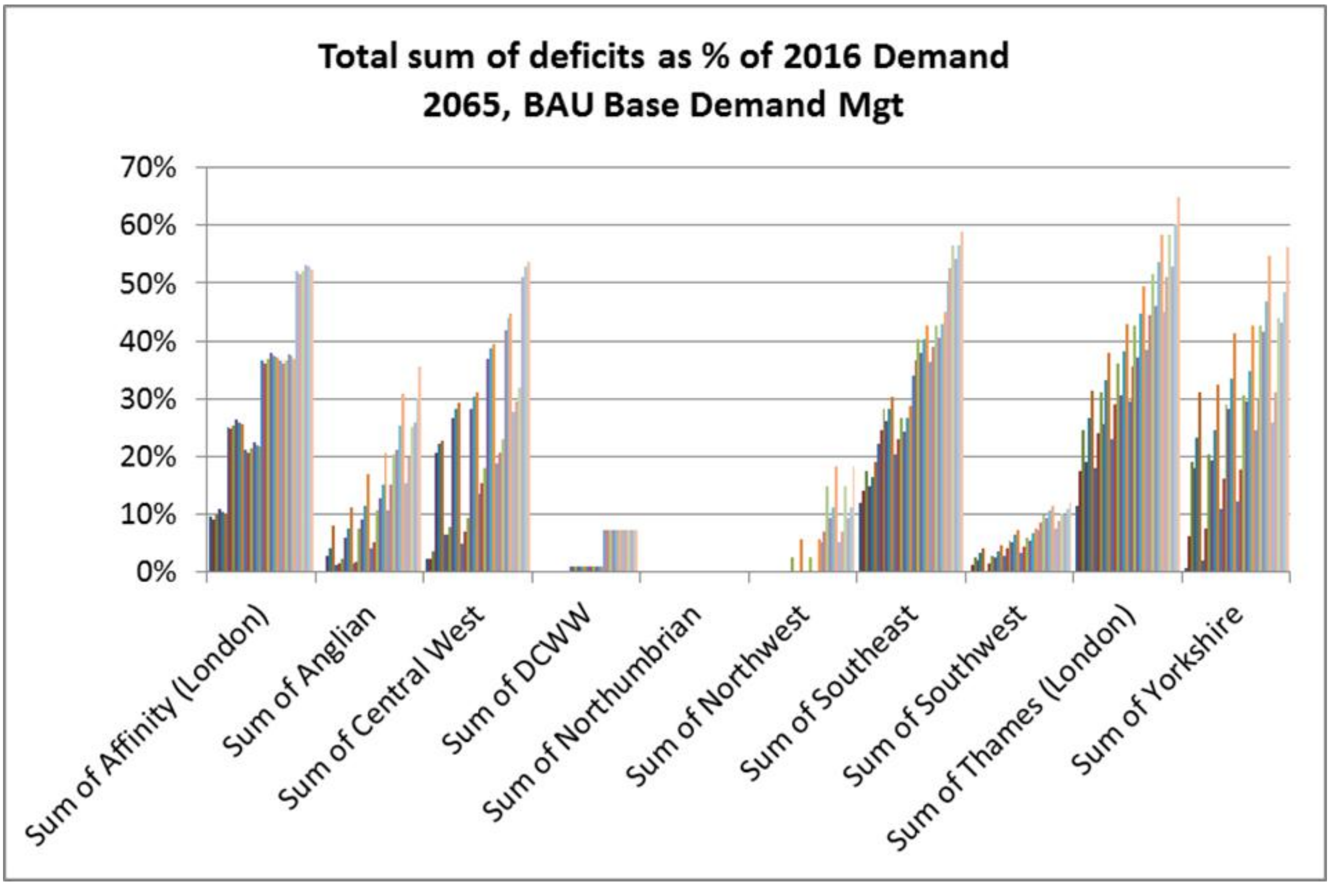


Figure 6-29 Breakdown of SDB 2065, extended abstraction changes



The figure below shows the additional supply side resources required by region in 2065 as a % of existing demand.

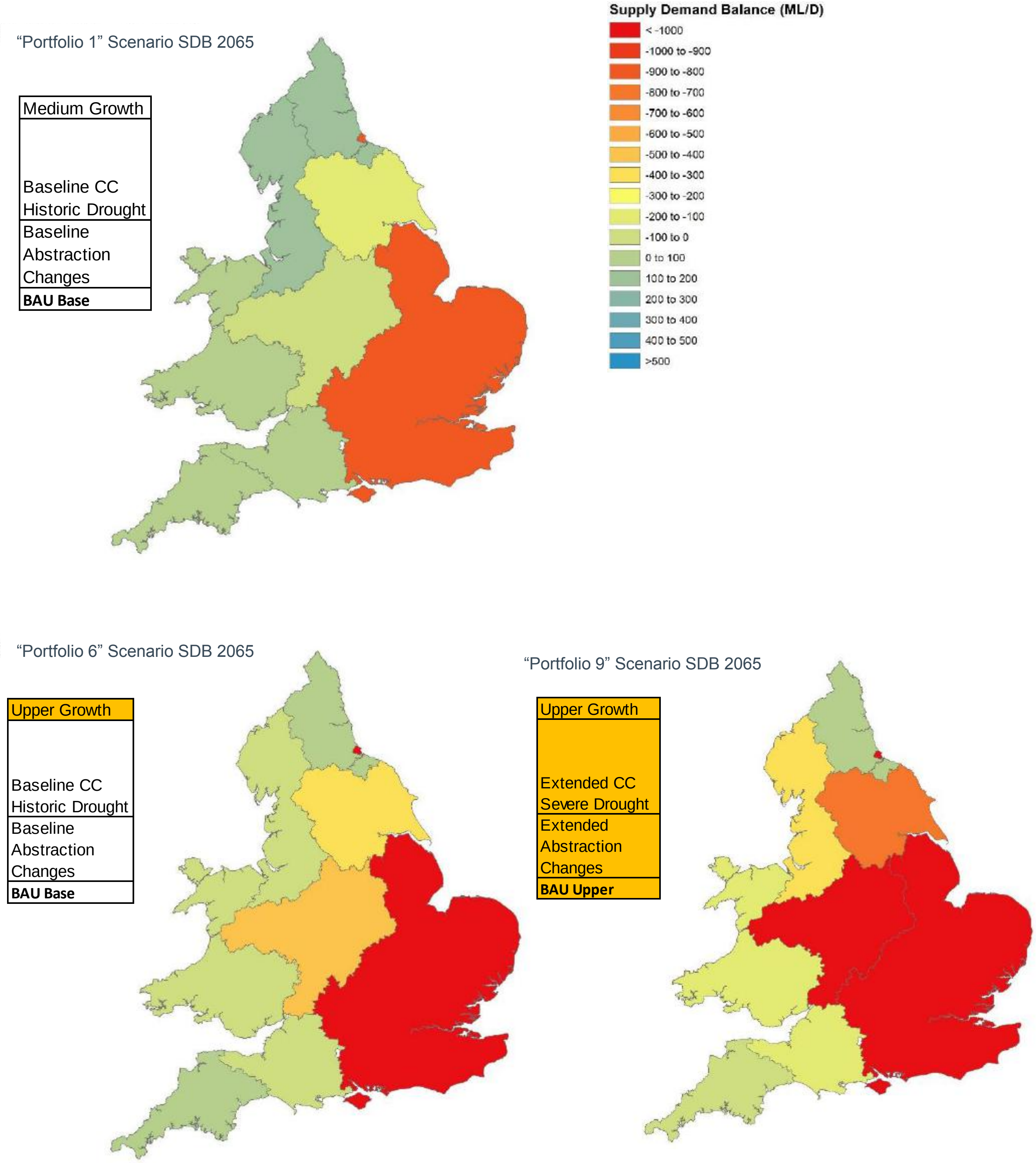
Figure 6-30 Sum of 2065 Supply Area deficits as % of 2016 demand, BAU Base demand management strategy (for the 36 future scenarios)



London and the Southeast Regions require an increase in supply side resources of between 10% and 65% by 2065 under this demand management strategy. The Central West and Yorkshire Regions require between 2% and 55% increase, Anglian between 1% and 35%, and the Southwest up to 10%. Welsh Water and the Northwest become potentially vulnerable under upper demand growth, with supply side shortfalls of 7% and 5 to 18% respectively. Northumbrian remains drought resilient under all scenarios by 2065. The flat profile for Welsh Water is because its variation in deficits is driven only by growth variability.

As presented previously (for 2040), Figure 6-31 provides an illustration of the 2065 deficits by Region (again, these do not include any supply side options beyond AMP6 & 7).

Figure 6-31 Maps of forecast Regional deficits by 2065 (accounting for committed supply side options planned to 2025) under three key example future scenarios



7. How do we value the consequences?

7.1. Overview of the economic and societal consequences of drought

This study required a simple and tractable representation of the consequences of drought for different affected parties, one that captures the most important effects and can be used to scale and – where possible – value the effects emerging from the drought simulations. This section provides a summary of the anticipated consequences, which was generated from a series of more detailed technical appendices (Appendix F).

The literature on drought consequences suggests that the "size" of the consequences for a given water user depend mostly on the severity of the restrictions placed on water use, and on the duration of those restrictions. In the current and foreseeable UK drought management frameworks, the severity of the restrictions applied to a given user at any time will fall into one of a few discrete levels (farming and environment aside, arguably), with the severity of restrictions becoming more severe as the drought worsens and continues.

For the sake of simplicity, three discrete levels of consequence were defined for each affected water-using group at any point in time in a drought. **These levels of consequence were used to link to the consequences of Public Water Supply (PWS) restrictions within the cost/benefit analyses described in 8.5.**

Previous research suggests that the raw consequences and costs of early calls for voluntary restraints in water use during droughts are low. Accordingly, the three levels of consequence correspond to relatively more severe degrees water use restrictions. These *consequences* were defined as Severity 2, Severity 3, and Severity 4, which acted as a reminder that there is a lesser drought Severity 1 that was not modelled. The basis and extent of the restrictions applying to user groups in the severity levels are set out in Table 7-1 below and the text following it.

The consequences and value effects are necessarily aggregated or averaged across fairly large groups of users. They do not represent the consequences that every affected water user will experience. Rather, it was considered that the severity steps and affected groups were a sensible approximate structure to use in "sizing" and in valuing the consequences of the droughts that have the largest effects when considered on a national basis.

Table 7-1 Three degrees of drought severity and water use restriction

Severity:	Households	Non-households				Environment
	(PWS supplies)	(PWS supplies)	(private abstraction)	(spray irrigation)	(rain-fed agriculture)	
S2	Level 2: Temporary Use Bans	TUB (for the few affected activities)	Hands off Flow limits apply	Partial S57 restriction	Second	Second
S3	Level 3: Extended temporary Use Bans	Ordinary Drought Order (demand-side)	Ordinary Drought Order (demand-side)	Full S57 restriction	Third	Third
S4	Level4: Emergency Drought Order	Emergency Drought Order	Ordinary Drought Order (demand-side)*	Full S57 restriction	Fourth	Fourth

Source: NERA

* At the point where Emergency Drought Orders (EDO) are applied to public water supply (PWS) customers, we presume the EA/NRW imposes a correspondingly more severe level of demand side Drought Order restrictions on non-household non-PWS abstractors. We

note that this step of application of EDOs and associated Severity 4 restrictions would be regarded as “system failure”, has not been experienced since 1976 in the UK, and is not set out in any detail in drought management guidance.

For household water users, it was assumed that all households are connected to public water supply (PWS) systems. They were modelled at two different severities (with associated consequences) of water use restriction:

- *For Severity 2 and Severity 3, it was assumed that affected households face the water use restrictions applying under Temporary Use Bans (TUBs) (Level 2 ‘normal’ TUBs, and Level 3 ‘extended’ TUBs)*. TUBs prohibit the non-essential use of water for particular purposes by households (and also in some businesses such as sports grounds and landscaping see below). These restrictions include a ban on watering parks, lawns and gardens, washing of private vehicles, and cleaning the exterior of domestic buildings[6]. They thus include the older legal form of restrictions commonly known as “hosepipe bans”.

- *For our Severity 4, it was assumed that affected household face restrictions applying under Emergency Drought Orders (Level 4 restrictions)*. These restrictions would consist of the cessation of supply to all properties whether household or non-household, with consequent use of some mix of rota-cuts, standpipes, bowsers, and bottled water supplies. In some previous studies these have been referred to as “Level 4 restrictions”.

  Before Emergency Drought Order (EDO) restrictions were applied, the lesser step of Ordinary Drought Order demand-side restrictions would be implemented by PWS companies for PWS supplies to non-households, but this step is not expected to restrict households much more where a TUB restriction is already in place.

Non-household business and public sector water users, were separated into groups experiencing consequences arising from restrictions to supplies from PWS systems and from restrictions on private abstraction of water.

Restrictions on non-households’ use of PWS supplies, as shown in Table 7-1, are related to the two severity levels used for households. At Severity 2 TUBs were assumed to restrict the few relevant business and public activities, and the extreme Severity 4 Emergency Drought Order (EDO) restrictions apply to non-households as well as households. The third level, Severity 3, applied to all PWS connected non-households and relates to the introduction of demand-side Ordinary Drought Orders.

- *Severity 3: Non-household restrictions applying under demand-side Ordinary Drought Orders*. Ordinary drought orders apply to PWS supplies to all non-households and restrict much the same kind of usage as TUBs do for households and a subset of businesses, but as well they restrict non-household use of water for a defined set of “non-essential” purposes. This includes restricted usage of water for commercial car washing, cleaning services on non-domestic premises, and filling of non-public non-domestic swimming pools.[7]

The water supplies that non-household users obtain by their own abstractions are subject to a different restrictions regime that depends in part on the sector concerned. In a drought, a Hands Off Flow condition in the user’s water abstraction licence will act to limit the allowable abstraction when river flows fall below a specified point. The Environment Agency (EA) and Natural Resources Wales (NRW) can also apply water law provisions (known as Section 57) to restrict abstraction of water for spray irrigation[8], and can apply Ordinary Drought Orders to limit any abstraction.[9] Notionally there could also be a linked set of consequences for rain-fed agriculture, although in reality the consequences of drought for rain-fed crops will be dependent on hydrologically effective rainfall, which depends on seasonal timing as well as total precipitation. The risk of impacts on rain fed agriculture from PWS drought measures was therefore considered to be limited.

Drought effects on environmental goods and services, were considered in a similar way to rain fed agriculture – i.e. whilst some links between the droughts that affect PWS and the droughts that affect

[6] Water Use (Temporary Bans) Order 2010.
[7] Drought Direction 2011.
[8] EA (2012) “*Section 57 spray irrigation restrictions - Working together to make water last longer*”.
[9] Water Resources Act 1991, Section 74(1)(c).

environmental goods and services might be expected, causal links between PWS restrictions and environmental goods and services are likely to be limited.

The following sub-sections provide a series of monetised and non-monetised indicators to reflect the economic and social consequences of drought events. These are summarised in Table 7-2. It should be noted that they reflect the "total consequence of the drought event" − and its implications for aggregated costs or monetary values. They vary according to the duration of application of each restriction severity step and the numbers or sizes of affected entities in the impacted group (numbers of affected households, amount of affected non-household economic activity as measured by sectoral and regional gross value added (GVA), number of affected water bodies).

Table 7-2 Indicators of drought consequences by affected group

	Raw indicators (by severity level, per area)	Monetised evaluation	Non-monetised assessment
PWS companies	Population or properties affected. Duration of restrictions.	Communication campaign cost. Emergency measures to maintain supply (tankers, bottled water supplies).	Reputational damage.
PWS customers			
Households	Number of households affected. Duration of restrictions.	Welfare loss, based on willingness-to-pay to avoid restrictions.	
Business and public sector	Affected activity extent measured as GVA by sector. Duration of restrictions.	Economic loss, based on proportion of GVA lost, cross-checked by willingness-to-pay to avoid restrictions.	
Wider public service effects	*Acute hospitals in area.* *Schools in area.*	*GVA losses include loss to public sector.*	*Count of acute hospitals affected.*
Non-PWS abstractors	Affected activity extent measured as GVA by sector. Duration of drought or restriction.	Economic loss, based on proportion of GVA lost.	
Environment	Occurrence of HOF levels (at or below), and duration. *Area of affected water bodies.*		*(Surface area affected)* (days at HOF level). *(Count of SSSIs heavily dependent on water affected).*
Wider societal	*Density of affected urban conurbations, and duration.*	*Knock-on economic effects based on Input-Output tables.*	*Number of days urban centers with population / greater than 150,000 face restrictions.*

Source: NERA

Note: The indicators and assessments expressed in italics within Table 7-2 were considered for potential inclusion and could be used in future studies, but it was not possible or necessary to include them within the cost/benefit analyses carried out for this study given its scope and strategic nature.

7.2. Valuing household and wider societal effects

Estimating household welfare losses from restrictions to water service is not straightforward. Households cannot act on their preferences for different degrees of water service reliability by switching between suppliers offering different packages of quality and price.[10] They cannot choose to pay a different price for a higher or lower level of water service reliability, an act which would reveal the value they place on having a higher or lower risk of restrictions, assuming they are well informed. In the absence of this market or "revealed preference" information about service values, a technique widely adopted at water price reviews − including the most recent "PR14" review – to elicit customer valuations for different levels of service is "stated preference" studies.

Stated preference (SP) studies measure the "willingness to pay" (WtP) of consumers for changes in service levels. Typically, in surveys customers are asked to make a series of choices between service packages with different service level attributes and different bill levels. The answers can be used to infer willingness to pay for specific changes to service levels.

The review of a wide range of stated preference studies that cover water use restrictions to some degree shows that on average households are willing to pay relatively little to avoid temporary use bans (similar to what were previously known as hosepipe bans) which do not affect in-home uses. Households' willingness to pay to avoid more extreme restrictions (i.e. rota cuts or supply via standpipes only) is very much higher, as would be expected.

On the basis of the evidence reviewed it was possible to generate a function to represent household welfare effects for different restrictions' severities, which could be scaled to different regions and different points in time. In view of the range of evidence we provide a central figure as well as a low and high sensitivity for each value figure. Table 7-3 presents the household valuation figures for Severity 2 and Severity 3 combined, and for Severity 4 restriction levels. The evidence reviewed confirms that avoiding the consequences of "Severity 4" restrictions is much more highly valued than avoiding "Severity 3" – by a factor of 80 in our central estimate.

Table 7-3 Value of avoiding household water restrictions

(£ / HH / yr per avoided expected day of interruption/ year)	S2 – S3 – Temporary Use Bans	S4 – Emergency Drought Orders
Low	£0.25	£40
Central	£1.00	£80
High	£2.50	£160

S2-S3 - Temporary Use Bans: these are comparable to previously called Hosepipe Bans.

S4 - Emergency Drought Orders: these are the most severe type of restrictions on household water use and imply the use of standpipes and/or rota cuts.

Source: NERA review of stated preference studies.

A full description of the sources reviewed and the methodology employed when comparing results across studies is provided in Appendix F.

7.2.1. Public health

In the event of a severe drought, there may also be concerns for public health, particularly for vulnerable customers, such as the elderly, children, infants and those with pre-existing illnesses.[11] A lack of clean water and sanitation can also increase the risk of contagion for infectious diseases. Furthermore, water shortages have been documented to cause panic, despair, feeling of exposure, distress and helplessness among

[10] NERA (2007) "*The Line in the Sand – the shifting boundary between markets and regulation in network industries*", p.485.
[11] Health Protection Agency and Drinking Water Inspectorate (2012) "*Health impacts from extreme events water shortages*".

affected populations. This may be exacerbated in the elderly, persons with disabilities, parents with small children, those without money or cars who could not get to water provision.

Notwithstanding that PWS companies and the authorities would be expected to make strenuous efforts to protect vulnerable water users and guard against public health effects in droughts, these are serious potential impacts.

The Health Protection Agency and Drinking Water Inspectorate (2012) study notes that *"[d]espite the number of published reports and reflective reviews following extreme events, these do not contain rigorous scientific evidence on the health outcomes of these same episodes*".[12] No quantified estimates of the consequences of drought on public health were found within the papers that were reviewed for this study.

In the absence of any studies that provide a scalable metric or valuation, these public health impacts were only considered on a qualitative basis, where other monetised considerations did not provide a clear cost/benefit case for different types of future planning. This may be an area for future studies, to fully understand the potential water quality and health implications of altered network flows, reduced pressure, and the risks associated with importing water across different resource areas.

7.2.2. Civil unrest and political implications

A third additional set of possible effects is that severe water restrictions, especially in densely populated conurbations, could result in civil unrest and have knock-on political impacts. It is understood from previous severe events, such as the Mythe floods, that a high degree of social solidarity has often been exhibited. However, there have also been examples of civil unrest in the UK in recent years, and severe water restrictions in major cities could have important knock-on effects of this sort.

There may also be political implications of long and/or widespread drought events. In Australia, for example, severe drought and climate change prompted many of Australia's major cities to construct large-scale desalination plants on a rushed-basis to provide a rainfall-independent source of drinking water. In many cities, this decision became a political issue. The then CEO of the Australian Water Association, Tom Mollenkopf, mentioned in an interview with Bloomberg that "*unless you can get bipartisan political support it can always degenerate into a political bunfight*". He added that, in the state of Victoria, *"[i]t was used in the last state election as a weapon by the new government to attack the former government*".[13]

No UK studies were identified that have looked at the effect of drought on the potential for unrest. It is possible that the UK government may have undertaken work along these lines, but if so at the time of writing such studies were not accessible to us. Similarly, we have not found any evidence which attempts to provide an indicator of, or place a value on, political consequences.

In the absence of robust, quantified and scalable supporting evidence from existing studies, it may be possible to report one indicator from the drought modelling, referred to as a "Societal knock-on indicator". This is defined as number of urban conurbations of more than 150,000 inhabitants that face a severe water use restriction of more than a week.[14, 15] The overall number of people affected is an important metric for measuring the size of welfare impacts (and is used as a scaling factor in our valuation for household effects), but does not capture potential conflict and large-scale protests that are more likely to take place in large, dense urban areas. However, the granularity of the water resources modelling that was used meant that such an indicator was not available or necessary to use in the cost/benefit analyses.

[12] HPA and DWI (March 2012) "*Health impacts from extreme events water shortages*", p.5.
[13] Bloomberg BNA (2013) "*Drought Prompts Australia to Turn to Desalination Despite Cost*".
[14] We propose a 150,000 population cut-off, as this is the population of Gloucester. We understand that management of the Mythe floods in 2007 affected Gloucester and did not result in any major unrest.
[15] As described in AECOM (2016) - Annex C, p.15, Defra defines a Part 2 incident as "*a major water or sewage incident of a size that is greater than the response capability of the water company even with any mutual aid and the planning and response required is likely to involve a number of agencies*". This definition applies to a situation where more than 200,000 people lose access to piped water for a week.

7.3. Valuing non-household and PWS-company effects

There are several potential approaches to measuring the importance of a reliable supply of water to non-household PWS users and private abstractors. It was considered that the most tractable approach to forming estimates of losses for all non-household sectors, and to tailoring these to the sub-regions of England and Wales and to the future years considered in this study (2040 and 2065), was to model the loss of economic worth as measured by lost gross value added (GVA) as a result of water shortages and restrictions. These were formed into a GVA loss function from estimates made in previous studies. The evidence base is very limited, one reason for this being that serious restrictions have not been applied for many years. Values within this function were therefore checked against evidence from stated preference willingness to pay studies to provide reassurance that the results of each approach are broadly comparable.[16]

The GVA statistics encompass all sectors of the economy,[17] including rain-fed agriculture and public sector institutions. Rain-fed agriculture is not affected by either PWS or non-PWS water use restrictions but is affected directly by drought so we include estimates of the corresponding GVA loss. No reduction in GVA for the water supply and sewerage sector was included because the economic costs directly borne in the first instance by PWS companies in drought are estimated separately, as described below.

Table 7-4 sets out the central proportional GVA loss figures for each sector and drought severity level. The severity level S2 is shown for illustrative purposes only, but is not included in the model due to its limited economic impact.[18] The percentage losses in Table 7-4 apply to the daily-GVA of each affected sector within an affected region for each day that the water use restrictions are in place.

Unlike household impacts, ranges of GVA effects could not readily be interpreted from the literature, but it is noted that the likely range is of the order of +/-50% around the central estimate. For example, for sectors that have a 50% reduction in production in the central case, they would have a 25% reduction in the low sensitivity and a 75% reduction in GVA in the high sensitivity.

Table 7-4 GVA losses per sector by drought severity level (central estimate for proportion of daily-GVA lost per day of water-use restriction)

Industry			PWS			Non-PWS		
			S2	S3	S4	S2	S3	S4
Agriculture, forestry and fishing	Rain-fed agriculture	Cereals	N/A	N/A	N/A	0%	15%	30%
		Potatoes rain-fed	N/A	N/A	N/A	0%	15%	30%
		Other rain-fed crops	N/A	N/A	N/A	0%	15%	30%
	Irrigated crops	Potatoes irrigated	N/A	N/A	N/A	53%	59%	59%
		Strawberries	0%	100%	100%	0%	100%	100%
		Other irrigated crops	N/A	N/A	N/A	24%	37%	37%
	Livestock	Livestock	0%	0%	25%	0%	10%	25%
Wholesale and retail trade; repair of motor vehicles	Retail sale of flowers, plants, seeds, fertilizers, etc.		0%	30%	30%	15%	30%	30%
	Other wholesale and retail		0%	0%	25%	0%	0%	25%
Administrative and support services	Landscape service activities		25%	100%	100%	0%	0%	25%
	Other administrative and support services		0%	0%	25%	0%	0%	25%
Arts, entertainment and recreation	Sports activities		50%	50%	50%	50%	50%	50%
	Other arts and entertainment		0%	0%	25%	0%	0%	25%
Manufacturing	Food products, beverages and tobacco		1%	10%	75%	1%	10%	75%
	Textiles, wearing apparel and leather products		1%	10%	75%	1%	10%	75%
	Wood and paper products and printing		0%	0%	50%	0%	0%	50%
	Coke and refined petroleum products		0%	0%	50%	0%	0%	50%
	Chemicals and chemical products		1%	10%	75%	1%	10%	75%

[16] A full description of the relative merits of the GVA approach and non-household WTP surveys is provided in Appendix F2.
[17] We use SIC07 industry classification, in correspondence with ONS GVA datasets.
[18] A discussion on the modelling assumptions behind these numbers can be found in Appendix F2.

Industry		PWS			Non-PWS		
		S2	S3	S4	S2	S3	S4
	Basic pharmaceutical products and preparations	1%	10%	75%	1%	10%	75%
	Rubber and plastic products	0%	0%	50%	0%	0%	50%
	Basic metals and metal products	1%	10%	75%	1%	10%	75%
	Computer, electronic and optical products	0%	0%	50%	0%	0%	50%
	Electrical equipment	0%	0%	50%	0%	0%	50%
	Machinery and equipment not elsewhere classified	0%	0%	50%	0%	0%	50%
	Transport equipment	0%	0%	50%	0%	0%	50%
	Other manufacturing and repair	0%	0%	50%	0%	0%	50%
Mining and quarrying		0%	0%	50%	0%	0%	50%
Electricity, gas, steam and air-conditioning supply		N/A	N/A	N/A	0%	0%	50%
Water supply; sewerage *		N/A	N/A	N/A	N/A	N/A	N/A
Construction		0%	0%	50%	0%	0%	50%
Transportation and storage		0%	0%	50%	0%	0%	50%
Accommodation and food service activities		0%	0%	50%	0%	0%	50%
Information and communication		0%	0%	25%	0%	0%	25%
Financial and insurance activities		0%	0%	25%	0%	0%	25%
Real estate activities		0%	0%	25%	0%	0%	25%
Professional, scientific and technical activities		0%	0%	25%	0%	0%	25%
Public administration and defence; compulsory social security		0%	0%	50%	0%	0%	50%
Education		0%	0%	25%	0%	0%	25%
Human health and social work activities		1%	10%	75%	1%	10%	75%
Other service activities		0%	0%	25%	0%	0%	25%
Activities of households		0%	0%	50%	0%	0%	50%

Source: NERA analysis drawing on Vivid (2013) and NERA (2006).

*** We model PWS company costs separately and therefore do not model any reduction in GVA.

7.3.1. PWS companies

PWS companies face direct consequences from drought events: incurring costs to minimise the impacts on their customers, and costs to manage the process of engagement with their customers and the authorities. These costs are different from the cost of investing in options that reduce the risk that drought affects supply capability, although in including them care is needed not to double count them with the portfolio costs considered elsewhere in this investigation. For example, if some planned capital expenditure is brought forward to mitigate an actual drought event, this timing change should only be considered as a direct cost of the drought to the extent that the acceleration increases the NPV of the capital investment programme.

PWS company drought costs were categorised into two broad categories:

- **Direct financial expenditures** borne by the PWS company during the management of the drought, such as the costs of running communication campaigns, extra staff dedicated to manage the drought restrictions, extra investment to enhance short-term capacity, or the costs of providing alternative supplies to the customers.

  The PWS companies are also subject to licence conditions and could incur financial penalties if there are interruptions to supply, of the order of £10 per day for household customers and £50 per day for business customers.[19] However, these are not considered to be significant as (i) in aggregate such fines represent a transfer not a loss (the company is fined but customer receipts offset this, so the impact is distributional), and (ii) it is unclear how the penalties would operate in the case of extreme drought

[19] Company Licence Condition Q.

events – they would not be applied under circumstances where it would be unreasonable to expect the interruption to have been avoided.

- **Other effects**. These would include income loss through reduced volumes sold, fines, compensation, fall in shareholder value and reputational costs.

The estimated costs for the PWS companies of a drought of Severity 2 – implying mainly the implementation of TUBs and the application for drought permits – roughly coincide across companies. For Severity 3 – the application of ordinary drought orders – the estimated cost range is wider. No data were available for Level 4 restrictions (under a Severity 4 drought), so a conservative assumption equal to double the Severity 3 impact was assumed. In all cases, the costs for PWS companies are incurred when the drought arrives at each corresponding severity level, scaled by the number of customers served by the company. This means that they are generally *significantly* lower than the consequences associated with household WTP or non-household GVA impacts, so it was not necessary to include them in the cost/benefit analysis described in Section 8.4.

Table 7-5 shows the range of costs proposed for direct PWS company costs, for each level of severity. There may be additional consequences beyond those described above, such as reputational damage to the water companies involved, or a fall in shareholder value. For example, although Yorkshire Water narrowly avoided imposing EDO restrictions on customers during the 1995-6 drought, it suffered major reputational damage and was fined more than £40m by Ofwat.[20]

Table 7-5 Direct company costs (£ / property / occurrence)

	Severity 2	Severity 3	Severity 4
Central	2.5	25	50
Low	*0*	*10*	*20*
High	*5*	*45*	*90*

Source: NERA

7.3.2. Public sector users

Drought events resulting in PWS restrictions have the potential to affect public sector activities and services – from general functioning of public offices, to operation of acute services such as the running of hospitals or fire-fighting. These services are heavily dependent not only on the availability of supplies but in many cases also on the quality of water. Fire-fighting in urban settings requires access to the pressurised mains, which could be cut off by district metering zones in the case of PWS rota-cut restrictions, while hospitals require a high quality (and large volume) of water in order to treat patients.

The impact of restrictions on public sector output is in part reflected in the GVA approach summarised in Table 7-4, which includes lines for "*Public administration and defence; compulsory social security", "Education*", and "*Human health and social work activities*". However, this does not capture any externalities arising from welfare losses associated with loss of provision of non-market public services, such as cleanliness of the urban environment and maintenance of public parks and gardens. It is also considered that the GVA approach is not appropriate to capture the potential consequences of severe restrictions on public services such as schools and hospitals. These issues were not specifically captured in the cost/benefit analyses described in 8.5, and therefore represent an additional risk beyond the consequences presented within that Section. Some further analysis of such drought risk could be carried out, for example, by mapping the postcode locations of acute NHS trusts[21] to latitude and longitude locations, and then linking these to the areas modelled in this investigation.

[20] AECOM (2016) "*The Socio-Economic and Environmental Impacts of Drought*", p.19.
[21] Available from http://www.nhs.uk/servicedirectories/pages/acutetrustlisting.aspx

7.4. Valuing environmental consequences

Drought events may have direct and indirect effects on the environment. These effects may operate on terrestrial ecosystems, for example through impacts on soil or hydrological ecosystems as the water level in rivers and lakes are reduced.[22]

Not all of the environmental consequences will be substantially impacted by the investment portfolios modelled in this investigation. That is, there may be some (potentially substantial) environmental impacts of drought that have very little scope to be reduced by the investment and demand management options modelled and which therefore have a common valuation across all of the modelled investment portfolios.

There is very limited evidence to inform a monetised valuation of the potential environmental consequences of drought, and none that can be robustly and readily scaled to the drought events modelled in this project (in terms of severity, geographical extent and duration), or to future snapshots in 2040 and 2065.

Given the sparsity of the valuation evidence, and the insensitivity of much of the environmental drought effects to the PWS supply portfolios examined in the wider study, monetary valuation of environmental consequences of drought events was not included in the analysis.

The qualitative and quantitative indicators that were used for identifying environmental consequences of drought were therefore entirely based on:

- Occurrence and duration of Hands-Off-Flow levels.
- Occurrence and duration of supply side Drought Orders and Permits. These could be expected to have a detrimental impact on surface water bodies beyond that caused by abstraction down to the HoF level.

As noted previously, it could be possible to enhance this type of analysis by considering, for example, the area of water bodies in zones affected by restrictions, multiplied by duration, or by counting affected specific sites where environmental consequences could be most important (e.g. SSSIs). However this was not considered to be relevant to a project of this strategic scope and was not feasible within the timescales allowed.

7.5. Scaling economic valuations to regions and years and multiplier effects

7.5.1. Scaling to specific regions

Having defined the raw consequences and methodology for socioeconomic appraisal, it was necessary to scale these consequences for droughts affecting different regions and at different points in time.[23]

Scaling welfare valuations across studies is discussed in the EA's *Benefits Assessment Guidance* (BAG) and subsequent notes. Particular aspects of the context and sample for stated preference survey evidence would ideally be accounted for. For example: income level/elasticity,[24] baseline level of service, scale of change examined.[25] However, accounting for such factors would require a much more extensive body of research than currently exists and conducting new primary research was outside of the scope of this project. The default estimate of WTP per household was therefore applied on a nationwide basis.

For non-household water users and abstractors, the economic losses resulting from drought restrictions was estimated. The GVA levels that were used were taken primarily from the ONS NUTS2 dataset, which

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[22] A selection of environmental consequences of drought from the literature is discussed in Appendix F3.
[23] A full description of our approach to scaling the consequences is described in Appendix F5.
[24] Different regions may have different income levels and different income elasticity (cultural or behavioural patterns may vary from region to region) with respect to water consumption.
[25] See EA (2003) "*The Benefits Assessment Guidance for PR04: Review of Non-use Values for Water Quality and Water Resources and Values for Bathing Water Improvements. Report of an Expert Workshop in Peterborough, May 2003*".

includes 40 regions. These were mapped to the regions modelled, so the GVA losses were therefore scaled to represent the sector composition in each region.

In all cases, the costs per day of restriction were scaled to the duration of the event on a linear basis – i.e. each additional day of restriction had the same associated cost as the first. This is acknowledged to be a simple assumption, but at the moment there is insufficient available evidence to form a robust non-linear relationship.

7.5.2. Forecasting effects and values for future years

With regards to non-household effects, the growth in GVA by region to 2040 and 2065 was analysed based on government five-year forecasts[26], assuming the composition of the economy (relative shares of each industry within overall GVA) does not change over time. This is a strong assumption, but given the nature of uncertainties in this project and the lack of a strong evidence base to make alternative assumptions, it was considered to be reasonable for the purposes of this study, and an area for future research.

Similarly, aspects such as the resilience of different sectors to drought events may evolve over time, as the technology mix changes, or businesses may invest in their own resilience to mitigate the future impact of usage restrictions. However, the project team was not aware of any studies that have investigated how business activity resilience to extreme drought events may change in the future.

With regards to households, there are good reasons to believe that customer preferences will not be the same in 2065 as they are today. For example, customer expectations with respect to levels of service may be expected to rise and tolerance for interruptions to service to fall. Behavioural change may also affect the way that today's services are valued in the future. However, for the purposes of this investigation it was assumed that the ranges of willingness to pay we have formed above do not change over time.

7.5.3. Scaling for economic multiplier effects

The GVA loss in one sector may lead to losses in other sectors. The Leontief Inverse matrix provided by ONS (2015) gauges the effect of changes in final demand on output, sector by sector. The effects are of three sorts:

- **Direct effects**: This type of effect is defined as "*the immediate effect caused directly by the change in final demand*". Final demand for products other than water itself is unlikely to change very substantially in the event of a drought. Therefore, for the purpose of this study, direct effects should rather be defined as being caused *directly* by a change in the supply of an input, i.e. water. These are the costs that have been discussed in the sections above.

- **Indirect effects**: This is "*the subsequent effect caused by the consequent changes in intermediate demand*". For the purposes of our study, we identify two sub-types of effect within this category:

    - *Forward linkages*: Industries further down the value chain that depend on obtaining output from directly drought-affected sectors (as an input for their own production) may be affected; and

    - *Backward linkages*: Directly affected entities may reduce their demand for input products from further up the value chain.

- **Induced effects**: This is "*the effect attributable to the ensuing change in compensation of employees and other incomes, which may cause further spending and hence further changes in final demand*". Indeed, if production is affected by drought so owners lose profits and dividends, and employees see a reduction in their wages, their reduced incomes may lower aggregate demands as they no longer spend elsewhere in the economy – with consequent economy-wide effects.

To estimate the knock-on effects of the modelled GVA reductions by sector that are set out in Table 7-4 above, the starting point was to consider the ONS GVA multipliers by sector, which estimate the effect on total annual GVA implied by a one unit change in the annual GVA of a specific sector, all else being equal. For example, the GVA multiplier for agriculture is 1.8; that implies that for a change resulting in a 1.0 percent

[26] Regional GVA growth projections available from UKCES (March 2014) "*Working Futures 2012-2022*", Evidence Report 83

reduction in agricultural GVA, the impact on total economy-wide GVA would involve a further reduction in total GVA equal to 0.8 percent of the sector reduction by the time the ripple effects (forward, backward, and induced) had all been allowed for.

It was considered that the estimation of total indirect economic costs using national-level GVA multipliers was only relevant to incorporate as a potential sensitivity analysis because of the many possibilities for substituting economic inputs and outputs in reaction to a drought shock. In light of previous studies for compound effects (e.g. the 1.22 quoted in Brozovic et al. (2007),[27] and the 1.3 – 2.0 range derived by Crawford Brown et al. (2013)),[28] a multiplier range of 1.2 to 2.0 could be used. However, the cost/benefit ratios that were calculated from the consequence modelling described in Section 8.5 were high enough to remove the need to investigate or include such multiplier effects.

[27] Brozovic, Sunding, Zilberman (August 2007) "*Estimating business and residential water supply interruption losses from catastrophic events*", published in Water Resources Research, Vol 43.
[28] Crawford-Brown, Syddall, Guan, Hall, Li, Jenkins and Beaven (2013) "*Vulnerability of London's Economy to Climate Change: Sensitivity to Production Loss*", published in Journal of Environmental Protection, Vol 4.

8. What do we need to do to avoid or mitigate the problem?

This section sets out what options and portfolios are available to avoid or mitigate the problems identified, including the analysis of the resilience of potential portfolios of options and the key outputs from the modelling work.

8.1. What are the options?

There are three means of mitigating a potential deficit between the supply and demand of water in a given supply area. The first is to reduce demand, through a combination of leakage and water efficiency (household and non-household) measures. The second is to increase water available for use in the supply area through a local increase in deployable output. The third is to import water from an area of surplus into the area of deficit. Some combination of these may also be used.

Historically, there has been a general trend in reducing demand in spite of increases in population, as a result of considerable reductions in non-household (industrial) use, and a general reduction in per capita consumption (PCC) through more efficient appliances and increased metering of properties as well as reductions in leakage.

Deployable output has been increased in places through the construction of new raw water assets, and water available for use has been distributed more evenly by expanding water resource zones and improving connectivity between them, enabling areas in surplus to support those at risk of deficit.

All of these approaches remain available to address the supply/demand problem, but in order to keep the price of water as low as possible, the water resource management process has always sought to take advantage of lowest cost solutions before implementing more expensive options. Much of the "low hanging fruit" of supply/demand planning has therefore already been adopted; indeed, the majority of companies have already invested beyond the economic level of leakage in order to meet customer challenges. That is not to say that further demand management is not feasible, but that the cost of remaining demand management and supply options is now relatively high and increases non-linearly with the size of deficits, as described further below.

Given the high degree of spatial variability in deficits, large-scale transfers of water between companies and regions may potentially offer some of the best value options remaining to address the supply/demand problem, though they face significant technical, environmental and commercial challenges.

8.1.1. Demand management strategies

Demand management forms a key part of all water companies' water resource management plans. Companies have invested considerably in reducing demand over many years, and in undertaking research into options for further savings. In 2012, Waterwise summarised much of this research and built upon it to define options for ambitious efficiency savings on the scale of a small town (Waterwise, *Evidence Base for Large-scale Water Efficiency*, 2012). All companies are required to determine an economic level of leakage, based on the marginal value of water saved through reducing leakage and most companies have already invested beyond this economic level in order to meet the expectations of customers and regulators.

The strategic nature of this project meant that the potential for ambitious demand management to mitigate future imbalances in the supply/demand balance needed to be evaluated at a high, but plausible, level. The starting point for this was a review of options presented at WRMP14 across all water companies, the Waterwise evidence base paper for large-scale demand management and an UKWIR research paper on the potential for large-scale leakage published in 2011 (UKWIR WR25). The difficulty with using WRMP14 demand options as a basis for the national study was that they are highly company-specific, vary enormously in size and cost and are therefore impossible to compare consistently at a regional or national level. They are also too small in total to form the basis for the more highly ambitious demand management strategies.

This study uses an alternative top-down approach of reviewing PCC and leakage per property for every WRZ, both in 2016 and by 2040, and using a statistical approach to fully quantify the demand management proposed at WRMP14 (both volume and cost) and identify where cost effective savings beyond WRMP14 may be achievable. Details of this method are provided in Appendix D. The assessment uses regression analysis to identify potential costs and savings of demand management options for each WRZ, on the premise that cost and feasibility of given levels of reduction will depend on both the starting point and the rate of change required to achieve the different levels of demand management for the four strategies developed in this project. The key assumptions and outputs of this analysis are detailed below.

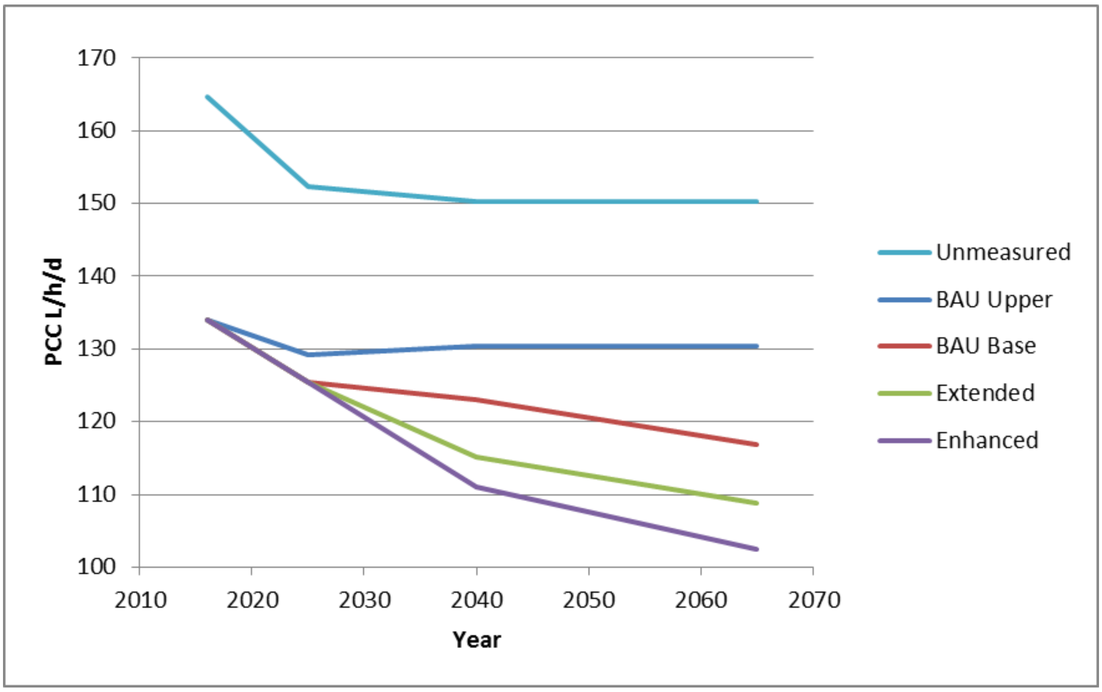
8.1.1.1. Water efficiency

Potential water efficiency option portfolios were defined for each of the following demand management strategies.

- **Business as Usual (BAU) Upper**: this is the strategy outcome that could be expected if measures to reduce PCC are largely ineffective or challenging to implement.
- **Business as Usual (BAU) Base**: this reflects a strategy where ongoing, significant investment continues to ensure that the trend in PCC planned at WRMP14 through water efficiency schemes and more sustainable new homes is continued into the future (although it should be noted that this relates to the 'underlying' trend – initial high meter penetration achieves a higher rate in the early years of the period).
- **Extended**: this reflects a strategy of more ambitious savings that are potentially cost effective but culturally challenging. For example, the savings might require retrofitting and/or smart metering 65% of existing properties to achieve 40 l/property/day saving; or 50% new builds achieving 105 l/h/d and retrofitting/smart metering 50% of existing homes; and requires significant behavioural change.
- **Enhanced**: this strategy contains the most ambitious savings that could theoretically be delivered over the time period, but would come at considerable expense. For example, this might involve all new homes achieving at least 105 l/h/d, 50% with greywater reuse (80 l/h/d); retrofitting/smart metering 30% of existing properties; major behavioural campaigns; and mains replacements. Such options are economically feasible but given the combination of cost and impact would require further policy, legislation and regulation change to support implementation where the cost/benefit supports such interventions.

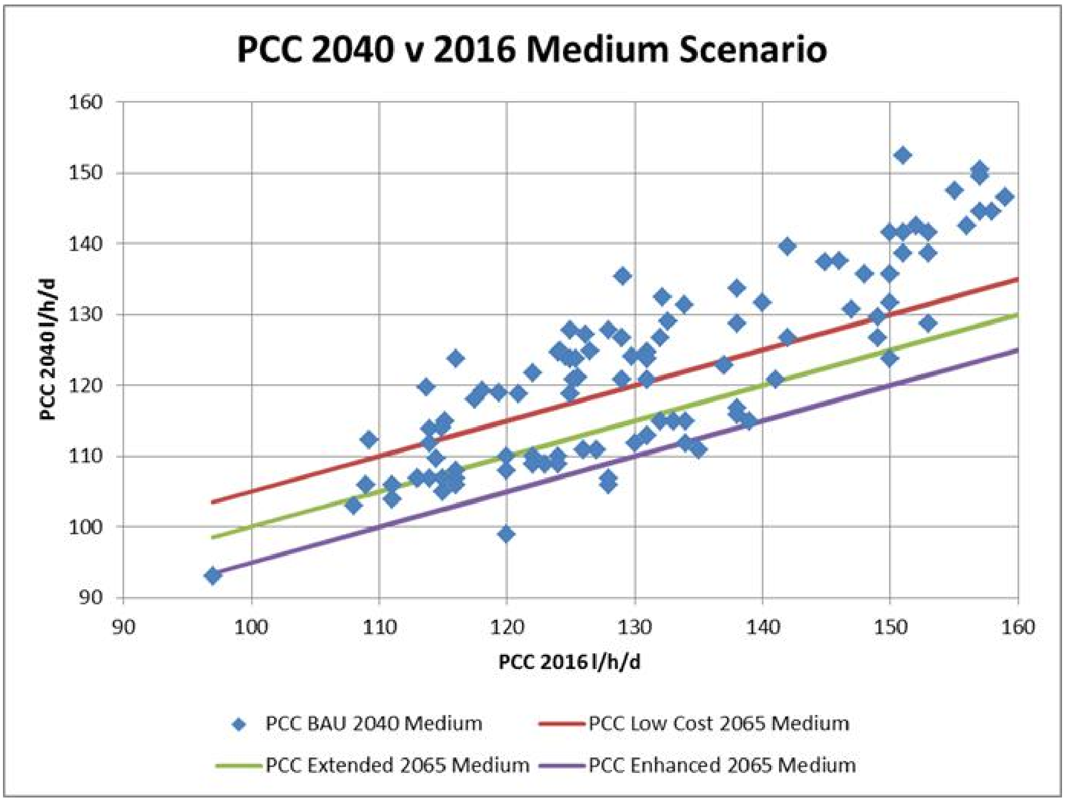
Based on the above definitions, 'target' PCCs were defined for 2040 and 2065 under the extended and enhanced strategies. The 'global' PCC targets designed for each of the four strategies between 2016 and 2065 are illustrated in Figure 8-1 below.

Figure 8-1 PCC changes between 2016 and 2065 for the BAU Base, BAU Upper, Extended and Enhanced strategies



These ‘global’ targets were used to calculate the target savings required within each strategy at water resource zone level. An example of this is illustrated in Figure 8-2 – the current baseline of each WRZ is determined to identify the extent to which further lower cost options may be available to reduce demand (i.e. to achieve the target through ‘Business as Usual’), and progressively more expensive options under the ‘extended’ and ‘enhanced’ scenarios. By setting the PCC targets on a global level, the most cost effective combinations of initiatives could be identified, focussing measures on those WRZs where there was a greater (and hence lower cost) potential for doing so.

Figure 8-2 Example plot of water efficiency savings across all WRZs for a 2040 medium growth scenario



The exact method for developing the costs of each strategy are detailed in Appendix D, but in summary these were calculated by defining the cost to move from one demand saving strategy to the next, and then applying this to the WRZs as required. Costs for moving a WRZ from BAU to Extended demand saving levels were based on the Waterwise evidence base for achieving large-scale water efficiency. Enhanced costs were determined by calculating costs associated with achieving highly ambitious PCC levels. Details of the cost differential associated with each strategy at different levels of demand growth are provided in Appendix D.

This analysis was applied to existing properties only – new properties were assumed to be constructed according to different policies associated with building regulations. The cost implications of each strategy were therefore determined by estimating the number of existing properties requiring retrofitting assuming that newly built properties could achieve a pre-defined PCC level. This analysis was carried out at the regional level.

8.1.1.2. Leakage reduction options

For leakage reduction options, the WRMP property counts were used as a starting point and some growth was allowed under all scenarios at a fixed percentage of population growth. This percentage was higher for “BAU Upper” than “BAU Base”. Overall the process of evaluation was similar to that described for water efficiency – WRZs were sorted according to start point, and costs for strategies were developed depending on how many WRZs had to move into 'extended' or 'enhanced' strategies for leakage reduction. For extended and enhanced strategies, savings were calculated using the UKWIR study (2011) into large-scale leakage as a basis, which provided cost curves associated with achieving a particular leakage reduction for a "type WRZ". Exact details of the methodology used are provided in Appendix D.

8.1.1.3. Metering options

For metering, correction factors were applied to the WRMP-based unmeasured population in each year to calculate different levels of metering under each strategy and scenario. The total change in the supply/demand balance as a result of metering combined with efficiency savings was then calculated. The table below shows how overall metered property percentages varied according to each demand management strategy.

Table 8-1 Percentage metered properties in England and Wales

Scenario	Year		
	2016	2040	2065
Medium growth			
BAU Base	46%	78%	83%
Extended	46%	83%	90%
Enhanced	46%	87%	94%
Upper growth			
BAU Base	46%	81%	86%
Extended	46%	85%	91%
Enhanced	46%	88%	95%

Costs were applied on a unit cost basis, with increasing costs of installation for the higher percentages associated with the extended and enhanced strategies (associated with the increased difficulties caused by internal installations, shared supplies, etc.). Details of the costing methods used are provided in Appendix D.

On a qualitative basis it was noted that, as well as representing good value for money over the long term, metering would also provide highly valuable data on water use and identification of any unknown leakage.

8.1.1.4. Overall results for demand management

The modelled total water savings (Ml/d) at 2040 and 2065 for medium and upper growth are presented in the following two figures.

Figure 8-3 Demand management strategy savings for England & Wales (Ml/d) at 2040 under medium and upper growth scenarios

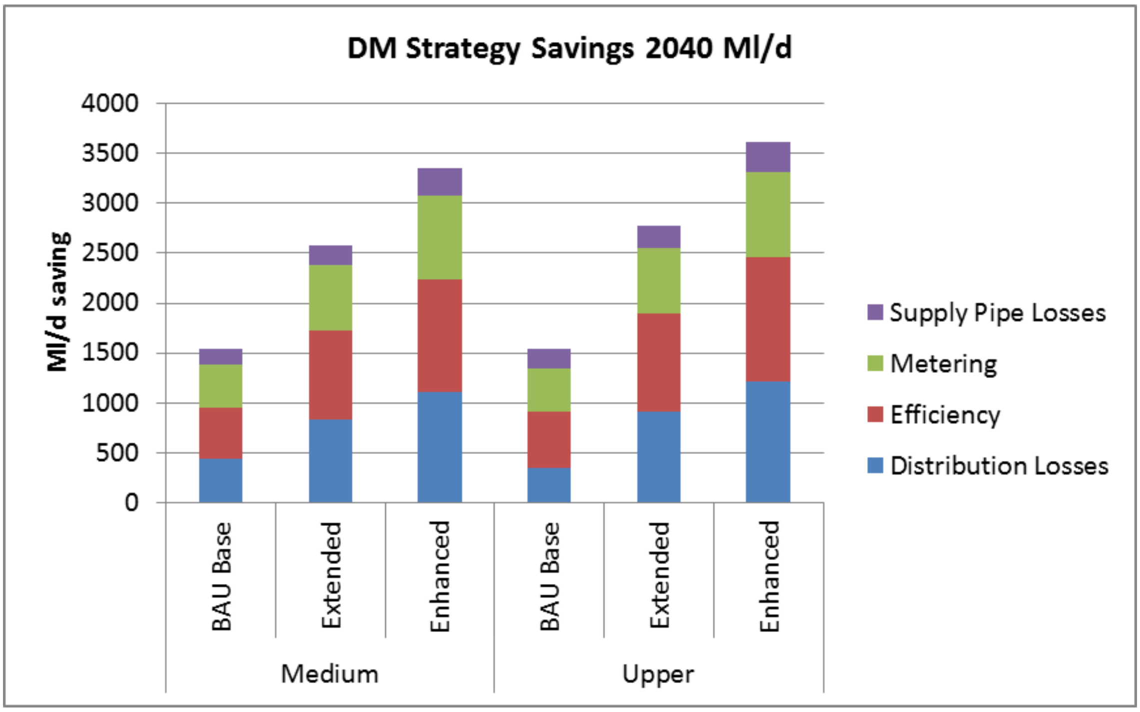
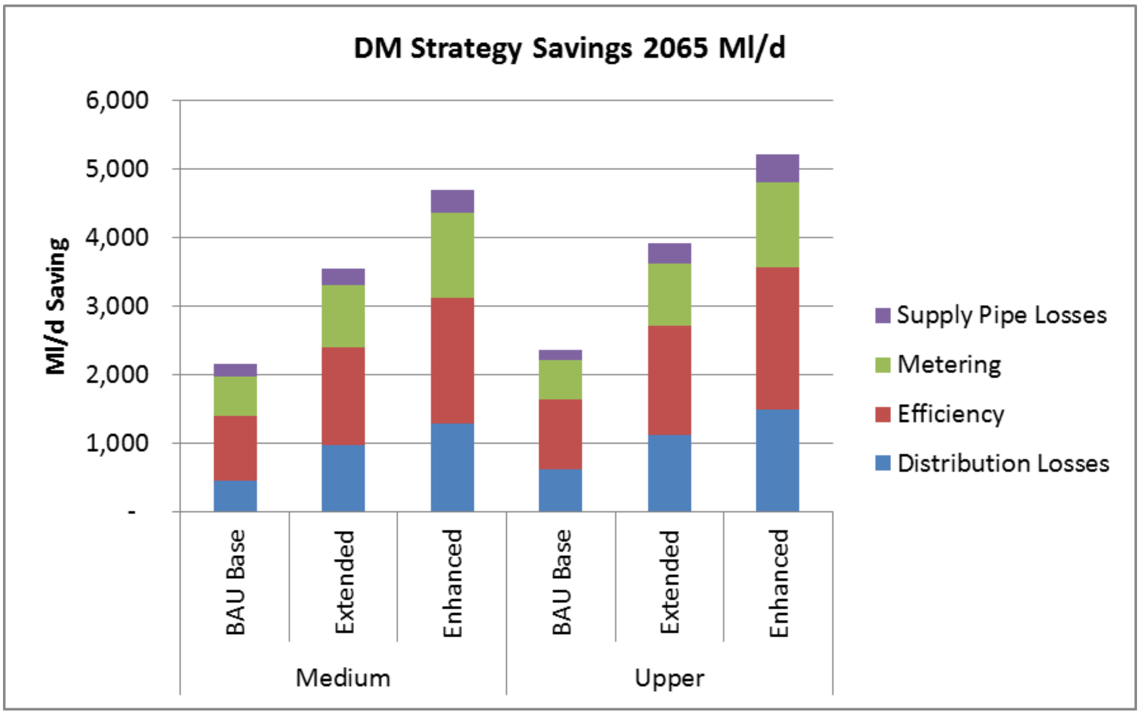


Figure 8-4 Demand management strategy savings for England & Wales (Ml/d) at 2065 under medium and upper growth scenarios



The associated NPV (in £M) at 2040 and 2065 are presented in Figure 8-5 and Figure 8-6 below. These demonstrate the large increase in costs associated with an enhanced demand management strategy in comparison to the BAU and extended strategies, across both efficiency and leakage. This shows that the relationship between demand management cost and savings is highly non-linear, which is driven by the high costs of retrofitting for some measures (e.g. greywater re-use), leakage (e.g. mains renewals) and metering (incorporating difficult property installations). It is acknowledged that there may be some, more cost effective, elements that could be taken out of this strategy and added to the 'extended' strategy if a policy decision is made to pursue high levels of demand management on a national level, but in reality the scope of such cost effective enhanced methods is likely to be limited.

Figure 8-5 Demand management strategy NPV costs (£M) at 2040 under medium and upper growth scenarios

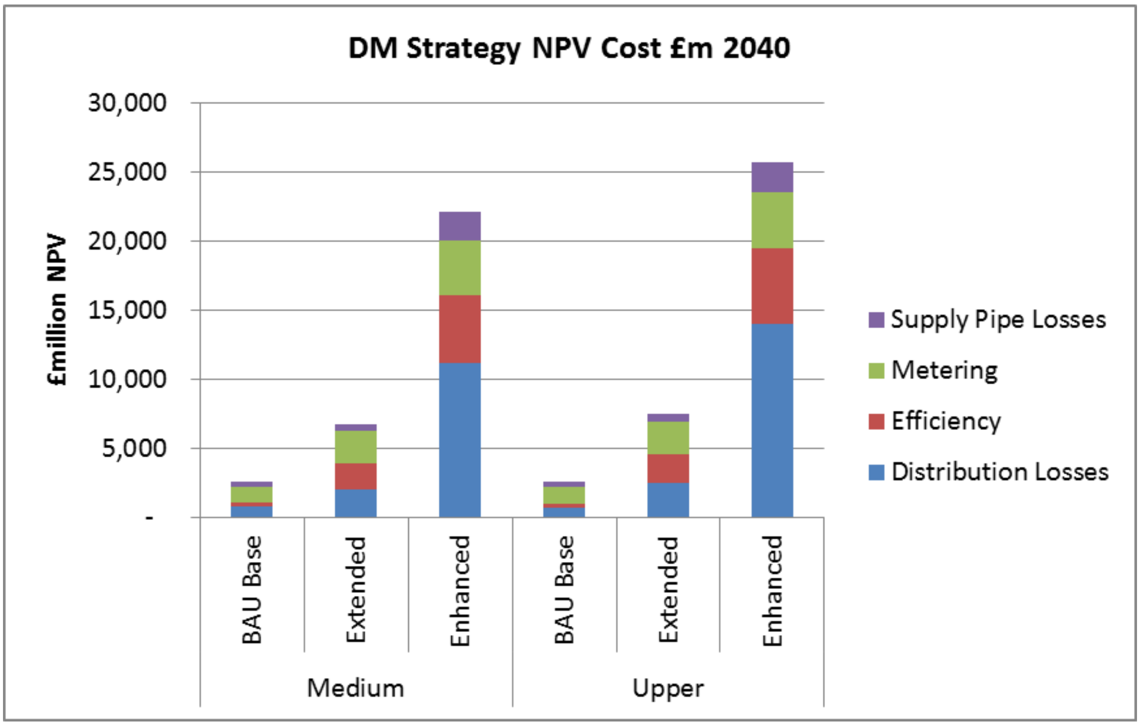
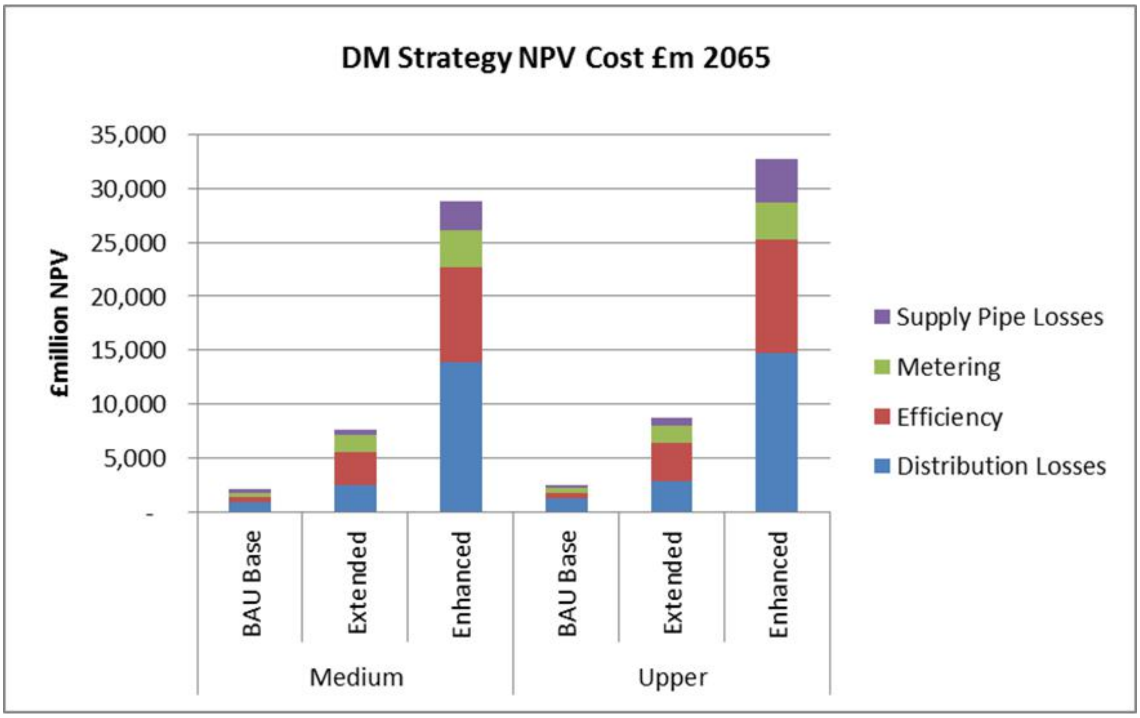


Figure 8-6 Demand management strategy NPV costs (£M) at 2065 under medium and upper growth scenarios



8.1.2. Supply side options

The Water Resource Management Plans (2014) identify 588 supply options to increase “Water Available for Use” (WAFU), through new deployable output and transferring water from one zone to another. Given the extensive time and expertise devoted by companies in compiling these options, WRMP14 was taken as the starting point for supply option development across England and Wales.

All WRMP options were screened for exclusivity and whether they were already “committed” for development during AMP 6 and 7, after which 424 independent feasible supply options remained. Excluding multiple versions of the same scheme, a total of 5800 Ml/d of new supply options were identified and costed across all water companies at WRMP14, with a total NPV of £27 billion (assuming all options would be required).

Final preferred WRMPs specified 1000 Ml/d of supply-side options (including bulk transfers) at a cost (NPC) of £2.9 billion from 2015 to 2040. 542 Ml/d of this was identified as being committed for development prior to 2025 (AMP 6 & 7) at a NPC of £850 million.

As the primary aim of this study is to look at plausible supply/demand scenarios to 2065, it was necessary to look beyond WRMP14 for other potential options. WRZs not at risk in 2040 may have a number of significant supply options not presented at WRMP14 that could be necessary to fill deficits due to growth/climate change by 2065, to support abstraction licence changes not foreseen in WRMP 14, or to provide key support to bulk regional transfers by 2040. Under the worst case scenarios described in section 6.5, many supply zones may need to instigate ambitious supply options, not presented in WRMP14. Potential resources outside of the WRMPs were therefore identified through:

- Questionnaires issued to all companies and follow-up telephone calls where appropriate.
- An extensive review of national and regional studies into water resource options over the last 40 years, many of which have not yet been implemented due to a lack of need or various delivery risks. Deployable outputs and costs for all of these were compiled and updated as far as possible to allow the derivation of NPV values over an 80 year time period from 2020 to 2100, such that they could be compared on an equal basis with WRMP14 options.

A high-level screening process was then carried out to exclude options that relied on the same source water, duplicate options, and those that are likely to remain unfeasible on technical or cost grounds.

The full set of potentially feasible strategic options were defined at a high level and require considerable refinement of costs, yield and engineering scope before definition as feasible. Various issues and risks are associated with each, as specified in the appendix.

The Average Incremental Social Cost (AISC) was used as the basis for option selection to develop the 13 ‘example’ Portfolios, and hence develop the overall cost curves for all supply side inputs to all 144 potential future Portfolios. WRMP14 costs were taken as a starting point for this process, but refinement of costs was necessary to account for differences in utilisation between companies and options. Details of this costing and normalisation process are provided in Appendix D.

In terms of utilisation factors, this project used the analysis from Southern Water’s WRMP14 which examined how frequently new schemes would be operated in the face of developing droughts. This indicated that a ratio of approximately 10:1 of utilisation versus ‘in hindsight’ need was appropriate (e.g. a scheme that is required to satisfy the supply/demand balance under a 1 in 100 year drought or worse would typically be ‘switched on’ and used operationally approximately once every 10 years).

8.1.3. Regional transfers of water

The supply/demand analysis described previously demonstrated considerable surplus volumes of water in parts of England and Wales under many scenarios, at least to 2040. For the first time this project was able to provide an indication of the scale and distribution of this surplus at a national level under nationally consistent scenarios of future uncertainty in population growth, climate change, changes to abstraction licences and taking account of the likely spatially coherent impacts of drought on deployable output.

Supply and demand options also differ in cost noticeably between regions. This project has assessed where implementing low cost supply/demand options nationally opens up areas of surplus, which could then be utilised to transfer water to areas where the marginal cost of water is significantly higher.

Although surplus volumes of water are theoretically available, transferring water is expensive due to the mass and distances involved. There are also a number of potential barriers to transfer associated with drinking water quality, environmental water quality and other environmental risks. At WRMP14, only 11 raw water transfers > 10 Ml/d in volume were presented as feasible options, totalling around 345 Ml/d. This lack of large-scale options was primarily associated with the technical and commercial difficulties in transferring large volumes of raw water across the country.

A greater volume and number of *potable* bulk transfer options were included at WRMP14, but these were mainly intra-company, and largely focused on the south east of England.

Given the size of the deficits and the high cost of potential supply options, this report concentrated on establishing the *theoretical* possibilities and costs associated with transfers as part of the Portfolios development stage of the options appraisal. The practical limitations and potential resilience issues associated with transfers were evaluated separately through:

1. The resilience testing described in Section 8.3; and

2. Discussions with the DWI, the EA and water companies held during the data gathering stage of the options definition, relating to specific concerns over water quality, environmental risks, institutional arrangements and practical infrastructure constraints.

The outcome of the discussions associated with item 2 above are entirely qualitative in their nature at this stage, so have been translated into the notes within Table 8-2 below, and the sub-Regional conclusions detailed within Section 10.2.

In order to calculate the potential cost of transfers, a simple uniform incremental cost of capex and opex was assumed for all transfers based on Ml/d capacity. This is a major simplification, but given the infinite number of potential transfers in multiple directions, was considered a pragmatic decision for this strategic level study. It can also be justified to a certain extent in that larger transfers benefit from economies of scale but typically cover greater distances. Smaller transfers involve shorter lengths of pipeline and reduced pumping head, but have a higher proportion of fixed costs. Details of the costing process are provided in Appendix D, but in summary the capital costs for each transfer were fixed initially at £700k / Ml/d; operational costs varied between £60k and £300k NPV per Ml/d, depending on utilisation (i.e. depending on the drought scenario). These assumptions equate to an AISC of approximately 25 p/m3 for the transfer element alone. Whilst the costs were highly uncertain, this methodology provided a consistent, easily understandable means of identifying transfers. The cost of the associated raw water resource that provides support to the transfer is often the key deciding factor in relation to its cost effectiveness, and these were fully associated with the relevant supply scheme, as described in Section 8.1.2 above.

As well as cost, pragmatic but ambitious upper limits were assigned to transfer volumes for major regional transfers, as shown in Table 8-2. Note that these are based on potential transfer capacity of any carrying water bodies, or required transfer volumes under the worst case scenarios and are generally well in excess of the volumes that existing institutional arrangements and infrastructure on the receiving system could cope with. **However, in developing and testing the resilience of the ‘example’ Portfolios it was important to understand the theoretical limits that could be achieved if futures occurred that were significantly more challenging that the current ‘standard’ planning assumptions.** This allowed the relevant constraints to be tested through the resilience modelling, and the practical considerations were then accounted for on when drawing conclusions about the nature of potential national strategies.

Table 8-2 Assumed upper limits and notes on transfer volumes for major regional transfers

Transfer	Maximum Ml/d	Notes
Severn to Thames	675	Beyond the level of transfers previously considered by Thames and may be impractical for a number of key reasons. Would require support from Welsh reservoir developments and/or some form of River Dee transfer to provide this volume of water.
Anglian to Affinity	300	Higher than currently feasible through the existing Affinity network, and likely to be limited by water quality constraints.
Thames to Affinity	550	Linkages do exist, but network upgrades would be needed to support this level of transfer.
Anglian to Thames	160	Method for transfer not currently clear – support to Essex & Suffolk and associated reduction in the Thames-Essex transfer could be one indirect method.
Wessex to Southern	225	Highly theoretical, but mentioned as a possibility in discussions. Likely to be significant practical and environmental constraints.
Central West import from Northwest or DCWW	720	As above – would require extensive development of Welsh reservoirs and/or a River Dee transfer to achieve these volumes.

8.1.4. Abstraction reform and third party supplies

The current process of abstraction reform (Defra 2016) is intended to allow greater flexibility and hence capability for transferring water between licence holders where it is environmentally acceptable to do so. This was reflected within the options appraisal process through the analysis and promotion of transfers where it is potentially economically advantageous. It is entirely possible that the abstraction reform process will allow licence holders other than water companies to be able to trade water to companies for use in drought situations. This potential was not specifically explored for this study, other than by incorporating the third party options identified within the water company WRMPs, so there is the potential that abstraction reform could result in additional third party resources being identified to help address future supply needs. However, the need to ensure that such resources are available under the levels of drought severity described in this report are likely to limit this potential. The study is also 'neutral' about ownership, and water from the relevant resource systems could just as easily be supplied by non-water company suppliers as the current incumbents. It is therefore not considered likely that abstraction reform would change the general conclusions of the study.

In addition to the opportunities to use third party licences, the possibility of relying upon tankering of water during severe or extreme drought events might be considered. Such interventions have only been used on a relatively small scale before (e.g. during the 1995/96 drought event in Yorkshire), and are known to involve large logistical issues at that scale. Proposals have been put forward by third party suppliers involving overseas sources which are not subject to climatic conditions occurring in and affecting neighbouring companies in UK. These proposals indicate that there should be no insurmountable water quality implications, and additional infrastructure requirements should be comparable to that required for bulk transfers between incumbents. The option is relatively expensive compared with more local solutions, but it may be prudent for companies to keep this option open as an Insurance and Emergency facility.

8.2. Bringing the options together – portfolio solutions

As described in section 4, for the purposes of defining portfolios of options and estimating the costs of mitigation required, 36 future scenarios were developed across all water resource zones in England and Wales. These were then evaluated under 4 different demand management strategies (as described in section 8.1.1) resulting in a total of 144 potential Portfolios, each of which would require a different set of supply-side options to maintain the security of water supplies until 2065.

Of these 144 potential Portfolios, 13 were selected for resilience testing and the development of cost curves to support the costing of all the other Portfolios. The nature of these 13 'example' Portfolios was therefore important, but it should be noted that they only formed one part of the overall appraisal, and were not solely relied on when drawing conclusions. The selection of the future scenarios behind each of these 13 Portfolios was carried out by varying each of the key parameters methodically, whilst also ensuring a sufficient spread and range of portfolio deficits. The majority of them focused on the BAU base demand management strategy, as this provided the most varied information about potential costs and configurations of strategic supply side schemes.

Total net deficits for England and Wales across all 144 futures are shown below, with the 13 sampled scenarios for portfolios highlighted by red circles.

Figure 8-7 Total net deficits for England and Wales across all 144 futures and portfolio selection

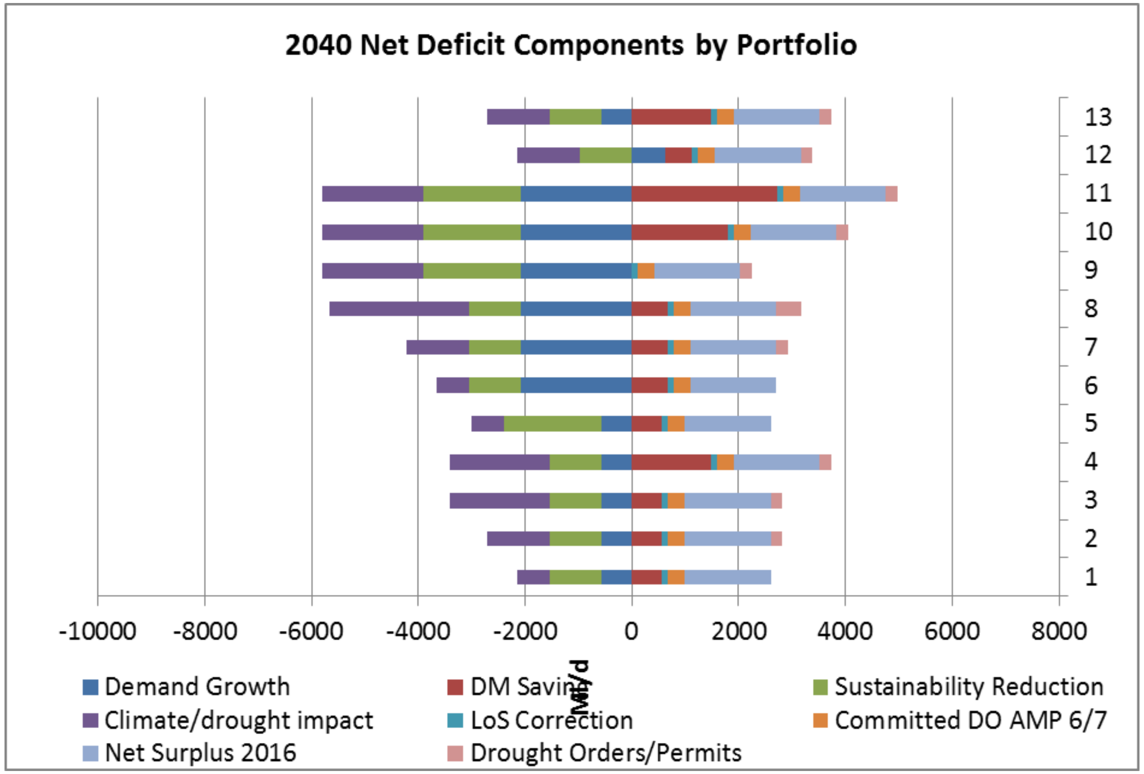
The parameter selection and regional breakdown of deficits associated with each of the 13 'example' Portfolios is shown in Table 8-3. The breakdown of components across the 13 future scenarios in 2040 and 2065, along with corresponding net deficits for England and Wales as a whole is then shown in Figure 8-8 and Figure 8-9. Regional deficits are considerably more variable than this, as discussed previously in section 6.5. This shows that the 13 'example' Portfolios provided a good range of deficits and balances of challenges, which was important when the resilience testing and cost curve derivation for the full 144 potential Portfolios was being carried out.

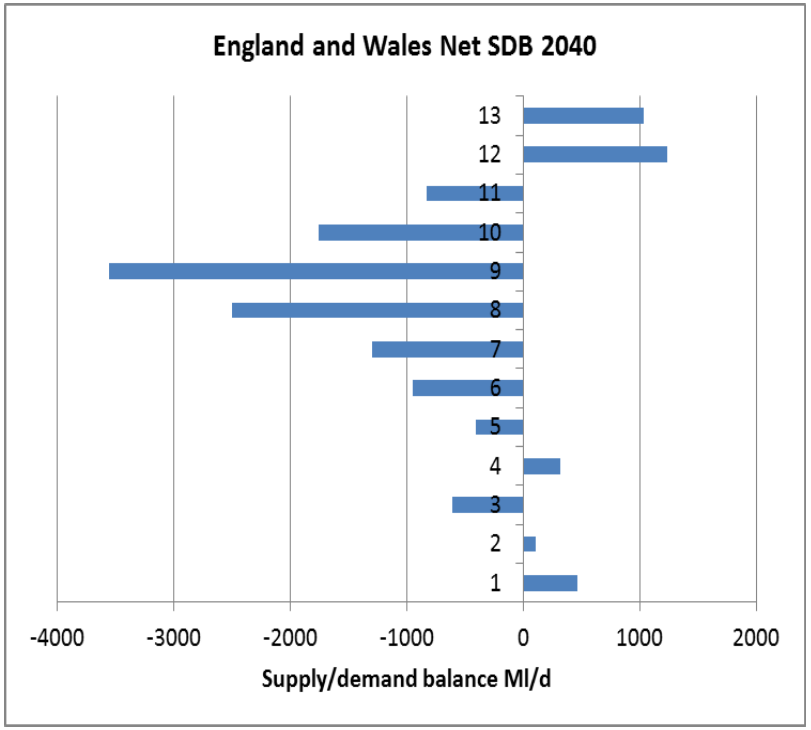
Table 8-3 Future scenarios used to provide the 13 'example portfolios – summary of makeup and initial regional deficits

Portfolio	1	2	3	4	5	6	7	8	9	10	11	12	13
SDB Scenario	1	2	5	5	7	13	14	18	23	23	23	26	2
Growth	Medium Growth	Medium	Medium	Medium	Medium	Upper Growth	Upper	Upper	Upper Growth	Upper	Upper	Lower	Medium
Climate/Drought	Baseline CC Historic Drought	Baseline CC Severe Drought	Extended CC Severe Drought	Extended CC Severe Drought	Baseline CC Historic Drought	Baseline CC Historic Drought	Baseline CC Severe Drought	Extended CC Extreme Drought	Extended CC Severe Drought	Extended CC Severe Drought	Extended CC Severe Drought	Baseline CC Severe Drought	Baseline CC Severe Drought
Sustainability	Baseline Abstraction Changes	Baseline	Baseline	Baseline	Extended	Baseline Abstraction Changes	Baseline	Baseline	Extended Abstraction Changes	Extended	Extended	Baseline	Baseline
Demand Mgt	BAU Base	BAU Base	BAU Base	Extended	BAU Base	BAU Base	BAU Base	BAU Base	BAU Upper	Extended	Enhanced	BAU Base	Extended
2040 Committed options only													
Central/West	41.4	-13.6	-324.7	-214.0	-153.0	-155.1	-210.1	-570.0	-806.8	-577.9	-459.1	141.1	97.1
DCWW	98.0	98.0	98.0	165.4	98.0	22.5	22.5	22.5	-8.8	103.3	148.7	159.3	165.4
Northumbrian	188.7	188.7	188.7	233.2	188.7	123.3	123.3	123.3	105.8	178.6	208.8	242.2	233.2
Northwest	216.2	173.2	133.9	244.6	216.2	56.3	13.3	-218.2	-109.2	119.4	229.8	302.4	283.9
South West Water	62.4	62.4	62.4	78.9	62.4	28.2	28.2	28.2	7.2	49.2	65.4	89.4	78.9
Southeast	-232.8	-577.7	-828.6	-380.5	-883.5	-912.3	-1257.2	-1833.3	-2490.3	-1625.9	-1288.3	-36.1	-129.6
Southwest	111.1	94.1	81.7	123.7	107.1	30.9	13.9	-8.5	-38.4	48.5	84.2	159.9	136.2
Yorkshire	-24.4	-127.4	-229.4	-148.4	-44.7	-141.0	-244.0	-496.0	-430.6	-265.8	-185.2	-33.2	-46.4
Grand Total	**460.5**	**-102.4**	**-818.1**	**103.0**	**-408.9**	**-947.1**	**-1510.0**	**-2952.0**	**-3771.1**	**-1970.6**	**-1195.8**	**1024.9**	**818.7**
2065 Committed options only													
Central/West	-98.9	-187.9	-659.7	-499.0	-293.3	-404.9	-493.9	-1013.5	-1366.4	-989.0	-792.9	38.0	-27.2
DCWW	71.2	71.2	71.2	162.0	71.2	-42.6	-42.6	-42.6	-110.5	58.3	127.4	158.1	162.0
Northumbrian	181.3	181.3	181.3	244.5	181.3	84.3	84.3	84.3	41.9	155.1	205.6	255.7	244.5
Northwest	148.2	87.8	27.8	180.1	148.2	-88.9	-149.3	-401.5	-385.3	-47.7	118.3	266.0	240.1
South West Water	57.2	57.2	57.2	81.3	57.2	7.2	7.2	7.2	-36.6	32.2	54.4	93.5	81.3
Southeast	-903.9	-1327.4	-1692.9	-1053.2	-1554.6	-1959.8	-2383.3	-3079.9	-4147.7	-2670.2	-2124.4	-534.9	-687.6
Southwest	82.2	56.7	37.1	94.0	78.2	-32.6	-58.1	-87.7	-160.3	-14.7	38.5	143.9	113.6
Yorkshire	-137.3	-305.3	-460.3	-343.3	-157.6	-310.9	-478.9	-783.9	-789.2	-525.7	-403.9	-174.6	-188.3
Grand Total	**-600.0**	**-1366.3**	**-2438.3**	**-1133.6**	**-1469.5**	**-2748.1**	**-3514.4**	**-5317.4**	**-6954.0**	**-4001.7**	**-2777.0**	**245.8**	**-61.6**

Note: drivers highlighted in gold represent future scenario elements that are 'worse' than the standard planning assumptions

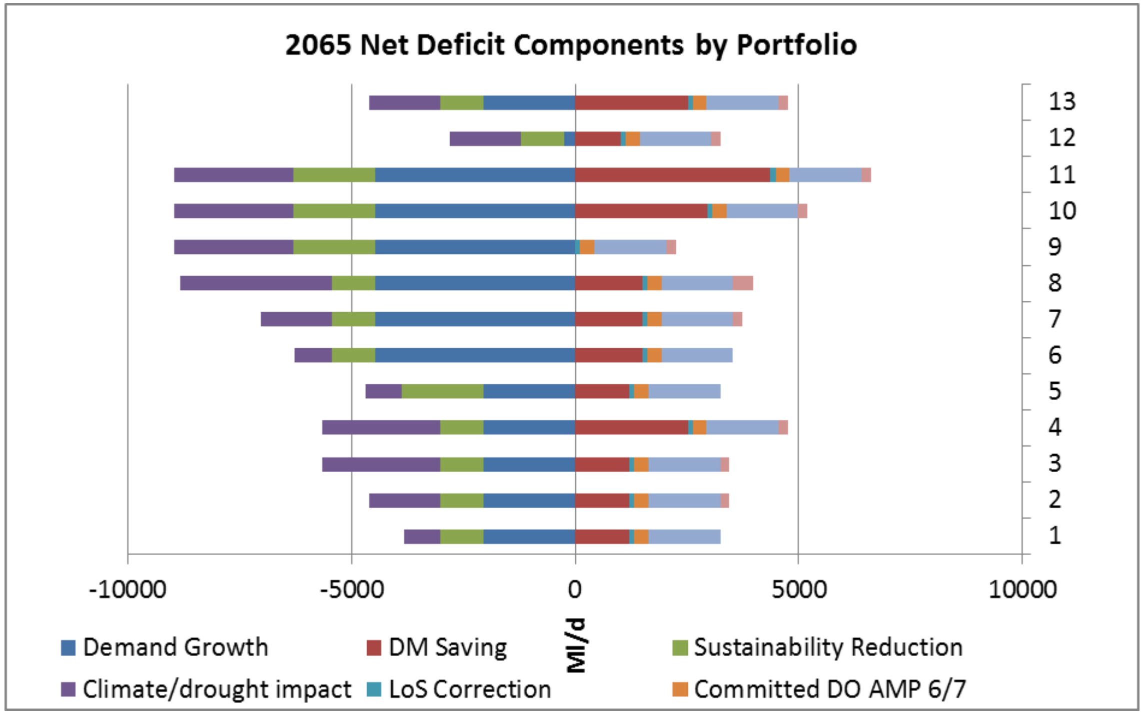
Figure 8-8 Breakdown of net deficits by component across the 13 'example' futures used for Portfolio analysis in 2040

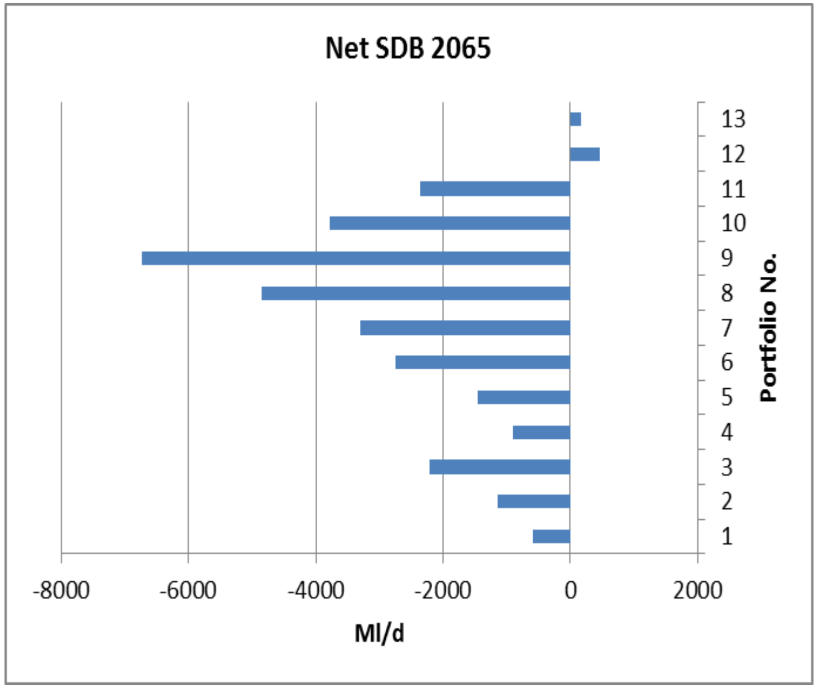




The chart on the left hand side shows the positive contributions to the overall supply/demand balance (bars>0) compared against the challenges (bars<0). The chart on the right hand side shows the net balance that results across the country as a whole as a result of these contributions and challenges.

Figure 8-9 Breakdown of net deficits by component across the 13 'example' futures used for Portfolio analysis in 2065





The chart on the left hand side shows the positive contributions to the overall supply/demand balance (bars>0) compared against the challenges (bars<0). The chart on the right hand side shows the net balance that results across the country as a whole as a result of these contributions and challenges.

The approach to populating portfolios of options for each of the 13 'example' scenarios was then carried out using a "ranked AISC approach", broadly as follows:

1. Start by specifying a likely AISC threshold. Recalculate the supply/demand balance for every supply area, filling with new resources up to this threshold. Aim for a net supply/demand balance of around 1000 Ml/d.

2. If an AISC of less than 25 p/m3 is sufficient to mitigate all deficits, then no transfers are required. Instead remove surplus resource in order of total NPV. Adjust the opex NPV in light of the utilisation assumption that is appropriate to the drought scenario under consideration.

3. For required AISC greater than 25 p/m3, specify bulk raw water transfers, intra-regionally initially and then inter-regions. Take account of geographical and hydrological constraints when specifying transfers. Adjust the opex NPV in light of the drought scenario.

4. Remove any remaining surplus resource in order of total NPV.

5. Ensure 2040 and 2065 portfolios are consistent, with the aim of minimising any stranded assets.

6. Produce total costs for each portfolio, broken into 2020 to 2040 and 2040 to 2065, including both demand management and supply side options. Add in costs for treatment and any additional distribution where necessary.

Examples of this portfolio generation process are provided in Figure 8-12 and Figure 8-13.

8.2.1. Typical strategic option portfolios

In specifying portfolios of options, a number of assumptions were made about the cost and feasibility for different supply options:

- WRMP14 costs are comparable for small options at a national level. No cost normalisation was carried out for options smaller than 20 Ml/d.

- All new effluent reuse options require reverse osmosis treatment prior to discharging final effluent into reservoirs or rivers. Only tidal discharge volumes are used as a basis for identifying reuse options.

- Large scale transfers of water are technically and environmentally feasible at a total cost of between 25 and 50 p/m3.

- Utilisation of options, as described under Section 8.1.2, is based on a rate of operation of new schemes of one year every 10 under historic drought scenarios, one year every 20 under severe drought scenarios and one year every 50 for extreme drought scenarios. This is not the frequency of these types of drought, but the number of times options are assumed to be called upon to prepare for a potential drought of the respective magnitude.

- National cost curves are appropriate for costing strategic desalination and effluent reuse.

The complete deployable output of each portfolio, broken down by option type, is shown in the figures below. Here, strategic options are those that are greater than 30 Ml/d in size.

There are clear trends in the order of option types, reflecting cost:

- Groundwater development contributes to most scenarios, with smaller options adding up to a notable volume in total.

- Supported strategic surface water transfers (i.e. transfer supported by the use of existing storage) and effluent reuse tend to make the largest contribution to smaller deficit scenarios.

- New storage reservoirs are important for a number of 2065 scenarios, and for some 2040 portfolios.
- The combination of strategic surface water and storage options assumes that technical and institutional complications associated with storing and transferring water within existing systems can be made to work without significant additional cost or impractical operational arrangements. If this is not the case, this would drive a significantly greater need for new reservoir development.
- Desalination is limited to high deficit scenarios only.

Figure 8-10 New water resources by portfolio 2040

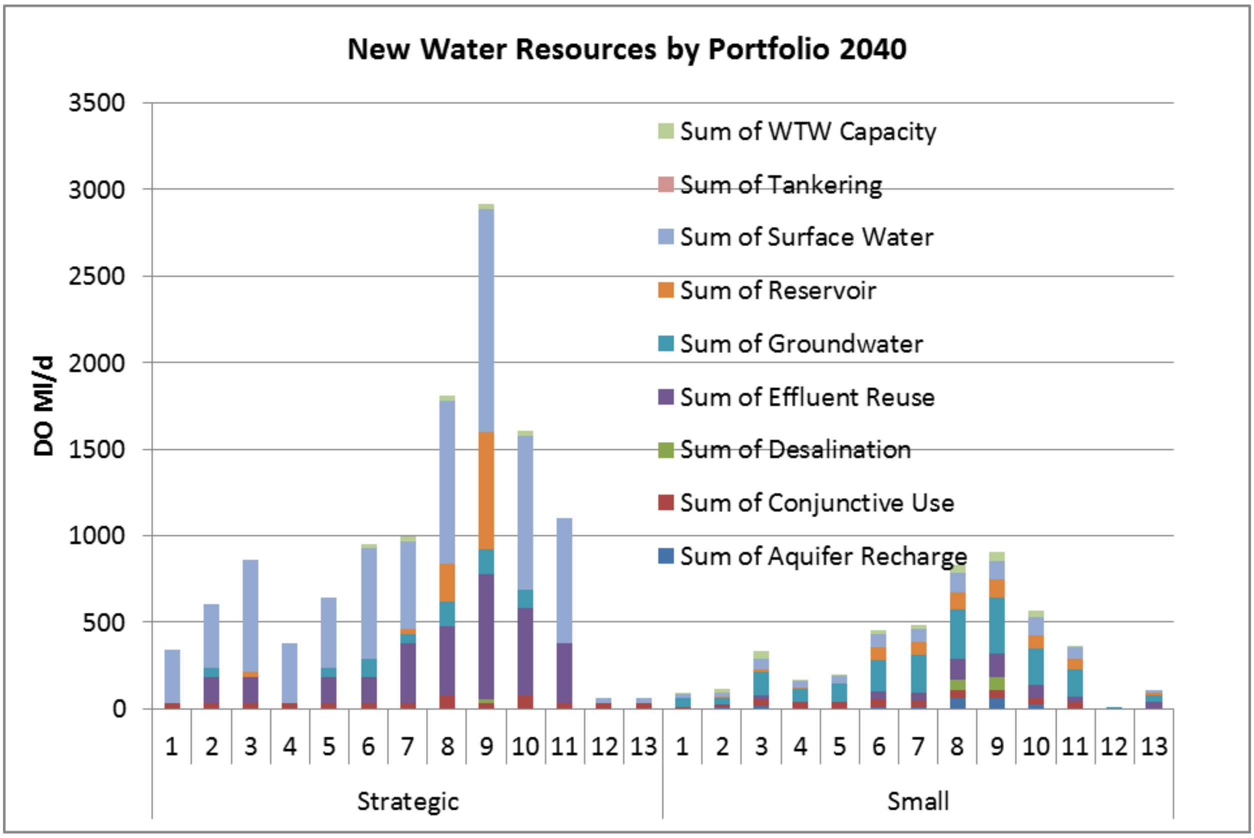


Figure 8-11 New water resources by portfolio 2065

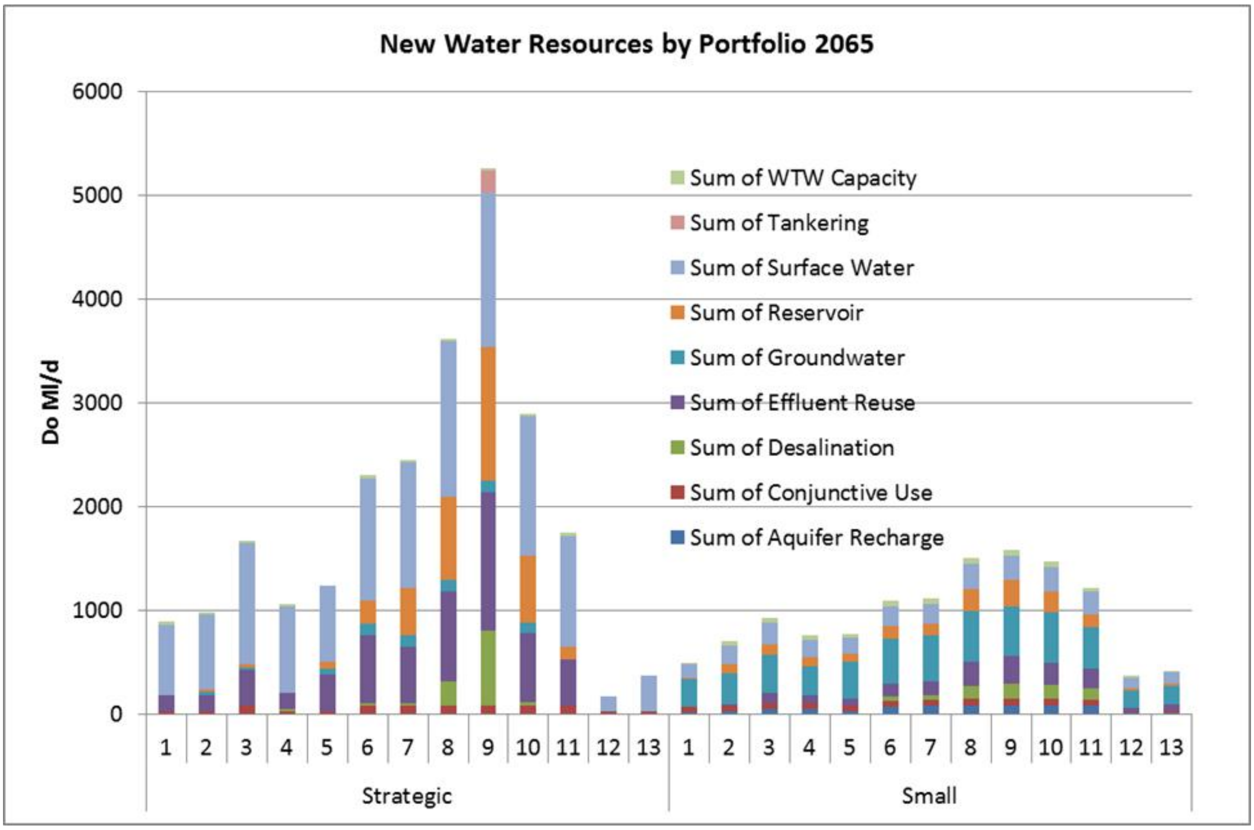


Figure 8-12 Bringing the options together - example: portfolio 1 (2040)

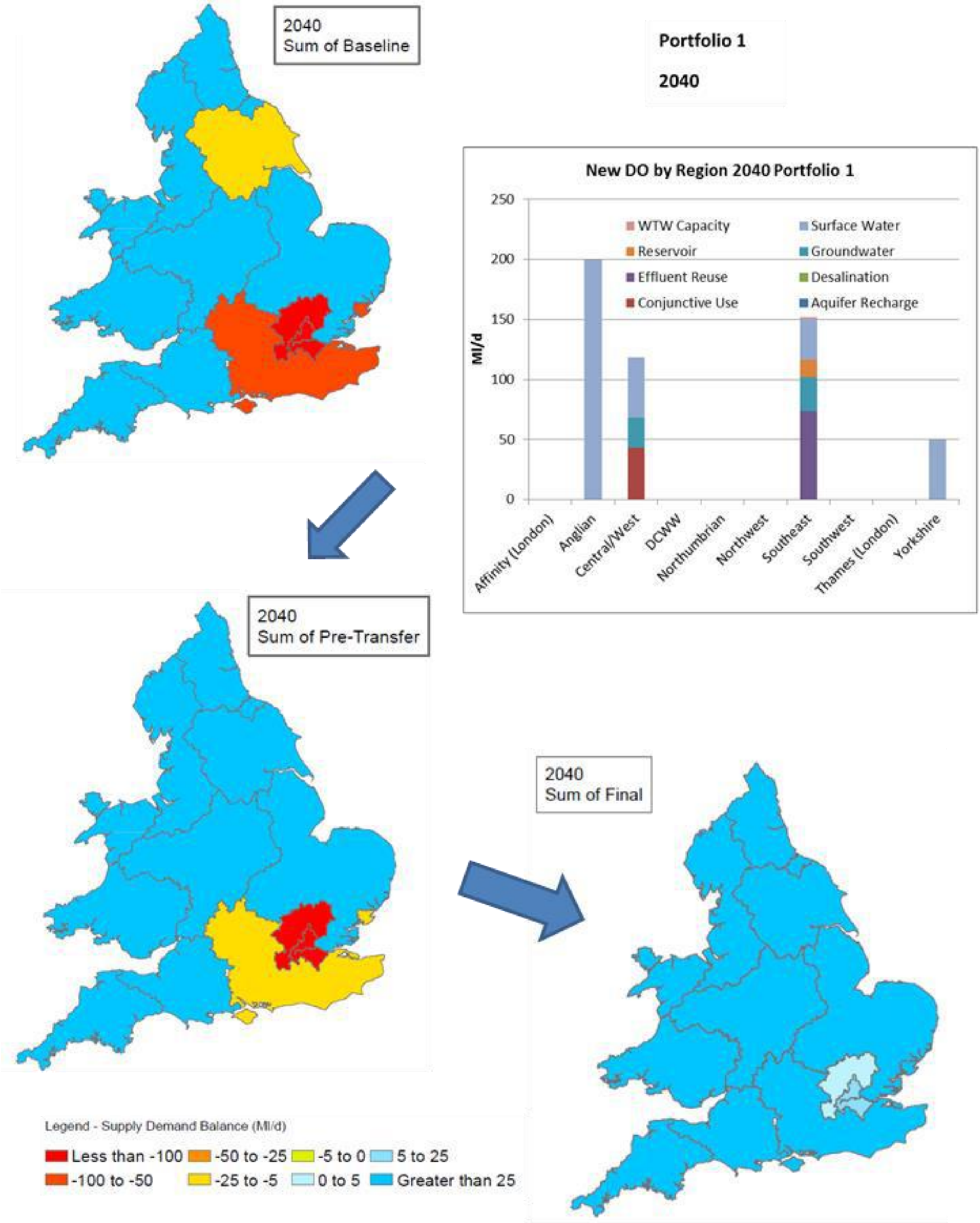


Figure 8-13 Bringing the options together - example: portfolio 1 (2065)

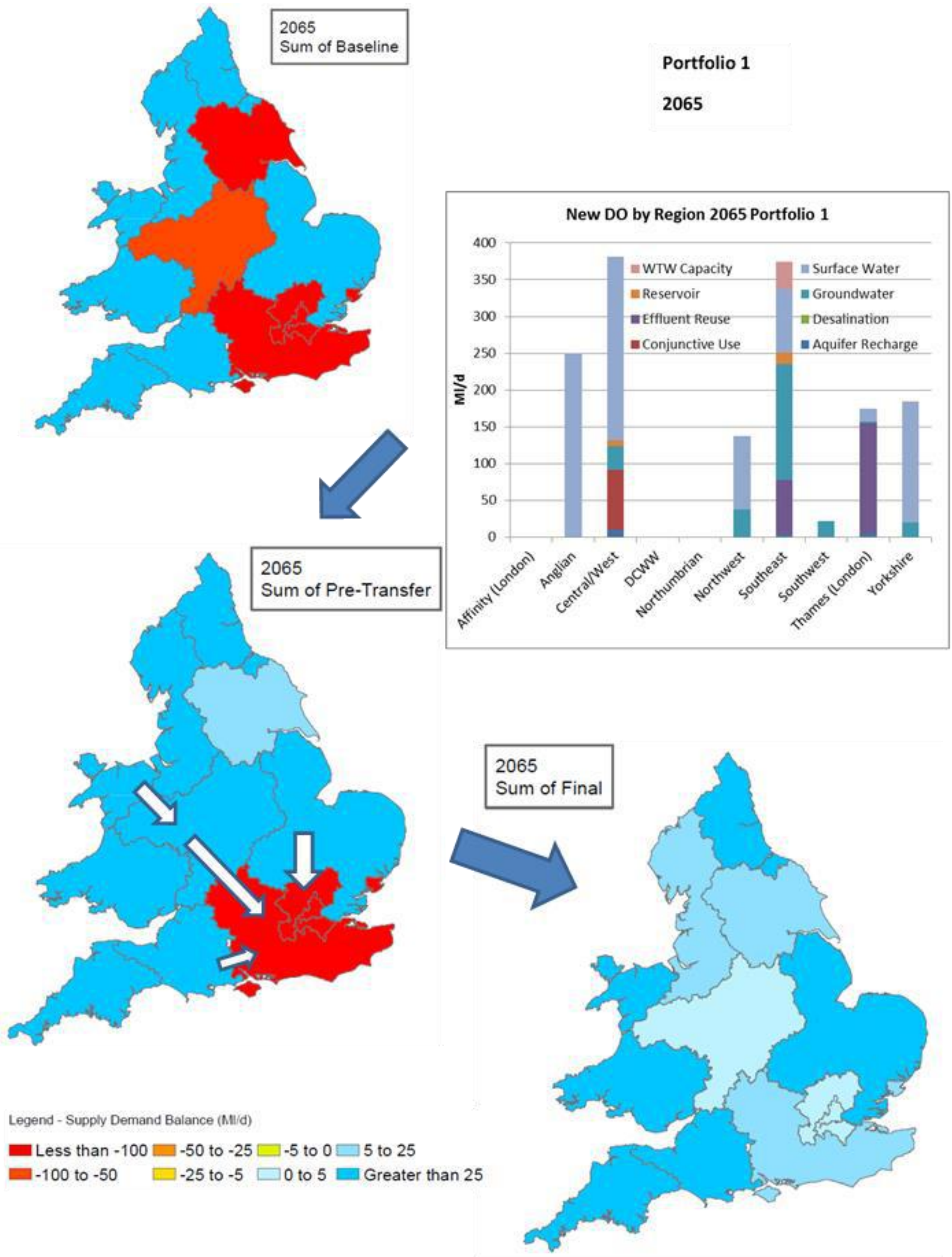


Figure 8-14 provides an indicative portfolio of options required to meet the ‘mid-point’ of supply/demand risks identified at 2065. The question of which developments might be needed first was addressed on an AISC basis as part of the Portfolio developments, but obviously this is too simplistic to draw any meaningful conclusions from. However, the makeup of the individual Portfolios was used within the resilience testing and hence the final conclusions drawn in Section 10.

Figure 8-14 Typical Portfolio of strategic supply-side resources and transfers by 2065 under ‘mid-range’ scenarios or by 2040 under more extreme scenarios

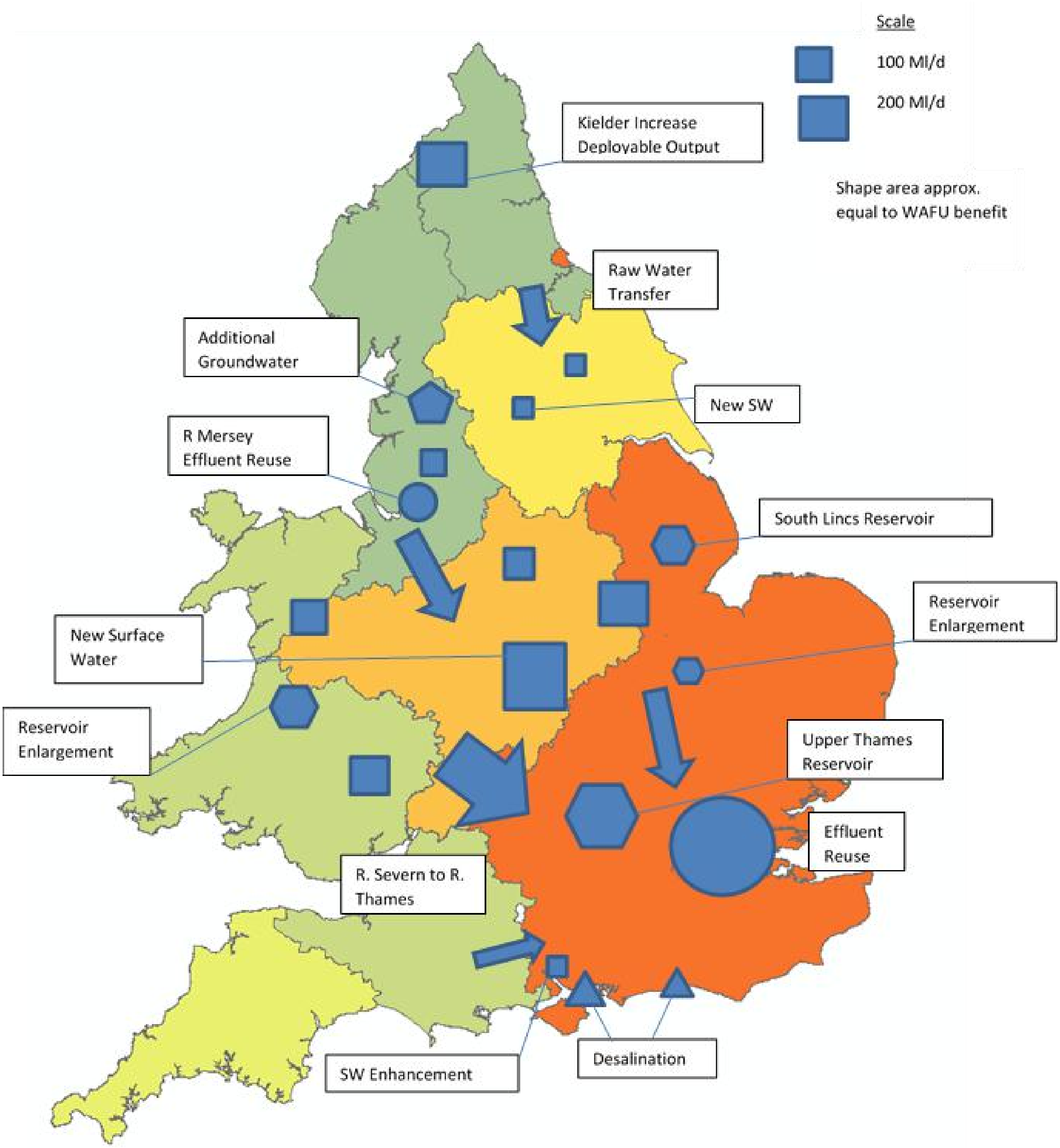
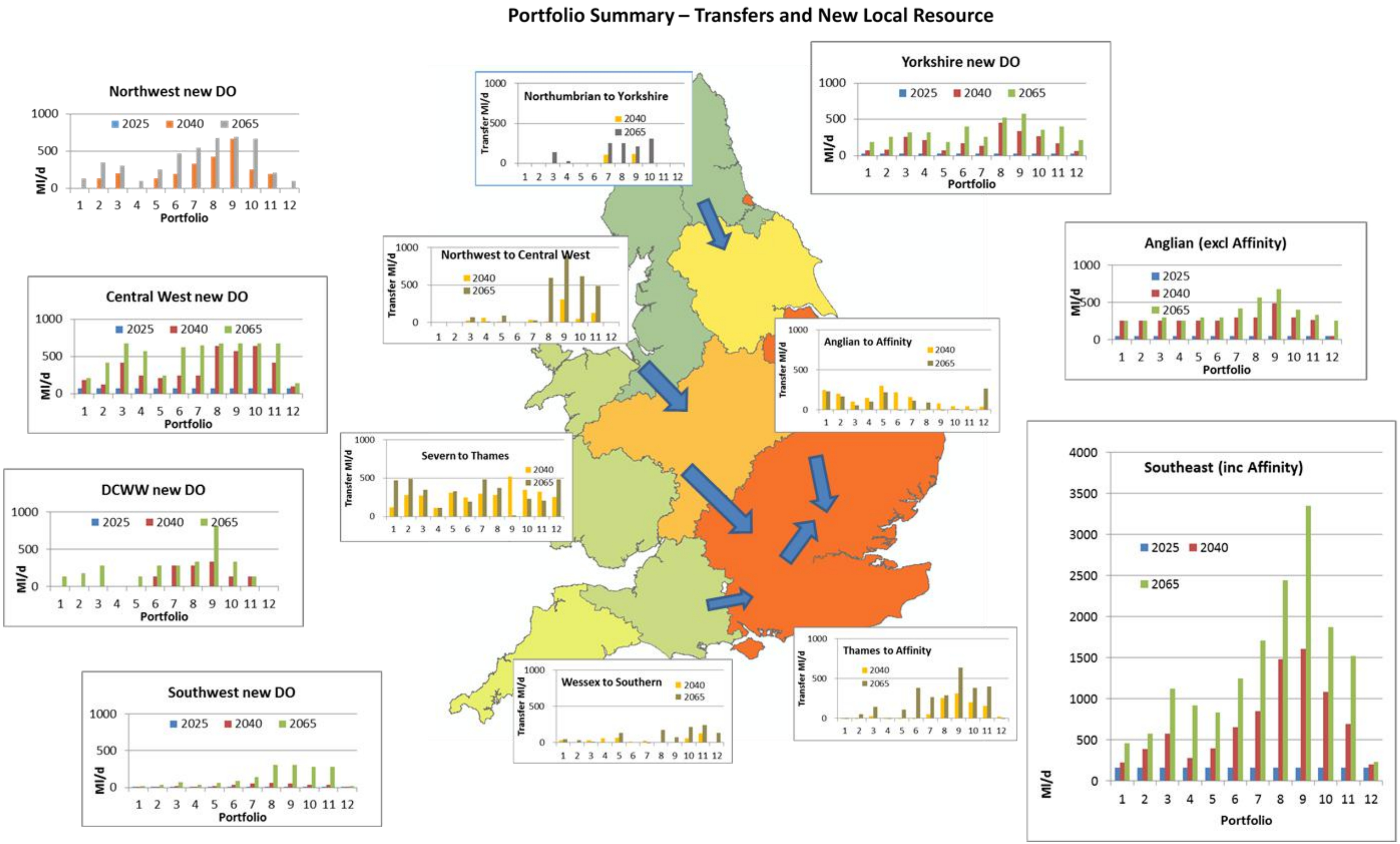


Figure 8-15 provides an indication of the variability of resource development and transfers that occurs under the different ‘example’ Portfolios. It should be noted that transfers are described according to the ultimate recipient – for example under a number of Portfolios there is development within the Northwest that is ultimately required to support the Thames sub-Region; this does not appear within the ‘Northwest to Central West’ transfer graphic as the resource is not actually required in Central West.

Figure 8-15 Map summarising the volume of new deployable output and transferred volumes across different portfolios

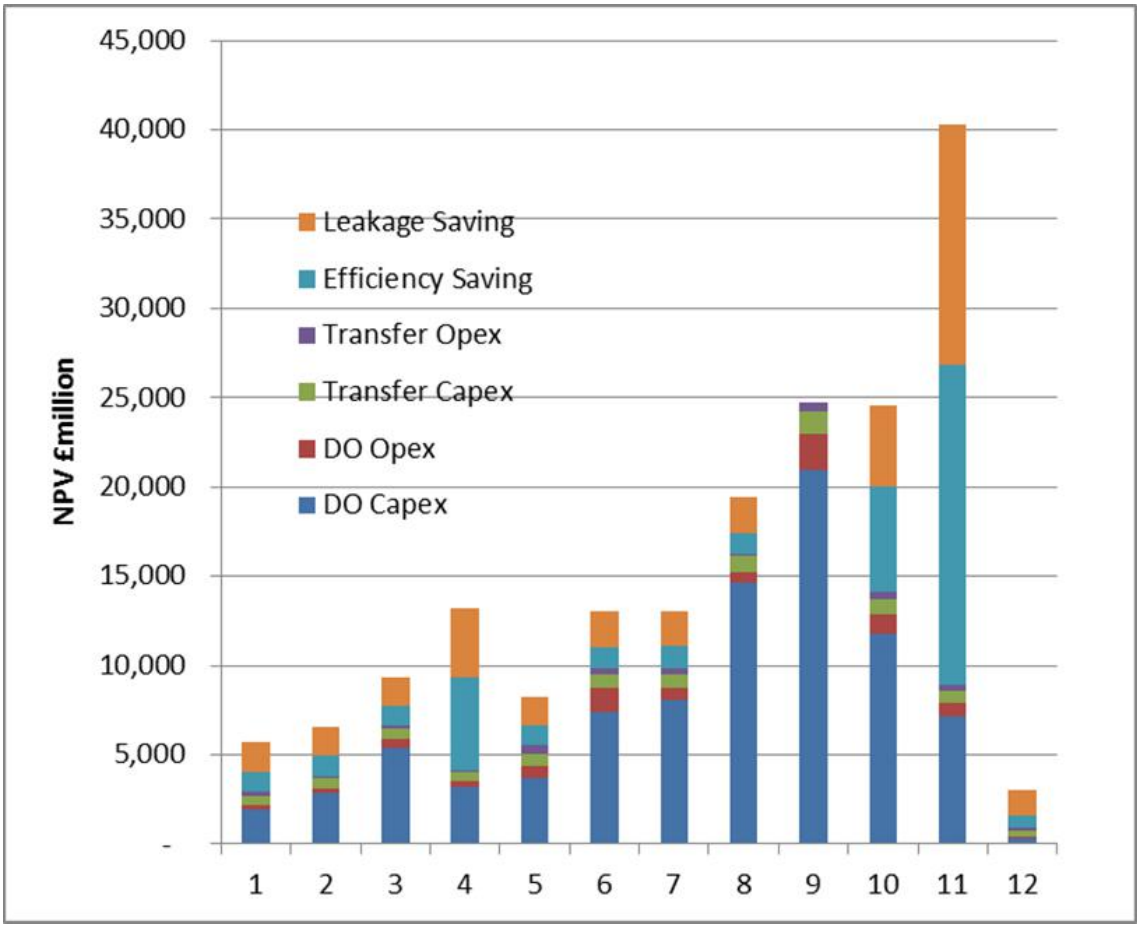


8.2.2. Analysis of cost implications across the full range of potential portfolios

Following derivation of the portfolios, high-level treatment cost estimates were specified for all new surface water resources (reservoirs and direct abstraction), effluent reuse and conjunctive use options. It was assumed that most treatment costs for groundwater and desalination are included in the WRMP costs (normalised where necessary as described previously). Total demand management costs were determined as discussed in section 8.1.1.

The total NPV across the 13 'example' Portfolios varied between £3 billion and £40 billion (Figure 8-16).

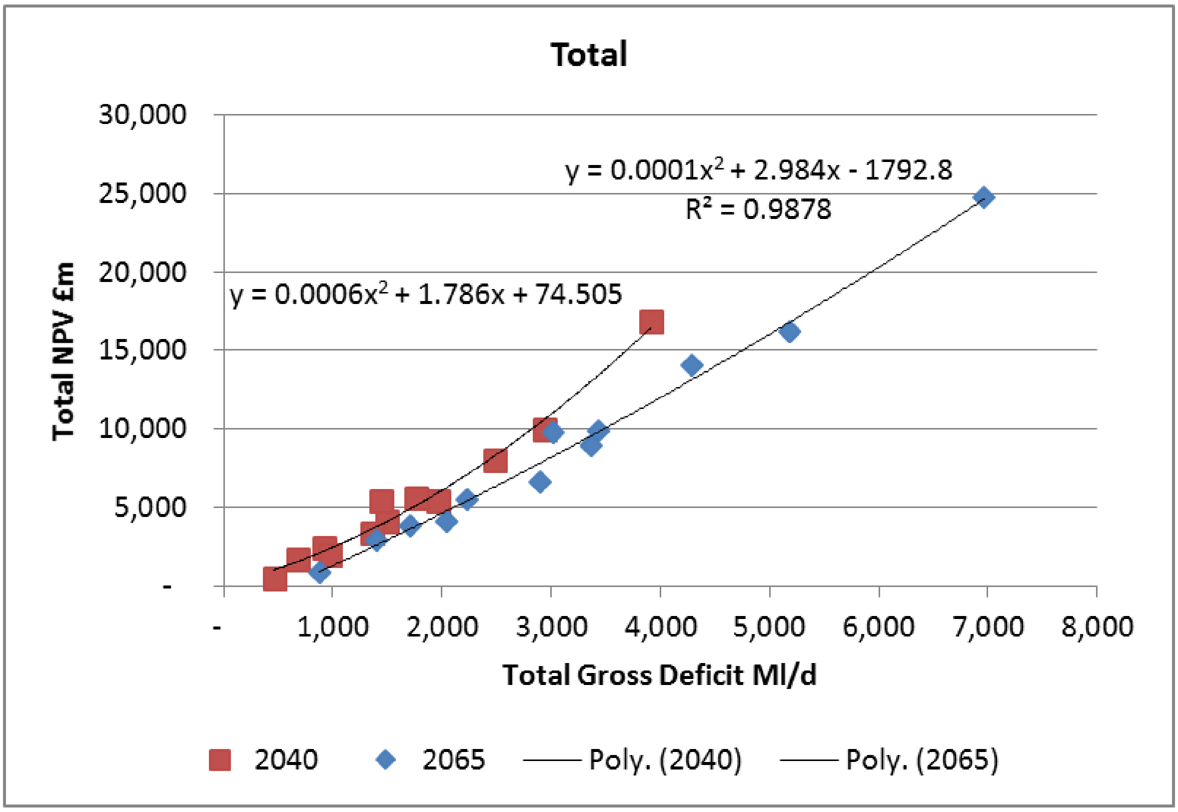
Figure 8-16 NPV costs of portfolios, showing breakdown of costs across capex and opex, supply options, transfers and demand management



These correspond to annualised costs of between £140 million and £1.9 billion, assuming costs are distributed evenly over 80 years and with a 4.5% discount rate. Excluding the very expensive enhanced demand management strategy, portfolio 11, this equates to approximately £5 to £35 per household per annum, assuming all costs are divided evenly across the number of households in 2040. These costs are not equivalent to changes in the household price of water, as they do not include the increase in revenue associated with growth in number of households, or any contribution to finance by the non-household sector. They also do not account for the distribution of cost between capital and operational costs. The majority of supply side costs are associated with generating new deployable output and treatment.

In order to estimate costs across the full range of 144 futures, the portfolios were used to plot total NPV cost versus the sum of all the supply area deficits in order to generate cost curves for 2040 and 2065 as follows.

Figure 8-17 National cost curves from portfolios used to estimate costs of supply-side new resources and transfers for all scenarios and demand strategies



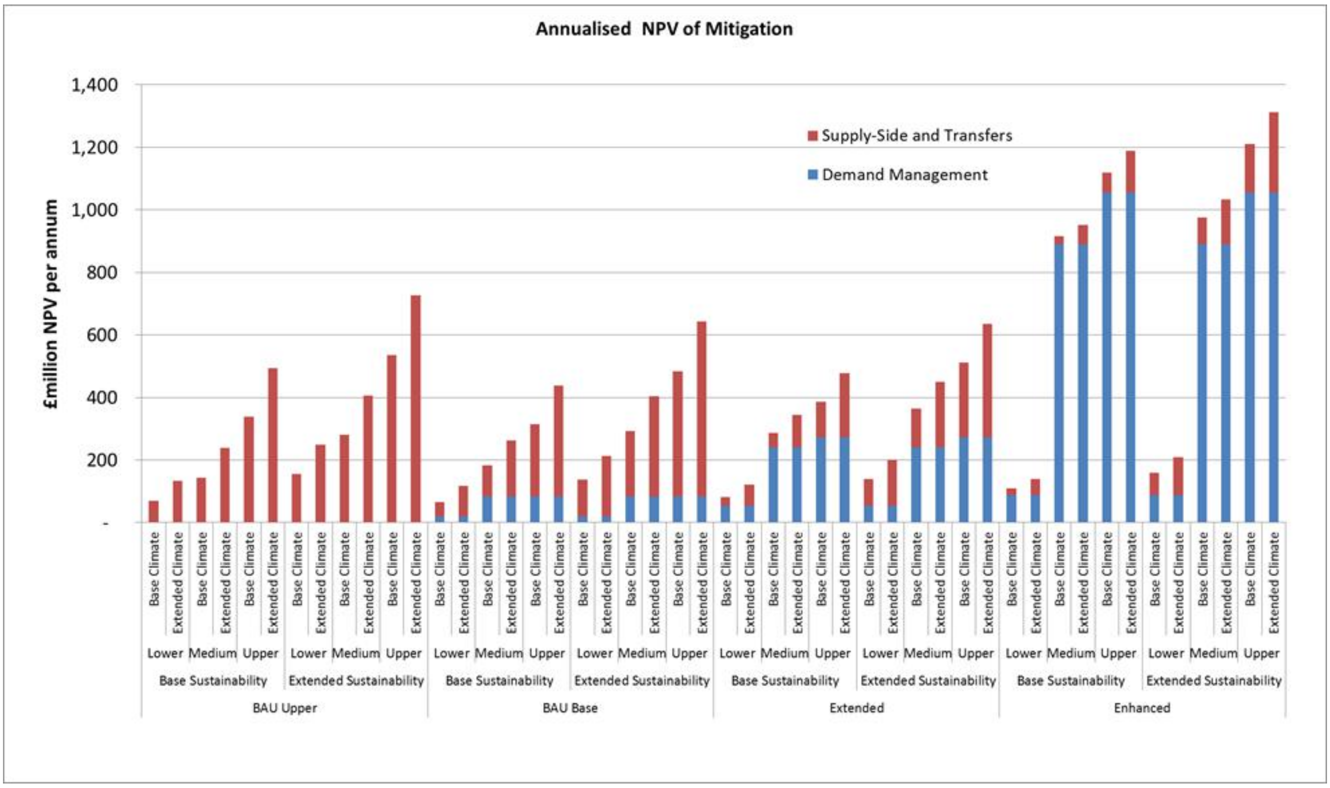
A total "sum of the deficits" was then obtained for each region by summing all the supply area deficits (excluding any surplus) in each region. Costs for each region and nationally were then calculated by applying the cost curve to each sum of deficits. This provided a total NPV cost estimate for every region under every future scenario and demand management strategy – by 2040 and 2065. These were then used to calculate annualised costs and costs per household.

Based on this analysis, summaries of the key findings relating to the different aspects of potential supply/demand mixes and costs associated with the different future challenges were:

1. **Demand/supply investment mixes and costs.** A comparison of the different combinations of demand management strategies and associated supply side investments is shown in Figure 8-18, all under resilience to severe drought. The chart shows annualised NPV cost of mitigation (£million per annum) for England and Wales across all scenarios of abstraction licence changes, climate change and population growth. This indicates that:

    - BAU Base and Extended demand management strategies are very similar in cost across most scenarios.
    - BAU Upper (with largely minimal demand management) is ~10% to 50% more expensive, depending on scenario.
    - Enhanced demand management approximately doubles the cost of mitigation under most scenarios.

Figure 8-18 Estimated annualised investment costs across all scenarios for England and Wales



2. **Level of drought resilience:** Based on a 'BAU Base' demand management strategy, the variability of cost to different levels of resilience is shown in Figure 8-19 to Figure 8-21. This indicates that the cost of maintaining the supply/demand balance is fairly sensitive to the selected level of drought resilience, with costs increasing by between 35% and 75% to mitigate extreme drought, and particular sensitivity across Thames, the Southeast (excluding Affinity) and Yorkshire.

Figure 8-19 Estimated annualised investment costs across all scenarios for England and Wales – for 'worst historic' drought resilience

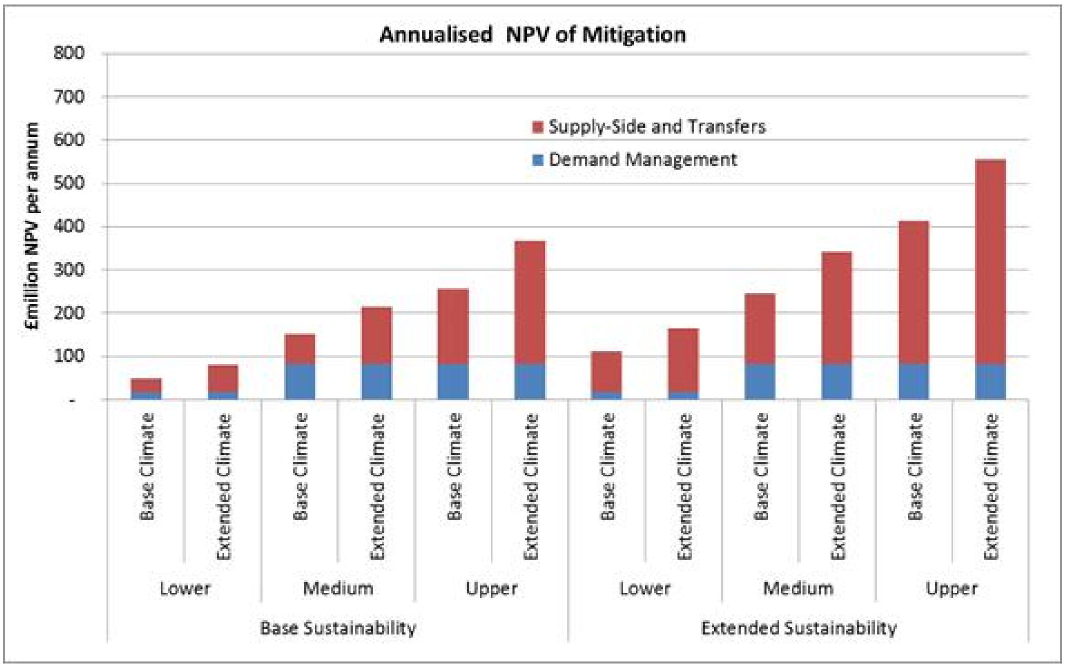


Figure 8-20 Estimated annualised investment costs across all scenarios for England and Wales – for severe drought

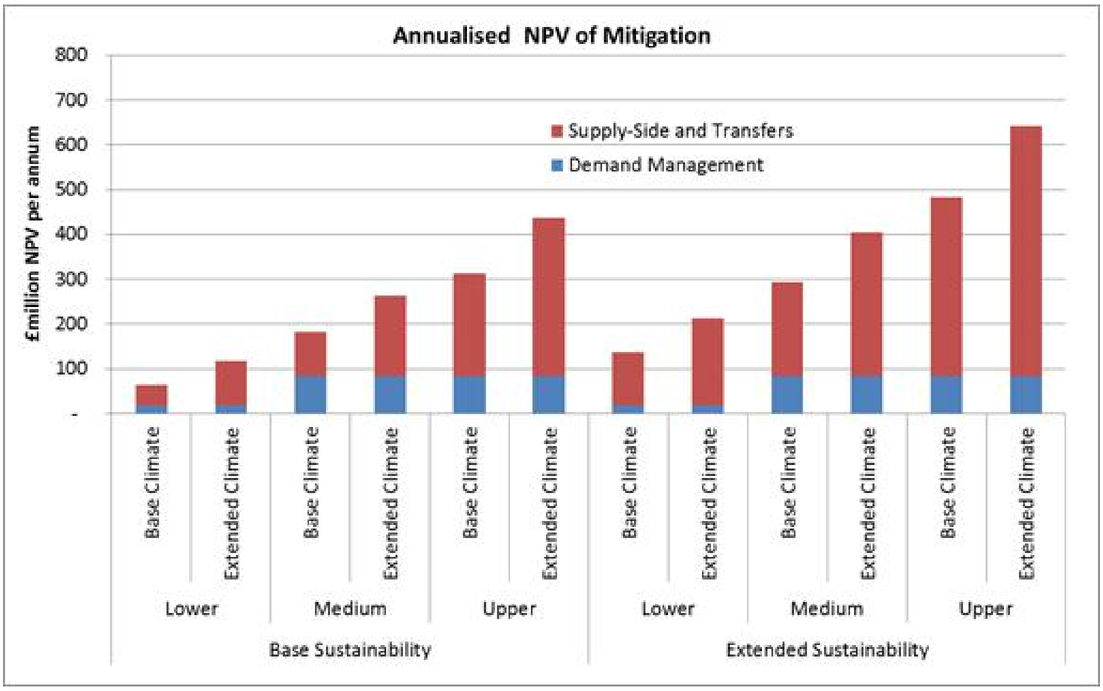
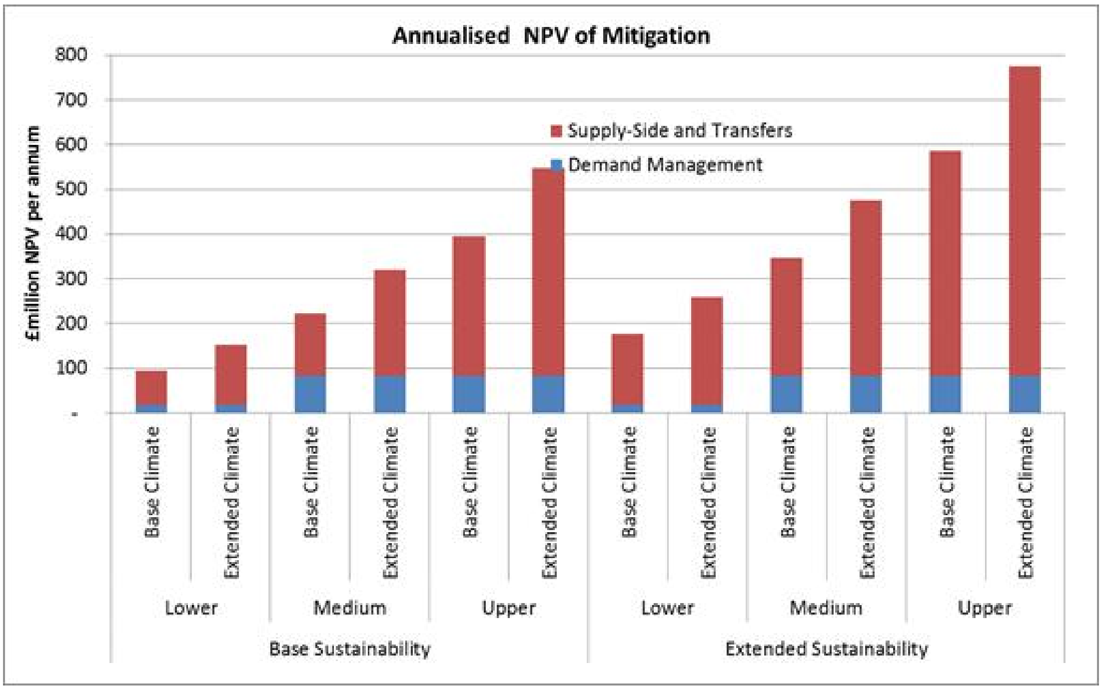


Figure 8-21 Estimated annualised investment costs across all scenarios for England and Wales – for extreme drought



3. **Population Growth**. As demonstrated in Figure 8-22 to Figure 8-24, the cost of maintaining the supply/demand balance is highly sensitive to population growth, with costs varying by approximately +/-100% about the medium growth scenario. The timing of uncertainty of investment is also critically important as the delivery time for major new assets varies by several decades depending on growth.

Figure 8-22 Estimated annualised investment costs across all scenarios for England and Wales – lower population growth

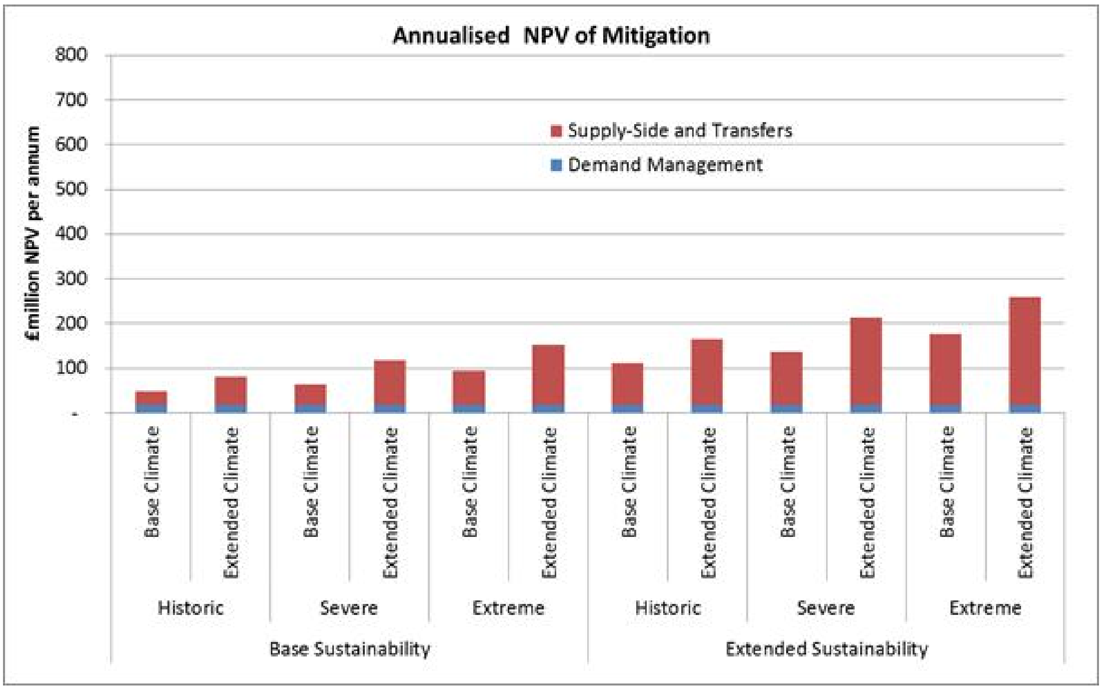


Figure 8-23 Estimated annualised investment costs across all scenarios for England and Wales – medium population growth

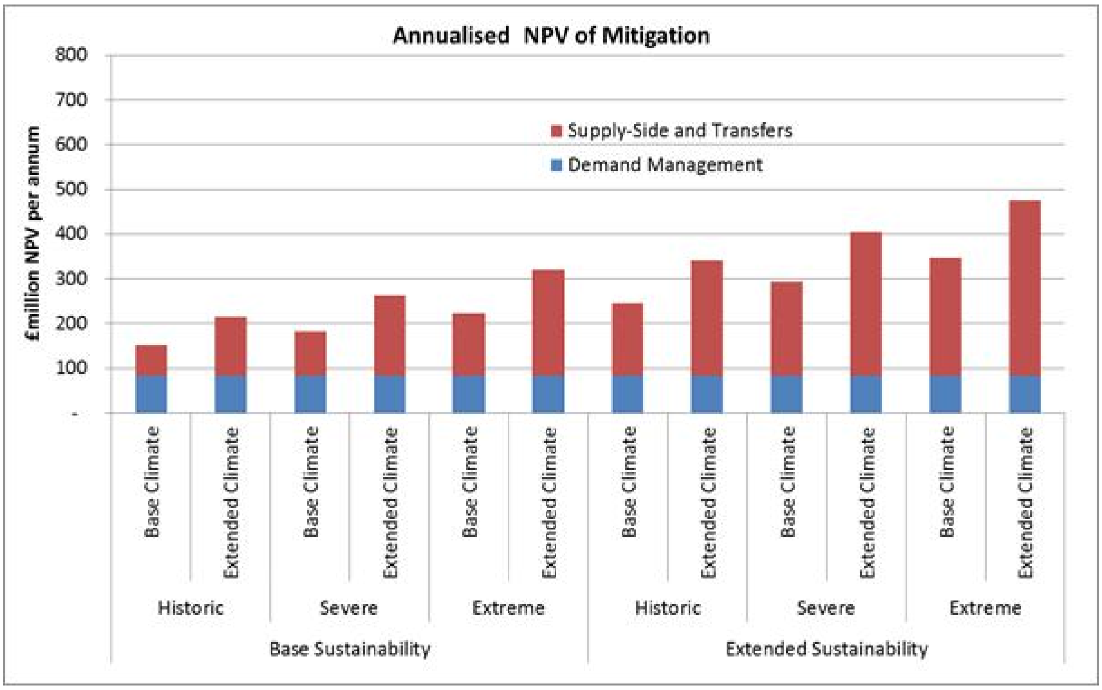
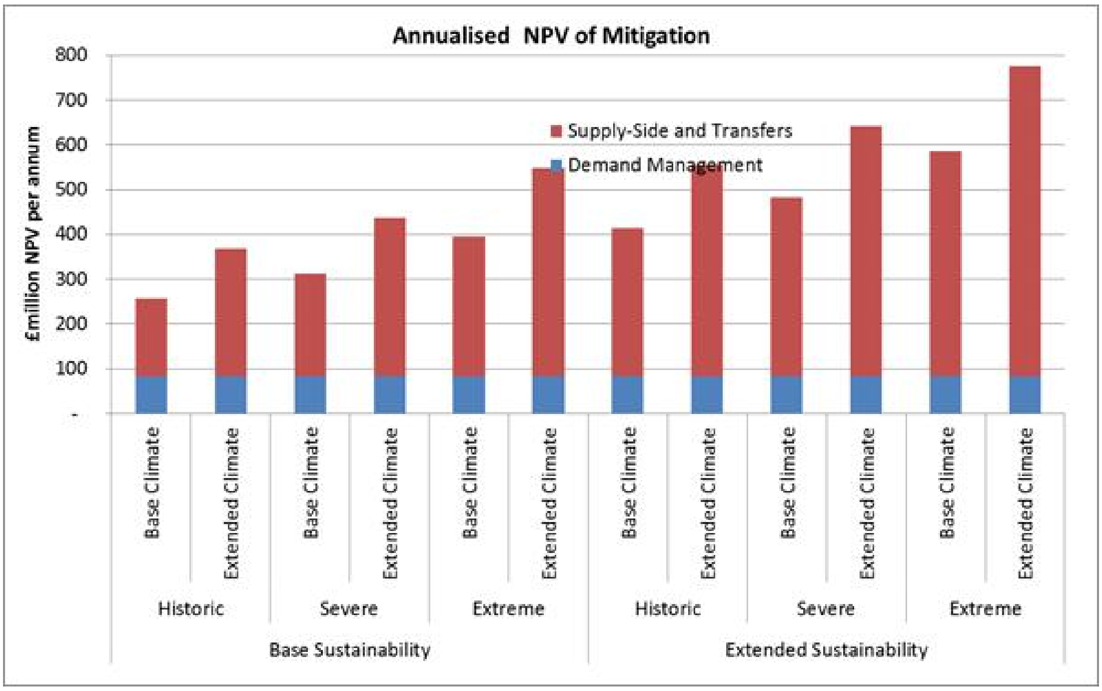


Figure 8-24 Estimated annualised investment costs across all scenarios for England and Wales – high population growth



4. **Climate change:** Climate change uncertainty translates to approx. 30% to 40% cost variation between baseline and extended scenarios at the national level. As for demand growth, it could also significantly affect the required timing of strategic assets. Climate change impact is highly variable between regions, depending on forecast weather patterns and type of resource. The Central/West region is especially sensitive to climate change uncertainty. Yorkshire is also notably sensitive.

Figure 8-25 Estimated annualised investment costs across all scenarios for England and Wales – base climate change

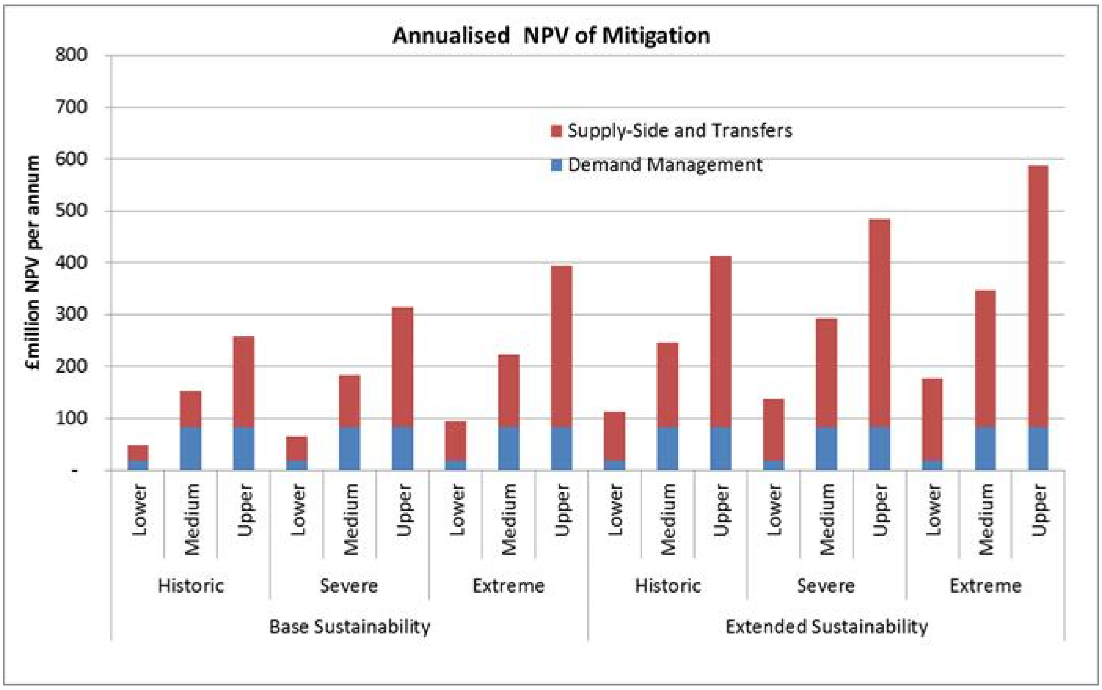
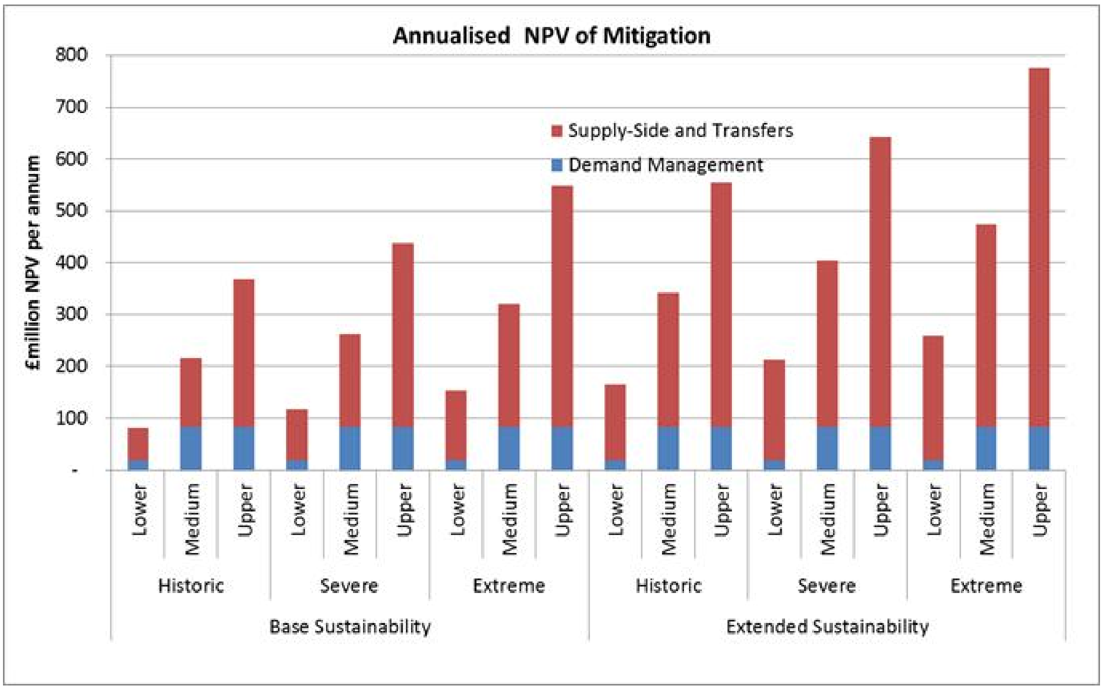


Figure 8-26 Estimated annualised investment costs across all scenarios for England and Wales – extended climate change



5. **Changes in abstraction to protect the aquatic environment:** Uncertainty associated with environmental protection equates to around 50% cost variation. Again, this could significantly affect the required timing of strategic assets, particularly as much of the required mitigation should be achieved by 2027. Environmental mitigation uncertainty varies considerably between regions and companies. London is especially vulnerable, particularly the Affinity sub-region. The remainder of the Southeast and the Central-West also show significant sensitivity.

Figure 8-27 Estimated annualised investment costs across all scenarios for England and Wales – base abstraction changes

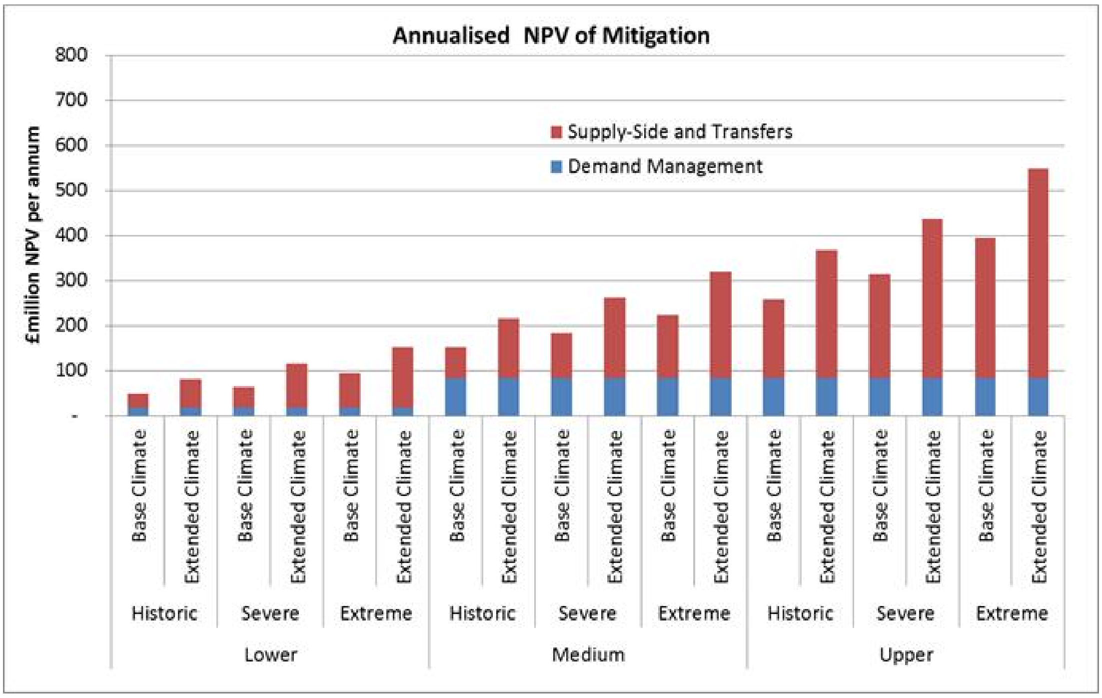
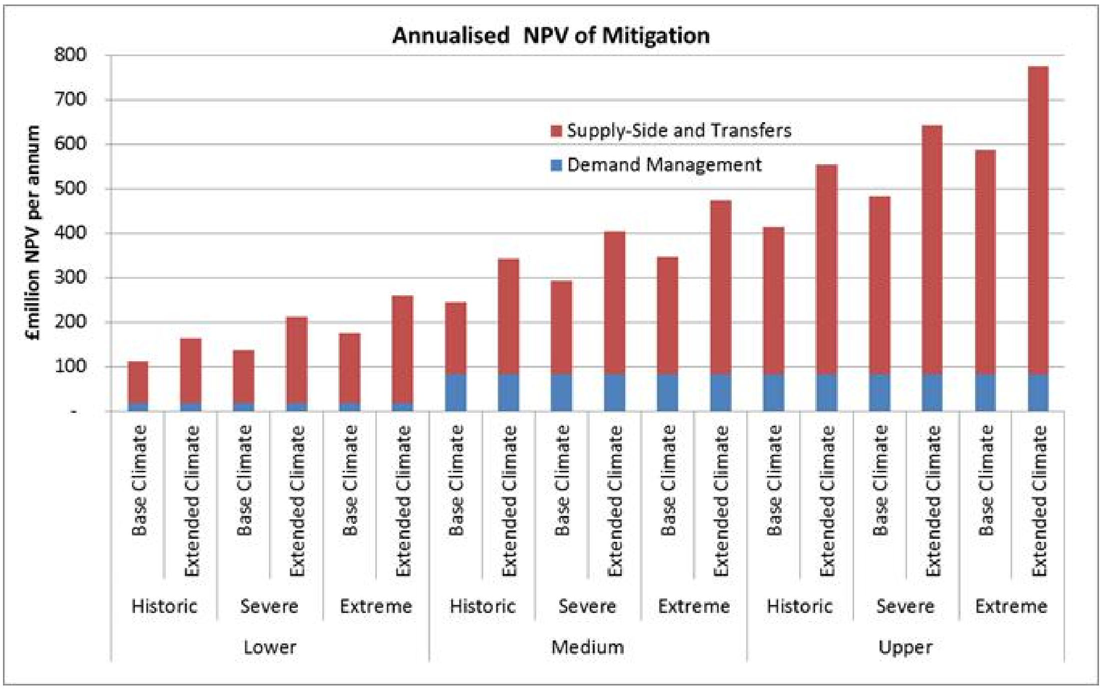


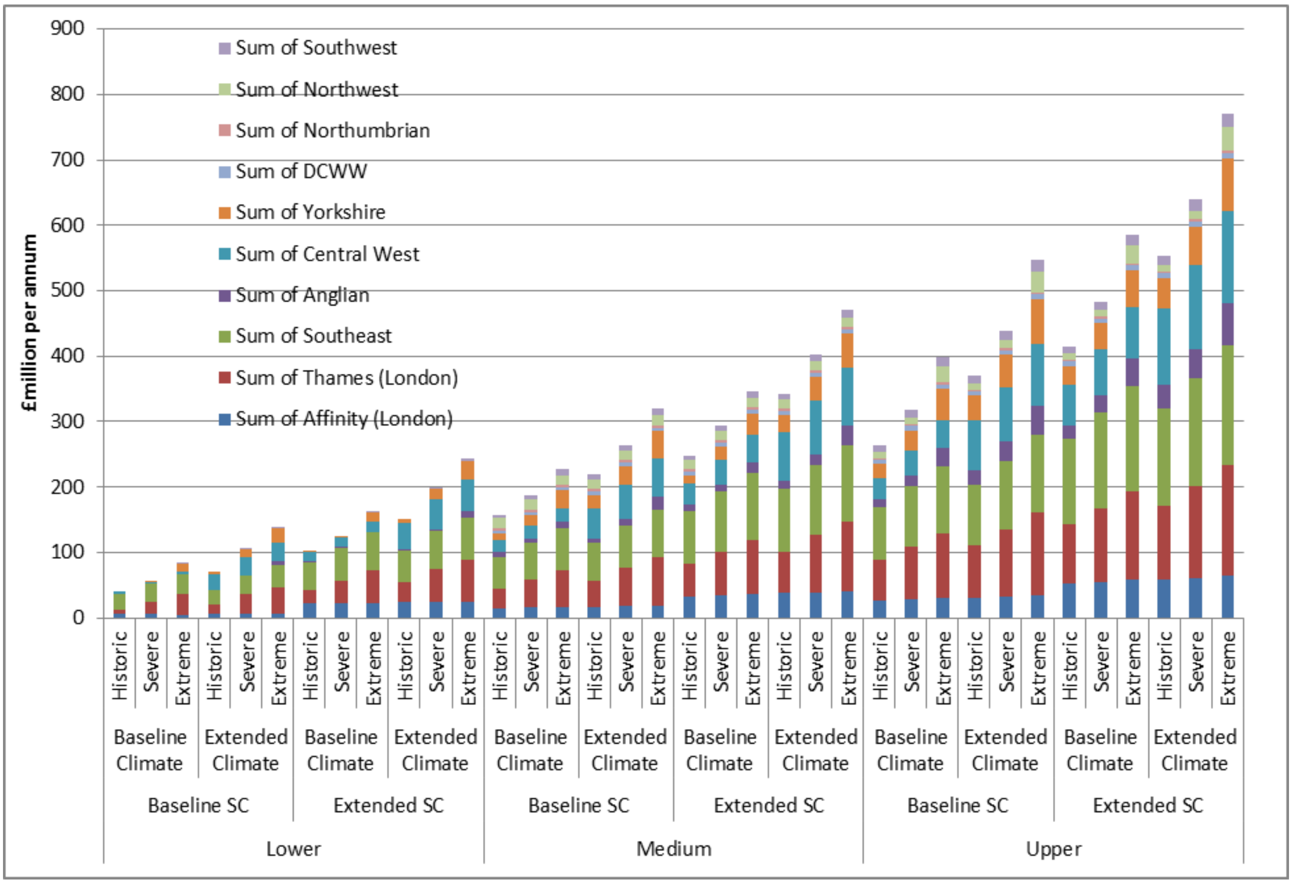
Figure 8-28 Estimated annualised investment costs across all scenarios for England and Wales – extended abstraction changes



8.2.3. Summary of potential cost ranges for the national strategy

Total estimated costs per annum for all potential future scenarios under the BAU base demand management strategy are shown in Figure 8-29 below.

Figure 8-29 Total annualised costs across all scenarios broken down by region for the BAU Base demand management strategy (by 2040)



This indicates that, in order to maintain resilience at existing levels, England and Wales will need to invest between £50 million and £500 million per annum in demand management and new water resource options. If resilience to 'severe drought' is adopted, this increases to between £60 million and £600 million and for resilience to extreme drought, between £80 million and £800 million per annum.

These costs assume between 500 and 1000 Ml/d of bulk transfers are implemented by 2040. The pay-off of these transfers is potentially significant. The transfers themselves are estimated to cost between £20m and £50m per annum, but could theoretically save investment in infrastructure of between £100m and £400m per annum for England and Wales as a whole. Conversely, if the environmental, institutional and technical challenges associated with strategic transfers mean that some of this transfer capability is not possible or turns out to be considerably more expensive than the 'optimistic' assumptions contained within this analysis, then this would tend to increase costs.

The analysis covered by Figure 8-30 to Figure 8-34 below provides estimated costs per household for all scenarios, where costs are divided evenly across all households only, under the BAU base demand management strategy. It should be noted that:

- These costs assume that investment is accurately tailored to population growth, so no additional costs are assumed if investment has to be implemented rapidly in response to growth, or if growth turns out to be lower than the relevant future scenario and associated Portfolio.

- The costs take no account of growth in revenue due to increasing population, and are not equivalent to impacts on household bills. Water supply revenue generated by population growth is likely to be on the order of £300m, £500m and £800m per annum for lower, medium and upper demand scenarios respectively. Not all of this will be available for financing water resources and treatment, but growth may offset the costs of much of the supply and demand mitigation, such that the impact on customer bills is low or possibly even negative over the long term. Calculating prices is complex, depending heavily on capex/opex splits and the timing of investment, and the impact on customer bills is beyond the scope of this study. But purely in terms of overall costs in the long term, it should be possible to maintain the security of water supplies to drought, growth, climate change and good environmental status without significant cost to society.

In terms of costs per household, there is considerable variation between regions, if costs are allocated to households within the region where deficits occur. Estimated costs for baseline and extended climate change under medium and upper growth scenarios are shown below, with costs allocated to where the resource is required (i.e. not where investment takes place). All these assume BAU base demand management, but the costs are reasonably similar for BAU upper and extended demand management.

Figure 8-30 Total annualised costs across all scenarios for the BAU Base demand management strategy, normalised to number of households forecast in 2040

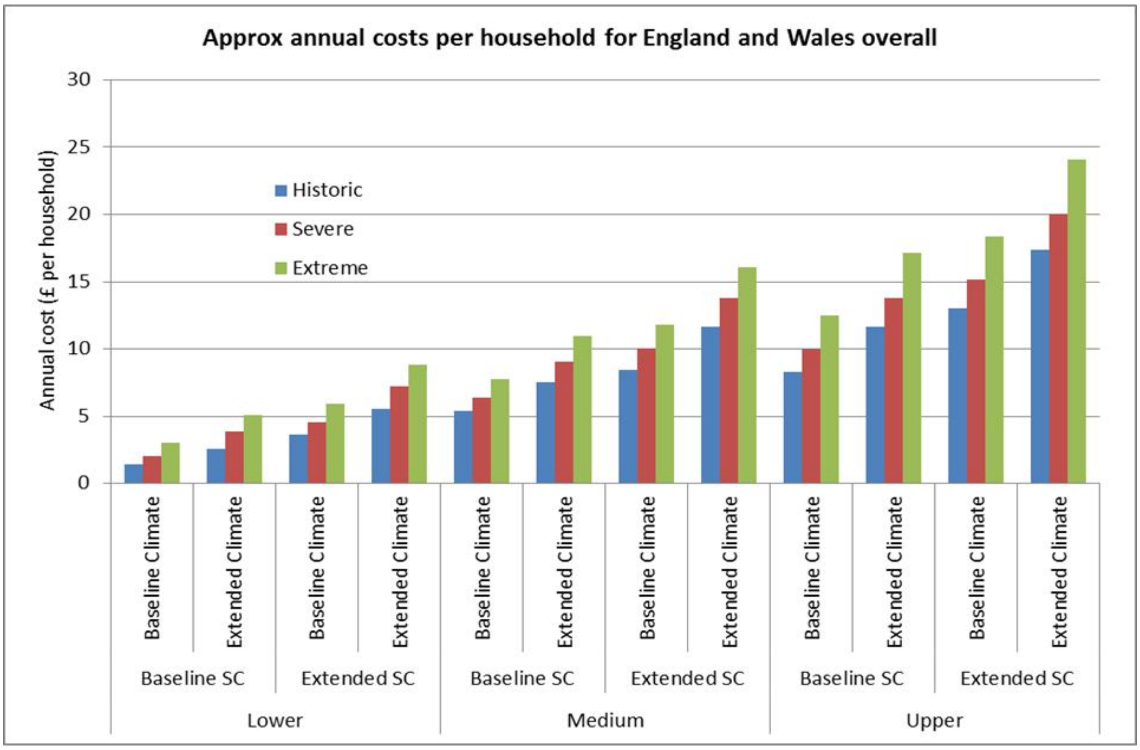


Figure 8-31 Total annualised costs for the BAU Base demand management strategy, normalised to number of households forecast by region in 2040, under Medium Growth, Baseline climate change

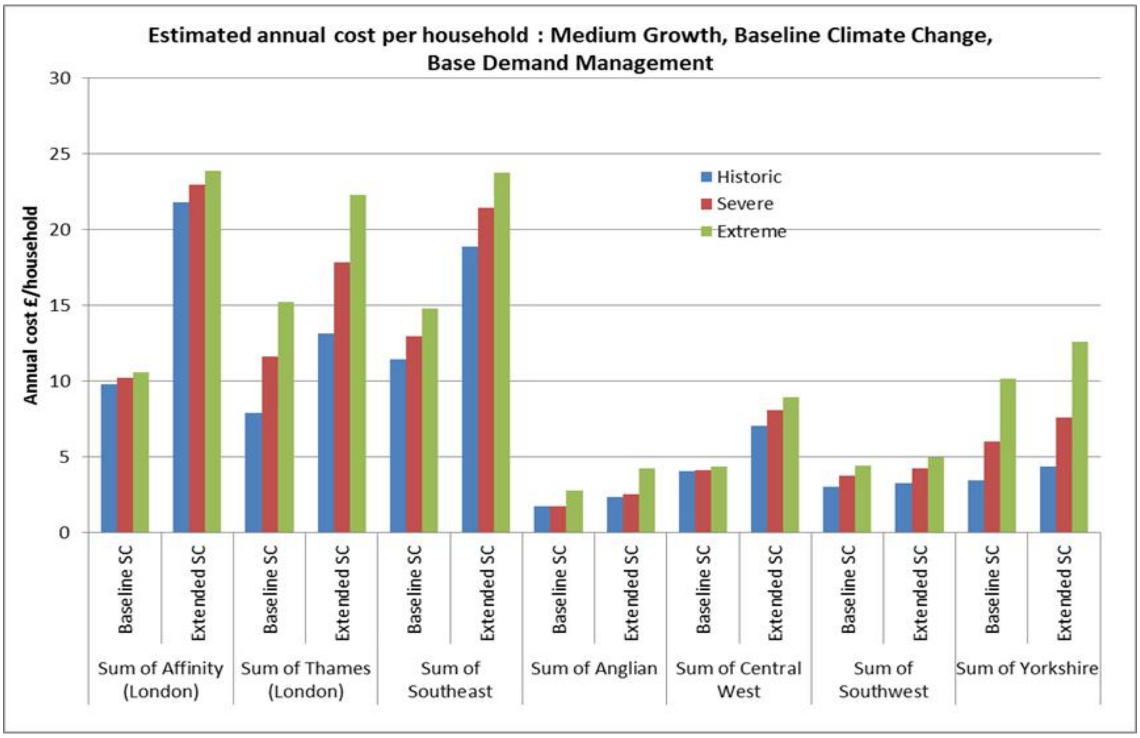


Figure 8-32 Total annualised costs for the BAU Base demand management strategy, normalised to number of households forecast by region in 2040, under Medium Growth, Extended climate change

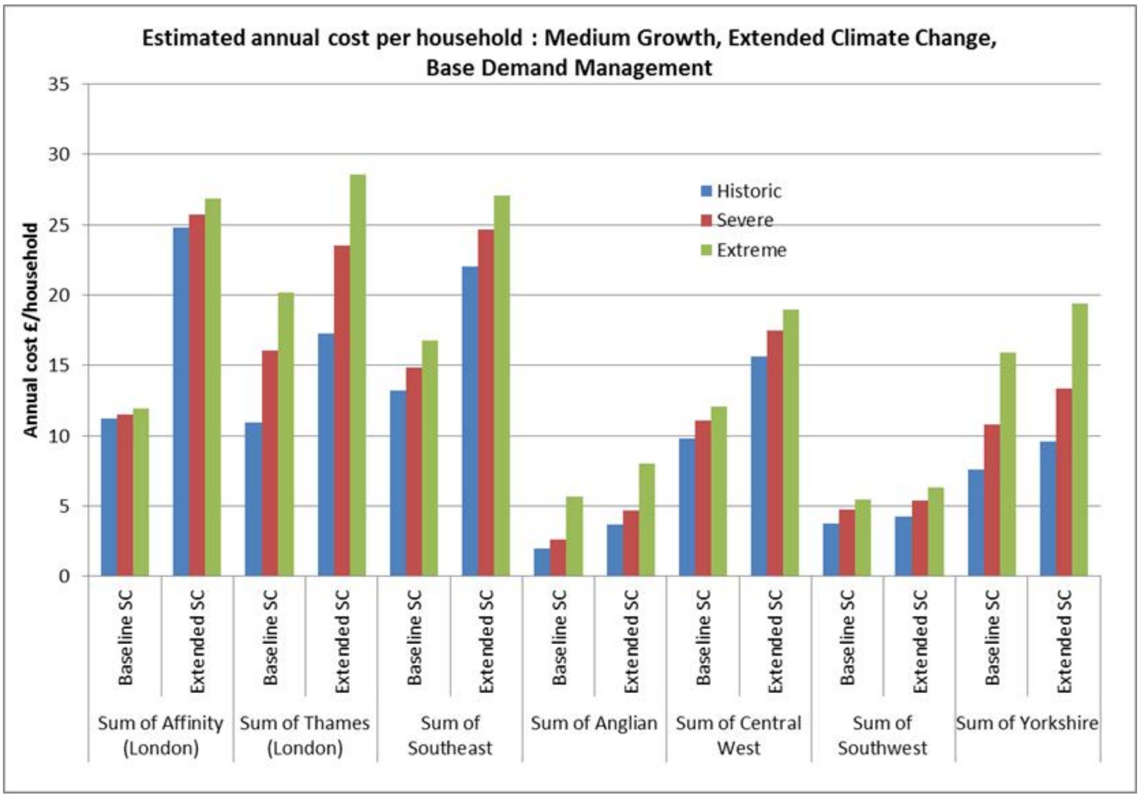


Figure 8-33 Total annualised costs for the BAU Base demand management strategy, normalised to number of households forecast by region in 2040, under Upper growth, baseline climate change

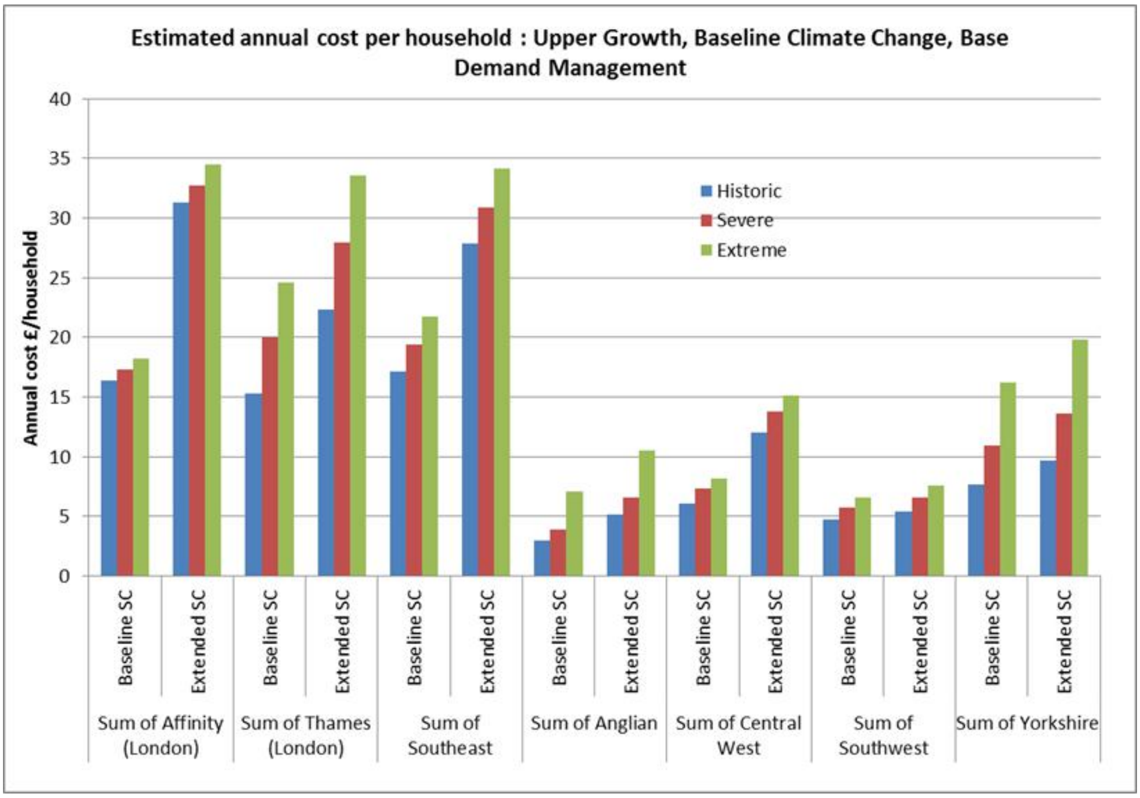
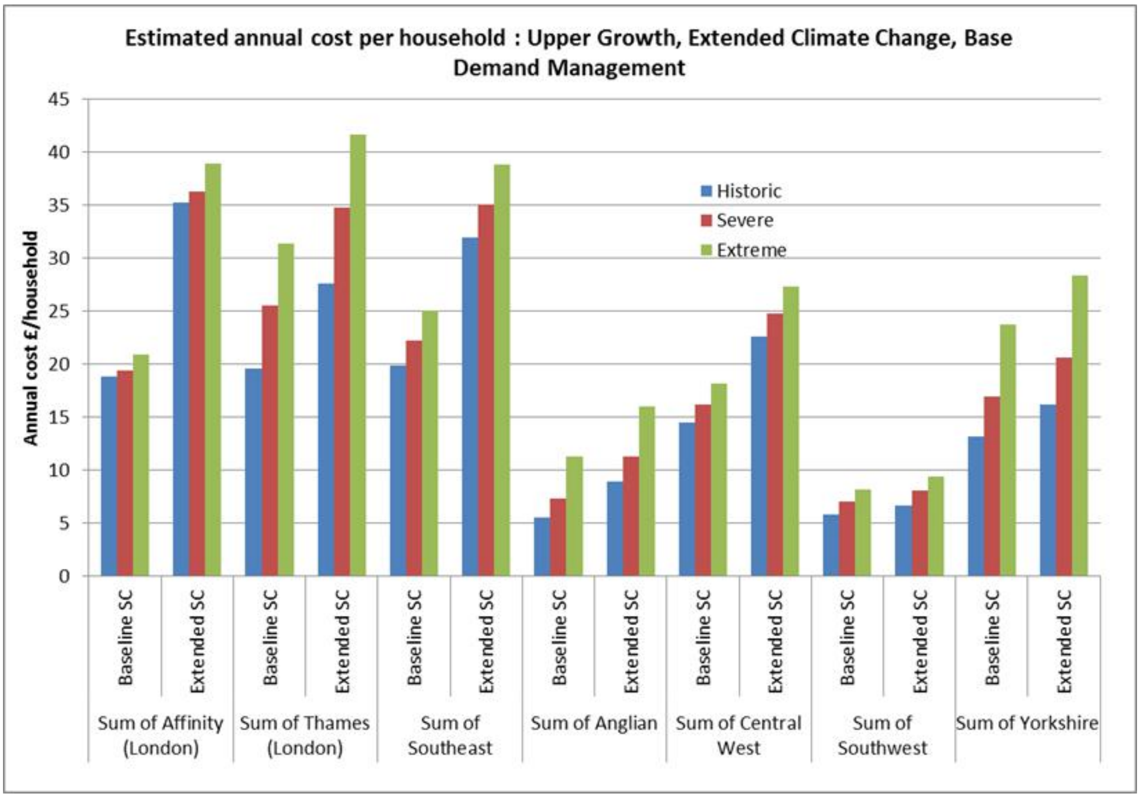


Figure 8-34 Total annualised costs for the BAU Base demand management strategy, normalised to number of households forecast by region in 2040, under Upper growth, extended climate change



8.3. Resilience testing – What does this tell us about the suitability of the different portfolios?

For the Drought Deficit sub-Regions outside of the Wathnet model, the inputs to the Portfolio already reflected the estimated DO that would occur under different drought severities and climate futures. Because there are no large-scale transfers that involve the transfer and storage of water resources across these sub-Regions (i.e. the 'conjunctive use' benefits in the future Portfolios are comparatively limited), no further resilience testing was considered to be necessary. The following key analyses were therefore used to draw the resilience conclusions for these particular sub-Regions:

- The Portfolio development process (see Section 8.2).
- The understanding of the potential duration of failure under different levels of supply/demand deficit that was gained by running the Drought Configurations through the RETs (see Section 6.1.3).
- The findings of the coherence analysis (see Section 5.1.2).

The key findings in relation to potential future Portfolios and resilience within these sub-Regions are provided in Table 8-4 for the sub-Regions outside the Wathnet model.

Table 8-4 Resilience evaluation findings for those sub-Regions outside of the Wathnet model

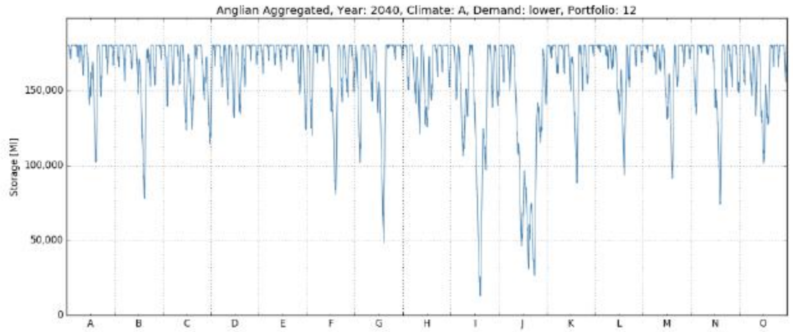
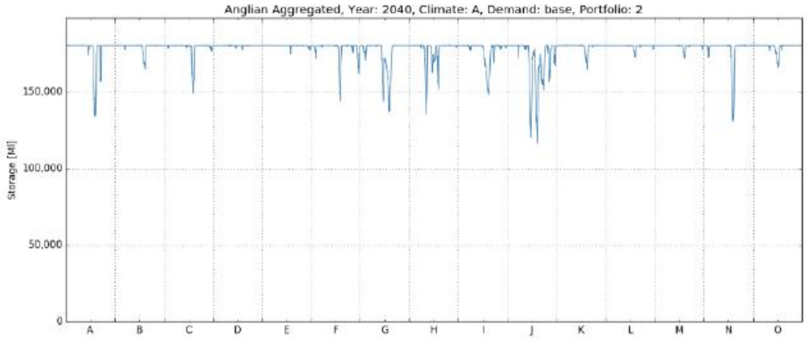
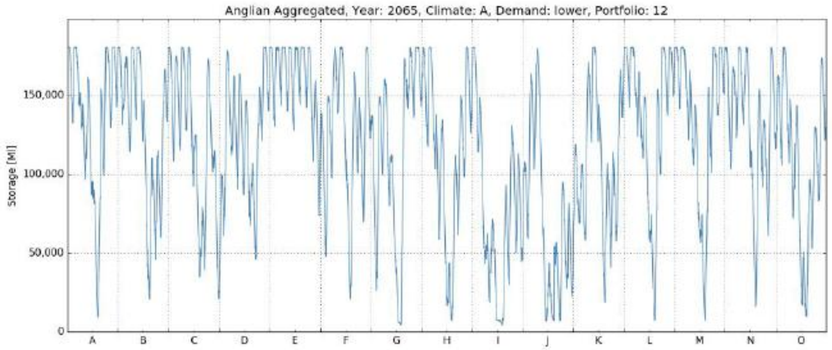
Essex sub-Region	Although this sub-Region is potentially vulnerable to droughts that are more severe than the historic record, it generally maintains a small supply surplus under most Portfolios in 2040. It then requires transfers from Anglian in many Portfolios in 2065, so becomes part of the overall resilience picture described under Table 8-5 below.
South East (excluding London)	Many of the companies here are at, or close to, a supply/demand deficit, and some companies (e.g. Sutton & East Surrey Water) do not currently plan to be resilient to the worst historic drought on record, so have a higher level of risk than described above, whereas Southern Water plans to be resilient to a 'severe' event by 2020. These differences were accounted for by the resource evaluation described in Section 6.1.2, so are not an issue for the development of Portfolios, but it does highlight a need to harmonise the understanding of drought resilience across this sub-Region. Much of the resilience within this sub-Region relies upon the transfer of water between neighbouring companies, so it is important that a common understanding of risk and planning assumptions can be reached through bodies such as the Water Resources in the South East (WRSE) group. It is noted that there are a number of potential new water storage options that are selected by the Portfolio analysis, and these were reviewed for resilience under climate change and 'severe' drought as part of this analysis. The relevant DO expectations used in the Portfolio development reflect that analysis.
South West	Evaluation of WRMP14 technical information and the CCRA report shows that both Wessex Water and South West Water are currently very resilient to the risk of severe droughts. Bristol Water, on the other hand, currently plans to a lower level of resilience than the 'worst historic drought' and has a risk of Level 4 restrictions (standpipes) of approximately 23% over the WRMP 25 year planning horizon. The need for resource development within this Region is relatively straightforward, and Scenario testing out to 2065 indicates that challenges can be met without having to rely on transfers from the Central-West Region.

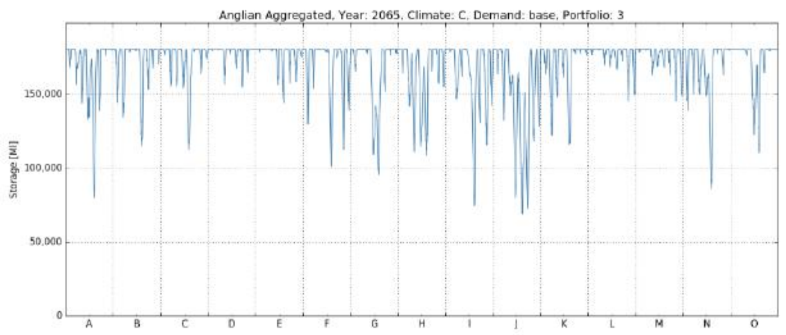
For those Drought Regions contained within the Wathnet model, the resilience assessment process was designed to answer the following two questions:

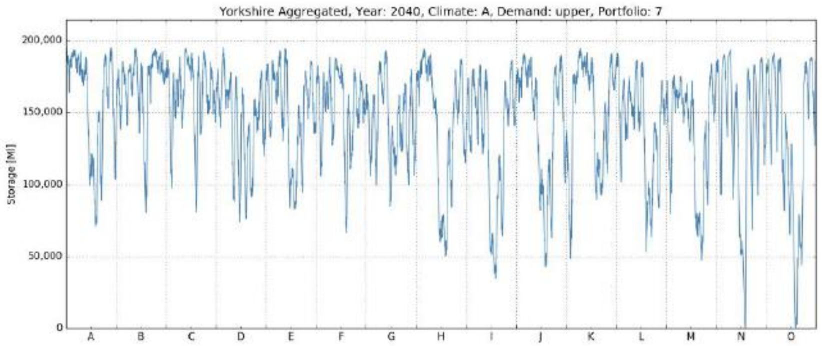
1. Do the Portfolios perform as expected (i.e. do they offer resilience to the level of drought severity, growth and climate change that the Portfolio has been designed for)?
2. Do the future conditions and Portfolios change the nature of risk in the Supplier or Deficit sub-Regions involved?

These were answered by examining the aggregated storage behaviour of the main resource systems that resulted when each of the 13 ‘example’ portfolios were run against all of the 36 future scenarios for the 2040 and 2065 time horizons, described in Section 4.5. A summary of the findings, grouped according to Drought sub-Regions, is provided in Table 8-5 below.

Table 8-5 Summary of the Wathnet resilience testing

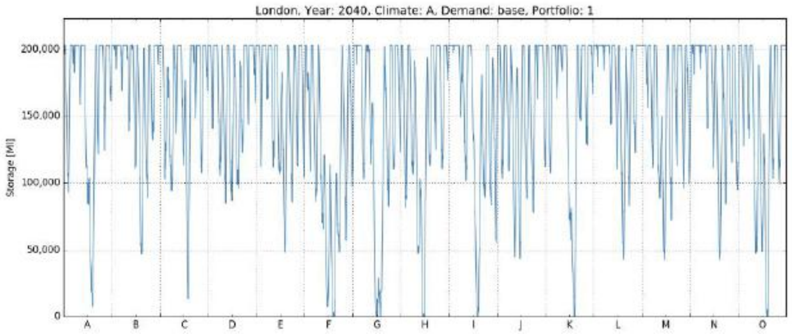
Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
Anglian (plus transfers to Affinity-London)	Almost all of the Portfolios incorporate a transfer from the River Trent to storage within the Anglian system (Trent to Rutland is the lowest cost option, so is generally selected first, although this involves a number of assumptions and the exact choice and location of storage requires much more detailed regional modelling, as discussed below) In order to test the potential benefit provided by this scheme, it was defined within Wathnet so that it would maximise winter abstraction and storage. This showed that there is a potentially significant benefit to the sub-Regional resilience from developing a scheme to transfer and store water from the River Trent. This is demonstrated from the outputs of Portfolios 2 and 12 below.   	The findings for 2065 were similar to 2040, with the exception that the allowance for climate change contained within the Portfolio may have been under-estimated in the resource assessment used for the Portfolio analysis. As shown below, Portfolio 12 (enhanced demand management without the development of a River Trent transfer), does not achieve the anticipated level of resilience for the sub-Region, even under median climate change and lower growth.  Portfolios that contain transfer and storage continue to show some additional resilience beyond the expectation of the Portfolio, even under a ‘dry’ climate (Both Portfolio 12, above, and Portfolio 3, below, were designed to be resilient to a ‘severe’ drought according to the simple supply/demand balance calculations).

Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
	Portfolio 12 is applied under a low growth scenario and relies on enhanced demand management to provide resilience to severe droughts (which it does; it only experiences Level 4 failures under the ‘extreme’ Drought Compositions). Portfolio 2 is also designed to provide resilience to a severe drought, but includes the Trent-Rutland scheme. The difference in the potential levels of resilience indicated by the above charts is clear. There are, however, some key points to note in relation to this: • The Trent-Rutland scheme has been designed in the model to maximise volumetric storage without considerations of issues such as raw water quality or the use of control curves to reduce pumping costs, or impacts on other downstream users (e.g. cooling water intakes for power stations) • Introducing such a scheme to address increasing levels of demand in Ruthamford and beyond (primarily Fenland and Affinity Water) would require significant infrastructure to increase connectivity from Ruthamford north to south, and distribute the water beyond Ruthamford. The Portfolio analysis only included very high level (and probably lower end) costs in relation to this, and did not consider quality or engineering issues that could result. Overall, whilst the potential benefit of transferring and storing water within the Anglian sub-Region is clear as part of a long term strategy, the exact nature of such a scheme would require further work, both to confirm the amount of raw water availability and to determine the least cost option for achieving the desired resilience. If raw water availability is lower than anticipated, then the outputs from Portfolios such as 8, 9 and 10 (which incorporate the South Lincolnshire reservoir) indicate that additional storage has a synergistic benefit when combined with the transfer.	 The caveats around network capability and scheme design, as noted for 2040, still apply for the Portfolios that incorporate transfers from the Trent. Finally it was noted that Portfolios such as 4 and 5, where the intention is to use large volumes of water to satisfy demand in Affinity Water (and even allow transfers through to Thames), appear to cause excessive demand on Grafham reservoir unless infrastructure were upgraded to the extent where Grafham could be used fully conjunctively with either Rutland or a new storage reservoir. This means that the lower cost ‘extended’ demand management portfolios that have been designed for 2065 (e.g. Portfolio 4) may not be realistically priced, as they would either require very large infrastructure investment, or need to source water from the Thames-London direction to support Affinity Water instead.

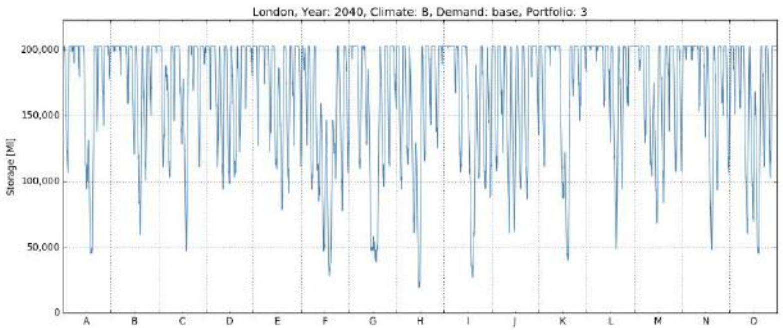
Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
Yorkshire (Strategic Grid)	The 2040 Portfolios that were designed for Yorkshire all performed as expected under the relevant climate change scenarios. This included the performance from the proposed new river abstractions. Where Portfolios, such as number 7 (see below), planned for a lower level of resilience than currently exists in Yorkshire in order to save investment costs under upper growth scenarios, then these also performed as expected. Overall this indicates that the proposed long term strategy, which consists of a 'twin track' approach that relies on demand management combined with 'local' schemes and the more modest transfers from Kielder WRZ are sufficient to provide drought resilience under most 2040 scenarios, except in two, which represent 'extreme' Drought Configurations. 	The 2065 findings are similar to those in 2040, and the Portfolios continued to perform as expected, although it is noted that the Future Flows scenarios that were used are relatively modest in their climate change impacts on the eastern side of Yorkshire, so most of the outputs resulted in higher storage volumes than the equivalent conditions in 2040. Overall this indicates that the proposed long term strategy, which is basically a continuation of the 2040 strategy, but with some increase of transfer capacity from north to south Kielder WRZ to support demands under some of the scenarios, appears to be appropriate for this Region.
Thames - London, Affinity-London, Central-West and Northwest	This represents the most complicated 'conjunctive use' section of the model, and much of the behaviour depends on the size and nature of the transfers that are proposed between the River Severn and the River Thames (the Severn-Thames transfer). Differences between Portfolios 1 (shown below) and 3 clearly show that an un-supported transfer struggles to produce the level of resilience that is anticipated by the Portfolio. Portfolio 1, where the transfer isn't 'supported' should be resilient to the worst historic event, but fails to achieve this. This is because the Portfolio assumes that Severn Trent can release water for transfer simply by reducing abstraction from the Severn. In reality the	The findings from the 2065 analysis were generally similar to the 2040 analysis. It was noted that, under higher growth scenarios that required very large transfer volumes, the risk profile of Thames Water started to change because it had effectively become extended so that it incorporated the Welsh mountains (via Vyrnwy and Welsh Water options in some cases), the Peak District, the River Severn and the River Wye. This type of behaviour is shown in Portfolio 10 below. This is partly a model artefact, as the model assumed that Thames could take water via transfer preferentially over the existing Severn abstractions (to facilitate transfer behaviour)

<table>
<tr><th>Sub-Region(s)</th><th>Key findings for the 2040 Portfolios</th><th>Key findings for the 2065 Portfolios</th></tr>
<tr><td></td><td>

timing of need between the two regions isn’t straightforward, so releases of raw water need to be supported by dedicated storage systems before they can be made to work.



With support in place, either through ‘local’ storage (e.g. the Upper Thames reservoir) or the use of remote storage (e.g. Portfolio 3 below, which includes Vyrnwy, and should be resilient to a ‘severe’ event), there are still some concerns about the level of resilience that is achieved; however, this appears to be associated with assumptions on the effect of climate change, which may be having a larger than anticipated effect at 2040 due to the underlying hydrological model, rather than around the inherent capability of the support schemes to achieve the DO assumed in the Portfolio.



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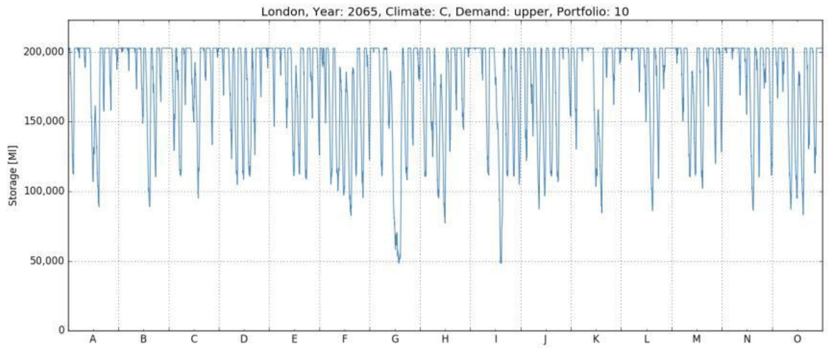
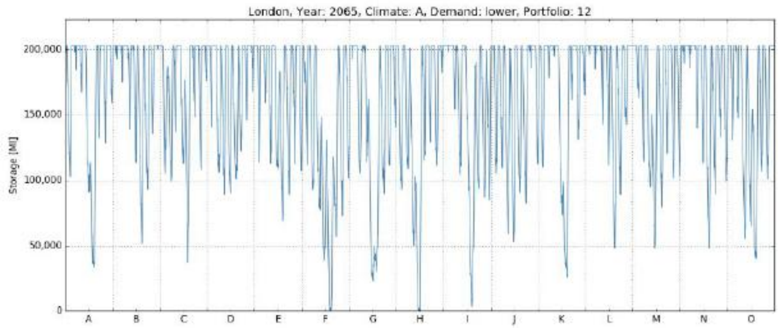
This improvement in resilience tends to come at the expense of Severn Trent, which was shown to be much more vulnerable to a variety of droughts, as shown below.

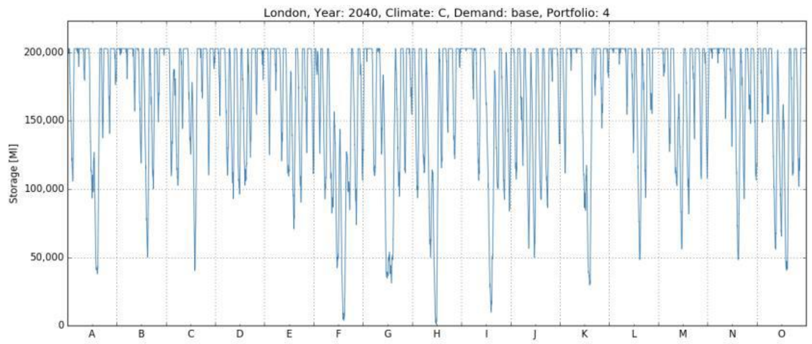


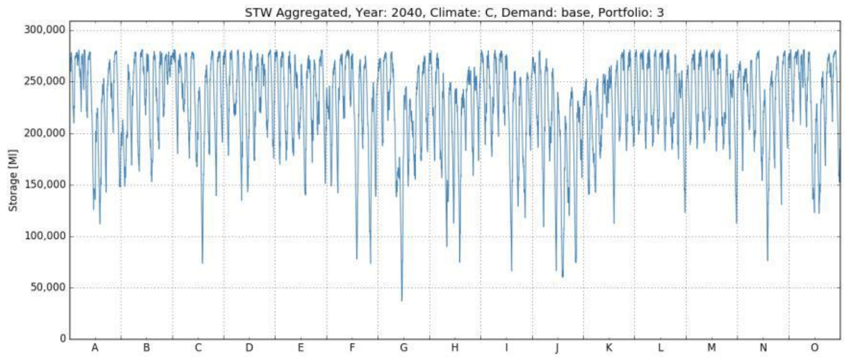
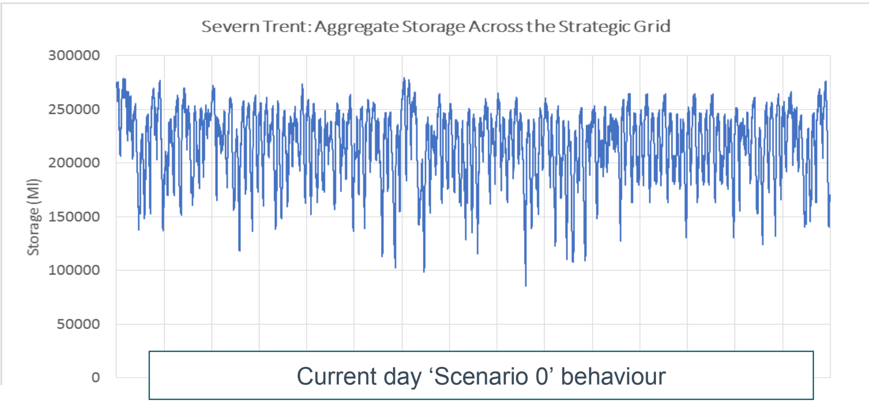
Obviously such findings are mainly a result of model set up, but it does highlight some of the complexities surrounding the management and transfer of risk that might have to be considered if large, supported, transfers start to result in a much greater degree of integration between Drought Regions in the future.

Finally, it was noted that the performance of Portfolios that relied on large volumes of transfer without adequate support (e.g. Portfolios 1, 12) continued to deteriorate below expectations as the impacts from climate change continued to grow.



</td></tr>
</table>

Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
	Options such as Portfolio 4, which rely on extended demand management to 'free up' demand in Severn Trent and reduce abstraction to allow larger amounts of *unsupported* transfer, do not appear to perform well, as shown below.  Where supported transfers are used, then this does not appear to have a detrimental impact on the resources in **United Utilities**, which remain well above the Level 4 control curve due to the relatively low severity of the Drought Compilations in that Region. Most of the Portfolios require the transfer of large volumes of water from **Severn Trent**, and this appears appropriate in terms of *residual* resilience in most cases, although the modelling indicated a risk of failure under portfolios 3 and 10, where the schemes such as the Draycote transfer result in large volumes being moved from the eastern side of the Strategic Grid across to the River Severn. The modelling also shows that the influence of climate change, combined with the movement of water from the eastern side of the system across to the Severn for transfer, results in a change to the 'risk profile' of the Severn –Trent system from one where it is clearly limited by localised risks and the frequency of TUBs, to one where there is more of a risk of absolute failure in aggregate storage across the system under more severe drought events. This is shown below, where Portfolio 3 is compared against the 'current' system, as evaluated through the 'Scenario 0' analysis. This is partly as	

Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
	a result of increased supply/demand balance stresses (the Portfolios do not plan for maintaining the surplus that is present in the current day situation), but partly as a result of more intense, widespread use of storage. This can be seen by examining the relative difference between the more severe drought events and the 'lesser' historic droughts – the size of this difference increases notably under the 2040 situation.  	

Sub-Region(s)	Key findings for the 2040 Portfolios	Key findings for the 2065 Portfolios
	Finally it is noted that many of the Portfolios assume that large volumes of water will be transferred between the Severn and the Thames, with volumes of between 400 and 500 Ml/d being assumed during all of the significant drought periods. There are a number of significant environmental, practical and institutional barriers associated with doing this, including: • Risks to environmental quality, particularly from invasive species • Risks to drinking water quality (in terms of treatment and implications for algal bloom risks in the Thames reservoirs) • Difficulties with ensuring that water that is stored for transfer via the Severn would actually reach the Thames. This is both a hydrological issue, but, more importantly an institutional issue. The modelling confirmed that abstraction by existing users would need to be maintained, so there would need to be an unprecedented level of co-operation between a number of stakeholders if existing storage within the Severn could be used. The above issues are all the subject of ongoing investigations, but the ‘take home’ finding from the resilience analysis was that, if a resilience system is to be created and those issues cannot be addressed within a reasonable timescale, then any transfer from the Severn would have to be supported by <u>new</u> storage, preferably located within the Thames to provide additional refill benefit.	

8.4. Infrastructure development subject to demand management strategy

As noted in Section 4.1, the development of conclusions relating to the potential nature of infrastructure development for this study was based on a combination of portfolio development, costing of the overall scenarios, resilience testing and evaluation of the practical constraints that might exist in relation to the various options that are available. This section therefore brings together all of those aspects to provide a summary of the nature of infrastructure development that is anticipated for each of the sub-Regions, **alongside the demand management savings that are anticipated to be achieved through the ‘extended’ or ‘Business as Usual’ demand management strategies** (discussed in Section 8.1.1). If ‘enhanced’ demand management strategies were adopted then this would reduce the supply-side investment proposals accordingly. Conversely if demand management were not to realise the savings that have been assumed then additional supply-side development may be required.

Where necessary the infrastructure developments have been grouped to reflect the potential strategic transfers that emerged from the portfolio development. Because it is not the intention of this study to replace WRMPs, all supply-side development has been described in semi-qualitative terms, quoted in very broad ranges (generally to the nearest 25 or 50Ml/d). It should be noted that potential barriers to, and technical challenges for, developing infrastructure associated with drinking water quality, environmental water quality and other environmental risks have not been considered in detail. This together with the necessarily high level options appraisal means that it should be noted that there is some uncertainty around the balance of option types in the tables below. Supply-side development has been broadly grouped into the following categories:

- Transfers into the sub-Region. This covers all transfers that need to be supported by trading agreements and/or support from third party resource infrastructure.
- ‘Conventional’ supply schemes. These cover surface water developments (including reservoir storage), and groundwater developments (including aquifer storage and recovery).
- Effluent re-use. These cover schemes that involve the treatment and transfer of effluent for subsequent re-abstraction, normally from existing river intakes.
- Desalination. This covers both full seawater desalination and brackish water estuary type developments.

Note: All of the summaries below use the following descriptive terms:

- ***‘Reasonably likely to need’*** *means that a given level of development is required if one of the more significant risks (such as drier climate change) materialises, even if ‘extended’ demand management strategies are adopted. Under a ‘business as usual’ demand management strategy these are relatively likely to be required if any risks beyond the medium forecasts materialise in the future.*
- ***‘May need’*** *refers to larger levels of infrastructure developments that become necessary as a result of two or more of the significant risks for that sub-Region materialising under the ‘extended’ demand management scenario, or as a result of one of those risks materialising under a ‘Business as Usual’ demand management scenario.*

For desalination and effluent re-use, where there is a relatively limited chance that this would be required at a particular time horizon, then this has been categorised into ‘unlikely to be needed’, which means that there are a few combinations of more severe futures where some development may be needed, versus ‘very unlikely’ which means that they are only required under the most adverse future circumstances.

It should be noted that these levels of development ***are in addition to ‘committed’ schemes that are scheduled within AMP6 and AMP7*** *(i.e. up to 2025).*

The tables below demonstrate potential need up to the ‘severe’ drought resilience level. If ‘extreme’ resilience is chosen as a policy then infrastructure development needs would increase accordingly.

Summaries according to each sub-Region are provided in the sections below. These are presented in general terms, and more information on the schemes that could contribute at the different levels of severity and risk are provided in Appendix D to this report.

8.4.1. South East Excluding London

The portfolio development indicates that, because of the potentially large deficits in London, the majority of the potential future deficits in this sub-Region will need to be met through a combination of ‘indigenous’ resource development and demand management. A significant amount of *intra*-Regional transfers are anticipated to be required. This is one of the primary focuses of the Water Resources in the South East (WRSE) group, who will be examining needs at a much more detailed level than were required as part of this study.

Table 8-6 and Table 8-7 provide a summary of the strategic position at 2040 and 2065 (based on an assumption that extended or BAU demand management strategies would be pursued).

Table 8-6 Summary of SEEL options development for 2040

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)	
Business As Usual	Extended
80 to 100Ml/d	180 to 280Ml/d

Breakdown of Potential Supply Side Developments		
Type of scheme	Usage – 2040 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	Reasonably likely to need some (less than 50Ml/d). May need more than 50Ml/d Total *inter*-regional transfers (between water companies in the sub-Region) are likely to be much higher than this.	The portfolio analysis indicated a potential transfer from Wessex to Bournemouth and then to Southern Water's western area. The feasibility of this is not clear, and may need to be replaced by either bringing forward some of the conventional options or developing and transferring resources in Thames.
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 75Ml/d. May need around 130Ml/d.	Does potentially include some new reservoir and reservoir raising schemes.
Effluent re-use	Reasonably likely to need up to 50Ml/d. May need up to 100Ml/d.	Reasonable level of development; no specific issues.
Desalination	Reasonable chance none required. May need around 50Ml/d.	Largely depends on the extent of reductions in abstraction to protect the aquatic environment.

Table 8-7 Summary of SEEL options development for 2065

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)	
Business As Usual	Extended
160 to 230Ml/d	290 to 460 Ml/d

Breakdown of Potential Supply Side Developments		
Type of scheme	Usage – 2065 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	Reasonably likely to need around 50-150Ml/d. May need between 50 and 200Ml/d. Total *inter*-regional transfers (between water companies in the sub-region) are likely to be much higher than this	Larger volumes are associated with some resource development or extended demand management reductions in Wessex to support transfers. Realistically this may be more reasonably likely to be supported via development and transfer in Thames-London.
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need up to 150Ml/d. May need most feasible schemes.	Includes a number of new reservoir and reservoir raising schemes.
Effluent re-use	Reasonably likely to need up to 75Ml/d. May need around 100 to 150Ml/d.	Reasonable level of development across a number of different river basins; no specific issues.
Desalination	May need up to 150 to 200Ml/d.	Largely depends on the extent of reductions in abstraction to protect the aquatic environment.

8.4.2. Anglian sub-Region

The development of options for this sub-Region are dominated by the potential transfer and storage of raw water from the River Trent, and the amount of transfer out that is required for the Affinity Water London sub-Regions. Without this raw water source then much larger storage (e.g. more than one new reservoir) and/or more expensive sources (additional effluent re-use) is reasonably likely to be required.

Table 8-8 and Table 8-9 provide a summary of the strategic position at 2040 and 2065 (based on an assumption that only BAU or extended demand management strategies would be pursued).

The analysis covers all WRZs within the Anglian sub-region, including Essex & Suffolk and Cambridge Water.

Table 8-8 Summary of Anglian options development for 2040

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
60 to 80Ml/d	80 to 130Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage – 2040 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	None – raw water transfers considered as conventional schemes because third parties not necessarily involved.	The main potential transfer is raw water in from the River Trent, which would not require support from other water companies. Intra-regional transfers to the Essex/Suffolk area are reasonably likely to be required.
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need up to 200Ml/d.	Incorporates transfer and storage from the River Trent. This would result in a large scale scheme, so additional development would only be needed under the worst future scenarios. If such a scheme is not viable then it would need to be replaced by additional storage and some effluent re-use.
Effluent re-use	Very unlikely that this would be needed.	See above – some may be required if Trent storage and transfer cannot deliver significant yield.
Desalination	Very unlikely that this would be needed.	Unlikely to be needed even if Trent storage and transfer is not viable.

Table 8-9 Summary of Anglian options development for 2065

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
120 to 170Ml/d	150 to 240Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2065 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	None – raw water transfers considered as conventional schemes because third parties not necessarily involved.	As above for 2040.
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 200Ml/d. May need 250 to 400Ml/d.	Generally the same as for 2040, but with additional schemes needed under the more severe 2065 future scenarios.
Effluent re-use	Reasonable chance none required. May need up to 50Ml/d.	Some potential need for the more severe futures.
Desalination	Very unlikely that this would be needed.	As above, although this would have to form a 'back stop' if a Trent transfer and storage scheme is not viable.

8.4.3. London (Thames and Affinity)

There are two key strategic considerations that affect the nature of potential development for this sub-Region:

- The viability and size of potential, supported (i.e. with dedicated storage) transfers from the Severn to the Thames. Single options could require complex control rules and transaction arrangements, and there are a number of future scenarios where more than one such support scheme would be required, which would introduce further complexities.
- The amount of Affinity Water's needs that can be supplied from the Anglian sub-Region. Under most of the portfolios that were developed, the Affinity-London deficits are primarily supported by Anglian, but the resilience testing indicated that significant network enhancement and reconfiguration would be required to achieve this under the more severe future scenarios. It is therefore reasonably likely that additional development within Thames-London sub-Region would be required to support Affinity Water. This has been reflected in the assessment tables below by adjusting the 'reasonably likely' and 'may need' classifications where appropriate.

Both of these considerations mean that there is a strong possibility that even more 'local' development is reasonably likely to be required beyond that indicated in the simple portfolio assessment, and this has been reflected in Table 8-10 and Table 8-11, which provide a summary of the strategic position at 2040 and 2065.

Table 8-10 Summary of London options development for 2040

<table>
<tr><th colspan="3">Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)</th></tr>
<tr><td colspan="2">Business As Usual</td><td>Extended</td></tr>
<tr><td colspan="2">110 to 150Ml/d</td><td>280 to 460Ml/d</td></tr>
<tr><th colspan="3">Breakdown of Potential Supply Side Developments</th></tr>
<tr><td>Type of scheme</td><td>Usage - 2040 (allowing for severe resilience)</td><td>Notes and constraints analysis</td></tr>
<tr><td>Transfer into sub-Region</td><td>Reasonably likely to need between 50 and 250Ml/d (yield).
May need around 200 to 400Ml/d (yield).</td><td>The lower values could be supported by a single storage option (Vyrnwy has the lowest AISC), but the upper values would require multiple storage schemes to support the transfers (i.e. United Utilities Vyrnwy and Middle Severn schemes).</td></tr>
<tr><td>‘Conventional’ (reservoir, SW, groundwater)</td><td>Very dependent on transfers and viability of effluent re-use; need varies between zero and 350Ml/d.</td><td>The key uncertainty remains around the upper Thames reservoir, which is the main ‘conventional’ local development. This will need to be brought forward if there are any issues (including cost pressures) with either transfers or effluent re-use.</td></tr>
<tr><td>Effluent re-use</td><td>Reasonably likely to need up to 200Ml/d.
May need around 400Ml/d.</td><td>The higher levels of effluent re-use development may not be feasible.</td></tr>
<tr><td>Desalination</td><td>Unlikely to be required.</td><td>(N.B. The Becton scheme is included within baseline yields.)</td></tr>
</table>

Table 8-11 Summary of London options development for 2065

<table>
<tr><th colspan="3">Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)</th></tr>
<tr><td colspan="2">Business As Usual</td><td>Extended</td></tr>
<tr><td colspan="2">240 to 340Ml/d</td><td>460 to 780Ml/d</td></tr>
<tr><th colspan="3">Breakdown of Potential Supply Side Developments</th></tr>
<tr><td>Type of scheme</td><td>Usage - 2065 (allowing for severe resilience)</td><td>Notes and constraints analysis</td></tr>
<tr><td>Transfer into sub-Region</td><td>May need between 100 and 550Ml/d yield.</td><td>Potentially unrealistic to go beyond this level, but higher values may need to be considered in combination with storage within the Thames basin if upper growth and climate change conditions occur.</td></tr>
<tr><td>‘Conventional’ (reservoir, SW, groundwater)</td><td>As above for 2040.</td><td>See above for 2040, although it is noted that even with high levels of transfer and effluent re-use, reservoir development may be needed by 2065.</td></tr>
<tr><td>Effluent re-use</td><td>Reasonably likely to need around 350Ml/d.
May need up to 600Ml/d.</td><td>The upper values may not be feasible or acceptable on environmental or water quality grounds.</td></tr>
<tr><td>Desalination</td><td>May need around 150 to 200Ml/d.</td><td></td></tr>
</table>

8.4.4. Central-West and North West Regions

The level of resource development across these two Regions is affected by both ‘local’ need, particularly in Severn-Trent, and the amount of water that may be transferred to the Thames. Requirements are therefore highly variable, and the two Regions have been amalgamated to indicate the total amount of development (i.e. transfers between the regions have not been separated out, as much of this then goes on to support London). Table 8-12 and Table 8-13 provide a summary of the strategic position at 2040 and 2065.

It should be noted that the analysis only includes the SEWCUS WRZ for DCWW and excludes the Eden & Carlisle WRZs for UU.

Table 8-12 Summary of Central-West and Northwest options development for 2040

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
120 to 170Ml/d	160 to 450Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2040 (allowing for severe resilience)	Notes and constraints analysis
Transfer into Region	N/A	See introductory notes above – transfers between Northwest and Central West are an integral part of the strategy
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 250Ml/d. May need up to 680Ml/d.	The 'reasonably likely' category could be met by just one of the more cost effective transfer support options, whereas the 'may need' would require multiple storage options, plus options within United Utilities and Severn Trent to support their own 'local' requirements, and possible support from DCWW. Most of the development is split approximately evenly between United Utilities and Severn Trent.
Effluent re-use	May need up to 10Ml/d.	Small scale, expensive compared to more conventional options.
Desalination	Very unlikely to be required.	

Table 8-13 Summary of Central-West and Northwest options development for 2065

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
250 to 380Ml/d	330 to 710Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2065 (allowing for severe resilience)	Notes and constraints analysis
Transfer into Region	N/A	See introductory notes above – transfers between Northwest and Central West are an integral part of the strategy
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 680Ml/d. May need around 1000Ml/d.	The 'reasonably likely' involves United Utilities, Severn Trent and DCWW options as discussed under 2040. Under drier climate futures and higher reductions in abstraction to protect the environment (i.e. 'possible'), then the majority of the Severn-Trent schemes are needed, and large volumes of development are required in United Utilities. Additional transfer routes involving the River Dee, or possibly options such as the development of Welsh reservoirs may become necessary.
Effluent re-use	Reasonably likely to need up to 10Ml/d. May need around 100Ml/d.	Under most future scenarios there is still limited need for effluent re-use.
Desalination	Still very unlikely.	

8.4.5. South-West Region

This is relatively self-contained in terms of development needs, with the only potential inter-regional transfers being out towards SEEL. Intra-regional transfers are needed between Wessex and Bristol under most future scenarios. It should be noted that, to date, there has not been a driver to investigate supply options within South West Water, so options may be available for transfer from either Wimbleball or Roadford following more detailed investigation. Table 8-14 and Table 8-15 provide a summary of the strategic position at 2040 and 2065.

It should be noted that the quantified analysis only includes values from the Bristol, Bournemouth and Wessex WRZs. This includes the demand management figures.

Table 8-14 Summary of Southwest options development for 2040

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
30 to 40Ml/d	60 to 90Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2040 (allowing for severe resilience)	Notes and constraints analysis
Transfer into Region	Not required.	N.B. Intra-regional transfers of at least 10Ml/d from Wessex to Bristol are reasonably likely to be required
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need up to 20Ml/d. May need around 50Ml/d.	The need at 2040 depends to a certain extent on transfer options and exact levels of forecast demand. Some conventional resource development is reasonably likely to be required if transfers from Wessex are limited to the 10Ml/d option described in WRMP14. Additional options may be needed by 2040 if higher growth occurs.
Effluent re-use	Not required.	
Desalination	Not required.	

Table 8-15 Summary of Southwest options development for 2065

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
60 to 80Ml/d	90 to 150Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2065 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	Not required.	N.B. Intra-regional transfers of at least 10Ml/d from Wessex to Bristol are reasonably likely to be required
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need up to 50Ml/d. May need up to 175Ml/d.	Reasonably likely to require the key 'conventional' options prior to 2065, with much larger levels of development needed under drier climates or higher growth scenarios.
Effluent re-use	Possibly need up to 50Ml/d.	This is the main 'support' development option if drier/worse futures occur post 2040.
Desalination	Unlikely to be needed.	The higher growth and drier climate scenarios may require some desalination, but only if abstraction reductions are required as well.

8.4.6. Yorkshire

This region remains self-contained under all future scenarios. Transfers from Northumbrian to Yorkshire have been separated out for ease of identification. Table 8-16 and Table 8-17 provide a summary of the strategic position at 2040 and 2065.

As Northumbrian is considered only in relation to its potential role as supplier, the demand management values do not include Northumbrian Water.

Table 8-16 Summary of Yorkshire options development for 2040

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
50 to 60Ml/d	90 to 170Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2040 (allowing for severe resilience)	Notes and constraints analysis
Transfer into Region	Reasonably likely to need up to 50Ml/d. May need around 100Ml/d.	First stage River Tees transfer is reasonably likely to be needed by 2040.
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 50Ml/d. May need around 100Ml/d.	Key uncertainty is around climate change & growth forecasts.
Effluent re-use	Not required.	
Desalination	Unlikely to be required.	

Table 8-17 Summary of Yorkshire options development for 2065

Demand Management Strategy Savings Assumed (absolute value, including leakage reduction)		
Business As Usual	Extended	
100 to 140Ml/d	150 to 260Ml/d	
Breakdown of Potential Supply Side Developments		
Type of scheme	Usage - 2065 (allowing for severe resilience)	Notes and constraints analysis
Transfer into sub-Region	Reasonably likely to need around 100Ml/d. May need more if other options are not viable.	Larger transfers are relatively remote from the areas of need, but could still be more viable than effluent re-use or desalination (depending on future network configurations, etc.)
'Conventional' (reservoir, SW, groundwater)	Reasonably likely to need around 100Ml/d. May need around 150 to 200Ml/d.	As above.
Effluent re-use	May need around 100Ml/d.	Potentially supplied by transfers from Kielder instead (see below).
Desalination	May need around 50 to 100Ml/d.	Potentially supplied by transfers from Kielder instead (see below).

8.5. Assessing consequences – what are the economic and environmental consequences of different strategies?

The analyses provided in this section are all derived from the **consequence models** described in Section 4.7. Three different approaches have been used to analyse the consequences and cost/benefit ratios of different levels of Portfolio development. These are described, in turn, in the sections below.

Two of the Drought Deficit sub-Regions have not been subject to the same consequence and economic analysis as the other sub-Regions:

- The **Affinity-London** sub-Region only has a few groundwater sources that are potentially vulnerable to drought risk, so there is insufficient information to derive a relationship between available storage and drought severity, and hence generate the relevant consequence model. Whilst this means that it is generally resilient to drought and climate change risk, a review of the nature of the groundwater hydrographs in the region indicates that any significant supply/demand imbalance caused by unsatisfied growth or un-mitigated sustainability reductions would result in frequent and very long demand restrictions (4 months, or more, Level 4 restrictions during any moderate event).

- The **Yorkshire** Region already plans for a level of resilience equal to an extreme event. It was not therefore possible to develop the same consequence models as were developed for the other Drought Deficit Regions. Quantitative analysis of the case for resilience has therefore concentrated on the cost per household to maintain this level of resilience into the future (see Section 8.2) and the Robustness Evaluation Tool (RET) analysis of the Portfolios that were costed to generate that analysis (see Section 8.3).

8.5.1. Probability/consequence outputs

The first type of analysis that was carried out was an evaluation of the level of drought risk that the water supply systems could face in 2040 if the ‘standard’ or ‘conventional’, central estimate, WRMP14 planning assumptions are maintained. This analysis provides an understanding of the relative level of risk that results from each of the four key future challenges (inherent drought risk, climate change, growth and environmentally-driven abstraction changes), which is useful when policy decisions are being made about the amount of expenditure that might reasonably be deferred through monitoring and associated adaptation (i.e. through the periodic Water Resource Management Plan review process).

For the purposes of this report, ‘standard’ or ‘conventional’ central estimate planning assumptions mean that a system is planned to be resilient to:

- Medium growth, median climate change and baseline sustainability reductions.

- No ‘Level 4’ failure during the worst drought in the historic record, perturbed for climate change.

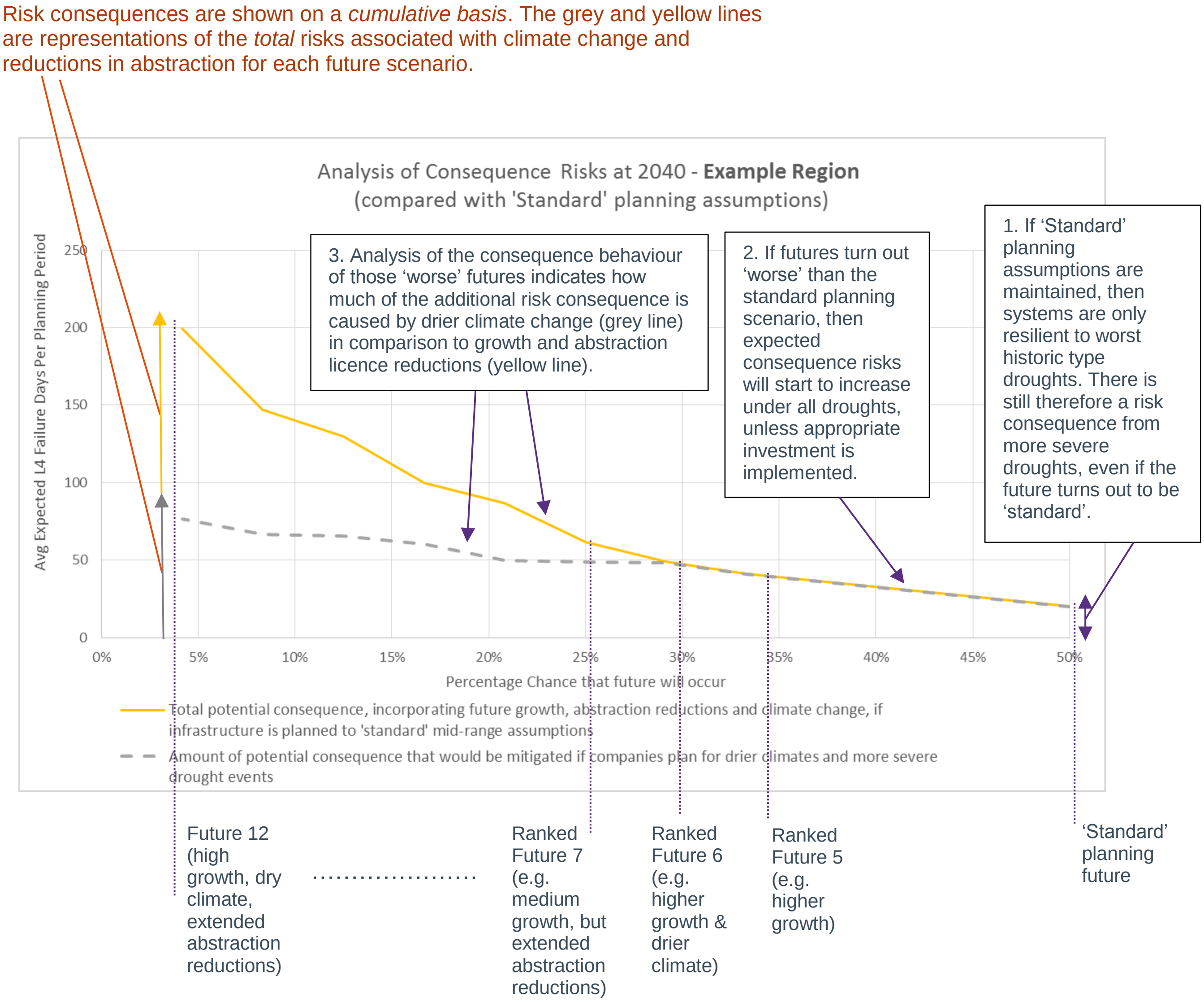
- A basic allowance for uncertainty (Target Headroom, set at the WRMP14 value) and a typical allowance for potential outages of critical resources during drought periods (WRMP14 outage allowances).

The analysis therefore concentrated on estimating the **probability weighted consequence** that could be *expected* from future scenarios where the supply/demand balance is worse than the ‘conventional’ central-estimate future. It should be noted that this was assessed relative to a supply/demand balance of zero under that future – i.e. for sub-Regions such as Anglian it was assumed that surpluses were already used to transfer and support other sub-Regions (this is reasonable, as all futures that are worse than the one anticipated by the ‘conventional’ central-estimate scenario *do* require the use of surplus DO to support other sub-Regions).

The probability/consequence charts for each Drought Deficit sub-Region are presented in the sections below. Information on how to interpret these charts is provided in Figure 8-35 below. Because Donor and Transfer sub-regions are typically those that already have a surplus in the ‘baseline’ and the transfer of water does not create deficits, these were not tested to the same level of resilience risk analysis as other regions. As a result, the potential impact of supply/demand deficits on the frequency and duration of Level 4 failures were not available to input to the consequence models.

Figure 8-35 Example Probability-Consequence Chart

This chart is a graphical representation of the way in which expected consequences would increase if a water company maintained its current **'standard'** planning assumptions (medium growth, median climate change and baseline environmentally-driven abstraction changes) in the face of futures that turned out to be worse than those assumptions. The X axis shows the probability that a given type of future might occur, and the Y axis represents the number of level 4 days over a typical planning period (25 years) that would be expected if each future developed *but where there was **no additional investment** to adapt to it*. It should be noted that the Y axis is simply a convenient way of showing risk.



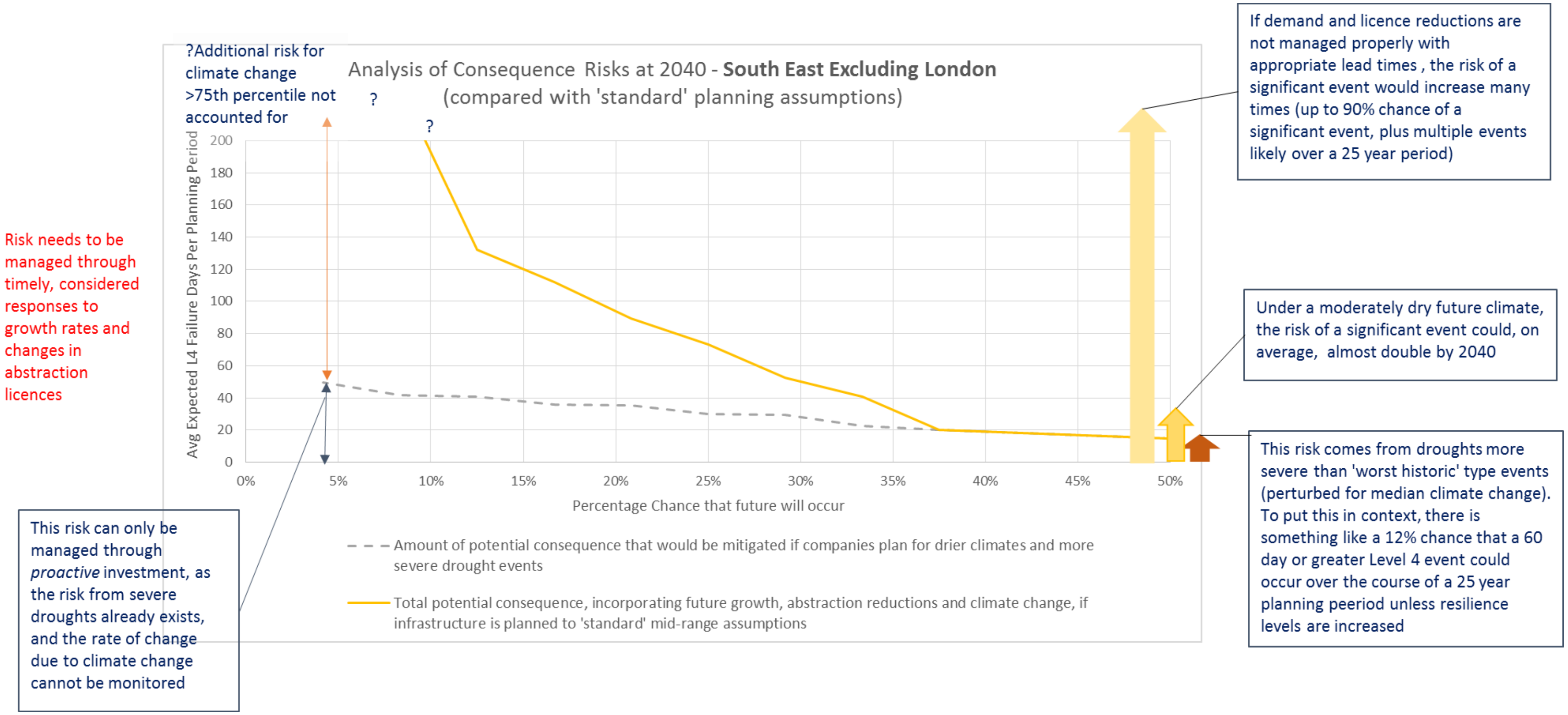
Note the 'standard' planning assumption has been assigned a probability of 50%, as it represents medium growth and climate change plus baseline reductions in abstraction. Between there and Future 5 there will be a combination of lower growth but drier climate change, wetter climate change but high growth and abstraction reduction futures etc. Because the wetter climate futures were not modelled, the line between the standard planning assumption and Future 5 is therefore nominal. Beyond that the probability of a given future being exceeded reduces by approximately 4% according to increasing severity of that future.

8.5.1.1. Probability/consequence output: South East excluding London (SEEL).

The probability/consequence chart for this sub-Region is provided in Figure 8-36 below. This indicates that:

- The risk at 2040 is dominated by uncertainties over growth and sustainability reductions. These could result in a very large increase in consequence risk, particularly if reductions in abstraction are not managed properly with sufficient lead time. If these risks are not managed then this could result in expenditure that is much higher than that suggested by the Portfolio analysis in Section 8.2.3, or frequent, severe demand restrictions under even relatively small droughts.
- The risks from a drier than median climate change are relatively modest, but could still double the consequence risk at around the 25th percentile.

Figure 8-36 Probability/consequence output for the South East excluding London sub-Region



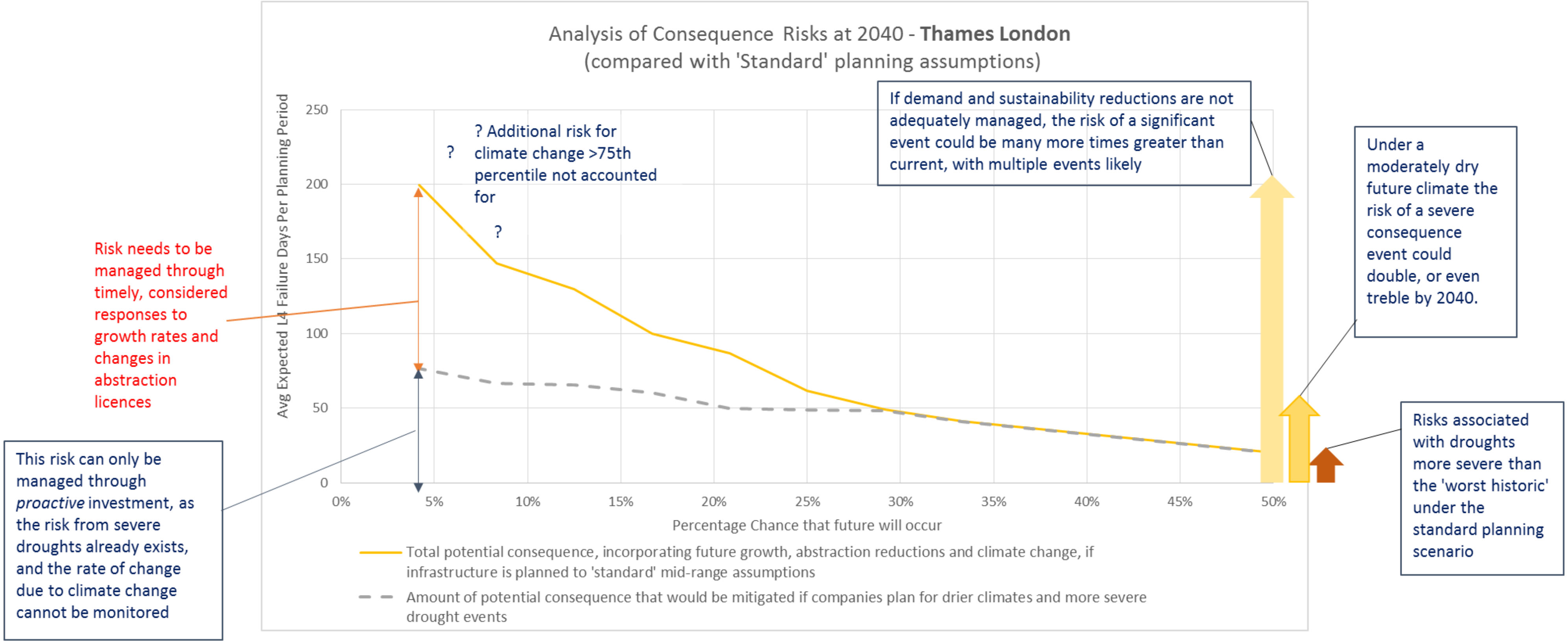
8.5.1.2. Probability/consequence output: Thames-London.

The probability/consequence chart for this sub-Region is provided in Figure 8-37 below. This indicates that:

- By 2040 growth, reductions in abstraction and climate change all lead to a considerable risk for the supply/demand balance. Failure to address these (delay in planning / implementation of schemes) results in a significant increase in consequence risk, even under moderate droughts, particularly if growth and reductions in abstractions are not managed with sufficient lead time for investigations and enabling actions.

- The risks from a drier than median climate change are relatively high for this sub-Region, resulting in a potential doubling or even trebling of consequence effects if it is not mitigated.

Figure 8-37 Probability/consequence output for the Thames-London sub-Region

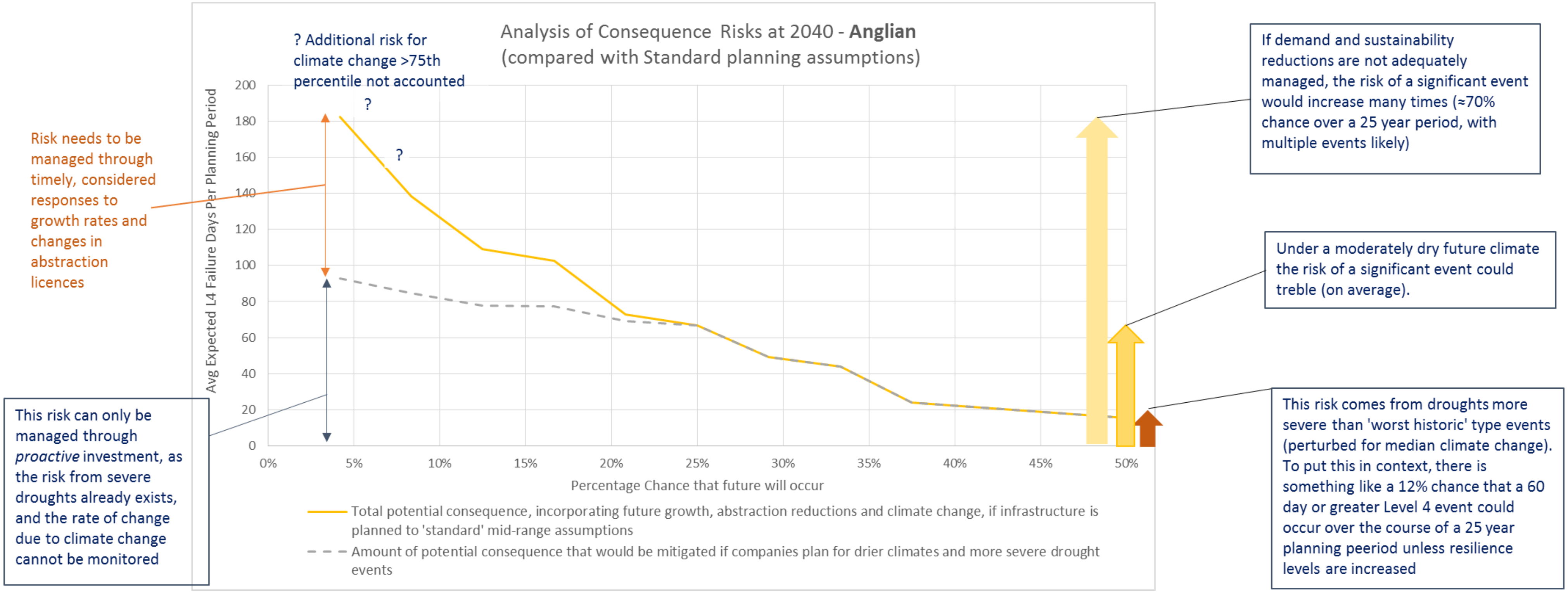


8.5.1.3. Probability/consequence output: Anglian

The probability/consequence chart for this sub-Region is provided in Figure 8-38 below. This indicates that:

- The risk at 2040 is dominated by climate change, although growth and sustainability reductions could add considerably to the risk if they are not managed properly with appropriate lead times and enabling actions.
- The risks from a drier than median climate change are very high for this sub-Region, with the risk of a severe consequence event trebling 2040 under a dry climate.

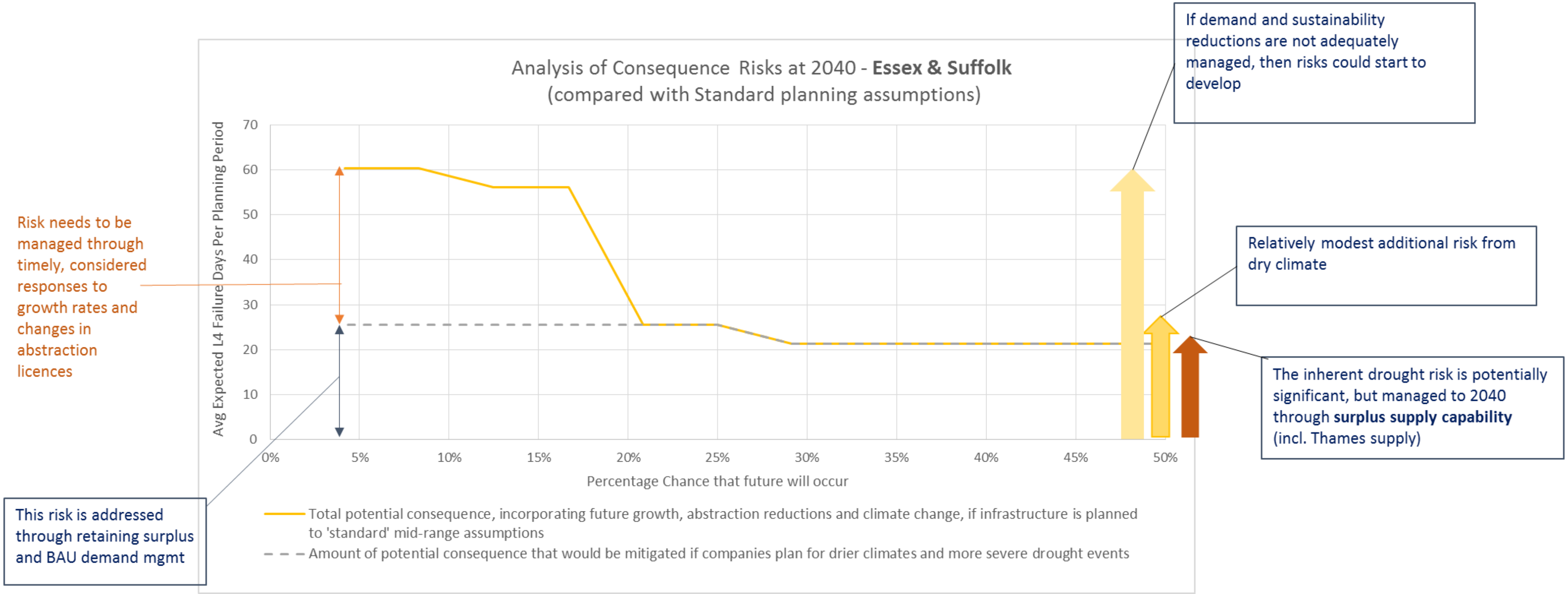
Figure 8-38 Probability/consequence output for the Anglian sub-Region



8.5.1.4. Probability/consequence output: Essex sub-Region

The probability/consequence chart for this sub-Region is provided in Figure 8-39 below. This indicates that the change in risk from the current situation is largely dominated by potential reductions in abstraction to protect the aquatic environment (also referred to as 'sustainability reductions'), which would significantly increase the consequences of drought if they are not properly planned for. Growth and climate change risks are both relatively modest.

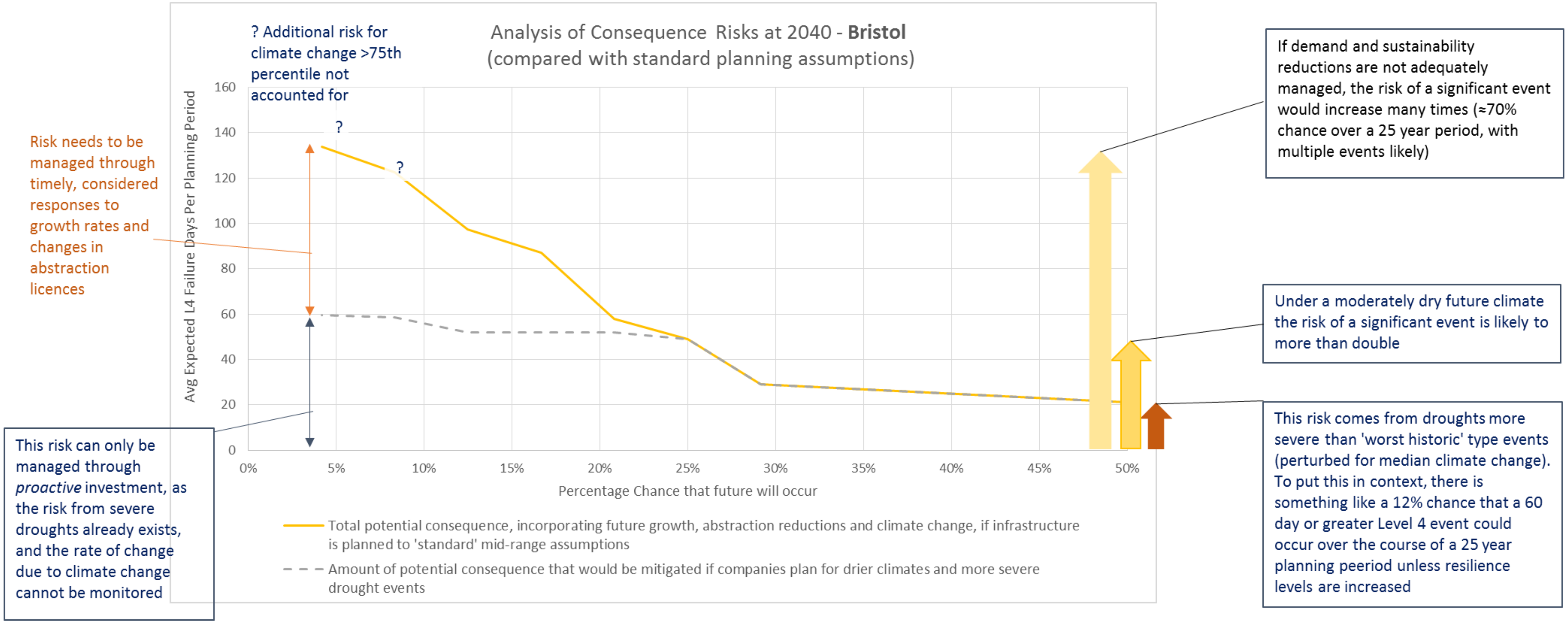
Figure 8-39 Probability/consequence output for the Essex sub-Region



8.5.1.5. Probability/consequence output: Bristol sub-Region

The probability/consequence chart for this sub-Region is provided in Figure 8-40 below. This has a similar risk profile to the Thames-London sub-Region, as described above, but it should be noted that currently Bristol Water does not use 'conventional' planning assumptions, but rather plans for a higher level of risk as it would anticipate significant demand restrictions if it experienced a drought severity similar to the worst historic (perturbed for climate change).

Figure 8-40 Probability/consequence output for the Bristol sub-Region



8.5.2. Cost/benefit analyses – analysis of portfolios

Based on the allocation of costs to each sub-Region, as discussed in 8.2, comparisons of the NPV of the costs (including environmental and social costs) of developing each 2040 Portfolio under the 'BAU' demand management strategy, compared with the expected central estimate of the economic consequences of adopting each Portfolio are provided in Figure 8-42 to Figure 8-44 below.

This analysis concentrates on the 36 Portfolios that were developed to meet the supply/demand deficits that could be expected in each of the *future scenarios,* given the adoption of a 'Business as Usual' demand management strategy. As noted previously, the BAU set of Portfolios was used because these were generally the most cost effective across all of the future scenarios, so this ensured that cost/benefit analyses were appropriately conservative. As a reminder, the makeup of the 36 *future scenarios* is illustrated below.

Figure 8-41 Development of the 36 future scenarios (copied from Section 4)

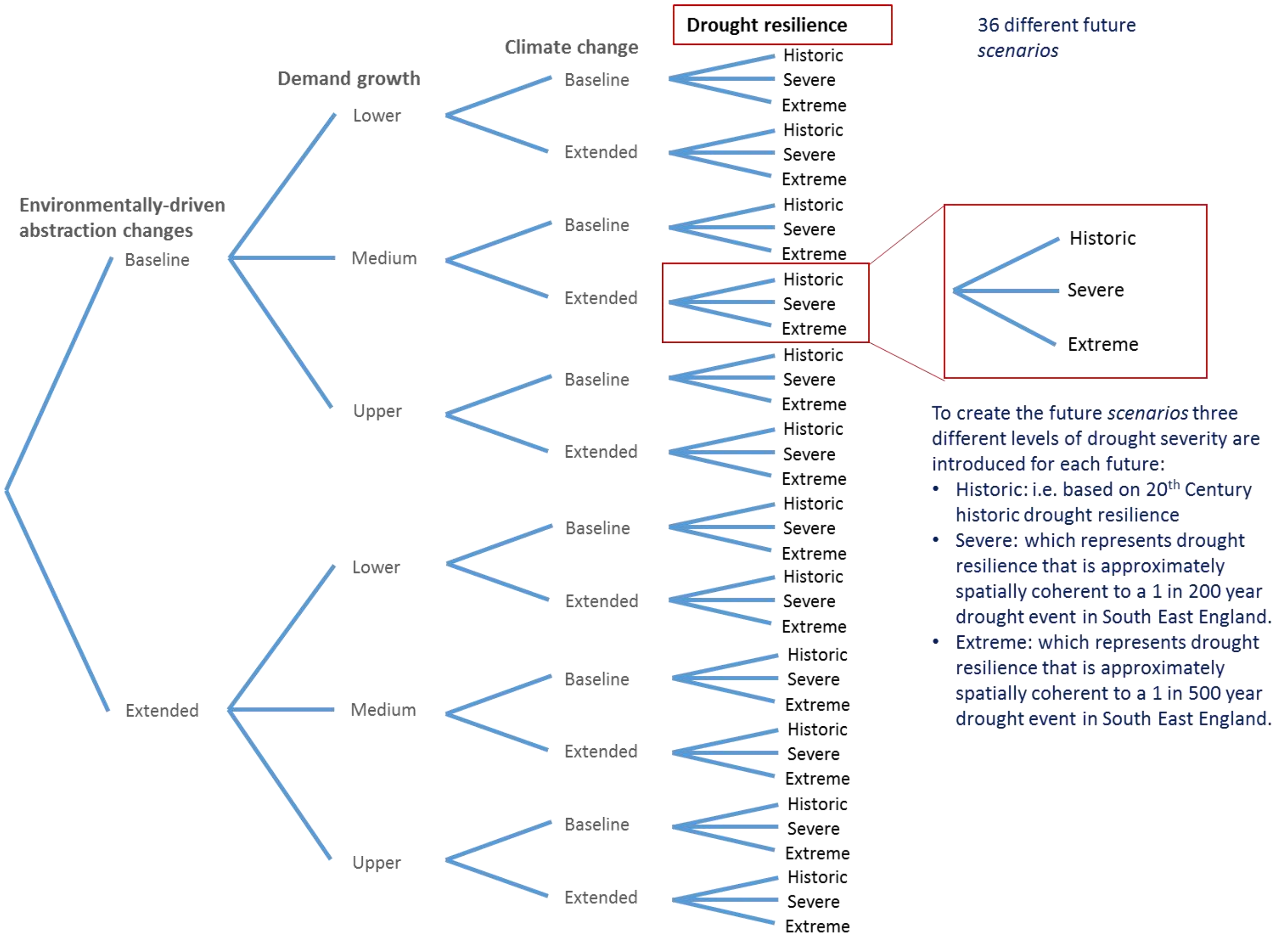
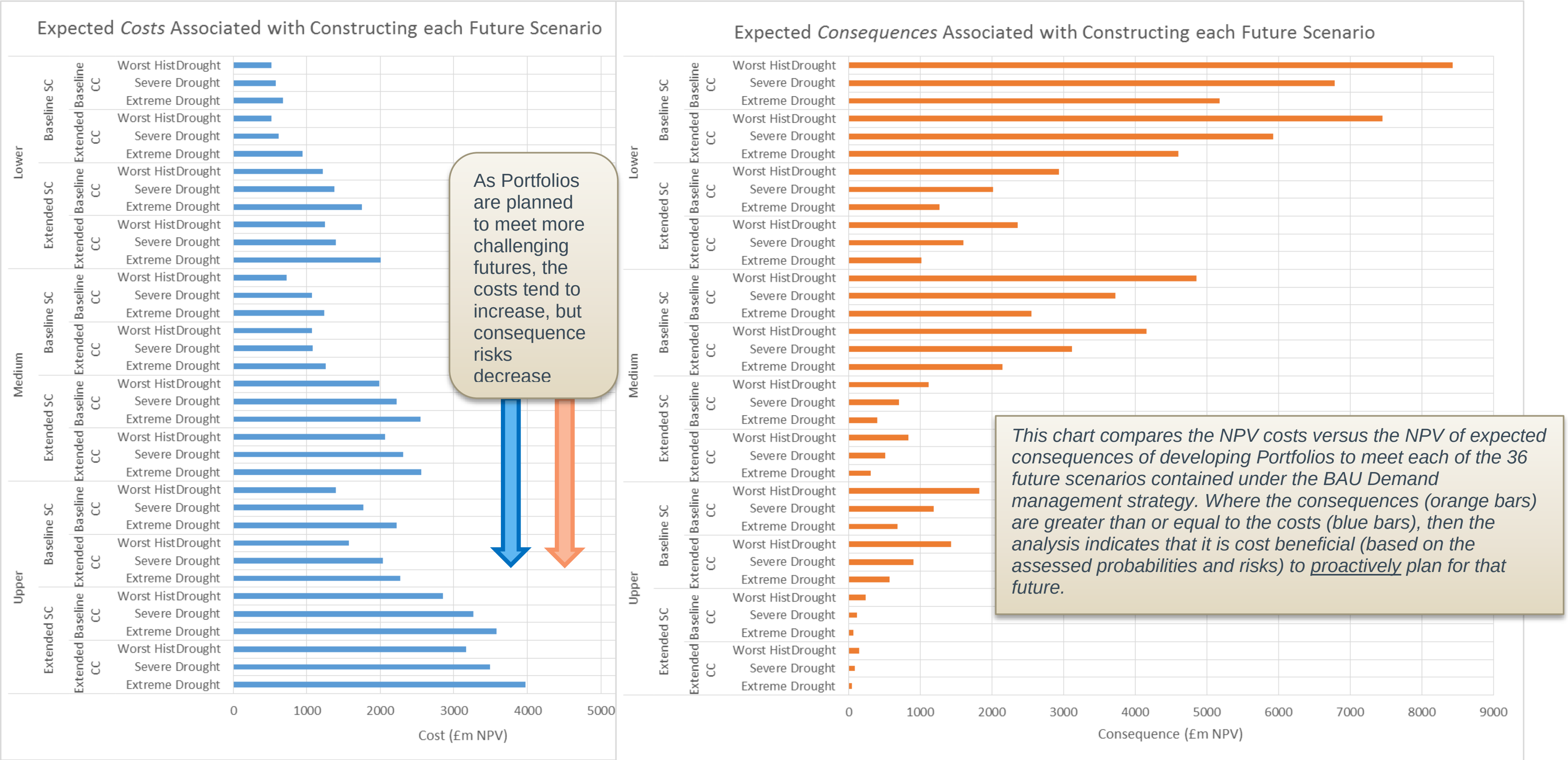
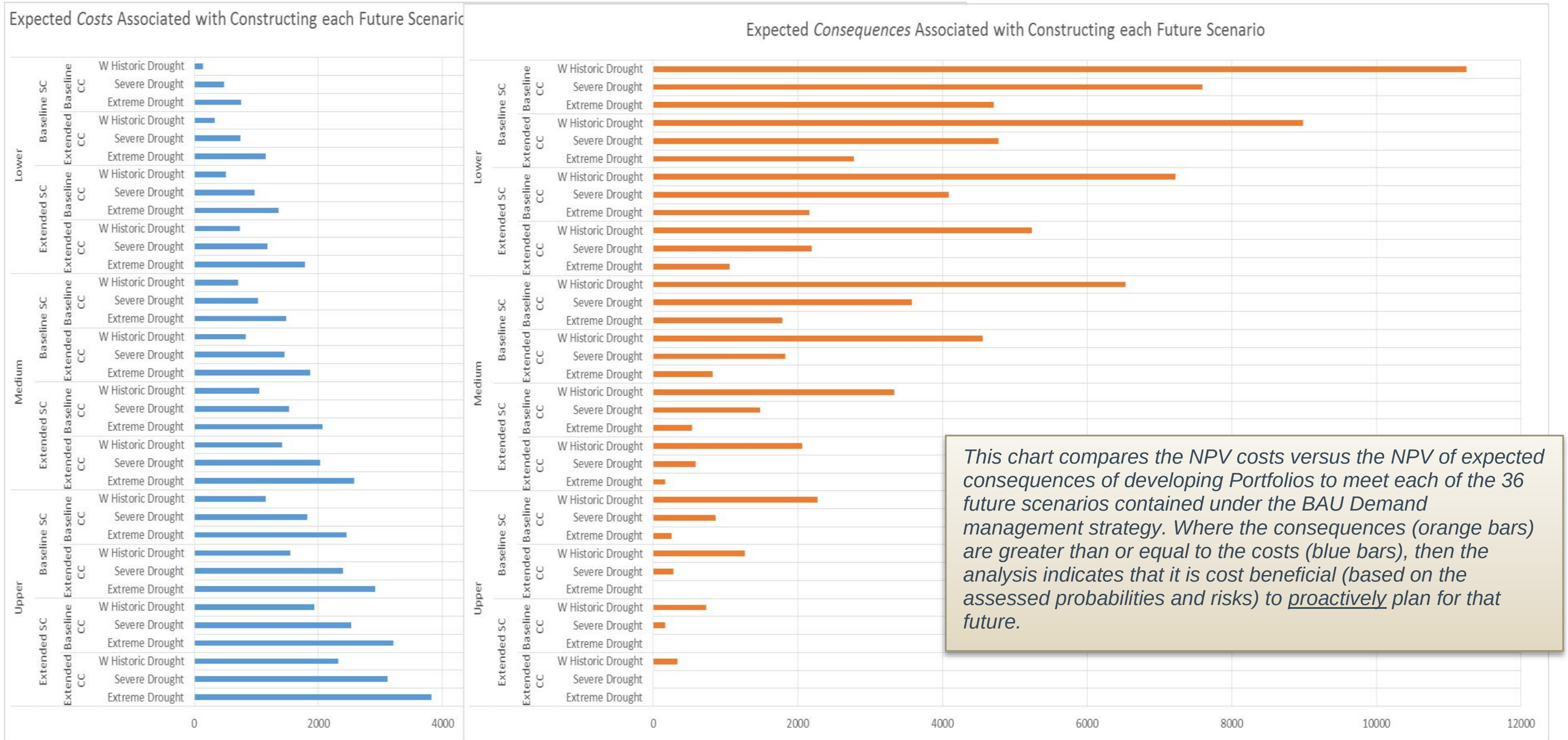


Figure 8-42 NPV cost/benefit comparison for the South-East Excluding London



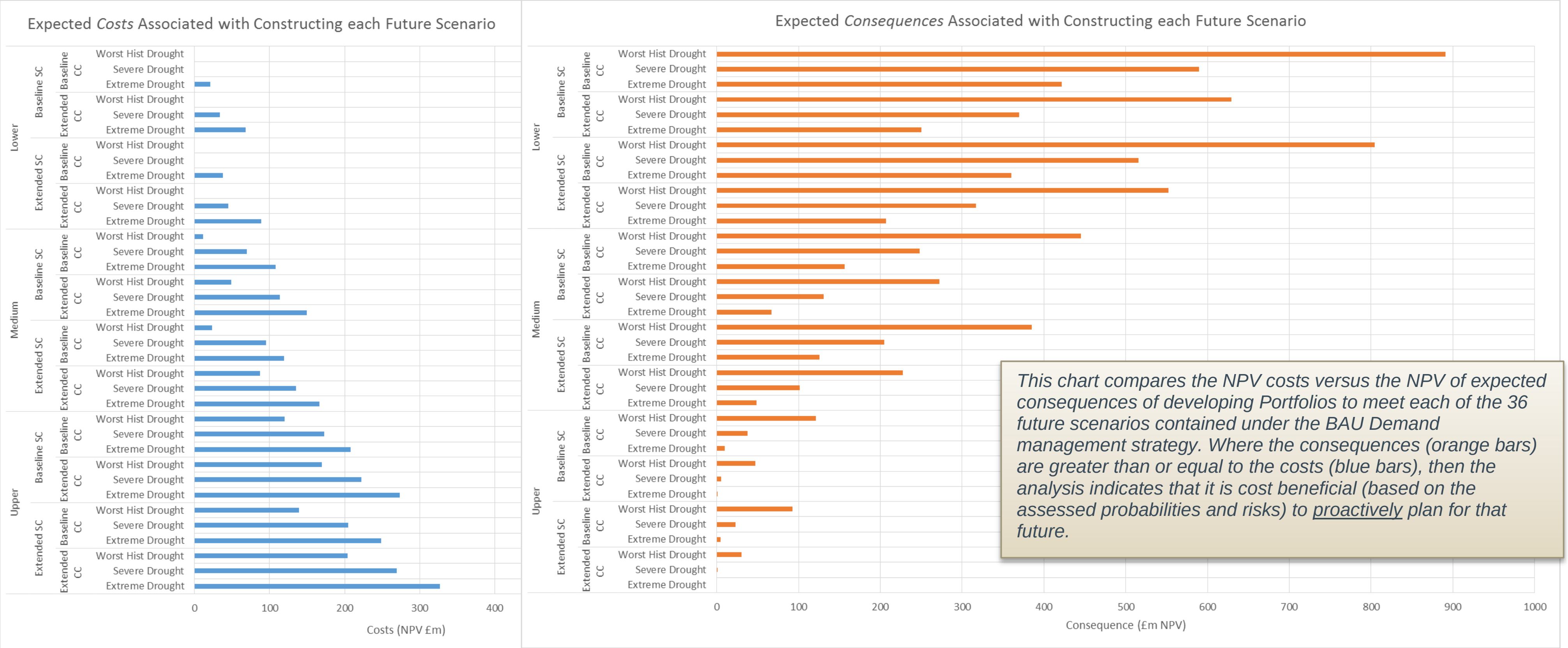
For the SEEL sub-Region this demonstrates the dominance of uncertainty in abstraction reduction scenarios, and indicates that it may not be *economically* prudent to proactively plan for ‘extended’ abstraction reduction scenarios in advance of any regulatory decision (i.e. better to adopt a ‘wait and see’ approach). Similarly it indicates that a ‘wait and see’ approach to managing higher levels of growth may be advisable, particularly if increased resilience is planned for. Under the baseline abstraction reduction and medium growth scenarios, it does suggest that, in economic terms, it is worth considering planning for both drier climates and ‘severe’ or even ‘extreme’ droughts.

Figure 8-43 NPV cost/benefit comparison for the Thames-London sub-Region



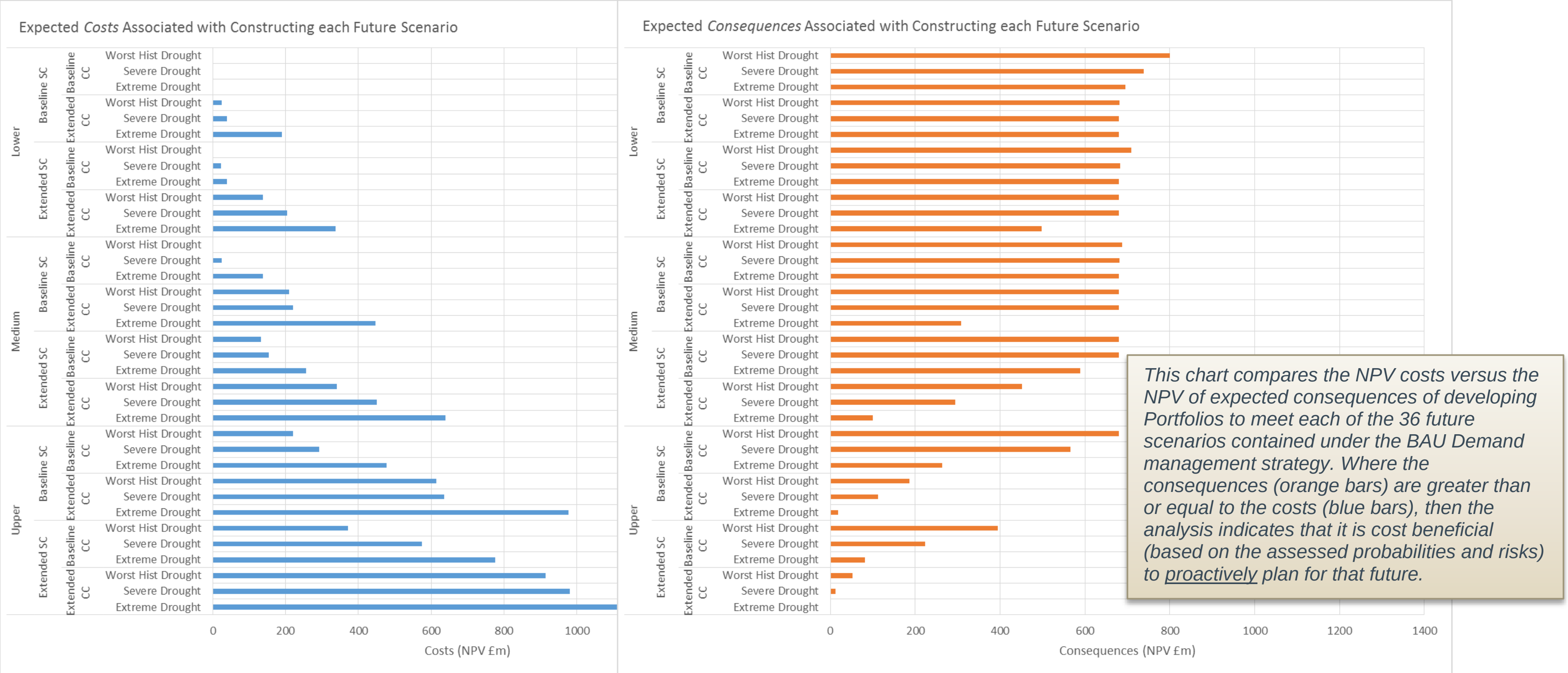
This chart reflects the high consequences associated with drought risk in the Thames-London sub-Region, and indicates that it would be economically prudent to adopt both higher levels of drought resilience and proactively prepare for drier climate futures, although the relatively high investment costs and benefits associated with extreme levels of resilience mean that it would not necessarily be prudent to plan for the full expected risks from a drier climate if that level of resilience is adopted. Effectively the analysis suggests that adopting an extreme level of resilience provides protection to customers that balances some of the risks from a drier climate, so an approach more akin to the current ‘Target Headroom’ method, where only a portion of the additional climate change risk is accounted for, would be advisable if resilience is increased to the ‘extreme’ level (N.B. if resilience were only increased to ‘severe’, then the analysis suggests it would be cost-beneficial to plan proactively against the full expected risks from a drier climate). As with the SEEL sub-region a ‘wait and see’ approach to growth and sustainability reductions appears to be the most cost-beneficial option.

Figure 8-44 NPV cost/benefit comparison for the Bristol sub-Region



The nature of the outputs for this sub-Region are very similar to Thames (Bristol has a lower non-household consequence value, but is at risk of longer events when failures do occur). The chart therefore indicates that it would be economically prudent to adopt both higher levels of drought resilience and proactively prepare for drier climate futures, although the relatively high investment costs and benefits associated with extreme levels of resilience mean that it would not necessarily be prudent to plan for the full expected risks from a drier climate if an 'extreme' level of drought resilience is adopted. As with the SEEL sub-region, a 'wait and see' approach to growth and sustainability reductions appears to be the most cost effective option.

Figure 8-45 NPV cost/benefit comparison for the Anglian sub-Region



The outputs for Anglian are slightly different to the other sub-Regions. This is because under 'standard' planning assumptions and future scenarios that are less severe than that, there is no significant supply/demand deficit at 2040, which is why no costs (beyond the committed investment proposed to improve connectivity) are attributed to the Anglian sub-Region under those scenarios (hence the lack of cost for those future scenarios). However, the analysis still supports the adoption of a higher level of resilience and some pro-active investment to mitigate against drier climate (although, as for Thames and Bristol it may not be cost-beneficial to proactively plan for the *full* expected risk from a drier climate if the level of drought resilience is increased to 'extreme').

These figures are not intended as a ‘guide’ to determine which Portfolio should be constructed. As shown in Section 8.5.1, provided there is appropriate monitoring, planning and sufficient lead times allowed to adapt to growth and potential reductions in abstraction licences, then much of the consequences risk contained within these Figures can be adapted to through a ‘wait and see’ approach, supported by appropriate investigations and enabling actions. However, there are a two significant conclusions that can be drawn from the Figures:

1. They suggest it would be prudent to proactively plan for increased drought resilience and drier climate futures.

2. They suggest that, where an area has a high economic value and hence high consequence of failure, it may be appropriate to plan more risk into planning assumptions in comparison to areas where there is less economic value. This would imply that cities, and London in particular, may wish to consider economic consequences when WRMPs and regional studies are being put together. Similarly, where there is an expectation that the nature of the resource system could lead to prolonged Level 4 events during severe droughts (e.g. Bristol), then it could be prudent to account for this in the WRMP.

8.5.3. Cost/benefit analyses – analysis of resilience

The analysis of the cost/benefit ratios for increasing the levels of drought resilience was based on an NPV analysis of the expected costs versus the expected benefits from adopting different polices between now and 2040. This was calculated based on the difference in the *expected probability weighted* consequence of adopting a 'conventional' or 'standard' planning approach (i.e. planning for median climate change, medium growth and baseline environmentally-driven abstraction changes) that incorporates different levels of drought resilience (i.e. worst historic, 'severe' or 'extreme' resilience) into the Portfolio. Because these are calculated based on the consequence associated with the risks of experiencing those futures that are 'worse' than the 'conventional' planning assumption, they have been compared against the *average* NPV of the associated Portfolios for those 'worse' futures.

There are a number of uncertain variables associated with this analysis, but the main two are:

1. The evaluation of the Willingness to Pay (WTP) by household customers to avoid Temporary Use Bans, Non-Essential Use Bans and Level 4 restrictions. The derivation of the relevant ranges (in terms of WTP per day of restriction avoided) is provided in Section 7. These ranges are therefore reflected in the results shown below.

2. The impact that restrictions on public water supplies (PWS) might have on non-PWS users. Two alternative comparisons have therefore been made – one that assumes no impact on non-PWS users, and one that assumes non-PWS users would be restricted in accordance with the assumptions described in Table 7-1.

Table 8-18 Cost/benefit ratio analysis for increasing drought resilience (to 2040)

Drought Deficit sub-Region	Level of Resilience Planned for	Net Present Cost required to achieve change in resilience (£m)	NPV of Consequence Benefits: without non-PWS allowances (£m)			Additional Analysis (£m)		Benefit:Cost Ratio; Lower bound	Benefit:cost Ratio; Central estimate incl. non-PWS benefits
			Lower	Central	Upper	Central Estimate including non-PWS Benefit	Lowest bound, no PWS and Level 4 restrictions only		
Affinity Water London	Severe	See note below							
	Extreme								
Anglian	Severe	£ 103	£ 897	£ 1,262	£ 1,992	£ 1,470	£ 802	9	14
	Extreme	£ 287	£ 817	£ 1,150	£ 1,816	£ 1,340	£ 731	3	5
Bristol	Severe	£ 47	£ 305	£ 490	£ 862	£ 540	£ 276	6	11
	Extreme	£ 39	£ 132	£ 212	£ 373	£ 234	£ 119	3	6
SEEL	Severe	£ 237	£ 2,479	£ 3,177	£ 4,751	£ 3,709	£ 1,706	10	16
	Extreme	£ 256	£ 1,423	£ 1,824	£ 2,727	£ 2,129	£ 979	6	8
Thames-London	Severe	£ 453	£ 6,364	£ 7,258	£ 9,583	£ 7,894	£ 3,974	14	17
	Extreme	£ 425	£ 3,125	£ 3,563	£ 4,705	£ 3,875	£ 1,951	7	9

**As discussed in Section 6.1.2, Affinity Water – London is generally less drought vulnerable than the above sub-Regions, so would generally require relatively modest transfers to improve its resilience (the vast majority of the expenditure requirements for Affinity relate to changes in the supply/demand balance caused by growth and changes to abstraction licences). At the same time the nature of the groundwater recession (see Section 8.5.1) means that any Level 4 events would last for a very long time. The cost/benefit case for Affinity Water is therefore stronger than any of the above companies.*

This shows that the **economic case for improving resilience is very strong**, even when lower bound estimates of household WTP are considered and no benefit is assumed to the level of restrictions that would be placed on non-PWS users as a result of improvements in the frequency of restrictions on public water supplies.

The analysis also shows that there are potentially significant benefits to non-public water supply business users if resilience in public water supplies is increased, as this will tend to reduce stress on abstraction in comparison to lower investment approaches, and hence reduce the risks that 'blanket' restrictions are placed on water bodies to preserve resources during a drought. The upper bound of this, which assumes that non-PWS users will experience restrictions as a direct result of 'failures' of the public water supplies, indicates that benefits of the public water supply increasing resilience to a 'severe' drought level could be in the order of £250m to £500m in each of the larger sub-Regions that were analysed.

The above analysis incorporates Level 2, 3 and 4 restrictions. Because the focus of the analysis in this report has been on drought resilience and hence Level 4 restrictions, the Level 2 and 3 consequence benefits are more uncertain. However, even if they were excluded, the cost/benefit ratio for increasing resilience so that companies could experience ‘severe’ droughts without Level 4 failures would still be greater than 5:1 (at the lowest bound) and the cost/benefit ratio for ‘extreme’ drought resilience would still be greater than 3:1.

8.5.4. Implications for the environment and other users

Outputs from the Wathnet model were evaluated to determine if there were any clear implications to the aquatic environment and other users as a result of:

- General increases in the duration of time at which rivers are at their ‘hands-off flow’ values under different portfolios across the range of scenarios and Drought Compilations tested.

- Changes in the frequency of ‘Level 3’ drought trigger breaches, which would potentially affect other abstractors as a result of changes in the frequency of Drought Orders/Permits.

Generally speaking, greater investment tended to reduce the total amount of time that rivers spent at their hands-off flow, largely because of additional demand management and schemes such as groundwater development that do not result in surface water abstraction. However, this was not necessarily true in sub-Regions such as Anglian and Thames, where either increased river support allowed greater overall demand to be placed on the surface water systems, or where major new resources (such as the Trent abstraction and transfer) are involved. The situation is therefore complex, and the only clear difference between strategies is where a large new resource is proposed as part of the strategy, in which case there are obvious implications to downstream users that need to be considered when planning such a strategic resource (e.g. there are a number of downstream abstractions for cooling water on the Trent that could potentially be affected if a Trent transfer scheme is built in the Anglian sub-Region).

Similarly, in the Thames region there are a number of abstractors who might benefit from strategic resource development and the transfer of water. This has particular implications for the licensing and management of river regulation to ensure that the resource transferred reaches its intended point of use. In taking forward reform of the abstraction licensing system, policy would need to be revised to ensure permissions were not able to take undue advantage of such schemes. This should not be a major barrier but will need appropriate regulatory management. It should be noted that the environment will also benefit in this instance from river regulation to the point of abstraction (London).

Increasing demand management appears to have a positive effect in reducing the number of days that rivers spend at their hands-off flow, although this was not particularly significant. For instance, moving from a ‘BAU’ to ‘Enhanced’ level of demand management only reduced the number of days at hands-off flow by between 2% and 10% (depending on the drought and location) across the Anglian, Thames and Severn Trent Regions, although it is noted that these are average across large numbers of gauging stations, and there may be much more significant localised benefits.

In all cases there was a clear positive relationship between increasing investment and reducing rates of Level 3 restrictions. The impact that this might have on non-PWS users is already largely accounted for in the cost/benefit analysis of resilience, as described in Section 8.5.3 above.

9. Enabling actions

This Section identifies a range of potential enabling actions that would support the portfolios of options required to mitigate future problems, and provides an indication of the appropriate timescales for the actions.

A key outcome from this project is the identification of portfolios of potential options (both supply and demand management) which can provide improvements to drought resilience in the face of future uncertainties. However, in order to ensure that these options can be implemented in time to meet potential future challenges, certain enabling actions may be necessary.

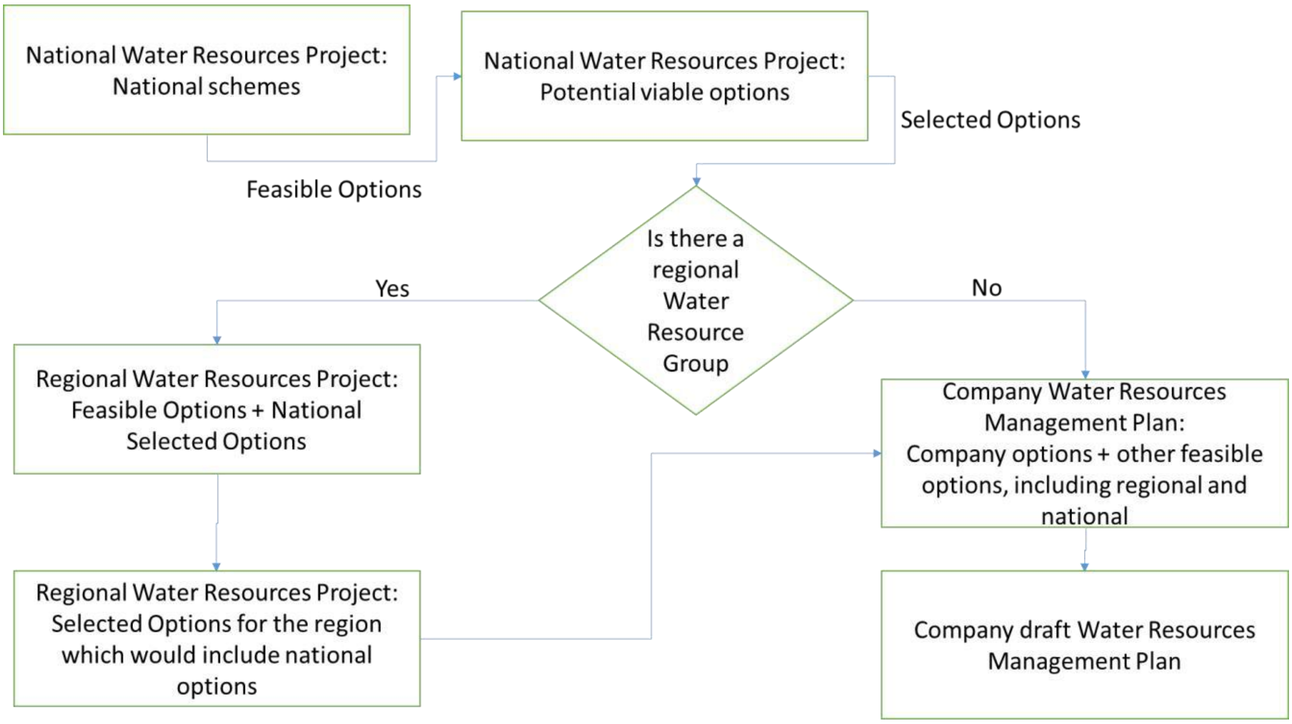
'Enabling actions' describes the actions that are essential to support or allow the timely development of options to implement the strategies identified in strategic terms in Section 8. Some actions may be required relatively urgently to help meet challenges in the period up to 2040. Beyond 2040, there may be greater flexibility and choice around timing, however, it is worth noting that:

- The 'lead time' for implementation of both significant change in demand management, and associated cultural / behavioural change, as well as new strategic water resources developments can be very long, and a number of the key enabling policy decisions and supporting studies/investigations need to start immediately (prior to the end of AMP6) to prevent unplanned delays and, therefore, potential additional impacts on cost.

- In the case of new strategic water resources schemes, specific options (and their locations) may need to be identified well in advance of any formal planning or promotion within local and/or strategic plans, and consideration given to securing land and water resources permissions to mitigate any potential risk of loss to other developers or abstractors.

This report is not intended to provide a single definitive plan for water resources in England and Wales through to 2065. The project outputs are intended to inform more detailed consideration and assessment through the water resources management planning processes (Figure 9-1) and identify more fully option-specific enabling actions and timescales for when a given option is required. Water companies' Water Resource Management Plans will need to verify the results, develop detailed plans that align with customers' wants and confirm the best value water infrastructure development plans. Inter-company planning forums such as Water Resources East (WRE) and Water Resources South East (WRSE) can conduct cross-company and stakeholder initiatives to better understand the risks involved, and the commercial/institutional arrangements required to support future transfers. There may also be the need for enabling actions that can increase the scope of these forums so that they can encompass larger national scale developments.

Figure 9-1 How the project outputs fit with other water resource planning outputs



This section seeks to address two key questions around enabling actions:

- What enabling actions are needed?
- When are enabling actions required, and are there any key constraints on achieving these?

9.1. Degree of urgency and key uncertainties

Although this report focuses on the 2040 and 2065 time horizons, it should be noted that the risks associated with drought events could be realised at any time in the future between now and 2065. These events have already been affected by climate change to an unknown degree, and that level of uncertainty will continue to grow through time. The scale and nature of investment that is required to address those risks is heavily dependent on the near-term decisions that will have to be made about the level of abstraction licence reductions that are required to tackle unsustainable abstraction[29]. Therefore, whilst risks associated with growth are more gradual, all of the other risks identified within this report are either immediate or relatively near term, and this should be borne in mind when actions to enable the development of a resilient water resource system are being considered. Although many of the risks from climate change will not have yet been realised, the *studies* and *enabling activities* that are required to allow potential changes in demand management and infrastructure need to be started given the evolving potential risk that could occur by 2040.

[29] These are based on the application of current legislation and regulations such as the Habitats and Birds Regulations and Water Framework Regulations, which we assume will remain in place although penalties for infraction may well change.

9.2. Nature and timing of enabling actions

In formulating the portfolios of potential options, a number of key actions have been identified in order to support national resilience. It is assumed that these will be undertaken within the framework provided by the WRMP process and Water Industry Asset Management Planning (AMP) cycles, and where appropriate in conjunction or through regional planning groups set up for this purpose, such as WRSE and WRE. These enabling actions include:

- **Investigations to confirm the feasibility and acceptability of inter-regional water transfers**, including assessment of:
    - The risk of transfer of invasive or non-native species. Clarity of regulatory policy and requirements with the EA, Natural England, Defra, NRW and Welsh Government will be essential.
    - The potential for changes in environmental water quality and any impact on / deterioration of WFD conditions and / or likely significant effects on Habitats Regulations designated sites.
    - The potential implications for potable water quality and water treatment processes as a result of the transfer and supply of new sources of water. Clarity of regulatory policy and requirements with DWI will be essential.
- **Engineering feasibility and planning investigations** to confirm the detailed design requirements, potential constraints (and mitigations) and least cost options for implementing strategic options (network capabilities, infrastructure upgrades, limits on abstraction, etc.).
- **Scheduling of investments**, reflecting detailed company / regional forecasts of supply/demand balances and detailed appraisal of the level of demand management necessary as part of the delivery of those schedules.
- **Stakeholder and customer engagement** in relation to demand management and resource development.
- **Identification of sites, planning needs, key constraints, etc.** for both strategic and non-strategic options and associated enabling actions (e.g. national or regional planning policy).
- **Consideration of adaptive, risk based approaches to planning**, as outlined in the UKWIR documents produced to support the 2019 Water Resources Planning Guidelines (16/WR/02/10 *Decision Making Process* and 16/WR/02/11 *Risk Based Planning* reports).

There are, however, a number of policy, information and planning enablers that may not be captured or delivered through the existing institutional structures. These are summarised within Table 9-1 below, and have been broadly grouped into the following categories:

1. Policy considerations.
2. Investigations and actions not currently covered by the WRMP process.
3. Planning and development enablers.

Table 9-1 Summary of enabling actions with indicative timing requirements

Option &/or driver	Description of enabling action(s)	Enabling action timing
Policy considerations		
P1. Consideration of the 'appropriate' level of resilience that water companies in England & Wales should plan for	If appropriate, direction on minimum standards of resilience that should be adopted, or definition of the evaluation mechanisms that water companies should use to decide upon a minimum standard.	Near term (within the next year for inclusion within the 2019 WRMPs)
P2. Consideration of the potential need for policies or institutions to enable greater *inter-*regional coordination	In order to understand the most appropriate options and timings for the strategic transfer and storage options discussed within this report (i.e. 'supported' Severn-Thames and 'supported' Trent-Anglian transfers), it will be necessary to obtain clarity on the regulatory issues, institutional barriers and stakeholder concerns that currently exist in relation to environmental water quality risks and potential future river regulation, storage and abstraction arrangements within those potential 'Supply' and 'Transfer' Regions. This would need to include the Welsh government and NRW if options associated with Welsh resources are considered. Although these issues are being considered by the WRSE and WRE groups, many of the stakeholders and institutions are not within their regions, so they will need to be able to incorporate meaningful assumptions about the relative costs, benefits and constraints of the two transfer routes in a way that is not later subject to challenge and delay if they are identified as preferred options. In addition, there are fundamental questions to resolve concerning the potential impact of water transfers on environmental water quality and WFD status, and risk of transfer of invasive non-native species. In addition, the potential risk to drinking water quality (e.g. from transfer of Metaldehyde) could drive the need for significant treatment that may render such schemes uneconomic.	Near term (by the end of AMP6)
P3. Consideration of policy decisions in relation to demand management initiatives	Review and decide upon any changes in policies relating to the extension of metering, 'smart metering', new tariff structures and any changes to requirements for water efficiency and innovative technologies (e.g. rainwater and greywater recycling) targets in new build homes, commercial development, government procurement commitments, seed funding programmes for innovation, links into carbon accounting from hot and cold water efficiency, guidance for local authorities. A key issue identified here is the question of the acceptability of requiring additional demand management measures in potential 'supplier' regions in order to make water available for transfer to deficit areas. Would the implementation of demand management policies to generate additional surplus for transfer be acceptable in areas that would not otherwise need it? Similarly the acceptability of transferring water to the area in deficit would also require consultation with customers, regulators and government in the 'supplier' region. In addition, the acceptability of any arrangements to increase the amount of water currently transferred from Wales to England would need to be discussed and agreed with the Welsh Government.	Near term (by the end of AMP6, for inclusion in the 2024 WRMPs)

Option &/or driver	Description of enabling action(s)	Enabling action timing
P4. Consideration of the role of Drought Permits and Orders in relation to investment for resilience	If a greater level of resilience is to be planned for then the role of supply-side Drought Permits and Orders needs to be better defined. Although the *process* for application is currently clear, it is subject to 'localised' risks from third party challenges, uncertainties in evidence needs and systems of monitoring and control during implementation that are not formalised in advance. Greater clarity on whether and how much water companies should be able to rely on Drought Permits and Orders, and possible changes to systems and processes for providing a greater degree of reliability should therefore be considered. Related to P1, determination as to whether Drought Permits and Orders should remain *in extremis* measures and applied to *extreme* rather than *severe* droughts as defined here.	Near term (early AMP7, for inclusion in 2024 WRMPs)
P5. Confirmation of the quantity of abstraction reductions required to tackle unsustainable abstraction and promote long term resilience for the water environment	The size of the uncertainties associated with how much water needs to be left in the environment to ensure long term sustainability / environmental resilience and, therefore, the scale of reduction in licensed abstraction, needs to be resolved to confirm the scale of supply/demand deficit to be met and the scale of investigations, studies and associated construction (described below) to allow implementation. Confirmation of the likely scale of these requirements is therefore urgently needed to avoid delays and associated risks for the other enabling actions.	Near term (preferably AMP6, although many likely to run into AMP7)
P6. Consideration of further guidance and/or institutional arrangements to promote trading arrangements to support resilience	The differing levels of currently planned resilience, particularly in the south east, mean that the reliability of trading arrangements to provide drought resilience can be uncertain, which could result in being a barrier to adoption because it calls into question the reliability and/or the equitability of potential transfer arrangements. For example, transfers may be constrained when the donor company has restrictions, or may require consistent application of levels of service. This issue is being partly reviewed between water companies and regulators through the WRSE and WRE initiatives, but the need for further policies and regulations, particularly where third party suppliers are involved, needs to be considered to ensure that trading is not constrained by technical concerns relating to reliability and resilience. The possible need for a specific institution(s) that provide guidance and support for such trading arrangements should also be considered to avoid criticism of water companies and accusations of anti-competitive behaviours.	Near term (as part of water 2020)
P7 Review regulatory incentive mechanisms in relation to improving resilience to drought	If there is no mandate on levels of resilience, as indicated under action P1, then companies may still wish to change their own Levels of Service as a result of customer preferences to guard against the 'High Impact, Low Likelihood' events analysed within this report. The potential regulatory incentives or disincentives that will exist in relation to this have not formed part of this study, and will need to be reviewed in light of Ofwat's Water 2020 proposals.	Near term (dependent upon item P1).
Investigations and research not currently covered by the WRMP process		
I1. Studies to confirm the suitability and preference for inter-regional transfers	Technical studies to support the policies and potential institutional arrangements described under item P2 above.	Near to Medium term (early AMP7)

Option &/or driver	Description of enabling action(s)	Enabling action timing
I2. Review of the suitability of control curves and current abstraction arrangements for the key systems where transfers and storage are proposed.	In addition to the concerns of regulators and stakeholders (as described under item P2), the potential River Severn and River Trent strategic options involve a number of users with existing licence conditions (and constraints) that could affect the viability of the transfer. For the River Severn there are also some Parliamentary Acts and relatively complex control curves in place that are not intended to support options for transfer out of the catchment. Further work is therefore required to understand the potential barriers that might exist in relation to the existing arrangements that are in place, particularly in relation to the level of certainty that transferred resources would actually be available at the point of transfer, given current arrangements (e.g. river regulation volumes cannot be excluded from existing licences, so other abstractors may preferentially benefit at the expense of the intended transfer).	Near term (start within AMP6)
I3. Development of additional methods for monitoring the evolution and degree of risks from climate change.	If overall plans are going to follow an 'adaptive pathway' type approach (i.e. balancing risk against opportunities to defer costs), then it will be important to try and develop appropriate metrics or a trigger system that can help focus the trajectory of climate change risk in relation to drought. The general understanding of climate change risks should be delivered through projects such as UKCP18, but there is a need to ensure that outputs are also translated into guidance about how 'current day' risks (i.e. the realisation of climate change to date) should be incorporated into the near term investment decisions contained within the WRMPs. That is too complex to do on an individual water company basis.	Ongoing (initial findings based on UKCP and others by the end of AMP6)
I4. Develop triggers and milestones that can be used in a national level adaptive plan, that supports ongoing WRMPs	The uncertainty around the exact choice of strategic schemes (e.g. where storage is best located) will reduce over time as WRMPs and the studies and policies described above are decided upon and implemented. Because there is a clear national level aspect to the development of longer term resilience, it would be advisable to use the outputs from this study to develop an 'adaptive plan' that identifies: • the key 'trigger points' that will determine which set of portfolios are needed for the 2040 and 2065 horizons. • how the information that will be generated by WRMPs and the studies described above can be extracted and used to determine where national level water resources are in relation to those 'trigger points'.	As soon as possible
Planning and development enablers		
P&D1. Review of planning constraints and risks for strategic options	Identify how companies, regulators and bodies such as the National Infrastructure Commission can work together to reduce the risks associated with the planning and promotion of the key strategic schemes identified in this report (primarily the Severn-Thames transfer and storage options, and the Trent-Anglian transfer and storage options, but this also applies to some of the larger Severn-Trent and south east region storage and effluent re-use schemes).	Near to medium term (AMP6 through to AMP8, depending on location)
P&D2. Development of a 'road map' to support key strategic schemes	Identify how liaison between the key institutions would be expected to work once the timing and likely location of strategic options has been confirmed. In particular there appears to be a significant need for some form of institutional 'co-ordinator' role that would allow for cross co-ordination of governmental, regulator and stakeholder inputs to the planning and promotion process (including Welsh government and NRW where appropriate). Without such a role there appears to be a high risk of planning uncertainty and delay given the large scale nature and complexity of some of the schemes.	Severn-Thames transfer options are potentially needed in the near term, so this should be reviewed prior to publication of WRMP19

10. Discussion and conclusions

This section provides a summary of the key headline messages and conclusions that can be drawn from the analysis undertaken for this project.

10.1. Headline messages

The headline, general messages that have been taken from the technical analysis are provided in the Tables in this sub-section. These are structured so that the 'message' nationally is provided first, followed by any Region (or sub-Region) specific comments that are considered to be worthy of note in relation to that message.

Discussion of the likely 'mix' of strategic solutions to achieve drought resilience in the long term is presented within Section 10.2 below.

Table 10-1 Headline message: Existing levels of drought risk

Headline message:	**There is a significant existing level of drought risk that is present across many regions in the east and south of England.**
(see Section 6.1 for the evidence base)	Putting this in context, the majority of companies where their Water Resources Management Plan presents a supply/demand balance that is close to zero, and that are planning to be resilient to the worst historic drought on record, still run a 12% chance of seeing a 'typical' 'severe' event (2 to 3 months with standpipes or similar in place) over a 25 year planning period. There is a lesser risk (circa 5%) that such an event could turn into an 'extreme' drought with drought restrictions lasting for 4 to 6 months.
	Regional commentary:
North West (United Utilities & Dee Valley)	• The United Utilities Integrated Zone and Dee Valley are currently running a supply/demand surplus across the majority of the system, so the risk is much lower.
North East (Northumbrian)	• Currently running a large surplus and highly unlikely to experience significant drought detriment.
Yorkshire	• The analysis in this report confirms that Yorkshire do plan for a much higher level of resilience than other Regions, primarily as a result of the significant consequences faced during the 1995/96 drought. The chances of any sort of standpipe type restrictions is less than 5% over 25 years.
Welsh	• Localised risks in a number of Water Resource Zones, which are generally quite isolated. Calculations indicate that the main WRZ (SEWCUS, which includes Cardiff) is likely to maintain some surplus through to 2040, so currently has a lower risk profile than stated above (although this was based on the assumptions in WRMP14, and we understand that this situation may have changed).
Central West (Severn Trent, South Staffs)	• The analysis in this report shows that Severn Trent Water's spatially diverse supply system means that risks of storage 'failure' tend to be localised rather than system-wide, under the 20th Century climate and current supply arrangements. The risk of a system-wide failure of storage is currently much lower than the 12% quoted above, but is particularly vulnerable to future uncertainties over climate change and potential reductions in abstraction to protect the aquatic environment.
South East (Anglian sub-Region)	• Currently there is some supply/demand surplus in this sub-Region, but this is likely to be eroded by growth prior to the 2040 time horizon, so risks will be similar to those indicated under the headline message, if current planning assumptions are maintained. The risk to resilience as a result of the need to tackle potentially unsustainable abstraction is significant and immediate.

South East (Thames/ Affinity London sub-Region)	• The Thames-London system is currently at, or close to, supply/demand deficit under existing planning assumptions, so there is a clear risk of severe restrictions (e.g. standpipes) in accordance with the 'headline' message above. • Affinity Water are relatively drought resilient because most of their sources are licence or treatment/infrastructure constrained, rather than drought constrained, so they may be less at risk provided they maintain a supply/demand balance. However, their reliance on groundwater sources, which have long periods of drought minima, means that risks to customers would be frequent and very large if a supply/demand balance is not maintained. The risk to resilience as a result of the need to tackle potentially unsustainable abstraction could therefore be significant and immediate, but can be managed through appropriate liaison and planning with the environmental regulator.
South East (excluding London)	• Many of the companies here are at, or close to, supply/demand deficit, and some companies (e.g. Sutton & East Surrey Water) do not currently plan to be resilient to the worst historic drought on record, so have a higher level of risk than described above, whereas Southern Water plans to be resilient to a 'severe' event by 2020. Whilst these differences were accounted for within the resource assessment in this report, it does highlight a need to harmonise the understanding of drought resilience across this sub-Region to facilitate water trading. This is important, as trading between WRZs and companies forms an important part of the wider resilience strategy that is proposed for this sub-Region through WRSE (see Section 10.2.2.6).
South West	• Analysis indicates that Wessex Water and South-West Water are currently very resilient to the risk of severe droughts. Bristol Water, on the other hand, currently plans to a lower level of resilience and has a risk of Level 4 restrictions (standpipes) of approximately 23% over the WRMP 25 year planning horizon.

Table 10-2 Headline Message: Maintaining resilience through Drought Orders and Permits

Headline message:	**The potential benefits from supply-side Drought Orders and Permits are significant when considering the impacts of 'severe' and 'extreme' droughts on supply system capabilities. However, there are uncertainties about the reliability of such interventions for planning purposes. The environmental consequences of relying upon Drought Orders and Permits as a means of deferring expenditure should also be considered if enhanced resilience is sought for the industry.**
(see Section 6.1.2 for the evidence base)	Although links between Drought Plans and WRMPs are starting to be made for planning purposes (see latest Water Resources Planning Guidelines), the 'reliability' of such operational supply-side interventions as a means for mitigating drought risk and deferring investment in resilience is very uncertain. As well as issues with the timing and lead times required for Permit/Order preparation, application and potential public hearings prior to implementation, environmental concerns mean that companies are often limited to winter Permits/Orders, or have to introduce mitigation that could severely limit the benefits of the actions. Supply-side Drought Permits / Orders are by their very nature contentious because of the potential environmental impacts at times of drought stress. If a policy decision is made to plan for a higher level of drought resilience than is currently allowed for within WRMPs (i.e. worst historic in most cases), then there will be a need for stakeholders to agree on the methods that can be used to determine the reliability of Permits and Orders *as a means of providing resilience* or to prioritise investment. This could result in significant additional expenditure, above and beyond that described within this report.
	Regional commentary:
North West (United Utilities)	• Although United Utilities has a large number and volume of Permits and Orders potentially available, only limited benefits have been assumed (or are necessary) here. This would not necessarily be the case if United Utilities were examining their own resilience to 'severe' or 'extreme' events.

North East (Northumbrian)	• No significant impact.
Yorkshire	• Large assumed benefit; potentially significant increase in investment if Permits and Orders cannot be relied upon.
Welsh	• Not analysed as DCWW was considered to be a 'Supply' Region for this strategic analysis.
Central West (Severn Trent, South Staffs)	• Large assumed benefit; potentially significant increase in investment if Permits and Orders cannot be relied upon.
South East (Anglian sub-Region)	• Large assumed benefit (in relation to the impact from severe droughts); potentially significant increase in investment if Permits and Orders cannot be relied upon.
South East (Thames/ Affinity London sub-Region)	• Large assumed benefit for Thames Water; potentially significant increase in investment if Permits and Orders cannot be relied upon. Less relevant (smaller scale) to Affinity Water due to the inherent drought resilience of most of its sources.
South East (excluding London - SEEL)	• The potential benefits from Drought Permits and Orders are significant, but not as significant in relative terms as some other sub-Regions. There is also more experience of Permit and Order application in this sub-Region. A number of the systems either rely on winter Permits or are affected by rapid onset of droughts, so there are concerns that the benefits assumed within this report may be optimistic.
South West	• Limited scope for supply-side Permits and Orders in Bristol or Wessex, so they have little impact on the findings described in this report.

Table 10-3 Headline Message: Risks from climate change

Headline message: *(see Section 6.1.2 for the evidence base)*	**Impacts of climate change on drought risks are uncertain, and companies may already be running a risk that is larger than those described in** Table 10-1**.**
	Companies currently plan for 'median' climate change effects and rely on an approach that 'imposes' these effects on the historic record to estimate drought risks. Although drier climate futures are partly accounted for through a system of uncertainty allowances, this is not explicit and tends to be lower than the scenario based analysis contained within this report. The way the WRMP process is currently managed also means that risks from 'drier' climates that might have already materialised since the 20th Century are effectively not accounted for in the 'base' (current) year analysis. Because droughts are infrequent and large scale in their nature, the period between 2000 and the current day has not included droughts of the sort of severity that are seen in the worst droughts of the 20th Century. The country has experienced some 'near misses' such as 2012, however, there is currently insufficient information to determine how the risks from climate change are affecting the likely frequency and severity of significant drought events, and further climate change research would be required to provide a system of monitoring/analysis that could provide the required understanding.
	Regional commentary:
All Regions	No additional comment.

Table 10-4 Levels of Forecasting Uncertainty

Headline message:	**Future levels of population growth and estimates of the impact of reducing abstraction to protect the environment are material uncertainties at the 2040 and 2065 time horizons. However, unlike climate change and drought risk, the risks from growth in population can be monitored and adapted to as it develops over time. Similarly, whilst the risks from abstraction reduction are very large for some companies, they are entirely within the remit of policy and the regulatory process to manage.**
(see 6.2 and 6.3 for the evidence base)	The Office of National Statistics (ONS) estimates population growth for England and Wales of between 6 and 16 million by 2040 and between 12 and 32 million by 2065; this represents one of the largest uncertainties in the future supply/demand balance. Reductions in abstraction licences to protect the aquatic environment have the potential to have a substantial impact on the supply/demand balance across England and Wales, especially under higher growth scenarios. There is considerable uncertainty over the magnitude of reductions. Reductions may be required in the near future, by 2025, and uncertainty should be resolved as soon as possible if reductions are to be reflected in WRMPs and PR19. These reductions equate to between 5% and 50% for the five companies (Affinity, Anglian, Severn Trent, Southern and Thames) that are most affected.
	Regional commentary:
All Regions	No additional comment

Table 10-5 Headline Message: Promoting and enabling demand management

Headline message:	**This analysis confirms that a 'twin track' approach of demand management coupled with appropriate development of new resources and potential transfers is the most suitable strategy for providing drought resilience in the future. However, the levels of demand management that have been analysed in this report are potentially ambitious and rely on significant behavioural change as well as significant future innovation to reduce costs below their current levels to make the options economically feasible.**
(see Sections 8.1 and 8.2 for the evidence base)	This report has provided an examination of the resilience and costs of demand management based on fairly 'optimistic' assumptions about the level of cost reduction that could be achieved through technological innovation, and policy support for measures such as innovation in tariff structures and levels of demand achieved through new property builds. Achieving cost effectiveness in the 'extended' demand management strategy would therefore require significant policy and regulatory support.
	Regional commentary:
All Regions	No additional comment – specific issues surrounding the 'mix' of solutions are covered in Section 10.2.

Table 10-6 **Headline Message: Promoting and enabling transfers**

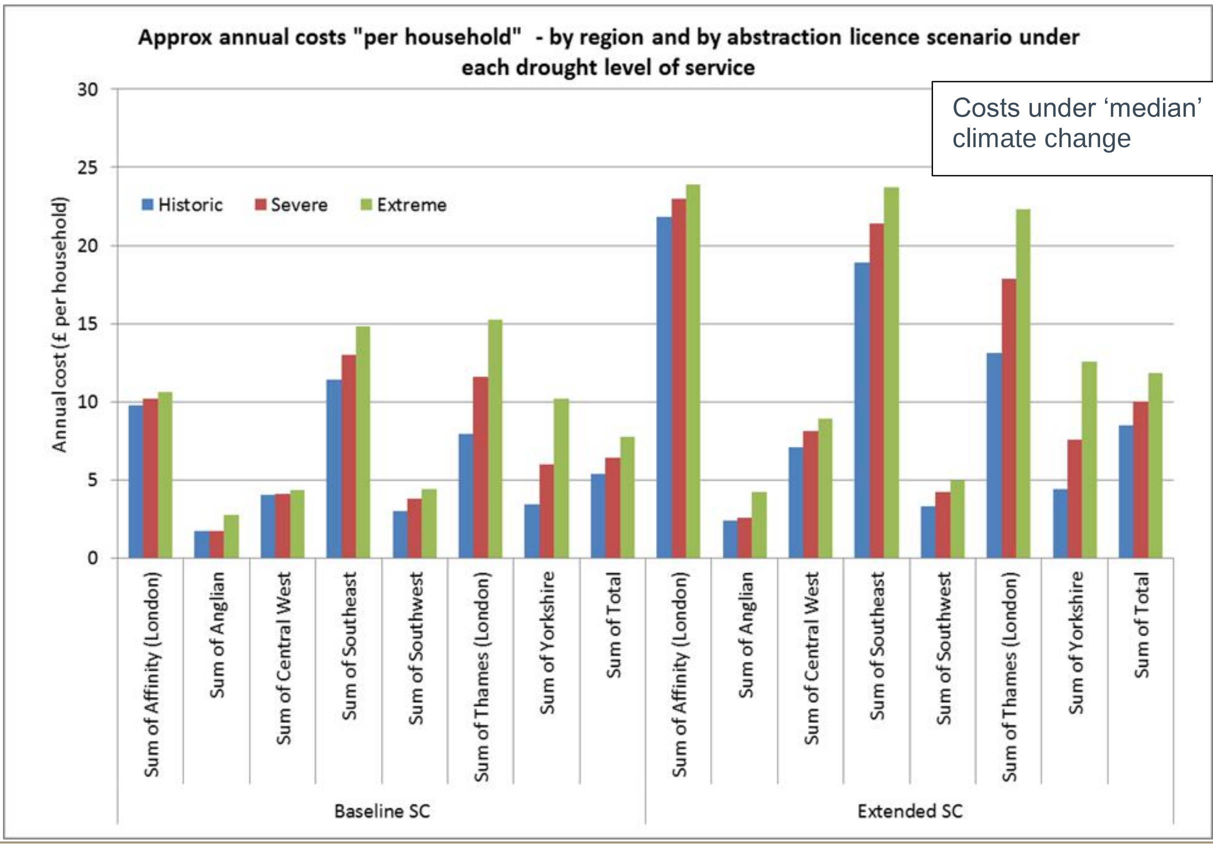
Headline message:	**Inter-regional transfers have been identified as a possible, potentially cost effective, component of a resilient supply system. However, the analyses of the potential for inter-regional transfers presented within this report do not take into account key constraints that could limit the feasibility of those options. These primarily relate to existing, complex abstraction, storage and regulation arrangements, quality considerations (including potable water quality and environmental risks), and the ability of the parties involved to evaluate the levels of resilience risks and hence agree appropriate operational, institutional and financial arrangements.**
(see Sections 8.1 to 8.23 for the evidence base)	The portfolio development and resilience testing indicate that there are some strategic inter-regional transfers that could potentially form a resilient, cost effective part of the future water resources system, although it is noted that the costs and benefits of these strategic transfers have only been examined from a technical basis that accounts for the volumes of raw water involved. There are considerable potential water quality risks associated with the promotion of such schemes, particularly concerning issues such as invasive non-native species, environmental impacts on receiving water courses and the management of potable water quality risks, such as those associated with the treatment of metaldehyde pesticides. It is also noted that the existing arrangements for storage and abstraction of water in these major river systems is highly complex and it may not be feasible to actually provide reliable quantities of water for transfer to other rivers, as these effectively lie at the ‘bottom’ of these complex systems. The analysis has also shown that large scale transfers could (particularly in the long term) act to change the nature of the resource systems involved, and mean a greater sharing of risks than currently exist between water companies. If existing storage within the supplying river systems cannot be reliably used, then the analysis strongly indicates that alternative, new storage would be required within the receiving resource systems. Achieving the levels of cost efficiency and benefits from transfers that have been assumed within this report could therefore take a considerable length of time and interaction between multiple stakeholders, and should therefore be included as a key ‘enabling action’ to allow cost effective delivery and development of feasible solutions in the future. As noted in Section 9, it is advisable that some form of ‘roadmap’ should be considered that confirms when decisions to proceed (or not) with the major transfers need to be made, and provides support to infrastructure planning once that decision is in place.
	Regional commentary:
All Regions	No further comment – specific issues surrounding the ‘mix’ of solutions are covered in Section 10.2

Table 10-7 Headline Message: Costs and benefits of increasing resilience to drought events

Headline message: Costs and Benefits of Increasing Resilience *(see Section 8.45 for evidence base)*	**The costs of increasing resilience to drought are relatively modest (less than £4 per customer per annum to achieve resilience to 'severe' events – see** Figure 10-1 **below) and the economic benefits far outweigh those costs.**
	In all cases the costs of moving to, or maintaining, resilience to 'severe' events are less than £4/customer/annum (which only increases to £5/customer/annum under drier climates, as the relative cost increases). The 'central estimate' of the benefit:cost ratio is greater than 10:1 in all cases and remains greater than 4:1, even if lower bound estimates of the benefits are assumed. There is a strong economic argument for considering a strategy that provides resilience to 'extreme' drought (central estimate benefit:cost ratio of greater than 5:1); this would typically cost less than £8/customer/annum (£10 under drier climates), compared with the 'baseline' worst historic drought resilience. Note that these costs only include the expenditure involved in demand management and new resource schemes (which includes some allowance for treatment and transfer costs). Where transfers are involved, no allowance has been made for any additional treatment or transaction costs that may be required. Treatment costs could be significant and will rely on the outcome of investigations outlined above. The effect of transaction costs should be modest within a correctly functioning market, and should not significantly affect the findings of the cost/benefit analysis.
	Regional commentary:
North West (United Utilities & Dee Valley)	• This is a surplus Region, so the cost/benefit was not specifically analysed. However, potential schemes to transfer water to 'deficit' Regions were accounted for and added to the costs of the relevant 'Deficit' Regions described below.
North East (Northumbrian)	• Surplus Region – see above (North West).
Yorkshire	• The costs of maintaining the current, very high, level of resilience, are in the order of £8 per customer per annum. It should be noted that *reducing* the level of resilience would involve customers having to 'accept' the increased risk in return for a reduction in bills. Standard economic theory suggests that 'willingness to accept' such a reduction in service would require a greater level of compensation than the equivalent 'willingness to pay' for improvements in service. The economic consequences of Yorkshire resorting to a lower level of resilience therefore massively outweigh the reduction in costs that customers would see on their bills.
Welsh	• Surplus Region – see above (North West).
Central West (Severn Trent, South Staffs)	• The Central/West is a 'transfer' region, so a cost/benefit analysis could not reasonably be undertaken as it was impractical to assign a cost or benefit from a change in resilience. However, it is noted that its level of resilience could be reduced if solutions that involve transfer through to the Thames are promoted. The economic consequences of this *were not* incorporated into the analysis, as discussed under Section 10.2 below.
South East (Anglian sub-Region)	• The assessed costs of moving to a higher level of resilience are theoretically very modest for Anglian Water (<£1 per annum to achieve resilience to a severe event). However, it should be noted that this results from a combination of an assumption that there is a large volume of water available from *reliable* Drought Permits that considerably reduce the relative risk of a 'severe' event, and lower than likely costs of supply-side investments that involve the transfer and storage of water from the River Trent. Actual costs per customer per annum could therefore be higher than this, but would almost certainly be lower than the 'typical' £4/customer/annum for 'severe' resilience, and £8 per customer/annum quoted for 'extreme' resilience quoted for companies such as Thames and Yorkshire.

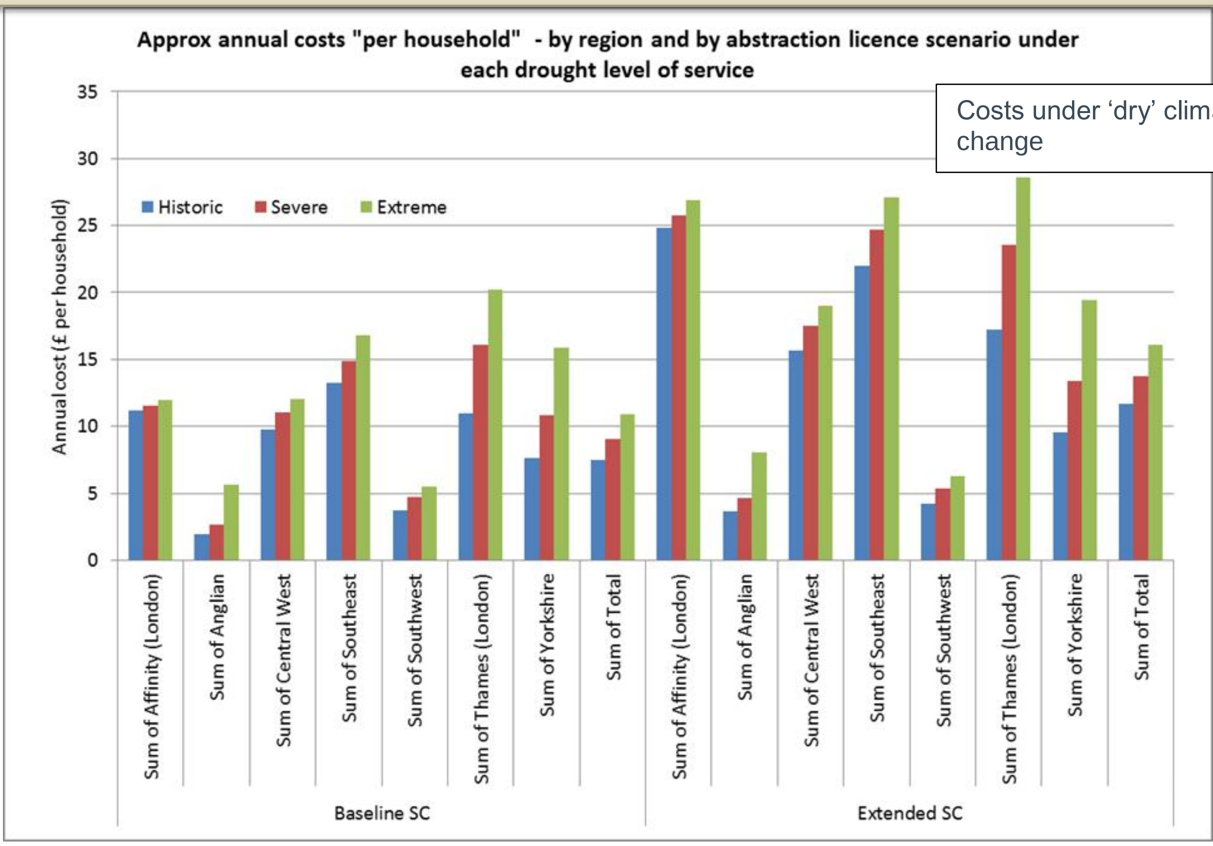
South East (Thames/ Affinity London sub-Region)	• The costs for improving resilience in the Thames-London system are typically expected to be in the order of £4/customer/annum for a move to 'severe' resilience and £8/customer/annum for a move to 'extreme' resilience. However, the high economic significance of the Capital means that the consequence benefits from this are larger than in other regions, meaning that the economic case is very strong. Thames-London maintains a benefit:cost ratio of *at least* 10:1 for a move to 'severe' drought resilience (the 'central estimate is much higher than this, at over 15:1) and 5:1 for a move to 'extreme' drought resilience. • For Affinity Water, the level of drought resilience is high (few resources are affected by drought severity, and supply availability is largely dictated by licence or treatment/infrastructure constraints). Therefore, although the costs of maintaining the supply/demand balance in the face of significant reductions in licence to protect the aquatic environment are large for this area, the additional costs associated with moving to higher levels of drought resilience are typically very small (<£1 per customer per annum), as only a few sources are affected. Although it was not possible to quantify the benefits, economic consequences of restrictions such as standpipes would be very large, so the benefit:cost ratio of an increase in resilience is likely to be the highest for any of the sub-Regions that were considered.
South East (excluding London - SEEL)	• Costs of increasing resilience are typically lower than those in the Thames-London region, but the economic consequences tend to be less, meaning the results are similar to those described for Thames-London.
South West	• Costs for increasing resilience in Bristol Water are relatively modest, although the economic benefits are also relatively small, so overall the case for increasing resilience is slightly lower than in SEEL, but still at or above the ratios described under the main 'headline' message above.

Figure 10-1 Summary of expected household costs associated with improving levels of drought resilience (2040 time horizon)



Costs under ‘median’ climate change

N.B. these costs relate to the amount of expenditure required to address demand in the sub-Region where the demand is situated – costs have been generated across England & Wales in accordance with the Portfolio analysis



Costs under ‘dry’ climate change

Table 10-8 Headline Message: Creating 'adaptive plans'

Headline message:	**Consideration is needed about the categorisation and management of the different risks presented within this report, along with the implications of regionally different levels of consequence, to avoid either excessive cost or unacceptable drought risks from developing.**
(See Sections 8.45 for the evidence base)	Some of the risks identified within this report are very large, but are either the result of policy impacts (tackling unsustainable abstraction to protect the aquatic environment) or can be monitored and plans changed on a periodic basis (growth in demand). Other risks, such as those inherently associated with the occurrence of periodic severe droughts, and the degree to which climate change is affecting the severity and frequency of such events, are not within the control of policy makers and rates of change cannot be monitored with current technology. Where risks are within the control of policy makers or can be monitored then it is important to ensure that adaptive actions are given adequate time, and that this is reflected within the WRMP process. Failure to do this could result in either increased risk or costs that are much larger than those proposed within this report. Similarly, to date there has been no consideration of the economic consequences of drought within WRMPs. Some Regions (e.g. London) clearly have a higher level of economic 'value' per non-household customer affected, and there are varying levels of reliance on the public water supply by non-household customers. It may therefore be important to consider how considerations relating to economic consequence might affect the choice of the level of drought resilience to plan for (and specific options / benefits) when policy decisions are being made. The cost/benefit and risk consequence analysis carried out for this study indicated that it would be economically *prudent* to proactively plan for drier climate futures, even if increased levels of drought resilience are proposed. The large costs and uncertainties associated with levels of growth and potential reductions in abstraction to protect the aquatic environment mean that it is recommended that these are managed through a more 'wait and see' type of adaptive approach, although it is noted that very large consequences would develop if insufficient time is given to plan and implement actions once policy decisions associated with reductions in abstraction have been made.
	Regional commentary:
All Regions	No additional comment – specific issues surrounding the 'mix' of solutions are covered in Section 10.2

10.2. Likely nature of resilient solutions

10.2.1. Balancing demand management and supply development

As shown in Section 8.2, the analysis of the overall need for investment and the relative economic costs involved clearly demonstrates that a 'twin track' approach that incorporates demand management alongside resource development and potential transfers is the most appropriate strategic mix for the future.

In terms of pure cost-effectiveness analysis there is only a small increase in cost associated with moving from a strategy mix that relies on challenging demand management savings brought about through 'Business as Usual' type initiatives from water companies and other stakeholders, to an 'extended' strategy that incorporates greater investment and policy enablers. Such an 'extended' strategy would include policies such as smart metering with associated tariff innovation in existing properties, or increasing the planning requirements for water efficiency in new homes. It should be noted that this relatively small cost differential is associated with optimistic assumptions about the costs of achieving such a strategy, and relies on achieving significant cost savings through future innovation.

Applying the ‘extended’ demand management strategy would mean a greater level of resilience to future shocks outside of those contained within this report (e.g. very dry climate change, higher growth), as the availability of cost effective supply-side options does become limited in some regions under some scenarios. It would also reduce the risk of ‘stranded assets’ if more favourable futures materialise, and may provide environmental benefits by reducing pressures from abstraction as well as the need for new water resource schemes, and could enable secondary benefits such as improvements in customer understanding of drought risks. However, it is noted that the ‘Business as Usual’ demand management strategy is already ambitious, and so just achieving this may require shifts in policy or potentially considerable change in behaviour by customers. Extending demand management beyond this strategy would therefore require a greater level of policy intervention, alongside customer acceptance for initiatives such as tariff innovation.

Overall there does not appear to be a strong case for introducing an ‘enhanced’ demand management strategy, either in terms of cost, societal acceptability, or a need to implement such a strategy to guard against longer term future risks (i.e. it is not a necessary component of even the more challenging 2065 futures). However, some of the large costs contained within this strategy, such as retro-fitting greywater reuse or large scale mains replacement to reduce leakage, do affect its cost effectiveness. Initiatives such as large-scale/comprehensive water efficiency fittings in new homes (and buildings), which could form the bulk of the housing stock towards the end of the 50-year period considered here, are already cost-efficient, and could be made even more so through some of the enabling actions set out in section 9. Similarly, although some of the initiatives, such as achieving very low levels of demand in all new homes, tend to affect its societal acceptability, it is feasible that customer views of water efficient products and behaviour could be positively affected by supply/demand patterns as well as cost, towards the end of the 50-year period being considered. This means that there may be some elements of the ‘enhanced’ demand management strategy that should continue to be reviewed, because of the additional environmental benefits that reducing demand may provide, but also because innovation and enabling actions could improve their cost effectiveness.

10.2.2. Strategic infrastructure investments

As shown in Section 8, most of the options portfolios and resilient future scenarios include strategic transfers alongside ‘local’ developments, although it is important to note that such transfers are not likely to be resilient without associated, dedicated, storage within reservoir systems. However, the analysis confirms that development of a full scale ‘water grid’ is unnecessary, as future resilience can be provided by a combination of localised initiatives and strategic schemes that use the River Severn and River Trent to carry water across to the south and east via transfers into the Thames basin and the Anglian water storage system. Systems that transfer water from further north (e.g. Kielder to the Midlands via Yorkshire) do not appear to be necessary, although by 2065 and under some of the more adverse futures in 2040 there may be a need to transfer water to the River Severn via the River Dee, or to enable further development of resources within Wales for transfer into the River Severn.

As discussed in Section 8.3, it is important to note that there may be environmental and institutional barriers that could severely limit, or even prevent, the opportunity for such transfers. Without the appropriate enablers (as described in Section 9) this means that there would be a much greater need for local resource development and, under some future scenarios, enhanced demand management may become necessary to limit the need for strategies that include very costly options, such as widespread desalination. Where institutional and/or practical barriers mean that existing storage within potential ‘supplier’ river systems cannot be relied on, then this will need to be replaced by new, additional storage that is directly and operationally controllable by the company that will receive the transferred water. Unsupported transfers between major river systems are not considered to be reliable by this study.

There are also likely to be practical upper limits on the capability to transfer water that have not been explored through this project (for example, would it be acceptable to transfer up to 600Ml/d to the upper Thames during drought conditions, as suggested under some portfolios (see Section 8.3), which would need to be defined as part of a long term plan.

10.2.2.1. North West Region (incl. Dee Valley)

The resilience testing described in Section 8.3 concluded that there is good potential for this Region to provide water to the River Severn and hence through to the Midlands and Thames basin, and that its drought resilience is unlikely to be significantly affected by the re-deployment of Lake Vyrnwy for this purpose. There are a number of low cost local options for improving drought resilience. Further transfers may be possible, although the cost and feasibility for doing this, most likely through a Dee-Severn transfer, is unknown.

10.2.2.2. Yorkshire and the North East

This Region already enjoys a high level of resilience, and the strategic analysis contained within this report indicates that this can be maintained through the 'twin track' development of demand management combined with local resources and some of the lower cost transfers from the River Tees (using part of the Kielder resource). It is noted that extensions to the available transfer from Kielder to the Tees may be required under some scenarios in 2040, and a number of scenarios by 2065, so the availability of water from Kielder reservoir for water resources purposes is a potentially important part of the resilience for these Regions in the long term.

10.2.2.3. Welsh Region

Although there are some localised issues within the Welsh WRZs, these are generally isolated and there are potential strategic resources available within Wales (either through enhancing key reservoirs, or by replacing the need for water that is currently abstracted from the River Wye) that could act as support to Severn Trent and hence London, if this is required in the future. These generally occur in the 2065, rather than 2040, Portfolios, but this depends on the level of transfer need that is assigned to Thames Water and the south east, and on the availability of transfers from United Utilities once the Lake Vyrnwy option has been used. It is important to recognise that the designations applied to the majority of water bodies in Wales, recognising their environmental value, may constrain the resource available.

10.2.2.4. Central West (Severn Trent), Thames and Affinity-London

The Portfolio analysis and resilience testing for Severn Trent indicated that there are sufficient new resource schemes available to meet its own risks and obligations, whilst at the same time potentially using strategic options such as the Draycote transfer scheme to help provide a *dedicated* storage support for a Severn-Thames transfer. It also appears that such obligations and schemes do not result in flows within the River Trent that are too low to allow a viable transfer from the Trent into the Anglian storage system.

However, it is important to note that combining the Severn support schemes with options such as Lake Vyrnwy would result in very large volumes of water being transferred into the River Thames over extended periods of time. The resilience testing also indicates that the development of schemes that involve the transfer of Severn Trent resources, when combined with other pressures such as tackling unsustainable abstraction, growth in demand and climate change, could alter the resilience of the Severn Trent system, and start to place Severn Trent's customers under the risk of Level 4 restrictions (when this is currently unlikely except on a localised basis). The acceptability and potential cost of this to Thames Water as part of any transfer agreement would need to be much better understood before any specific long term strategy could be identified.

For Thames Water there is a need for both 'local' strategic resource development and transfers under most future scenarios. As noted previously, any transfers from the Severn would need to be 'supported' through dedicated storage in order to provide drought resilience. The choice of where this storage would be located, and whether it would utilise existing or new capacity, depends on the factors surrounding environmental acceptability, regulation and abstraction arrangements and water quality risks as described previously. Where existing storage other than Lake Vyrnwy is proposed (which appears to be available without increasing risks to United Utilities customers), then implications of the increased risks that this might place on the relevant water companies' customers as a result of using their storage need to be considered. This covers issues such as customer acceptability, additional transaction costs that reflect that risk, and potential concerns over the preferential use of storage by the supplying company *in extremis* in comparison to a reservoir that is directly owned and operated by Thames Water.

It is noted that increased transfer from Thames to Affinity Water is proposed under a number of Portfolios, and the scale of this largely depends on the balance between available supply and demand within the Anglian sub-Region (see below). This indicates that there will be a need to co-ordinate findings between the regional scale assessments being carried out for the WRE and WRSE initiatives, along with possible extensions that consider the implications of different transfer options to Severn Trent and beyond, if a cost-effective solution is to be identified for Affinity Water in the long term.

10.2.2.5. Anglian sub-Region

The strategic transfer and storage of water from the River Trent is a feature of almost all of the Portfolios that were developed, and the resilience testing indicates that there is a potential benefit to resilience from developing this source. It is noted that the analysis carried out for this project did not include a detailed assessment of the infrastructure costs associated with moving and treating that water, and only examined the upper limit of the potential benefit that could be gained from a winter transfer. As with the Severn options, environmental risks (e.g. water quality and transfer of invasive species) may limit the feasibility of this option. There are a number of significant potential costs and constraints that would be involved in transferring, treating and storing water from the Trent that mean it is not currently possible to identify the most appropriate approach for doing this, and these will need to be identified through the regional level WRE initiative. This area also contains a large number and volume of non-PWS users that need to be accounted for when considering the most appropriate form of strategic transfer and storage option for the sub-Region.

10.2.2.6. South East Excluding London sub-Region

The Portfolio analysis described in Sections 8.2 and 8.3 indicates that the most appropriate strategy for this region is a combination of local options and transfers, as already identified by the WRSE initiative. There is a relatively high probability that most of the more cost-effective supply-side options will be required by 2065, so the nature of the detailed strategy for this sub-Region is one of timing and adaptation to avoid abortive investment, rather than an uncertainty over strategic need. It is noted that some of the Portfolios suggest an inter-regional transfer of water from Wessex across to the Hampshire WRZ, but this may be an expensive and impractical option. If this is the case then there may be the need for a strategic transfer from Thames-London under some of the more adverse future scenarios, placing greater need on additional strategic solutions in the Thames basin.

This sub-Region is particularly strongly affected by uncertainties surrounding growth and the need for reductions in existing abstraction in order to protect the aquatic environment. If these are not well managed then there is a significant risk of either expensive, reactive investment, or a highly increased likelihood of Level 3 and 4 demand restrictions as a result of supply/demand imbalances within the sub-Region.

This sub-Region currently contains a mix of planned levels of drought resilience, and this could act as a barrier to transfer opportunities in the future. Similarly, although intra-Regional transfers present a major, low cost, opportunity for enhancing drought resilience in this sub-Region, care is needed to ensure that planning assumptions are compatible between potential suppliers and recipients of water resource transfers. The analysis of drought coherence contained within this report indicates that there is unlikely to be any reliable *differential* in expected severity across such a small area, so the basis of planning risk needs to be properly understood to facilitate and promote such transfers. It is understood that this issue is being investigated by the WRSE group.

10.2.2.7. South West Region

The likely deficits and potential need for new resources indicated in this Region centre on Bristol Water. Bristol Water could be made to be resilient to future droughts by adopting a ‘twin track’ approach that involves demand management and the development of water resource schemes, along with some transfer of water from Wessex. Some of the more cost effective local strategic resource developments (e.g. the Cheddar reservoir and/or the Severn Springs transfer) may be required prior to 2040, and there is a fairly high likelihood that more widespread development will be required by 2065.

It is noted that Bristol Water does not currently plan to be resilient to the worst historic drought event (perturbed for climate change), and that the Portfolio development assumes this will be addressed as a minimum, given the strong economic case for drought resilience. Some of the resource schemes referred to above could be deferred beyond 2040 if the current level of resilience is maintained, but obviously this comes with a higher risk to customers.

10.3. What does this mean for customers and stakeholders?

In economic terms, customers should gain significantly from a move to a more resilient set of planning assumptions because of the high Willingness to Pay values elicited from the available literature (between £40 and £160 per day of Level 4 restrictions avoided per household), and the likely high economic losses for non-household businesses during Level 3 and Level 4 restrictions. Enhanced resilience is unlikely to attract significant affordability issues, as a move to 'severe' drought resilience is estimated to require investment equivalent to less than £4 per household per year, with impacts on customer bills that are even lower. Improvements to the resilience and planning assumptions for public water supplies is also likely have a beneficial impact on non-household customers, with reduced restrictions likely during drought events resulting from a lesser need to protect available resources. Finally, improved levels of resilience could have a knock on benefit to opportunities for trading under less severe droughts, as water companies would be less likely to restrict supplies and regulators would be less likely to impose restrictions on abstraction.

The management of climate change risks is potentially more significant to customer bills, but that depends on the rate at which investment is increased, which in turn depends on the ability of researchers and the wider industry to be able to monitor and hence invest proportionally to that risk – recognising the potential consequences of not doing so. Currently the industry is facing an unknown risk from climate change, which it is choosing to manage by investing to the anticipated median climate future. However, the analysis contained within this report indicates that even a moderately dry climate future could serve to double or even triple the risk of Level 4 restrictions on customers in some sub-Regions by 2040. Investment in research to understand the 'direction of travel' for climate change is therefore of significant importance to customers.

The 'twin track' approach recommended within this report requires the 'right' behavioural response from customers, so initiatives to help influence lower demand and continued engagement with customers to raise awareness of water use and the value of water are important. It will also be important to understand whether the imposition of extended demand management measures in areas that are not water stressed in order to cost-effectively supply areas that are water stressed is acceptable to customers, and if so, what their expected compensation would be for such measures. Similarly, it will be important to engage with customers in situations where companies that do not currently have a significant resilience risk decide to increase that risk in order to trade water to areas of deficit, The same holds true where transfers of water from high value water bodies are required to supply water stressed areas, considering how benefit is transferred to the supplying region e.g. Wales or Cumbria.

Non-public water supply users are likely to be positively affected by increased investment in water supply infrastructure, as this would tend to reduce the risk that they would be affected by restrictions as part of actions to preserve water resources under drought conditions. There are large uncertainties associated with this, but the expected economic benefits could run into the hundreds of millions of pounds (as a 25 year NPV) across regions such as Thames and Anglian. Impacts of different types and levels of investment upon the water environment are harder to draw conclusions for, as they very much depend on the exact nature of the Portfolios that are developed and the future scenarios that are being considered, even when simple metrics such as 'days at hands-off flow' are considered. Broadly speaking there would tend to be an improvement, as the number of Drought Orders and Permits will tend to reduce as investment increases, however this needs to be offset against more localised, potentially significant negative impacts where strategic new abstractions are proposed. In those cases there tend to be more days at hands-off flow in the river, which would potentially affect downstream users and the aquatic environment. This type of issue would be investigated as a matter of course during any licence application process.

The benefits of increasing levels of demand management in comparison to similar, more resource focused Portfolios, are clear in terms of reducing abstraction stresses (as measured by the number of days at hands-off flow). However, they are not particularly large when viewed as an average across regional water resource systems (generally less than 5% reduction in hands-off flow days), so significant environmental improvement will still require focused measures on those more sensitive water courses.

10.4. Policy opportunities and risks

There are a number of recommended key enabling actions that are summarised within Section 9 of this report. These relate to:

- Policy initiatives to support and promote demand management.
- Policy decisions on levels of resilience and national infrastructure needs in relation to public water supply.
- Consideration of the role of Drought Permits and Orders in relation to investment for resilience.
- National level initiatives to better understand drought risks, particularly in relation to evolving climate change, which should better allow for informed, adaptive approaches to planning.
- Regulatory incentives to water companies and potential new entrants to plan for and provide solutions to ‘high impact, low likelihood’ events such as severe drought.
- Cross-company and stakeholder initiatives to better understand the risks involved, and the commercial/institutional arrangements required to support future transfers.
- Regional level investigations to support WRMPs and confirm the ‘best value’ approach to the development of large scale infrastructure.

The last two actions are particularly important for future plans, as strategic level developments such as those contained within this report will require cross-boundary initiatives and innovation, based on a better understanding of risks and opportunities than has been developed in previous WRMPs. Initiatives such as WRSE and WRE are positive developments in this area, but the long lead times and investigation needs involved in agreeing on investment plans should not be under-estimated. Similarly, the analysis contained within this report shows that measures to tackle unsustainable abstraction to protect the aquatic environment can be delivered without undue risk to resilience, provided that suitable lead times can be provided to the required plans and investment. Where that is not the case, significant (and immediate) investment will be required, which could be significantly more expensive than the Portfolio options described in this report.

The biggest risk in not enacting the policy opportunities that are described above is one of potentially abortive investment. This could be brought about reactively in response to a drought event, warnings from the climate change community or sudden regulatory changes, or it could result from an inability to actually promote and implement the most cost effective demand management measures or strategic infrastructure schemes. The drought experiences from Australia in the last decade serve as an example of the large sums of money that can be involved in such reactive responses.

11. The External Review Panel report

Peer review of the Water Resources Long Term Planning Framework

21 July 2016

Conduct of the peer review

The peer review has been conducted by:

- Professor Jim Hall, University of Oxford and member of the Adaptation Sub-Committee of the Committee on Climate Change
- Dr Colin Fenn, Hydro-Logic Services
- Robin Smale, Vivid Economics
- Dr Steven Wade, Met Office

The reviewers were contracted by Water UK to conduct an independent peer review. The reviewers engaged throughout the project, taking part in Steering Group meetings and technical discussions with the contractors, during which they sought to provide constructive advice to ensure that the project met its objectives and was technically sound.

At the end of the project the review panel conducted an independent assessment of the methodology and outcomes of the project, based on the version of the executive summary circulated on 12 July 2016 and the technical report circulated on 5 July 2016. This report documents the independent peer review.

Overview of the study

The Water Resources Long Term Planning Framework study (hereafter “the study”) is a significant and welcome analysis of the resilience of pubic water supplies in England and Wales.

Prior to this study, understanding of the risks of water shortages was fragmentary, based on analysis done by individual water companies in their Water Resource Management Plans and Drought Plans, and by regional joint planning exercises in the South East of England and in East Anglia. Integrative national studies, like the Environment Agency’s “Case for Change” and the UK Climate Change Risk Assessment have not been able to analyse the operation of water resource systems, the economic consequences of drought or the options for water resources management to the level achieved in the study.

A national perspective on the resilience of water resource systems is necessary because:

- Severe droughts are a risk of national significance and a matter of public interest. It is therefore necessary that the scale of risk is understood and communicated at a national scale.
- Were a severe drought to occur, it may require intervention from national governments. Information on the scale of the risk is therefore necessary for government to decide upon appropriate policies and plans. For example, further vigorous action to reduce demand for water could require further regulatory, and possibly legislative, interventions.
- Given the scale of challenges faced by public water supply, it may not be feasible to manage the risk of droughts and water scarcity using only current arrangements, which are based around individual water companies planning for their own needs and striking bilateral arrangements with other water companies. In particular, strategic water transfers would require a more coordinated national approach.

Whilst not prejudging any of these issues, the study begins to provide the evidence needed to assess their significance and urgency.

Several pragmatic approximations were made in order to arrive at the new national results in the time available. We draw attention to these approximations when we think they may have significant implications. We also identify limitations and uncertainties in the data, methods and models employed, and make appropriate caveats on the reliability of their use.

We applaud the development of national methodology for assessment of the resilience of public water supplies. The datasets, models and methodologies that have been assembled in the study provide the basis for further development. We make recommendations for further development at the end of this review.

Review of methodology

The study has involved several innovative methodological developments, notably:

1. National-scale drought simulations, for present and future climates, as well as analysis of historic droughts.
2. Development of a basic nation-wide water resource system model and integration of some water companies' own system models.
3. Economic analysis of the impacts of droughts.
4. Development of national portfolios of investments in water supply, and baseline, extended and enhanced initiatives to manage demand, along with estimates of costs and benefits.

We review each of these methodological developments in turn.

National-scale drought simulations

The analysis has combined the use of a novel stochastic spatial rainfall generator and methods for sampling potential evapotranspiration (hereafter referred to as a "weather generator") with UKCP09 Regional Climate Model outputs and Future Flows hydrological simulations. The use of a spatially coherent approach is an important development. We welcome the analysis of the spatial characteristics of historic droughts, which provides useful context for the study.

The weather generator accurately reproduces the extremal properties of aridity over a range of spatial scales, as illustrated in Appendix A. Future scenarios were developed by selecting outputs from the weather generator and factoring based on average changes extracted from the Future Flows analysis. Only three Future Flows simulations were used for this. Moreover, these are based on the UKCP09 Medium emissions scenario. This combination of a selected set of droughts and only three realisations of possible future climate based on only one emissions scenario is not sufficient to fully explore future drought risks. We do not agree that "it would not have significantly added to the overall findings if drier climates had been considered", even though we accept that this was a necessary simplification in the current study. In addition there is limited information presented on modelled river flows so it is not possible to comment on how well they reproduce low flows under severe and extreme drought. Nonetheless, we confirm that the methods represent a good use of the available observed and simulated data, so whilst they should not be relied upon for local assessment of water resources, they provide the best currently available national picture.

National water resource system modelling

A new national water resource system model was developed for the main (potentially) interconnected regions of England and Wales, using the Wathnet modelling system. This is a significant achievement. Its existence puts the industry and government in a better position for national-scale strategic assessment of water resources. The large-scale, reduced resolution Wathnet model was supplemented with Aquator system simulation and optimisation models used by individual companies, where those were available.

The Wathnet model represented complex water resource systems (including storage and internal/external transfers) at quite an aggregated scale, so was necessarily an approximation of more accurate operational models. However, the validation of the model against reservoir levels under observed droughts is reassuring, so we are satisfied that this system model is a reasonable representation of that part of the public water supply it covers.

Economic analysis of the impacts of droughts

The economic analysis of the impacts of droughts synthesises data from existing studies and water company surveys. It is a systematic compilation of the best available evidence. That evidence has a number of limitations:

1. Customer stated preference surveys have well known limitations, in particular when they relate to situations with which customers may not be at all familiar i.e. standpipes and/or rota cuts. The study reports sensitivity analysis around a wide range of willingness-to-pay to avoid these situations, which is welcome, given the limited range of the data upon which the analysis is necessarily based.
2. The study also scales up estimates of willingness-to-pay per day of avoided disruption to represent the effects of prolonged droughts. The linear scaling (of willingness-to-pay per day, multiplied by drought duration in days) is not based on any empirical evidence, so should be treated with great care.
3. Impacts upon non-domestic users have been calculated based on estimates of the impacts of droughts on Gross Value Added (GVA) in particular sectors. The evidence upon which these GVA loss factors are based is very limited.
4. Wider economic impacts due to upstream and downstream effects in the economic analysis have been estimated using multiplier factors. These factors are by necessity approximate and their origin is not entirely clear. Wider economic adjustments (e.g. via prices and wages) are not considered.

The report is realistic about limitations 1 to 3. The wider economic impacts (point 4) were not included in the benefit-cost analysis, so uncertainties in this aspect of the study are not significant for the results. Given these limitations (1 to3), the estimates of economic impacts should be treated with caution. This caution is reflected in the interpretation of benefits of risk reduction, which are robustly in favour of a higher level of resilience even taking into account the major uncertainties.

Appraisal of investment and policy portfolios

The study builds up portfolios of possible responses to water scarcity, starting with three possible levels of action on demand reduction, and then examining possible supply-side investments that could meet the residual supply-demand gap under each of the baseline, enhanced and extended demand management strategies. We endorse this approach.

The study focussed upon 13 possible portfolios of interventions, which, on the one hand, is a manageable number, whilst on the other hand seeking to cover a range of possible eventualities. The sampling of portfolios did not cover the most favourable possible situation (i.e. combining extended demand management with low climate change, low population growth and low sustainability reductions), apparently because this scenario would not require any further investment beyond what is already planned.

The study explored a range of levels of ambition for managing domestic water consumption. We endorse the approach taken. It also sought, quite properly, to differentiate per capital consumption (pcc) geographically, whist also recognising differences in methods and accuracy of reporting consumption and leakage. We do not however agree with the implication that high pcc is essentially ‘locked in’ i.e. regions with relatively high pcc now will continue to have relatively high pcc in future. We consider that water companies in those parts of the country with high pcc now could be expected to rise to a stronger reduction challenge than those whose pcc is lower, and particularly where it is now under careful management.

We welcome the extensive exploration of the costs of other interventions, including supply-side and distribution-side ones. The costs of leakage reduction are taken from a previous study (UKWIR, 2011). We find the treatment of costs of mains and supply pipe renewal in this study to be rather crude, not reflecting the wide range of costs of these renewal programmes, depending on context, and the potential for economies of scale and technological advances that could reduce costs in future.

Storage and transfer options emerge as important solutions to projected supply-demand shortages. Full attention is given to the upland reservoirs (in Wales, particularly) with reliable supply potential, and to the rivers Severn and Trent as key conduits, and to other enabling inter-company links. Whilst the key hydrological factors are well-covered, customer reaction to the transfer of water from their region, to another, when the risk of drought exists in both, albeit differentially, needs greater consideration. It may be that areas served by large-scale water transfers may be expected to have at least an extended demand management programme in place. This may be a matter for government to resolve, but it – and contract terms and conditions issues – need attention.

The aggregate cost estimates, expressed in the form of present values, do not take into account what the authors describe as 'adaptive management', which economists call real options theory. That is, they do not take into account the fact that future investments should and hopefully will only be made in circumstances in which they are justified, and that the investment programmes will be scaled back and optimised, reducing their cost, as we learn more about the costs and benefits of investment over time. The authors were right not to build this complexity into their modelling at this stage, but the effect is that the expected net present values and ratios of benefits to costs are significantly understated in the report.

Robustness of the results

In the light of the observations made above, we make the following comments on the robustness of the results for policy analysis:

- **The significant and growing risk of droughts and water supply shortages:** Whilst the analysis of drought scenarios has not been sufficiently exhaustive to robustly quantify the risk of water shortages (see our comments above), the study has demonstrated that the risk of droughts that are more severe than those in the historic record is already significant. Whilst there are major uncertainties in the drivers of future risk of water shortage (population, uncertainty on levels of demand, climate, reductions in abstraction limits), these factors are all likely to increase the risk of water shortage in future.
- **A portfolio approach to responding to risk of droughts and water supply shortages:** The study has demonstrated that there are several cost-beneficial responses to the risks of water shortage, by managing demand and increasing supplies in tandem. The study demonstrates that combinations of these interventions should be implemented as portfolios, matched to particular geographical contexts.
- **The costs and benefits of investing in resilience:** As discussed above, the estimates of the economic consequences of water shortages are subject to major uncertainties, as are the estimates of the costs of interventions. Nonetheless, the ratio of estimated benefits to estimated costs is sufficiently robust to confirm that further action to reduce the risk of water shortages is desirable.
- **The need for an adaptive approach:** The study has demonstrated the wide range of possible future conditions. It has identified the risk of stranded assets due to over-investment in major infrastructure. Under the circumstances, the recommended adaptive approach is a wise one, and the next step is to incorporate a real options approach into the investment planning process.
- **The need for consistent minimum standards of resilience:** The study demonstrates that the risks of water shortage are of national significance and that companies' decisions are already not independent of one another. The report also argues that stated preference surveys, upon which Levels of Service have been based, may not be an accurate way of assessing customers' attitudes to very severe or prolonged droughts. The extent to which government is willing to accept the current, geographically-varying levels of risk to public water supplies depends upon ministers' appetite for tolerating risk and their willingness to countenance customers having to pay more to reduce risk – it is not an analytical question. The study provides evidence to inform that judgement by government.

Recommendations

1. **Non-public water supply abstractors.** The study only dealt with public water supplies, so does it not address water use by other abstractors, notably agricultural and industrial (including energy) abstractors. The resilience of public water supplies depends upon how much water will be abstracted by these other sectors, and when, as well as upon overall water availability. Furthermore, the availability of water to these abstractors depends upon the resilience of public water supply, which takes precedence in times of water stress. This is another reason why companies' level of resilience is a matter of public interest and public policy. We recommend that subsequent analysis explicitly includes all significant water

abstractors requirements, particularly any further regional assessments in eastern and southern England, where other abstraction is significant

2. **Further development of datasets and models.** The study has assembled extremely valuable datasets and has built new modelling capability. The extent to which these new data and models have been exploited has been limited by the time available for the study. There will be considerable benefit in the data and models being made available, subject to appropriate licence conditions, so that other analysts and researchers can make use of them.
3. **Requirements for improved climatic scenarios.** Future national assessments, regional studies and water company plans should also consider a wider range of scenarios including high emissions scenarios to fully explore future drought risk. In addition, where risks are significant a wider range of climate modelling tools and statistical models should be employed to develop large ‘catalogues’ of plausible extreme drought scenarios to test the resilience of water supply. The water industry need to be fully engaged in the development of the UK Climate Projections 2018 (UKCP18) and other water resources research to develop robust and also practical methods for risk assessment. We recommend that UKCP18 should contain a larger number of spatially coherent scenarios as well as higher resolution outputs that will enable exploration of the implications of these three levels of uncertainty i.e. emissions scenario, climate model uncertainty, and natural variability.
4. **Managing and forecasting water demand.** The study has demonstrated how the risk of water shortages is sensitive to future demand for water. It also illustrated large geographical differences in pcc and leakage estimates. Further evidence of current consumption and leakage, as well as demand projection evidence, particularly per capita consumption and the effectiveness of demand side interventions, is strongly recommended before investment is committed.
5. **Drought management and drought forecasting.** Resilience to drought involves effective anticipation, preparation and operations as well as effective long term planning. The report highlights that many options in water company drought plans may be ineffective, in part because of the lead-time and risks of implementation. We recommend further research to explore the fullest possible range of instruments for drought forecasting and drought management, as well behavioural responses to drought, along with detailed analysis of the effectiveness of drought plans.
6. **Further exploration of resilience.** The study only examined three possible levels of demand-management resilience, whilst in practice decisions on the appropriate resilience level will have to be made across a continuous spectrum of possible levels. This more extended analysis is required. It would also be helpful to compare the resilience standard applied to water to the resilience standards for other critical infrastructure.
7. **Adaptive decision analysis.** The study has explored portfolios of response to drought risk at two timescales in the future. The next step would be to explore how sequences of policies and investments can be assembled in a framework for decision making under uncertainty.

12. References

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