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CCRA2: Updated projections for water availability for the UK

Final Report

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Executive Summary

Under the Climate Change Act 2008, the UK Government is required to publish a Climate Change Risk Assessment (CCRA) every five years. The first assessment was published in 2012 and the next is due in 2017 (CCRA2). This report presents the results of one of the four projects commissioned to inform CCRA2 using existing data and information. This assessment evaluates the contributing factors for the current levels of risk in water resource planning and then projects these according to a selection of various climate, population, adaptation and environmental protection approaches to 2100. The results of the assessment are provided at two scales: (1) for public water supplies alone and, (2) for 'all sectors' (i.e. public water supplies plus agriculture, energy generation, industry and commerce and the natural environment), for the whole of the UK.

Method

The method for this assessment is designed to improve upon existing projections of water availability using appropriate and, where possible, publicly available data. It is intended to be consistent with existing work undertaken by government agencies and bodies, water companies and may also be applicable to other water-dependent sectors and the academic community. The final results can be grouped into the following:

- **Public water supply analysis results:** For each water resource zone in the UK, projections of the supply-demand balance are estimated for the 2030s (i.e. to the end of the current planning period for all water companies), the 2050s and 2080s. The projections draw upon water company resource plans; following the trends explicit in the resource plans to the end of the planning period and then for the 2050s and 2080s extrapolating those trends according to a set of different scenarios of climate change, population growth and adaptation interventions.
- **'All sectors' analysis results:** For all catchments in the UK, the projections of the water balance are estimated for the 2050s and 2080s. The projections incorporate the results from the public water supply analysis plus additional future scenarios for water use in the agriculture, energy generation and industry and commerce sectors. Different assumptions regarding the amount of flow of water held back for the benefit of freshwater environment (known as the environmental flow) are also tested in this analysis.

Uncertainty

Uncertainty is inherent with any projections of the future. In particular, uncertainty is associated with the following aspects of this assessment:

- Climate projections;
- Population projections;
- Differing levels of uncertainty, assumptions made and methods used in the underlying datasets; and,
- Relatively simple extrapolation and modelling methods used in this assessment.

The results become increasingly uncertain over time i.e. there is higher certainty in the 2030s projections than the 2050s. The 2080s projections are the most uncertain. Rather than a precise prediction of change, this work provides an indicative level of risk and allows the spatial pattern of potential risks to be explored.

Headline messages

Impacted zones are not restricted to the south-east of England. All areas of the UK may be affected by deficits in the water balance either with respect to the environment or to public water supply, or both, depending on the scenario chosen.

The relative contribution of different factors in determining the supply/demand balance varies geographically. Population, adaptation decisions (including decisions on environmental flow calculations) and climate are the drivers of the availability of water for public water supplies, other sectors and the natural environment that have been explored.

Population and adaptation decisions (including decisions on environmental flow calculations) frequently have a greater influence than climate on the water balance of an area.

The freshwater environment is highly connected and its management for human uses and freshwater ecology is very complex. This assessment reiterates the important dichotomy with respect to how to maintain and improve the freshwater ecology whilst maintaining clean and sustainable water supplies for human uses.

The potential for large absolute public water supply deficits and widespread ecological impacts are of national scale importance. Whilst many adaptation actions need to be location specific due to local variation, there may be value in additional larger scale interventions.

Key messages: Current vulnerability, sensitivity and risk

Public water supply analysis results

- **The UK currently has a supply-demand balance surplus** of around 2,000 Ml/d;
  - However, there are modest deficits in some water resource zones that water companies are currently addressing. Importantly, the deficits in these zones are lower than target headroom[1] provided in these zones, and therefore the actual risk to public water supplies is low at present.
- **The current demand for public water supplies is largest where the population is largest**:
  - UK demand is over 17,000 Ml/d:
    - 85% of this demand is in England and Wales;
    - 11% is in Scotland; and,
    - 4% is in Northern Ireland.
- **Typically, household consumption dominates the demand for water**. However, some water resource zones have very high non-household public water supply demand reflecting the nature and intensity of local industry and businesses.
- **Leakage equates to more than 10% of the total demand in most water resource zones** despite recent success in reductions.

[1] Target headroom is the minimum buffer that companies should plan to maintain between supply and demand for water in order to cater for current and future uncertainties.

- **Target headroom varies** between water resource zones and reflects the different ways of calculating this figure.

'All sectors' analysis results

In their natural state[2] and taking into account the environmental flow that is held back in the rivers, all except one[3] of the catchments in the UK would have water available for human uses during low flows[4]. This is known as 'natural available resource':

- The catchments with the largest absolute natural available resource during low flows are the Thames and Severn Corridors in England and Wales and the Rivers Tay and Spey in Scotland.
- The catchments with the least absolute natural available resource during low flows tend to be small, coastal catchments, particularly in Scotland, south-east England and Northern Ireland.

Management of water in the UK is complex. The amount of water available for human uses is not simply a product of the natural available resource in a river. Discharges, mainly from sewage treatment works provide additional flow. Such **discharges help to ensure that all catchments today have 'available resource' for human uses**.

In some catchments present day abstractions would exceed the available resource at low flows if they were left unrestricted. This would mean that the environmental flows would not be met and freshwater ecology may be damaged. This is particularly the case in the south and east of England, but also in a small number of catchments in the north-west of England, Northern Ireland and Scotland. In many rivers today, abstraction licence constraints actively ensure that the environmental flows are met and that the freshwater ecology is protected.

Key messages: Future vulnerability, sensitivity and risk

Public water supply analysis results

- Supply-demand balance:
  - **Supply-demand deficits are reported by water companies by the 2030s**: 27 water resource zones report a supply-demand deficit of greater than 5 Ml/d, but water companies are already working to resolve these issues.
  - **Deficits are projected to be widespread by the 2050s** under a high population growth and a high climate change scenario, in the absence of any adaptation interventions.
    - The south-east of England and the large conjunctive[5] use zones in the north of England are particularly susceptible, but deficits are projected in other parts of the UK as well.

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[2] In the absence of impacts from people i.e. without any abstractions, discharges or uses of water of any kind.

[3] Moray Coastal in Scotland. The sensitivity of the downstream water bodies in this catchment means that all the water during low flows is required for the rivers' ecology. Therefore, there is no water available for human uses.

[4] Annual Q95, the flow that is equalled or exceeded 95% of the time, a commonly used low flow metric. In this assessment, Q95 refers to the 30-year annual average Q95 unless specified otherwise.

[5] Conjunctive use is the co-ordinated management of multiple sources with varying resource availability, quantity and quality in time and space (e.g. surface and groundwater supplies) in order to maximise the Deployable Output of a water resource zone.

- **Deficits become more widespread and more acute by the 2080s** under a high population growth and a high climate change scenario, in the absence of any adaptation interventions. All four UK countries have water resource zones with a projected supply-demand balance deficit under this projection. Furthermore:
  - The UK is projected to be in deficit when considered at a national scale[6] by:
  - Around 800 - 3,200 Ml/d (5-16% of the total demand for water at that time) in the 2050s; and,
  - Around 1,400 - 6,000 Ml/d (8-29% of the total demand for water at that time) in the 2080s.
- **In the 2080s, each UK country is projected to be in deficit overall under the upper bound scenario:** a high population, high climate change scenario in the absence of any adaptation interventions.

■ Supply:

- **In the 2030s, climate change impacts on the amount of water available for public water supply vary significantly** across the different water resource zones. At a national level, the proportion of water resource zones that report projected impacts from climate change in the water company resource plans is:
  - England and Wales: More than 50%;
  - Northern Ireland: Nearly 75%; and,
  - Scotland: Nearly 25%.
- **In the 2030s, absolute impacts on the amount of water available for public water supply is greatest in England, particularly in London and in the north–west.**
  - London is particularly vulnerable due to its large, growing population and specific abstraction licencing constraints.
  - The north-west is particularly vulnerable due to its large population and its reliance on surface water sources that are typically more vulnerable to changes in climate than groundwater sources.
- **By the 2050s and 2080s there are significant reductions projected in the amount of water available for public water supply under both medium and high climate change futures**, without any additional adaptation. This equates to:
  - 2050s: around a 6-11% reduction in available water compared to the baseline; and,
  - 2080s: around a 8-15% reduction compared to the baseline.
- **Parts of the chalk aquifer in the south-east of England may be particularly sensitive to climate change by the 2080s** despite that fact that groundwater sources are typically projected to be reasonably resilient to climate change.

■ Demand:

- **Total UK demand for water in the 2050s is projected to increase by between 2-9%[7]** compared to the baseline;
- **Total UK demand for water in the 2080s is projected to increase by between 4-18%[7]** compared to the baseline; and,

[6] Projection ranges from low population, medium climate change scenario to a high population, high climate change scenario, in the absence of any adaptation interventions.

[7] Projection range from a low population to a high population future scenario.

  - **Demand in each water resource zone may be significantly higher or lower than the national figures** because localised changes in population drive the pattern of demand.
- **Adaptation is projected to have the potential to substantially, but not completely, alleviate the supply-demand deficits that may occur in the future**.
  - However, this conclusion is based on the following assumptions:
    - Significant leakage and household consumption reductions could be successfully implemented; and then,
    - All other supply-side and demand-side measures outlined as preferred and feasible options in current water company plans are successfully implemented and would generate the yields forecast in the water company plans; and further,
    - Any additional measures which may potentially be available, but are not presented in the latest water company resource plans, have not been considered.
  - **The feasibility of implementing specific adaptation measures was not considered but may be a significant challenge.** The projected reductions in leakage and household consumption (and the associated behavioural changes that would be necessary), in particular, may be extremely difficult and prohibitively expensive to achieve in practice in all areas.

'All sectors' analysis results

- **The amount of natural available resource available for human uses is primarily driven by the approach used to calculate the environmental flow rate.** The climate scenario tested typically has a secondary influence on the future amount of natural available resource.
  - **In the 2050s and 2080s, many catchments in the west of the UK are projected to not be able to meet their environment flow requirements at low flows** under the upper bound climate and population scenarios, assuming no change in the absolute environmental flow rate compared to the baseline and, without any additional adaptation.
  - **In the 2050s and 2080s, the unrestricted demand in catchments in the east and south of the UK and across central Scotland at low flows is projected to be in excess of the total available resource,** under the upper bound climate and population scenarios, assuming no change in the absolute environmental flow rate compared to the baseline and, without any additional adaptation.
  - **Allowing environmental flow rates to change by being calculated as a proportion of future river flows, would increase the natural available resource** thereby reducing the potential abstraction pressure and allowing environmental flow requirements to be met. However, allowing absolute environmental flow rates to fall risks harm to the ecology of river water bodies.
- **Only the northern most catchments of Scotland and some central and west midlands catchments in England are projected to maintain a high level of water availability** under all the future scenarios assessed.
- **Discharges may be an important component to ensure enough water is available for some water resource zones.** Whilst population growth often places additional pressures on public water supplies and the local environment, the discharges associated with increased populations may actually support low flows in some rivers during critical low flow periods. However negative impacts upstream, where significant abstraction occurs, are a concern.
- **Adaptation influences the severity of the impact of the proportion of the available resource used**. Influence is most notable in the west where the adaptation scenario may make the difference between a projection of surplus or deficit.

Comparison to CCRA1 results

The results of this assessment and similar metrics in CCRA1 are broadly of the same magnitude. The two assessments used different methods and different scales of analysis. Specifically:

- CCRA presented results at a regional scale, this assessment focuses on the water resource zone scale;
- The magnitude of change in Deployable Output is similar in both assessments;
- Change in demand follows population growth in both assessments. However, the range is greater in this assessment due to the scale of the analysis;
- The absolute deficits in this analysis are slightly less severe than the deficits in CCRA1, probably due to the scale of the analysis; and,
- Per capita consumption adaptation actions are more extreme in this analysis compared to CCRA1.

Glossary

Abstraction

The removal of water from any source, either permanently or temporarily.

Abstraction licence

The authorisation granted by the Environment Agency to allow the removal of water from a source.

Adaptation

The adjustment of behaviour to moderate harm, or exploit beneficial opportunities, arising from climate change. Adaptation actions can directly reduce exposure and/or vulnerability to climate change or can minimise the impacts.

Available resource

Available resource is the water available in a catchment once Environmental Flow Indicators (EFI) and discharges have been taken into account. It is calculated as the natural flow minus the EFI requirement, plus additional water from discharges.

Confidence

A confidence score of low, medium or high is associated with each projection made in this assessment. The score is based upon the definition of confidence outlined for the main CCRA. A summary of this is re-produced here for information:

- **High confidence:** Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement between studies and experts.
  - Multiple sources of evidence that contain similar results
  - Based on robust techniques
  - Data used is of a high quality
  - Evidence has been peer reviewed
  - Published relatively recently.
- **Medium confidence:** Several sources of high quality independent evidence, with some degree of agreement between studies, and/or widespread agreement between experts**.
  - Some elements of “high quality evidence” and “little evidence”.
- **Low confidence:** Varying amounts and/or quality of evidence and/or little agreement between experts.
  - No, or very few, sources of evidence
  - Based on weak methodologies (e.g. anecdotal evidence)
  - Poor quality data
  - Evidence has not been peer reviewed
  - Published a long time ago.

Consumptive use

A use of abstracted water in which the water must be treated prior to being returned to the environment. Often, consumptive water is returned downstream of its abstraction point, near to or within transitional or coastal waters, rather than into the immediate environment whence it came.

Emissions scenarios

Future greenhouse gas emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties.

Deficit

For the purposes of water resources planning, a deficit is defined as where the balance between the demand for water and available supplies is insufficient to maintain an acceptable reliability of supply to customers. Acceptable reliability of supply is defined in terms of the ability to satisfy specified levels of service relating to the frequency and severity of shortages.

Deployable Output (DO)

Deployable Output (DO) is the amount of water that can be pumped from a water company's sources (surface and groundwater), constrained by licence, hydrology or hydrogeological factors and works capacity.

Distribution Input (DI)

Distribution Input (DI) is the average amount of potable water entering the distribution system within the area of supply. It is the sum of the total demand for water from people (i.e. household and non-household use), plus losses from leakage.

Environmental Flows

Environmental flows, also referred to as ecological flows and eflows, are the characteristics of the natural flow regime, including the quantity, frequency, timing and duration of flow events which maintain specified, valued features of a freshwater ecosystem.

Environmental Flow Indicators (EFI)

A nationally consistent flow screening approach in the UK. The Environmental Flow Indicator (EFI) represents a precautionary estimate of the flow regime necessary to support Good Ecological Status, or Good Ecological Potential for Heavily Modified Water Bodies (HMWBs). EFIs are set with reference to natural flows for every river, lake or estuary water body. The difference between natural flows and the EFI equates to the amount of net abstraction considered acceptable. The greatest level of protection is given to the lowest flows. EFIs are usually set between 10 and 20% below the natural Q95 depending upon the sensitivity of the water body.

Natural available resource

The natural flow of the river minus the environmental flow requirement. This indicator describes the amount of water available for human uses after allowing for environmental requirements. This indicator does not include any abstractions or discharges.

Non-consumptive use

A use of abstracted water in which the water is returned to the immediate environment whence it came, requiring little or no wastewater treatment. For example, non-consumptive uses are defined as the use of directly abstracted water in: fish farm/cress pond through-flow, hydropower generation, milling and water power, hydraulic rams, non-evaporative cooling, and transfers between sources. Consumptive uses of abstracted water are taken to be all uses excluding those non-consumptive uses listed above.

Outage

A temporary loss of useable water output because of planned or unplanned events. Planned events include maintenance of works; unplanned events can include pollution, turbidity, nitrate, algae, power failure and system failure.

Per Capita Consumption (PCC)

Measure of average water use for each person in an appointed water company's area. Companies are required to report estimates for both metered and unmetered customers.

Q95

The river flow that is equalled or exceeded for 95% of the time. Q95 is a common low flow reference (and conversely, Q10 is a high flow reference). In this assessment, Q95 refers to the 30-year annual average Q95 unless specified otherwise.

Shortage

A shortage is typically taken to be where the demand for water cannot be met (or cannot be guaranteed to continue to be met in the near future) and drought response measures need to be introduced to manage the consequences appropriately.

Surplus

When water supply exceeds demand.

Supply-demand balance

The difference between water available for use supply and demand at any given point in time.

Target headroom

Target headroom represents the minimum buffer that companies should plan to maintain between supply and demand for water in order to cater for current and future uncertainties.

Transitional waters

Estuarine waters. An estuary is a body of water formed where freshwater from rivers and streams flows into the sea, mixing with the seawater.

Uncertainty

A characteristic of a system or decision where the probabilities that certain states or outcomes have occurred or may occur is not precisely known.

Vulnerability

The degree to which a recipient is affected, either positively or negatively, by exposure to a climate hazard. Includes the ability of the recipient to prepare, respond and recover from a climate hazard (and conversely to benefit from positive impacts).

Water company resource plans

The collective term coined by this project to collectively refer to the water resource plans that are published by water companies across the UK on a 5-yearly cycle:

- Water Resource Management Plan (WRMP) (England, Wales and Northern Ireland);
- Water Resource Plan (WRP) (Scotland).

Water Available For Use (WAFU)

The Deployable Output plus bulk supply imports, less bulk supply exports and less reductions made for outage allowance and operational losses.

Water Resource Zone (WRZ)

The largest possible zone in which all water resources, excluding external transfers, can be shared. Hence, it is the zone in which all customers experience the same risk of supply failure from a resource shortfall.

Yield

Yield is the unconstrained water output of a source that can be sustained by the catchment or aquifer feeding the source.

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1. Introduction

1.1. Background

Under the Climate Change Act 2008, the UK Government is required to publish a Climate Change Risk Assessment (CCRA) every five years. The first assessment was published in 2012 and the next is due in 2017.

The Department for Environment, Food and Rural Affairs (Defra) has asked the Adaptation Sub-Committee (ASC) of the Committee on Climate Change to prepare an independent evidence report to inform the next CCRA by July 2016. The Government will lay the CCRA evidence report, and a Government report, before Parliament by January 2017. Both the ASC and Government reports will then feed into the development of the next national adaptation programmes for England, Wales, Scotland and Northern Ireland.

The majority of the ASC's independent evidence report will be based upon existing peer reviewed literature and research. However, four new assessments have been commissioned to help translate existing research into a usable format for the evidence report:

- Project A: Updated UK-wide projections of flood risk.
- Project B: Updated projections of water availability for the UK.
- Project C: Aggregated assessment of climate change risks to natural capital.
- Project D: Consideration of new extreme "high++" scenarios for extreme events other than sea level rise and storm surge (for which high++ scenarios already exist).

This report presents the results for Project B 'Updated projections of water availability for the UK'. As required by the evidence report, this assessment covers England, Northern Ireland, Scotland and Wales. It does not cover the Crown Dependencies or Overseas Territories.

1.2. Purpose

The purpose of this assessment was to produce one set of water supply-demand projections, for the UK, that are consistent with, or at least recognisable, in relation to the Environment Agency and Natural Resources Wales' Case for Change report and water companies' resource planning process.

Water company resource plans

Water companies in the UK have a statutory responsibility to produce a plan, revised every 5 years, showing how they intend to maintain the balance between supply and demand for water over the next 25 years.

- In England, Wales and Northern Ireland, these plans are known as Water Resource Management Plans or WRMPs.
- In Scotland, this plan is known as the Water Resource Plan, or WRP.

In this report, all these plans are collectively referred to as **water company resource plans**.

There are three key areas in which this assessment aims to build upon the analysis undertaken for CCRA 2012:

- **Water availability projections**:
  - The Case for Change analysis (C4C) (Environment Agency, 2011, 2013) and the CCRA 2012 water sector analysis (Rance *et al.*, 2012) resulted in two sets of national (England and Wales) water supply projections for public supply. This caused confusion with regard to which should be used for policy appraisal in England and Wales. This assessment has produced a set of projections for the UK (all four countries). The assessment for England and Wales is more consistent with the C4C analysis than the analysis in CCRA 2012 was able to be.
  - The CCRA 2012 projections also differ slightly from the projections used by water companies UK-wide; whilst water company planning tables informed CCRA 2012, the results were aggregated at a larger scale. This assessment more closely adheres to the methods and projections used by water companies by making use of the latest resource plans and undertaking the assessment at a Water Resource Zone (WRZ) scale, making direct use of the planning tables associated with the latest resource plans as part of the analysis.
  - This assessment will include an analysis of all major water use sectors.
- **Population growth, socio-economic change and adaptation**:
  - Similar to both the water company plans and CCRA 2012, this assessment will use government held population change data[8] to inform the projections into the future.
  - Unlike the first CCRA, this assessment will also consider the potential influence of certain adaptation scenarios that may alter the level of risk to water availability in the future.
- **Drought events:**
  - This assessment explores the pattern of extreme dry periods into the future.

1.3. Objectives

To achieve the main purpose and improvements outlined above, the assessment is broken down into the following objectives:

1. Develop hydrological projections (surface water and groundwater) to 2100 that reflect the range of emissions scenarios and equivalent probability levels found in the UKCP09 climate projections;
2. Quantify the amount of water available for supply to, and the demand from, 'all sectors'[9] to 2100 according to these climate change scenarios and consider the potential influence of a range of adaptation actions; and,
3. Qualitatively assess the pattern of droughts in the future using the Future Flows projections.

[8] Data obtained from Office for National Statistics (ONS) and/or the relevant Devolved Administration Governments and Local Authorities. (National Records of Scotland, 2014; Northern Ireland Statistics and Research Agency, 2013; Office for National Statistics, 2014; Office for National Statistics, 2013a, b, c, d, e, f, g, h, I; and, Welsh Government, 2013).

[9] Including industrial sectors, public water supply and environmental demand.

1.4. Structure of this report

The structure of this report is as follows:

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- 1. Introduction
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- Results
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- Appendices
  - A Method used
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2. Method summary

Summary

The primary tasks in this assessment are:

1. **Task 1 Climate projections and Task 2 Hydrology and groundwater projections:** Existing hydrological models (used for the Future Flows and Groundwater Levels project) were run using the full UKCP09 probabilistic climate projections for a range of emissions scenarios and future time periods to provide trajectories of estimated changes in river flows and groundwater levels. This information was used to calculate a selection of hydrological and hydrogeological indicators that were used in the subsequent tasks.
2. **Task 3 Water availability projections:** for each Water Resource Zone in England, Wales, Scotland and Northern Ireland, the outputs from Tasks 1 and 2 have been used to calculate the changes in supply, expressed as Deployable Output for public water supply. Future demand projections have been derived from the Case for Change analysis and ONS population projections. The supply and demand projections then form the basis for a supply-demand balance to 2100 for Public Water Supply and subsequently are incorporated into catchment-level balance calculations that also include environmental requirements and demand from other sectors, namely agriculture, energy generation and industry and commerce. The adaptation options previously identified by water companies as part of the Water Resources Planning process have been evaluated to identify locations which may be at risk of exhausting such options for mitigating emerging supply-demand deficits in the future.
3. **Task 4 Assessment of changes in drought characteristics:** Changes in drought characteristics have been assessed by using standardised indices of groundwater levels and river flows to explore patterns of extreme dry periods to 2100.

Each of the method tasks are summarised below and in Appendix A. The data required for each of these tasks are outlined in Appendix C.

2.1. Tasks 1 and 2: Climate and Hydrological projections

The aim of tasks 1 and 2 is to build upon the existing climate change projections allowing the complexity of catchment hydrology to be explicitly incorporated into this assessment. Together, tasks 1 and 2 have produced two sets of metrics:

- **09-Hydrology:**
  - Selected Future Flows (FF) (Prudhomme *et al.*, 2012) hydrological models[10] have been re-run using the full UKCP09 (Murphy *et al.*, 2009) probabilistic climate projections for low, medium and high emissions for thirty-year time periods centred on the 2030s, 2050s and 2080s to provide trajectories of estimated changes in river flows.
  - All 24 FF groundwater models have been re-run using the full UKCP09 probabilistic climate projections for 2050s medium and high emissions scenarios and 2080s medium emissions scenario

[10] Northern Ireland is not covered by the Future Flows products. Regional hydrological change projections are based upon climatic and hydrological analogues chosen from sites in Great Britain.

to estimate projected changes in groundwater levels. The metrics outlined in Table 2.1 have been calculated using these model runs.

- **Future Flows Hydrology (FFH):** The flow metrics in Table 2.1 have been calculated from existing FF results for selected sites and 'translated', to give an understanding of where the metric may lie in relation to UKCP09 high and low emissions projections (the original FF climatology was only developed for the medium emissions scenario).

Table 2.1 shows the metrics that have been calculated for 09-hydrology and FFH. Regional (UKCP09 river basin) average percentage change values for each emission scenario and time period for each metric have also been calculated. Following discussions with the Project Steering Group, for Task 3 , the 09-Hydrology, not the FFH, indicators were chosen as the most appropriate projections for projecting future water availability in order to distinguish the climate change signal from the influence of natural climate variability.

Table 2.1: Hydrological and hydrogeological indicators.

Metric	Description
River Flow Quantiles (% change in single value)	Q5, Q30, Q50, Q70, Q95, Q99
River Flow Means (% change in mean of 30 values)	Hydrological Year (Oct – Sept)
	Summer (Jun – Aug)
	Summer Half Year (Apr – Sep)
	Winter (Dec – Feb)
	Winter Half Year (Oct – Mar)
River Flow Rolling Means (% change in single value)	Lowest 30 day rolling mean flow
Groundwater Level	Change in groundwater level for the months with highest and lowest historical monthly mean groundwater level
	Change in average groundwater level

Source: *All metrics are calculated as the % change in 30-year future time periods compared with the average of 1961-90. Future time periods are 2030s, 2050 and 2080s.*

2.2. Task 3: Water availability projections

Water Availability projections are discussed and analysed from two perspectives:

- Public Water Supply (PWS) only;
- 'All sectors'.

The results of Tasks 1, 2, and 3.1 (the PWS projections) feed into the projections for 'all sectors'.

Whilst the source data for this task may be based upon sophisticated techniques i.e. climate or hydrological modelling for example, the national assessment projections, in the 2050s and 2080s in particular, are based upon simpler extrapolation methods. Such methods may introduce additional uncertainty over more sophisticated methods; however, they are quicker and more readily applied for a national scale assessment such as this.

Up to thirty-eight scenarios have been assessed. These scenarios are outlined in Table 2.2. The final column, Environmental Flow Options, only forms part of the 'all sectors' projections, for more information on environmental flows, see the box below.

Environmental flows

Environmental flows, also referred to as ecological flows and eflows, are the characteristics of the natural flow regime, including the quantity, frequency, timing and duration of flow events which maintain specified, valued features of a freshwater ecosystem.

The Water Framework Directive has driven the development of a nationally consistent environmental flow screening approach in the UK. The Environmental Flow Indicator (EFI) represents a precautionary estimate of the flow regime necessary to support Good Ecological Status, or Good Ecological Potential for Heavily Modified Water Bodies (HMWBs). EFIs are set with reference to natural flows for every river, lake or estuary water body. The difference between natural flows and the EFI equates to the amount of net abstraction considered acceptable at different levels of flow: usually between 10 and 20% below natural Q95. The greatest level of protection is given to the lowest flows and the most sensitive types of water body.

Table 2.2: Future scenario combinations.

		Climate change[i]		Abstraction growth[ii]		
ID	**Time**	**Emission**	**Percentile**	**Population**	**Adaptation**	**Environmental flow options[iii]**
1	Baseline[iv]	n/a	n/a	Current	n/a	Current
2	2080	High	UKCP09 - p90	High	No additional action	EFI fixed
3						EFI proportionate
4					Current objectives+	EFI fixed
5						EFI proportionate
6		Medium	UKCP09 – p50	High	Current objectives+	EFI fixed
7					No additional action	EFI proportionate
8				Principal	Current objectives	EFI fixed
9						EFI ‘no deterioration’
10						EFI proportionate
11				Low	Current objectives+	EFI fixed
12					No additional action	EFI proportionate
13		Low	UKCP09 – p10	Low	Current objectives+	EFI fixed
14						EFI proportionate
15	2050	High	UKCP09 - p90	High	No additional action	EFI fixed
16						EFI proportionate
17					Current objectives+	EFI fixed
18						EFI proportionate
19		Medium	UKCP09 – p50	High	Current objectives+	EFI fixed
20					No additional action	EFI proportionate
21				Principal	Current objectives	EFI fixed
22						EFI ‘no deterioration’
23						EFI proportionate

ID	Time	Climate change[i]		Abstraction growth[ii]		Environmental flow options[iii]
24				Low	Current objectives+	EFI fixed
25					No additional action	EFI proportionate
26		Low	UKCP09 – p10	Low	Current objectives+	EFI fixed
27						EFI proportionate
28	2080	High	UKCP09 – p90	Principal	NAA	EFI options not included. These future scenarios were carried out for the public water supply analysis only.
29	2080	Medium	UKCP09 – p50	Principal	NAA	
30	2080	Low	UKCP09 – p10	Principal	NAA	
31	2080	High	UKCP09 – p90	Principal	CO	
32	2080	Low	UKCP09 – p10	Principal	CO	
33	2080	High	UKCP09 – p90	Low	NAA	
34	2080	Low	UKCP09 – p10	High	NAA	
35	2080	Low	UKCP09 – p10	Low	NAA	
36	2080	High	UKCP09 – p90	Principal	CO+	
37	2080	Medium	UKCP09 – p50	Principal	CO+	
38	2080	Low	UKCP09 – p10	Principal	CO+	

Source: [i]*Regionalised climate and hydrology projections from Tasks 1 and 2.*

[ii]*A combination of PWS projections (including household and non-household demand) and figures from Case for Change analysis, scaled according to population and adaptation scenario (described in Table 2.3).*

[iii]*Environmental Flow Indicator (EFI) options.*

[iv]*Baseline years vary between 2007 and 2015 depending upon the dataset referenced.*

Table 2.3: Description of the plausible range of adaptation approach options considered in this assessment.

Water use factor	No additional action	Current objectives (end of final plan actions)	Current objectives+ (estimate to improve on final plan)
PWS leakage	Per capita leakage rates follow the water company resource plans to the 2030s. The trend in per capita leakage over the planning period is calculated. For the 2050s and 2080s, the rate of change in leakage with population follows the same trend as implied by the trajectory through the resource plans.	As for 'No additional action' but with an additional constraint that absolute leakage cannot increase beyond the resource plan end of plan values. This means that in WRZs where populations increase, the absolute leakage limit may be met and therefore will be held constant for the 2050s and 2080s. However, where population decreases, the per capita leakage will be allowed to vary.	Assume a trajectory of % reductions in per capita leakage from the final resource plans' planning year to 2050 as implied by C4C "Innovation" scenario and that absolute leakage does not increase above resource plan values. Values then held constant to 2080s.
PWS Household adaptation values	Metered and unmetered Per Capita Consumption (PCC) to remain at the levels as at the end of the current water resource planning horizon. All new properties (from today) are considered to be metered in England and Wales but for Scotland and Northern Ireland the split between measured and unmeasured is assumed to remain as at the end of the planning horizon.	Adopt the lower of the metered PCC rate as at the end of the planning horizon or, where higher than 125 l/h/d, follow a trajectory towards 125 l/h/d by 2050 across all WRZs where a supply-demand deficit is projected in the future.	Follow a trajectory towards the C4C "Sustainable Behaviour" scenario PCC value of 92 l/h/d across all WRZs by 2050 where a supply-demand deficit is projected in the future – and PCC values held constant for 2080s.
PWS Non-household demand (NHH)*	By WRZ, develop relationship between population growth and NHH demand growth to 2040 from the resource plans and then project forward.	As 'No additional action'.	As 'No additional action'.
Industry and Commerce (% change from baseline)*	Baseline figures from C4C (2013) scaled to our population figures (at a national scale).	As 'No additional action'.	Sustainable behaviour from C4C scaled to our population figures (national).

Water use factor	No additional action	Current objectives (end of final plan actions)	Current objectives+ (estimate to improve on final plan)
Agriculture (% change from baseline)*	Baseline figures from C4C (2013) scaled to our population figures (at a national scale).	As 'No additional action'.	Sustainable behaviour from C4C scaled to our population figures (national).
Energy Generation (% change from baseline)*	Baseline figures from C4C (2013) scaled to our population figures (at a national scale).	As 'No additional action'.	Sustainable behaviour from C4C scaled to our population figures (national).
Other water company adaptation options	None	All preferred adaptation options in the plans are included, except where they overlap with other factors in this table. In those instances, the values determined by this table above are used, to avoid any double-counting.	All preferred adaptation options in the plans are included, except where they overlap with other factors in this table. In those instances, the values determined by this table above are used, to avoid any double-counting.

Source: The 'adaptation approaches' reflect three options to describe different levels of adaptation that may be possible in the future. There are many combinations of potential adaptation options and they are not all covered by this assessment. Instead, these options are designed to provide a plausible range of options:

1: No additional action: All current behaviour of individuals, groups, companies and government remain the same as they are today (baseline), even where existing objectives are not currently being met.

2: Current objectives: This assumes the objectives and intentions of current policies, guidance and adaptation planning for water resources are all met.

3. Current objectives+: This future adaptation approach aims to improve on current objectives.

The end dates for the respective planning horizons are 2040 for England and Wales, 2032 for Scotland and 2035 for Northern Ireland.

**Non-household demand will include uses by agricultural, energy and industry and commerce. In the 'all sectors' analysis, the separate industry and commerce, agriculture and energy generation factors are driven by abstraction licence details, so double counting does not occur. However, this means that the total water use by each sector is not completely accounted for in these figures as some of their water use comes from PWS non-household figures.*

Table 2.4: Environmental Flow Indicator (EFI) option definitions.

Title	Definition
Fixed	Using the current Environmental Flow Indicator (EFI) thresholds and assuming that the absolute flow rate is fixed at those levels to meet environmental requirements including continuing to support WFD Good Ecological Status (GES). There are two significant caveats in using this scenario. Firstly, this does not represent the current status in all water bodies; some may or may not be in GES and may or may not currently meet their EFI thresholds. Secondly, until local investigations are completed there is no certainty that these nationally set indicators are at the right level to mitigate damage to the environment.
Proportionate	Using the same percentage deviations from natural flow as the current EFI thresholds, but applying them to a future flow scenario that may have more or less absolute flow. This keeps the proportion of environmental flow protection the same as it is now, compared to the total flow available, but the volume of water available for abstraction changes to reflect changes in the natural flow.
No deterioration	Future EFI is set at the absolute flow rate of either: 1. The current EFI threshold, or 2. Level of recent actual observed flow, whichever is less.
Proportional 'no deterioration'	Future EFI is set at the proportion of flow represented by the either: 1. The current EFI thresholds, or 2. Level of recent actual observed flow, whichever is less.

Notes: *Only the first three EFI options were included in this assessment, to maintain consistency with published information from the WRGIS for England and Wales.*

2.2.1. Public Water Supply

Task 3 delivers future water supply-demand balance estimates for public water supply across the UK, by WRZ. The vast majority of the data used in this part of the analysis are drawn from the latest water company planning tables. Water companies calculate the supply-demand balance to satisfy the following:

Water Available For Use (WAFU) >= Distribution Input plus Target Headroom

Water Available For Use (WAFU) is the Deployable Output plus bulk supply imports, minus bulk supply exports and minus reductions made for outage allowance and operational losses. Water companies calculate climate change impacts on Deployable Output (not WAFU) and the assessment presented here does the same.

This task comprises four parts: supply projections; demand projections; quantification of the supply-demand balance; and, quantification of the effects of different adaptation scenarios on the supply-demand balance:

- **Supply projections**: These are based on projecting estimated Deployable Output, and subsequently applying bulk supply imports and exports and allowing for reductions made for outage allowance and operational losses. Deployable output is the amount of water that can be taken from a water company's sources (surface and groundwater), constrained by licence, hydrology or hydrogeological factors and works capacity. Data on Deployable Output, and the impact of climate change on Deployable Output to the 2030s, are sourced from water company resource plans.

- **Demand projections**: This is described using Distribution Input. Distribution Input is the average amount of potable water entering the distribution system within the area of supply. Distribution Input is the sum of all household and non-household demand and leakage. Data on Distribution Input, and future projections of Distribution Input to the 2030s, are sourced from water company resource plans.
- **Supply-demand balance**: The difference between supply (WAFU) and demand (Distribution Input) at any given point in time including an allowance for uncertainty (called target headroom) in the supply-demand balance calculations. This may result in a surplus or a deficit of water. Deficits occur when demand for water outstrips the available supply (including the target headroom allowance).
- **Adaptation deficits**: This occurs when water deficits cannot be balanced by a given adaptation scenario.

The results are calculated for the combination of the following scenarios:

- **Time:** Baseline (year as per water company resource plans), 2030s (end of water company resource plans), 30-year average time periods for 2050s and 2080s.
- **Emissions:** 09-Hydrology metrics for low (UKCP09 – Low emissions -p10), medium (UKCP09 – Medium emissions - p50) and high (UKCP09 – High emissions - p90) emissions scenarios.
- **Population:** Low, principal and high population scenarios, see Table 2.5.
- **Adaptation:** Three adaptation approach options, “No additional action”, “Current objectives” and “Current objectives+”, described in Table 2.3. In addition, “Current objectives” and “Current objectives+” pathways include all water company preferred options – those measures identified by a water company in their latest plan to be implemented over the course of the planning horizon to mitigate emerging supply-demand deficits. Additional adaptation potential that may be realised from those feasible options (additional options considered viable) identified by water companies in England and Wales, in their plans, is also assessed.

Table 2.5: National level population projections from ONS and Devolved Government data.

Country	2012	2030s	2050s	2080s
Low projection				
UK	**63,700,000**	**69,670,000**	**74,210,000**	**76,450,000**
England	53,490,000	59,010,000	63,360,000	65,870,000
Wales*	3,080,000	3,210,000	3,250,000	3,180,000
Scotland	5,310,000	5,530,000	5,670,000	5,630,000
Northern Ireland	1,820,000	1,920,000	1,930,000	1,770,000
Principal projection				
UK	**63,700,000**	**70,890,000**	**78,510,000**	**86,220,000**
England	53,490,000	60,110,000	67,070,000	74,300,000
Wales*	3,080,000	3,250,000	3,430,000	3,590,000
Scotland	5,310,000	5,590,000	5,970,000	6,320,000
Northern Ireland	1,820,000	1,940,000	2,040,000	2,010,000
High projection				
UK	**63,700,000**	**72,130,000**	**83,100,000**	**97,220,000**
England	53,490,000	61,200,000	70,950,000	83,680,000
Wales*	3,080,000	3,290,000	3,640,000	4,070,000
Scotland	5,310,000	5,670,000	6,350,000	7,170,000
Northern Ireland	1,820,000	1,970,000	2,160,000	2,300,000

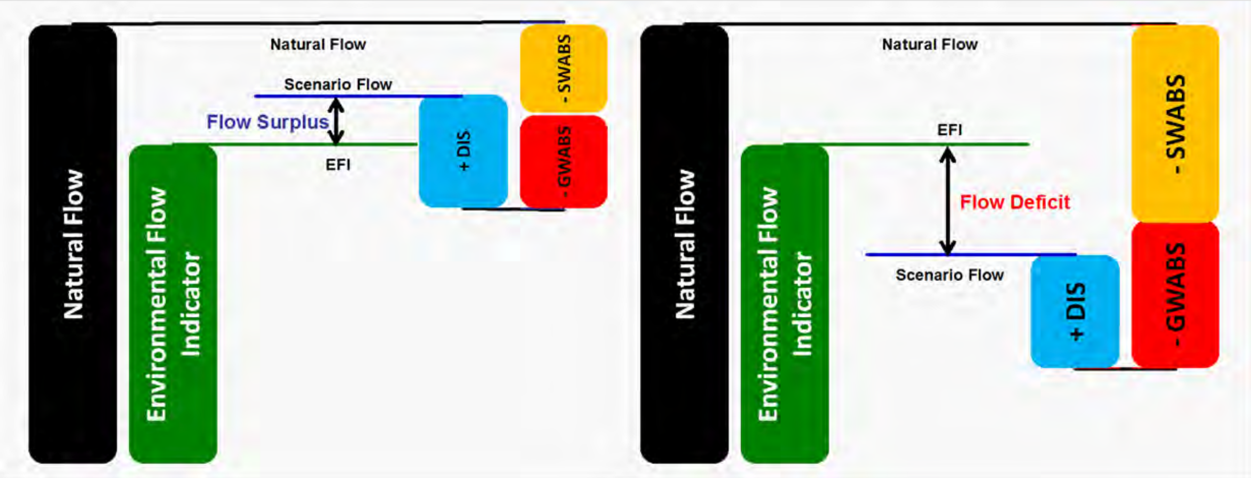
*Source: Population projections from ONS (2014, 2013a-l); National Records of Scotland (2014); Welsh Government (2013); and, Northern Ireland Statistics and Research Agency (2013). All figures are rounded to the nearest 10,000 people. *Political boundary*

2.2.2. 'All sectors'

Task 3 aims to incorporate other non-PWS sectors (agriculture, industry and energy) and environmental requirements into an all-sectors water balance assessment for the UK. The magnitude of changes in projected climate and Public Water Supply demand from earlier tasks are included in this part of the assessment. This component of Task 3 is done by using the existing Water Resources GIS tool, developed for the Environment Agency and Natural Resources Wales by AMEC (now AMEC Foster Wheeler), for England and Wales with a similar approach adopted for Scotland and Northern Ireland. See the box below for more details.

Water Resources GIS

Water Resources GIS (WRGIS) tool is the primary tool for undertaking national assessments of abstraction pressures to support Catchment Abstraction Management Strategies (CAMS) and the hydrological components of the WFD in England and Wales. The assessment in the Water Resources GIS is based on the principles of the Resource Assessment and Management (RAM) Framework. RAM Framework flow screening calculates both the EFI and an artificially influenced scenario flow from the natural flow estimated for every water body and then compares them to indicate whether there is a surplus or deficit, as illustrated below:



The Water Resources GIS is based on national datasets of natural river flows and artificial influences, which includes surface water abstractions (SWABS), groundwater abstractions (GWABS), sewage treatment works discharge returns (DIS) and other more complex impacts such as reservoir storage and inter-catchment water transfers. The datasets are updated and improved through an iterative process of upload from CAMSLedgers. CAMSLedgers are spreadsheets used to review and improve information on natural flows, abstraction pressures and other flow influences.

The Water Resources GIS is not a hydrological or hydrogeological model. The calculation of the impacts of abstraction and other flow pressures on natural flows is dependent on the input datasets described above that characterise natural flows and artificial influences. Surface water and groundwater models are used to characterise flows and impacts in CAMSLedgers, and this conceptualisation is then reflected in the water balance calculations in the Water Resources GIS. The Water Resources GIS applies a simplified version of the RAM Framework at four flow percentile ‘snapshots’ (Q95, Q70, Q50, and Q30). These ‘snapshot’ assessments are calculated independently.

Quantifying the balance between the available resource and the demand for abstraction is complex. Numerous assumptions have been made in the calculations. These are listed in Table 2.6. In addition, all of the caveats and assumptions made during the analysis of changes in climate and hydrology and assessment of public water supply in Tasks 1, 2, and 3.1, are also applicable as outputs from these tasks feed into this analysis.

The WRGIS tests the balance between the ‘available resource’ and the ‘demand for abstraction’ under a number of different future scenarios. **‘Available resource’** in this context is defined as the “*water available in a catchment once Environmental Flow Indicators (EFI) and discharges have been taken into account. It is* *calculated as the natural flow minus the EFI requirement, plus additional water from discharges*". **'Demand for abstraction'** in this context is defined as "*the unrestricted demand for abstraction; that is, the abstraction that abstractors want to have, rather than the abstraction that regulation or physical conditions would allow*".

A similar tool was not available for Scotland or Northern Ireland. This task has developed a 'WRGIS-lite' for these countries, using similar input data i.e. national datasets of natural river flows and artificial influences, including surface water abstractions, groundwater abstractions and sewage treatment works discharge returns. Whilst the principles of the analysis are the same, the calculations are slightly simplified and are carried out using a spreadsheet rather than using a geo-spatial database. For example, for both the WRGIS and WRGIS-lite tools, the recent abstraction data are translated into 'flow impacts' using 'impact factors'. In the WRGIS tool, this is done by considering the consumptiveness of the abstraction (only consumptive uses are considered) and for GWABS, considering the spatial distribution of water bodies and re-profiling the impacts across the flow duration curve i.e. typically less impact at low flows and more at high flows (Q50 impact will equal the average long term average consumptive pumping). SWABS complex impacts (often associated with storage reservoir releases) are subtracted from the SWABS flow duration curve impacts based on monthly profiles (i.e. positive at low flows providing low flow support, negative at higher flows, long term average equals zero). In the WRGIS-lite tools, simple equivalent calculations have been made, re-profiling abstraction impacts using the average impact factors known in England and Wales.

Using these existing and newly developed tools, **this task provides projections of the water-supply balance using the climate, hydrological and PWS demand projection factors from Tasks 1, 2 and 3.1**. The factors are used to scale the analysis undertaken by the tools into the future. The source data for these tools are described in Appendix C. The calculations are undertaken at the Water Framework Directive (WFD) water body scale across the UK and then aggregated to a catchment scale for publication.

Table 2.6: Water Resources GIS Datasets, Caveats and Assumptions.

Technical Area	Description
Edition of Water Resource GIS	The edition of the Water Resources GIS used is dated September 2014 (New Building Blocks).
Source of Artificial Influence Data Sets	The datasets within the WRGIS are based on those within the Environment Agencies' CAMSLedgers in September 2014. The September 2014 version of the Water Resources GIS has been updated with improved CAMSLedgers from approximately 70% of CAMS Catchments since its initial population in 2009. Updates and improvements continue to be uploaded every 6 months.
Source of baseline Natural Flow Data Sets	The WRGIS natural flow datasets are taken from CAMSLedgers using the same process as the artificial influences. The source of flow data includes a range of 'best available' groundwater or hydrological models (e.g. LF2K/LFE, CERF) and naturalised gauged records. Guidance indicates that natural flow records should be based on recent 18 year datasets (i.e. 1990 – 2007 for the first cycle of the Water Framework Directive River Basin Management Plans), but many CAMSLedgers currently have different periods of data.

Technical Area	Description
Difference in assessments between the WRGIS and CAMSLedger	The WRGIS calculates outputs at four flow percentile "snapshots" of the long term flow duration curve – Q95, Q70, Q50 and Q30 whereas the CAMSLedger calculations include all 100 percentile points. This difference in approach gives rise to some small numerical differences in the water resource availability calculations, especially with regard to impacts of surface water abstractions with Hands-Off Flow constraints and the complex impacts of reservoir storage (described at the end of this table).
Spatial Distribution of Groundwater Abstraction	Groundwater abstraction impacts are spatially distributed over up to 5 water bodies to reflect the reality that groundwater impacts are seldom only at the point of abstraction.
Temporal distribution of Groundwater Abstraction	Groundwater abstraction does not generally impact flows only during the period of abstraction, but rather results in a lowering of groundwater tables which can affect the year-round baseflow contribution to rivers. The RAM framework therefore allows for the spreading of groundwater impacts across the flow duration curve.
Temporal distribution of surface water abstraction	Surface water sources have an "as abstracted" impact on surface water flows. The monthly abstraction profile is translated as an impact onto the long term average flow duration curve by considering the distribution of monthly average flows through the year.
Application of Hands Off Flows (HOFs) to surface water licences.	Hands-off-flow conditions are sometimes applied to surface water abstraction to limit impacts at lower flows. In calculating the potential demand for abstraction hands-off flow thresholds from surface water abstractions have been removed in order to consider the abstraction that could occur should these restrictions not be in place. This means that the abstraction demand calculated is the potential aspiration for abstraction rather than that which is allowed under current regulation.
Complex impacts associated with reservoir storage.	There are two alternative ways in which support provided by reservoir storage for direct abstractions or flow regulation can be calculated in the WRGIS: As a default, a minimum regulation flow from the reservoir can be fixed. The WRGIS will calculate the support necessary to maintain this level of flow, taking into account the natural flow and artificial influences associated with it. If the natural flow falls, the amount of support provided by this default calculation might increase, to maintain the specified minimum outflow. As an alternative, a fixed profile of complex flow support may have been defined by the Environment Agency for a particular reservoir. Where these exist, they have been used. Flow support would not necessarily change with changing natural flows in this case.
Non-consumptive abstraction impacts	The WRGIS considers only consumptive abstractions. Abstractions for fish farm or hydropower purposes may have very large but localised impacts on flows in depleted reaches, but are assumed in both the WRGIS and CAMSLedgers to be non-consumptive use, unless they have a significant effect on flow at the water body scale and have been edited by Environment Agency staff accordingly. As a result, these may be under-represented abstractions.

Technical Area	Description
Transitional water bodies	The potential available resource from transitional water bodies and small water bodies that are around the margins of estuaries and around the coast have been excluded. These sometimes contain very large discharges, which are theoretically available for abstraction. However, these generally discharge straight to the sea, or do so via a short outfall channel, so could only be accessed by making virtually direct re-use of effluent.

Source: Rob Soley (2015) pers. comms. The WRGIS-lite tools were designed with the same caveats and assumptions in mind, although the data and information sources are different.

2.3. Task 4: Assessment of changes in drought characteristics

Changes in drought characteristics have been assessed by using standardised indices of groundwater levels and river flows. A standardised index of groundwater levels and river flows is used to assess whether a climate change signal, in relation to the frequency and severity of extreme groundwater level and river flows events¸ is evident in the Future Flows climate projections (which are based on the medium emissions scenario and eleven climate model simulations).

3. Results: Current vulnerability, sensitivity and risk

3.1. Public Water Supply

Summary

Current demand: Across the UK, the current demand for public water is over 17,000 Ml/d, with 85% of this demand in England and Wales, 11% in Scotland and 4% in Northern Ireland. The abstraction is largest in the more densely populated areas of the south-east of England and the significant urban settlements elsewhere. Household consumption dominates the demand for water (typically between 30 and 75% of total demand) in the vast majority of WRZs. Per capita consumption rates are significantly different across different WRZs of the UK, reflecting the different characteristics of each area. Although non-household consumption is typically less significant (typically between 10 and 30% of total demand), some WRZs have relatively high non-household demand reflecting the nature and intensity of local industry and businesses in the area. Leakage forms the other major component in the demand for public water supplies and whilst water companies have made significant reductions in leakage rates in recent times it still remains a significant (more than 10% of total demand) component of the supply-demand balance in most areas.

Available resource: The water resources management planning process typically assesses the performance of the water resource system against the worst historical droughts on record in order to design systems to secure a specified reliability of supply (i.e. frequency of implementing water use restrictions). This is based on projecting the estimated Deployable Output, and subsequently applying bulk supply imports and exports and allowing for reductions made for outage allowance and operational losses. Deployable Output reflects the amount of water that can be taken from a water company's sources (surface and groundwater), constrained by licence, hydrology or hydrogeological factors and treatment works' capacity. The total Deployable Output across the UK is over 20,000 Ml/d, with the relative splits across the four countries mirroring the national splits in the demand for water above.

Supply-demand balance: Through the water resources management planning process, water companies seek to maintain a supply-demand balance across their WRZs. Whilst some WRZs report modest deficits for the present day, overall the UK has a surplus of around 2,000 Ml/d in addition to the 'uncertainty' buffer (target headroom) that is also provided to account for uncertainties in the supply-demand balance assessment, which is around 700 Ml/d. The relatively modest deficits reported in some of the water company resource plans reflect those WRZs where the reliability of supplies is below the target set-out in the plans and therefore are being addressed by the water companies through the current planning process. However, to put this into the context of the overall provision of supplies, these deficits are lower that the respective WRZ's allowance/buffer provided in order to account for uncertainties in the supply-demand balance calculation and, overall, current public water supply provision is considered to be adequate.

3.1.1. Introduction

Every five years, water companies produce Water Resources Management Plans (WRMPs; Water Resource Plans in Scotland) which set-out how each water company will maintain adequate public water supplies over a 25-year planning horizon. These plans explicitly consider demand-side and supply-side pressures, including population growth and climate change, and describe how the water company intends to secure a sustainable balance between the supply and demand for water. Investment decisions for securing a sustainable supply-demand balance are also secured on the 5-yearly basis, not for the full 25-year planning period. This means that although plans look out to 25 years ahead, there is no guarantee that the measures included will be implemented, beyond what is agreed with the regulators on a 5-year timescale.

These water company resource plans are produced on a WRZ scale. The Environment Agency define a WRZ as the largest possible zone in which customers share the same risk of a resource shortfall (Environment Agency, 2012). For England, Wales and Scotland the WRZ definitions used in this study are as reported in the latest water company resource plans. All major water companies responded to the request for the planning table data for this project. For Northern Ireland, in consultation with Northern Ireland Water (NIW), this study has used the recently redefined WRZ boundaries being adopted for NIW's next WRMP.

In England and Wales there are 114 WRZs considered in this study. The data required for our analysis are not available for the WRZs managed by Cholderton and District Water Company Limited, Albion Water Limited and Peel Water Networks. All of these companies assume in their WRMPs that there are no climate change impacts in their WRZs. Independent Water Networks and SSE Water Limited gain all their supplies from neighbouring water companies. Any changes due to climate change are thus considered within the WRZs that provide the supplies. In Northern Ireland, the seven major WRZs, but not two very small WRZs, have been considered. For Scotland, 189 WRZs have been considered for this study, with 44 WRZs not included due to insufficient data. Of these 44, 35 have a zero population reported at the end of the water company resource planning period and the other nine all have a reported population of less than 500 people. Where these relatively small WRZs have been excluded they have been ignored in the presentation of results and the calculation of national figures.

Calculating the supply-demand balance

For each WRZ, a water company calculates a supply-demand balance, on an annual basis, over the 25-year planning horizon with both the supply-side and demand-side components reported in the water company resource plan planning tables. The supply-demand balance is typically undertaken for two design conditions that consider two demand scenarios; dry year annual average (to reflect annual average demands in a dry year) and dry year critical period (to reflect short term peaks in demand during a dry year). Some water companies undertake a third scenario; minimum Deployable Output (to reflect the timing of the minimum available resource availability). For consistency, in undertaking the analysis across all UK WRZs, only the dry year annual average scenario has been considered here. In terms of supplies, water companies determine the Deployable Output, typically based on hydrological and water resources modelling, with Deployable Output defined as:

> “Deployable Output (DO) is the amount of water that can be pumped from a water company's sources (surface and groundwater), constrained by licence, hydrology or hydrogeological factors and works capacity.”
>
> *Rance et al. 2012*

As part of the water company resource planning process, water companies also estimate the impact of climate change on Deployable Output. For the latest plans in England, Wales and Northern Ireland, climate change impacts were estimated for the 2030s and then these were scaled for each year in the planning horizon using the standard methodology set-out in the Water Resources Planning Guidance (Environment Agency, 2012). For Scotland, the planning tables do not currently report climate change impacts. Consequently, for this study, Scottish Water made available the outputs from a separate climate change study which used outputs from the Future Flows project (Prudhomme *et al.*, 2012) to estimate the projected climate change impacts on yield for the 2040s.

On the demand side, water companies develop 25-year demand forecasts, both for household and non-household customers, that take into account estimates of projected population growth, forecasts of per capita consumption (water consumption per person) and projected rates of leakage (water lost between the water treatment works and the customer's home or business). The total demand for water is presented as the total Distribution Input which is the amount of water that needs to be provided in order to meet customer demands and deal with losses in the system. Water companies also set a target headroom, which acts as a buffer to account for uncertainties in constructing the supply-demand balance.

> Distribution Input is the average amount of potable water entering the distribution system within the area of supply.
>
> *Adapted from Rance et al 2012.*

> Target headroom represents the minimum buffer that companies should plan to maintain between supply and demand for water in order to cater for current and future uncertainties.

For this study, the planning tables from the most recent Water Resource Management Plans were collated directly from the water companies, with all major water companies across England, Wales, and Northern Ireland responding to the project team's request for data. For Scotland, Scottish Water have made available updated planning tables that reflect the situation as of 2015, rather than the planning tables associated with their last WRP as there has been significant work since its publication, and these updated tables have been used for this study.

There is a medium level of confidence in this assessment with respect to the baseline and 2030s estimates.

3.1.2. Where in the UK faces the greatest level of PWS deficit?

Figure 3.1 presents the baseline supply-demand balances across the United Kingdom as reported by the water company resource plans. For England and Wales this reflects the position in 2012, for Scotland the position in 2015 and for Northern Ireland the position in 2009.

Figure 3.1 highlights that some WRZs, in the south-east of England, in the west of England and small WRZs in Scotland report a supply-demand deficit in the base year, although the majority of WRZs are reported by the water company resource plans as being in surplus. The largest deficits are 20 Ml/d in two WRZs in the south-east.

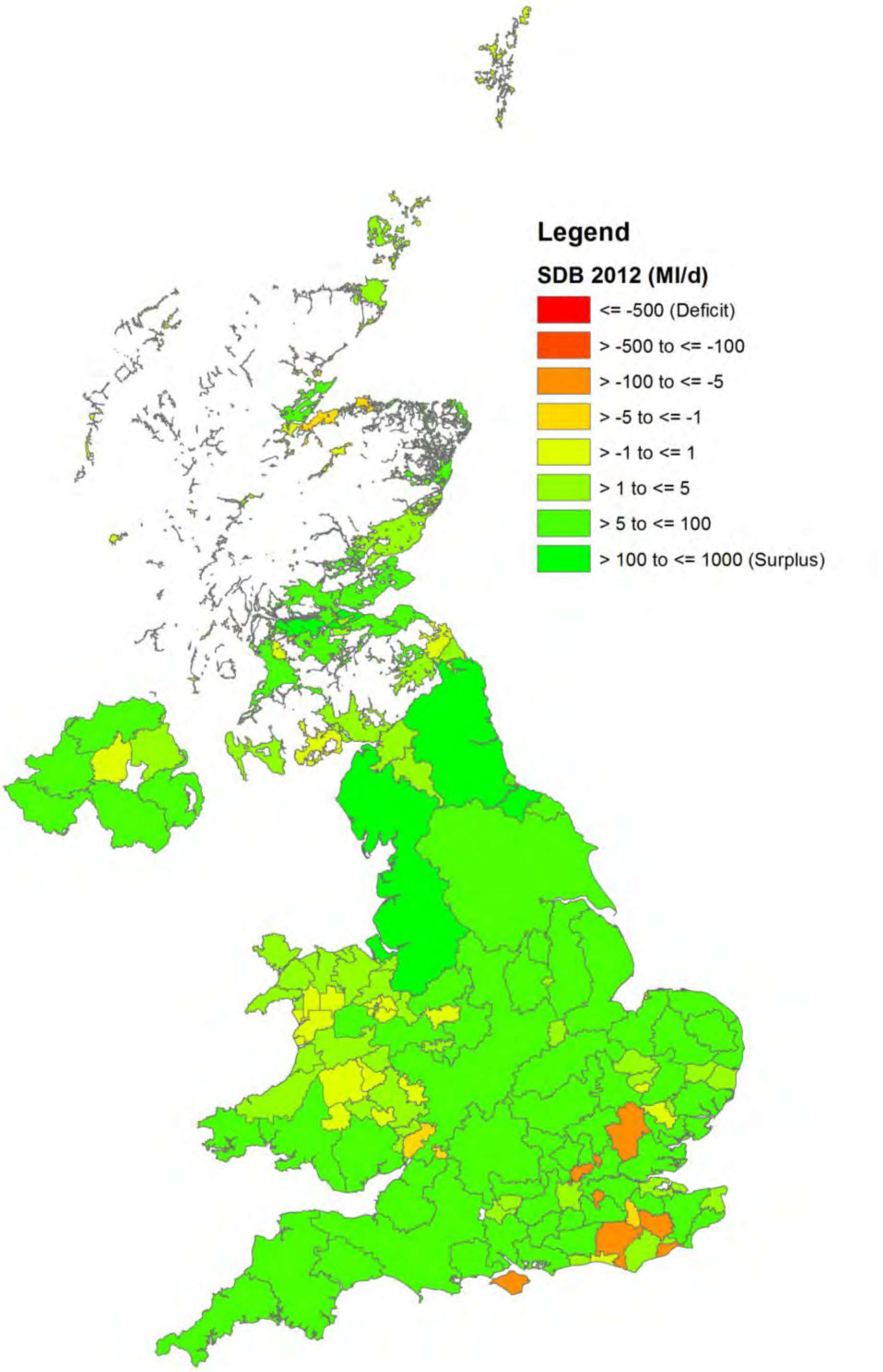


Figure 3.1: Supply-demand balance for base year (Ml/d).

Source: Water company resource plan, planning tables

Table 3.1 summarises the overall base-year supply-demand balance for each country. It should be noted that a few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England. Whilst some WRZs report modest deficits for the current day, all four countries in the UK report an overall surplus of water. In total, the UK has a surplus of around 2,000 Ml/d in addition to the 'uncertainty' buffer (target headroom) that is also provided to account for uncertainties associated with the supply-demand balance assessment. The relatively modest deficits reported in some of the water company resource plans reflect those WRZs where the reliability of supplies is below the target set-out in the plans and therefore are being addressed by the water companies through the current planning process. However, to put this into the context of the overall provision of supplies, these deficits are lower than the respective WRZ's allowance/buffer provided to account for uncertainties in the supply-demand balance calculation and, overall, current public water supply provision is considered to be adequate.

Table 3.1: Summary of overall base year supply-demand balance (in Ml/d and as a % of baseline Demand) by country, with positive numbers indicating a surplus. Base year total Distribution Input and Deployable Output also shown – note that target headroom values, which are also taken into account in the supply-demand balance, are not shown.

Country	Base year water company resource plans supply-demand balance, Ml/d (and %)	Base year water company total Distribution Input, Ml/d	Base year water company total Deployable Output, Ml/d
England	+1426 (+10%)	13,904	16,767
Wales*	+104 (+12%)	900	1,124
Scotland	+414 (+22%)	1,866	2,484
Northern Ireland**	+60 (+9%)	667	774**

Source: Water company resource plan, planning tables.

**A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

***This figure includes the Deployable Output from Public Private Partnerships (around 50% of the total DO) and are used as imports to Northern Ireland Water's WRZs.*

3.1.3. Allowance for uncertainty

Figure 3.2 shows the target headroom values adopted for each WRZ as a percentage of Distribution Input (i.e. the total demand). Target headroom presents the level of uncertainty that water companies allow for in their supply-demand balance calculations. Figure 3.2 highlights that although the majority of water companies in England and Wales allow for up to 10% uncertainty in their calculations, a large number of these companies actually allow for less than 5% uncertainty. Some WRZs in Scotland, such as Dumbarton, report target headroom values of more than 15% for 2015. It is also worth emphasising that, along with such differences in target headroom, different water companies may have adopted different assumptions and approaches to estimating the components of their supply-demand balance. Therefore, whilst the plans are broadly consistent given the regulatory process to which they are subjected, such factors are a potential source of uncertainty when comparing plans between different water companies and may become more significant when projecting future impacts.

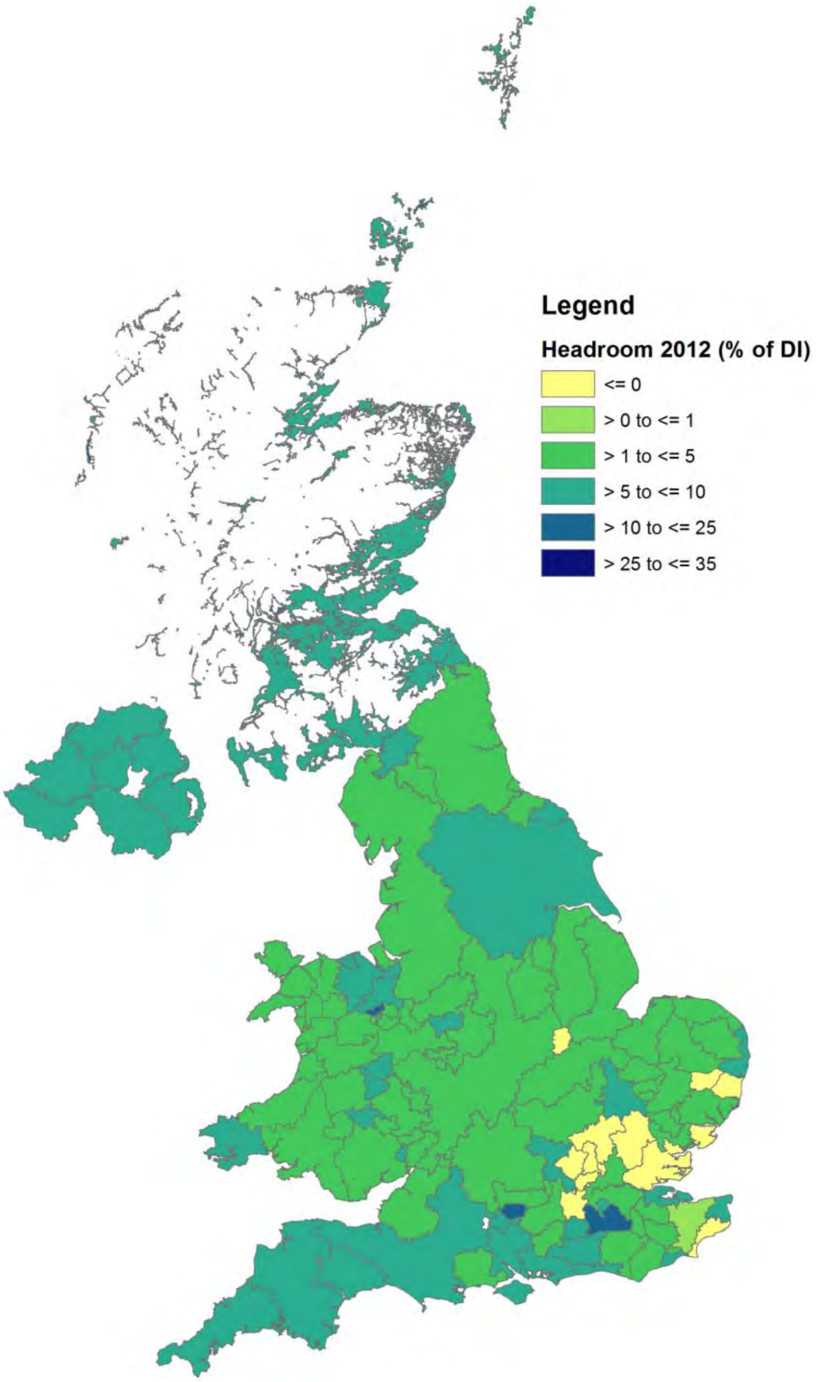


Figure 3.2: Target headroom (uncertainty buffer) for base year, as a % of Distribution Input.

Source: Water company resource plan, planning tables

3.1.4. Baseline population and the demand for public water supplies

To provide an overview of the baseline position, Figure 3.3 and Figure 3.4 present, for each WRZ, the baseline population and baseline total Distribution Input respectively. A summary of the total Distribution Input by country is provided in Table 3.2. The maps in Figure 3.5 show the relative contributions from household, non-household and leakage respectively, that make-up the total Distribution Input for each WRZ.

Across the UK, the current demand for public water is over 17,000 Ml/d, with 85% of this demand in England and Wales, 11% in Scotland and 4% in Northern Ireland. Abstraction is largest in the more densely populated areas of the south-east and the significant urban settlements elsewhere. The large urban centres in the midlands and northern England such as Birmingham, Manchester, Liverpool and Hull are largely responsible for the large DI values. Household consumption dominates the demand for water (typically between 30 and 75% of total demand) in the vast majority of WRZs. Although non-household consumption is typically less significant (typically between 10 and 30%), some WRZs, such as Bournemouth, Barmouth and Kinsall, have relatively high non-household demand reflecting the nature and intensity of local industry and businesses supplied from these WRZs. Leakage forms the other major component in the demand for public water supplies and whilst water companies have made significant reductions in leakage rates in recent times it still remains a significant (more than 10% of total demand) component of the supply-demand balance in most areas.

Table 3.2: Summary of total Distribution Input (Ml/d) by Country.

Country	Baseline water company resource plans total Distribution Input (Ml/d)
England	13,904
Wales*	900
Scotland	1,866
Northern Ireland	667

Source: Water company resource plan, planning tables

**A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

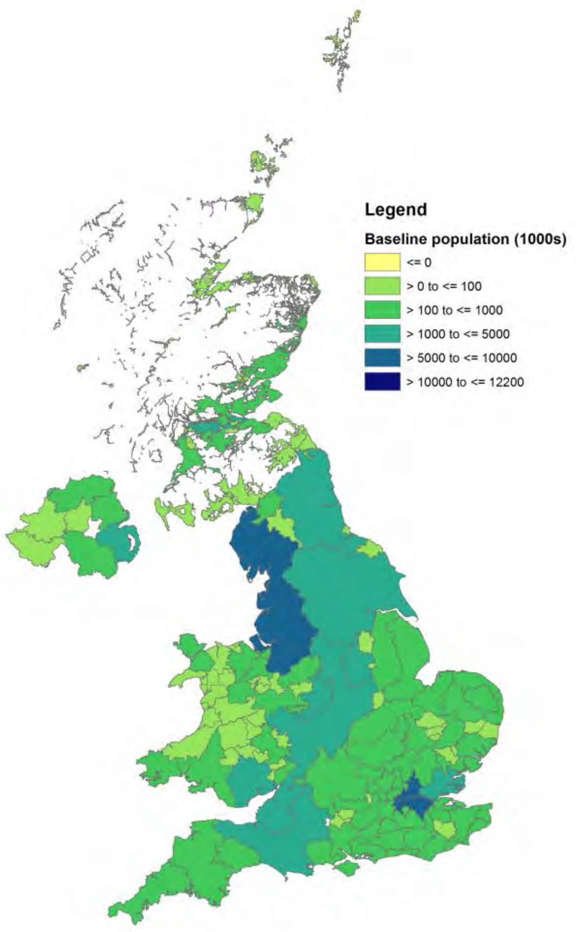


Figure 3.3: Baseline population plot for base year (1000s).

Source: Water company resource plan, planning tables

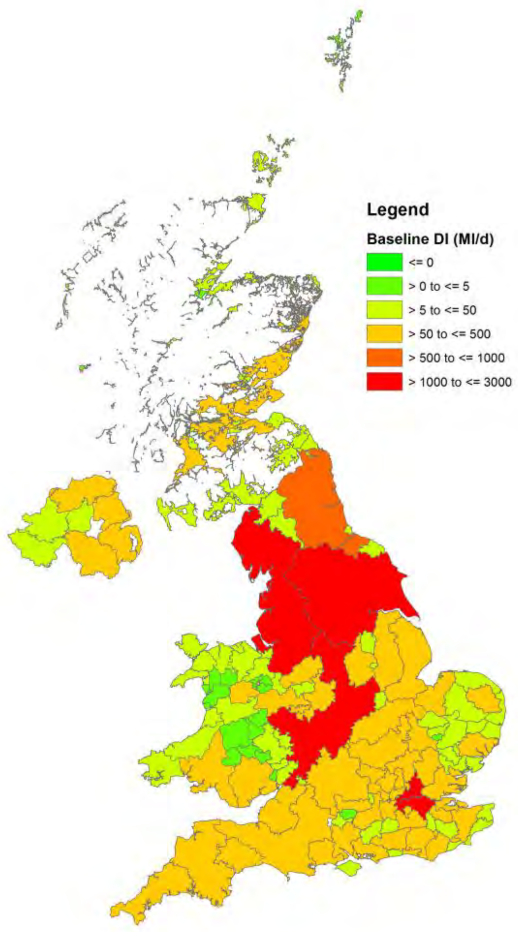


Figure 3.4: Plot of baseline Distribution Input (demand for public water supplies plus losses in their provision) for water (Ml/d).

Source: Water company resource plan, planning tables

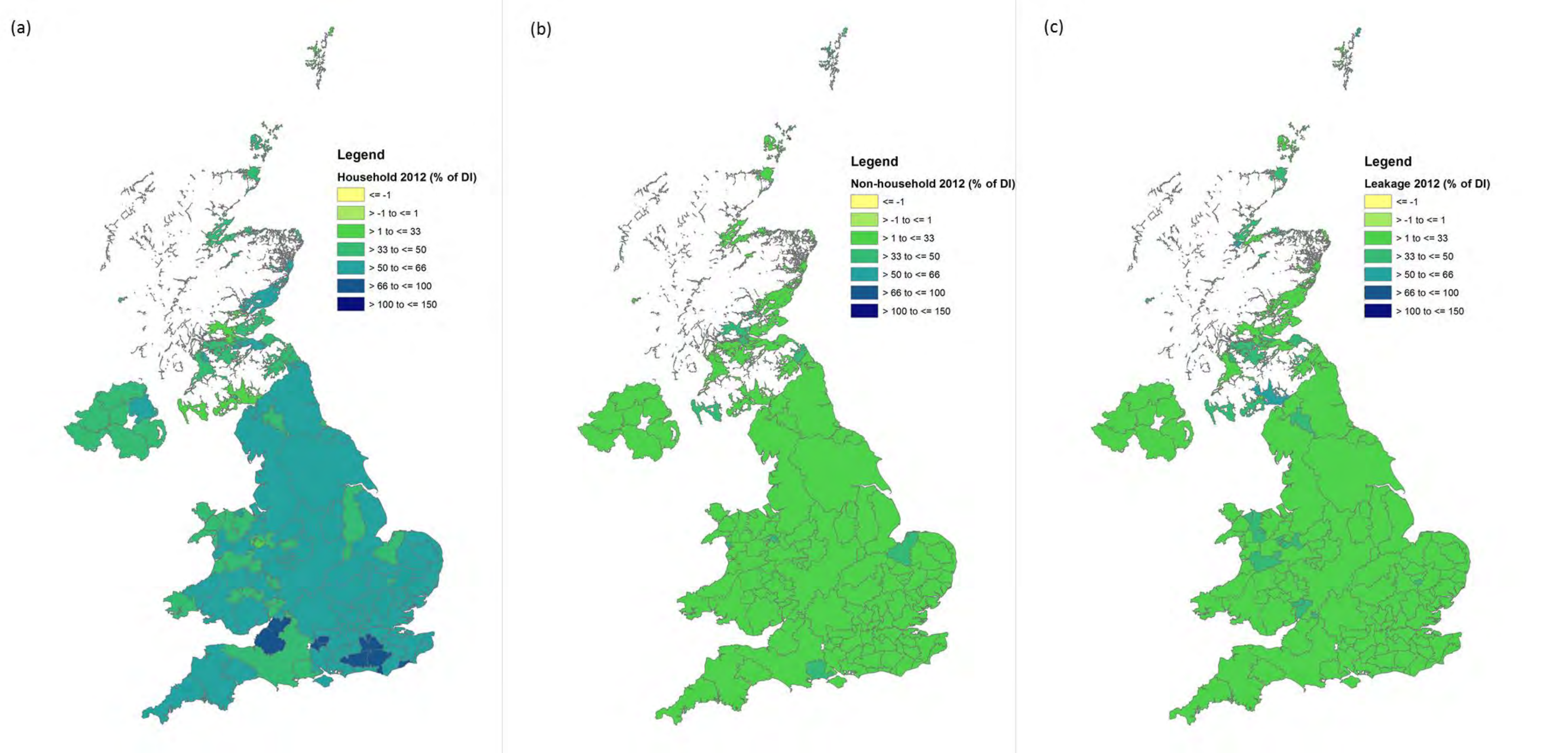


Figure 3.5: From left to right: (a) Plot of baseline percentage of public water demand for Household consumption (% of total Distribution Input); (b) Plot of baseline percentage of public water demand for Non-Household consumption (% of total Distribution Input); and, (c) plot of baseline percentage of demand lost to leakage (% of total Distribution Input).

Source: Water company resource plan, planning tables

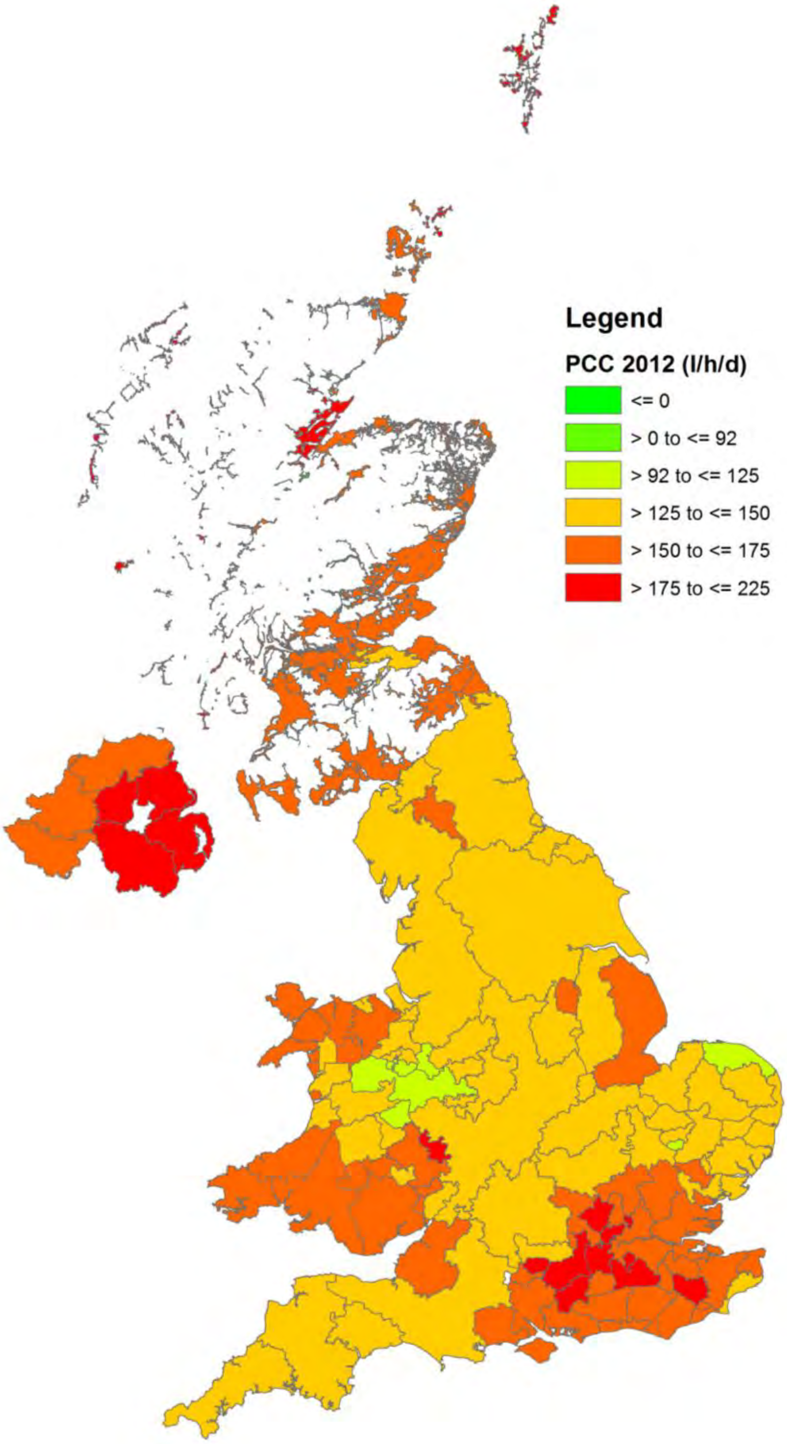


Figure 3.6: Plot of baseline weighted (measured and unmeasured) PCC (l/h/d).

Source: Water company resource plan, planning tables

The values adopted for Per Capita Consumption (PCC - taken as a weighted average of unmeasured and measured populations) for each WRZ are presented in Figure 3.6. With regards to household consumption, there is a wide variation in PCC values evident, with PCC values in some part of East Anglia for example significantly lower than in other parts of England, particularly parts of the south-east. The PCC values adopted by water companies are determined following detailed analysis of each WRZ and the differences shown are partly influenced by demographics, property sizes and meter penetration. The higher rates shown in general across Scotland and Northern Ireland are, in part, a reflection of the lack of metered properties in these countries.

3.1.5. Availability of water for public water supplies

Figure 3.7 presents the reported Deployable Output values for each WRZ. By design, the Deployable Output values largely mirror the demand for public water supplies across the UK. This emphasises the pressure placed on water resources in the south-east, but also in other densely populated urban areas across the UK. The total Deployable Output across the UK is over 20,000 Ml/d, with 85% of this in England and Wales, 12% in Scotland and 4% in Northern Ireland (when including imports from Public Private Partnerships).

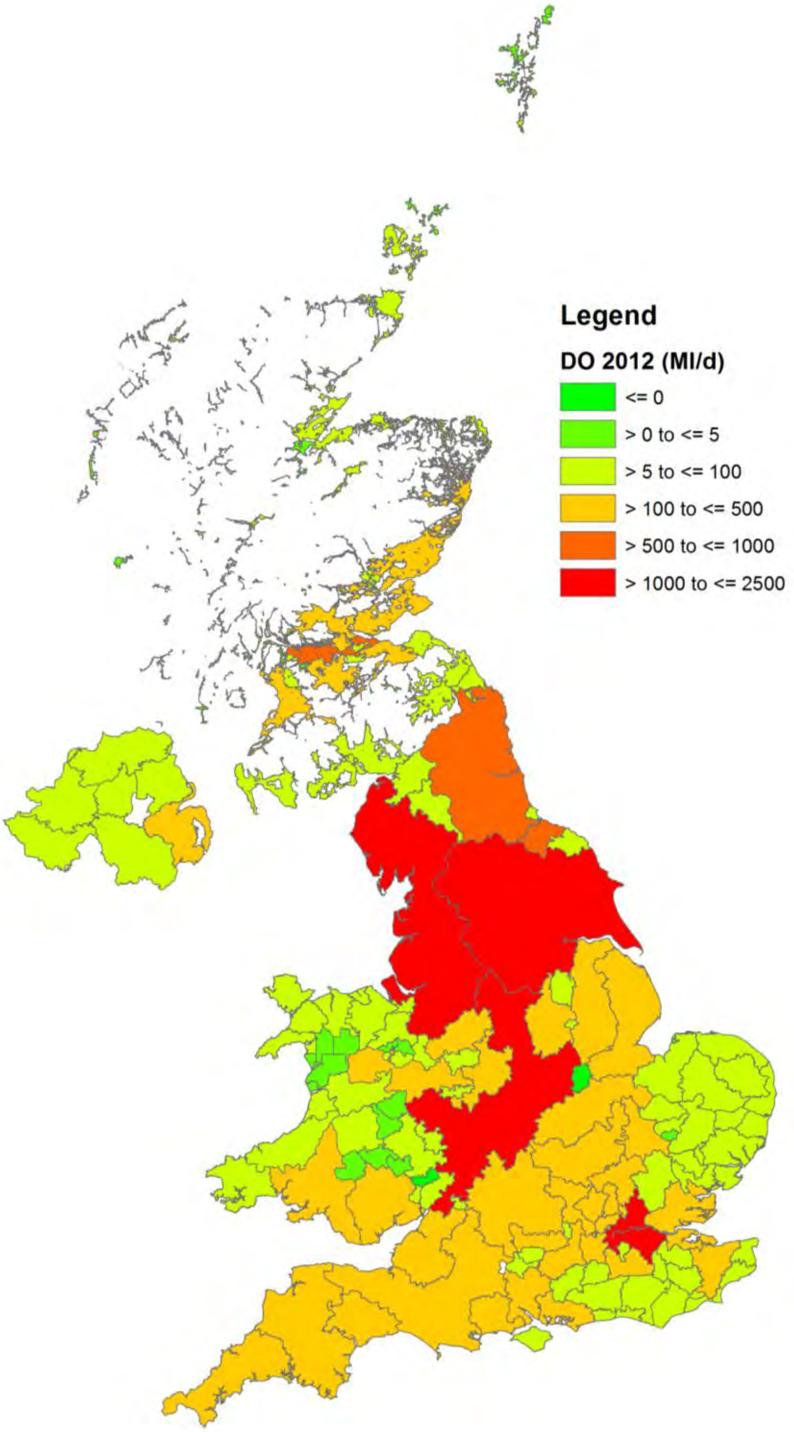


Figure 3.7: Plot of baseline Deployable Output (Ml/d).

Source: Water company resource plan, planning tables

3.2. 'All Sectors'

Summary

Overview: The high level results indicate that in the present day, assuming that current EFI thresholds according to existing regulatory approaches are met; levels of abstraction demand already exceed the available water resource in some catchments. This is particularly the case in the south and east of England, but also in a small number of catchments in the north-west of England, Northern Ireland and Scotland.

Natural available resource: Natural available resource is the natural flow of the river minus the Environmental Flow Indicator (EFI) requirement. The natural flow of a river is the flow without considering any abstractions or discharges. This indicator describes the amount of water available for human uses after allowing for environmental requirements. The results of this assessment indicate that there is currently natural available resource at annual Q95 in all, bar one[11], of the catchments in the UK i.e. the majority of catchments are able to meet the collective EFI requirements of their rivers without considering any abstractions or discharges. Many catchments have more than enough water to satisfy the EFI requirements and there is water left over that could be put to human uses. The amount of **natural available resource** depends upon location. The catchments with the largest **natural available resource** are the Thames and Severn Corridors in England and Wales and the Rivers Tay and Spey in Scotland.

Available Resource: Discharges, mainly from sewage treatment works, may increase flows in some catchments. Such discharges help to ensure that no catchments have negative **available resource** (natural flows minus EFI requirements, plus discharges, equating to a negative number) at Q95 today. **Available resource** is the water available for abstraction whilst meeting the EFI flow screening threshold and including discharges into watercourses.

The demand for water included in this analysis is the 'unrestricted' demand, i.e. the catchment accumulation of actual abstractions from surface and groundwater sources, excluding transitional zones and ignoring 'hands-off flow' requirements. In reality, abstractions would be limited by licence conditions and at certain times, hands-off flows restrictions when these are enabled, as well as (potentially) the actual quantity of water in rivers.

The final results of the analysis may be presented as abstraction demand as a percentage of the available resource at either Q95, Q70, Q50, Q30 or the average of Q95 and Q70, known as 'average low flows'. All the 'all sectors' results presented in this report are for either Q95 or average low flows as these are of most interest for water resources management. The results of this assessment indicate that in the present day, and assuming that current EFI thresholds according to existing regulatory approaches are met, levels of 'unrestricted' abstraction demand already exceeds the available resource[12] in some catchments i.e. the EFI threshold is not being met at a catchment scale. This is particularly the case in the south and east of England, but also in a small number of catchments in the north-west of England, Northern Ireland and Scotland.

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[11] Moray Coastal in Scotland. The sensitivity of the downstream water bodies in this catchment means that there is no **natural resource available** at Q95 according to this analysis.

[12] The water available for abstraction whilst meeting the EFI flow screening threshold. Available resource includes discharges into watercourses.

3.2.1. Introduction

The results from the analysis undertaken by the WRGIS and WRGIS-lite tools can be mapped to create an overall snapshot view of the order of magnitude of results under each scenario tested. The assessment combines the following variables into 27 future scenarios, see Table 2.2:

- **Time:** Baseline, 2050s and 2080s.
- **Climate change:** 09-Hydrology metrics for low (UKCP09 low emissions – p10), medium (UKCP09 medium emissions – p50) and high (UKCP09 high emissions – p90) emissions scenarios from Tasks 1 and 2.
- **Abstraction growth:** incorporating:
  - Low, principal and high population growth through public water supply growth trajectories from Task 3.1 (see Appendix A).
  - Adaptation assumptions considering other sector growth and levels of adaptation from the Case for Change analysis (see Table 2.3), categorised as "No additional action", "Current objectives" and "Current objectives+".
- **Environmental Flows:** Range of environmental flow options (i.e. 'Fixed' Environment Flow Indicators, EFIs, and 'Proportionate' EFIs), see Table 2.4.

The tools provide results on the following:

- **Natural Available Resource (see Figure 3.9):** the natural flow of the river minus the environmental flow requirement. This indicator describes the amount of water available for human uses after allowing for environmental requirements. This indicator does not include any abstractions or discharges.
- **Available Resource (see Figure 3.10):** the water that is available for abstraction whilst maintaining sufficient flow to support aquatic ecology (using the EFI requirements). There are three components to the available resource, natural available resource, discharges and other flow support (flow support received from reservoir storage and release, inter-catchment transfers and flow augmentation schemes).
- **Discharges (see Figure 3.11):** the majority of discharges are from Sewage Treatment Works. It is therefore important that the available resource total is viewed in the context of the pattern of abstraction, and should be distinguished from the natural available resource. Discharges do not include the direct return of abstracted water from non-consumptive abstraction uses.
- **Demand for abstraction (see Figure 3.12):** the baseline 'current' abstractions are the catchment accumulation of actual abstractions from surface and groundwater sources, excluding transitional zones and ignoring 'hands-off flow' requirements. These are based upon the best understanding of what has actually been abstracted, drawing upon recent annual returns data held by the relevant agencies in the UK. The assessment of demand is considered to be 'unrestricted'. This means that the calculations of demand ignore licence conditions such as hands-off flow requirements or the actual quantity of water in rivers so that it represents an estimate of what water abstractors would *like* to abstract, without constraining factors. Different types of abstraction are treated differently:
  - *Surface Water Abstraction*: Annual abstraction information has been translated into seasonal estimates to account for the fact that abstraction is not consistent all year round. Hands-off flow thresholds have been removed, consistent with work for C4C and the Water White Paper. Therefore, the demand calculated here is the potential 'unrestricted' abstraction rather than that which is allowed under current regulation.

- *Groundwater Abstraction*: Groundwater abstraction has been translated into flow duration curve impacts using factors which take account of the spatial and temporal impacts of groundwater abstraction.
- 'Consumptiveness factors' are applied to individual abstractions and are taken into account in the calculation of demand for abstraction. Abstractions that are for non-consumptive use only, i.e. water that is almost immediately returned from where it came without significant treatment being necessary, have a reduced influence on the demand for abstraction calculations. For example, most fish farm abstractions do not contribute much to the abstraction demand value used.

The final results of the analysis may then be presented as abstraction demand as a percentage of the available resource at either Q95, Q70, Q50, Q30 or the average of Q95 and Q70, known as 'average low flows'. The 'average low flows' measure was favoured in the C4C analysis because it reduces the chance that the results over-estimate the impacts of abstractions at Q95. The reason that it might do this is because hands-off flow conditions for surface water abstractions directly from rivers have been ignored (the level of information currently available on these is not complete enough for use). Current regulation would not actually allow some of the abstraction that would be suggested at Q95 and therefore the Q95 results could be overestimating the potential impacts.

The analysis for 'all sectors' was undertaken at a water body scale; however the results are aggregated and presented at a catchment scale. Therefore, localised impacts in water bodies may be more or less severe than those presented for the catchment as a whole.

There is a medium level of confidence in this assessment with respect to the baseline estimates.

Uncertainty

Due to the complexity of quantifying water resource balances at a catchment scale, there are many assumptions that needed to be made in order to carry out this analysis. In addition, the baseline data are not from the same years (generally either 1961-1990 or 2007-2013, values for 1961-1990 are scaled to create a baseline estimate), the results of this task should be treated as sensitivity analysis i.e. the results provide a rough order of magnitude on the levels of surplus or deficit for different catchments given a particular future scenario (incorporating parameters on time, climate change, abstraction growth and EFI option). The results should not be interpreted as an accurate and specific measure of the currently available resource or as a prediction of future resources at a particular point in time.

3.2.2. Where in the UK faces the greatest level of deficit?

The component results from the WRGIS and WRGIS-lite tools, shown in the figures in Section 3.2.3, have been aggregated and can be summarised as the 'abstraction demand as a percentage of the available resource' at average low flows, see Figure 3.8.

These results of the analysis should be reviewed with two factors in mind:

1. **Where is there 'Negative Available Resource'?**
2. **Where is more than 100% of the available resource being used?**

In Figure 3.8 'Negative Available Resource' means that natural flows minus environmental flow requirements, plus discharges, is a negative number i.e. there is no water resource available for human uses if the environmental flow requirement is adhered to. In these cases additional water would be needed to ensure no failure of the EFI standard. In the present day, this is not indicated as an issue for any catchment at the average of Q95 and Q70 i.e. “average low flows”.

The majority of UK catchments are not currently using 100% of the available resource of water at average low flow conditions i.e. there is a surplus of water available for human uses. The Environment Agency estimates that 13% of all rivers in England are at risk of not meeting good ecological status due to over-abstraction[13]. The deficit or surplus situation for individual water bodies within each catchment may be different to the catchment as a whole. However, there are some catchments where abstraction demand is already in excess of the available resource in average low flow conditions. These catchments are mostly located in the east and south of the UK, although there are a small number of catchments in Scotland, Northern Ireland and the north-west of England.

It is important to note that:

- In this assessment ‘available resource’ is the ‘natural available resource’ plus discharges. ‘Natural available resource’ incorporates the natural flow minus the environmental flow i.e. the river flow that may be required to support Good Ecological Status under the WFD. EFIs are defined as a percentage of the natural flow that is available for abstraction. At Q95, EFIs are set at 10%, 15% or 20% of the natural river flow, depending on the sensitivity of the river to abstraction pressures. This is the percentage of the natural flow that may be abstracted for human uses at Q95. The remaining 90%, 85% or 80% of the natural flow is left in the river to support the ecology. Not all rivers currently meet their objectives for environmental flows (see above).
- The demand for abstraction also ignores the hands-off flow requirements which are restrictions on the amount that can be abstracted that are applied to many surface water abstractions from rivers during times of low flows.

Therefore, this analysis should be considered to reflect current overarching environmental objectives for river flow and the approximate current aspirational demand for abstraction at average low flows, rather than an accurate representation of the realised flow for the environment and actual abstractions at average low flows.

[13] Environment Agency (2013). *Managing water abstraction*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297309/LIT_4892_20f775.pdf

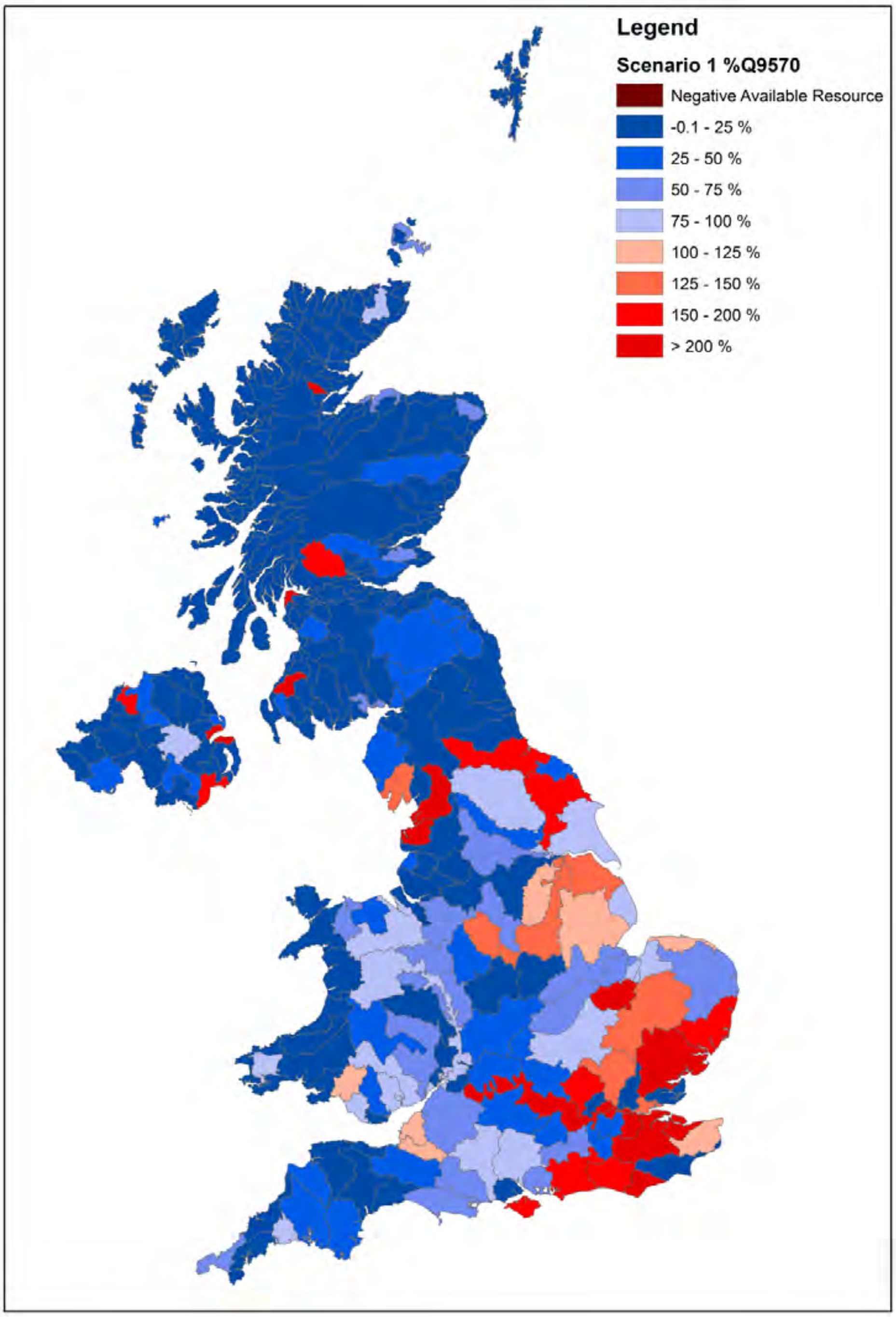

Figure 3.8: Present-day abstraction demand as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 1).

3.2.3. Components of baseline assessment results

The results presented in Figure 3.8 are made up of a series of components derived using the WRGIS and WRGIS-lite tools. These individual component results are shown in the figures in this section.

Natural Available Resource

Figure 3.9 shows the baseline (~2015) **natural available resource** at Q95. The natural available resource is solely the catchment accumulation of natural flows minus the current environmental flows set according to the regulator's rules, in Ml/d. The figure shows the variety of different levels of **natural available resource** in catchments across the UK. The catchments with the largest **natural available resource** include the Thames and Severn Corridors in England and Wales and the Rivers Tay and Spey in Scotland. Based upon these results, these catchments would have more than 101 Ml/d of water to abstract for human uses at low flows (Q95). Many, often coastal catchments, are shown by Figure 3.9 to have little or no **natural available resource** at Q95, such as the Moray Coastal catchment in Scotland. These catchments have very little **natural available resource** during low flows that could potentially be abstracted for human uses.

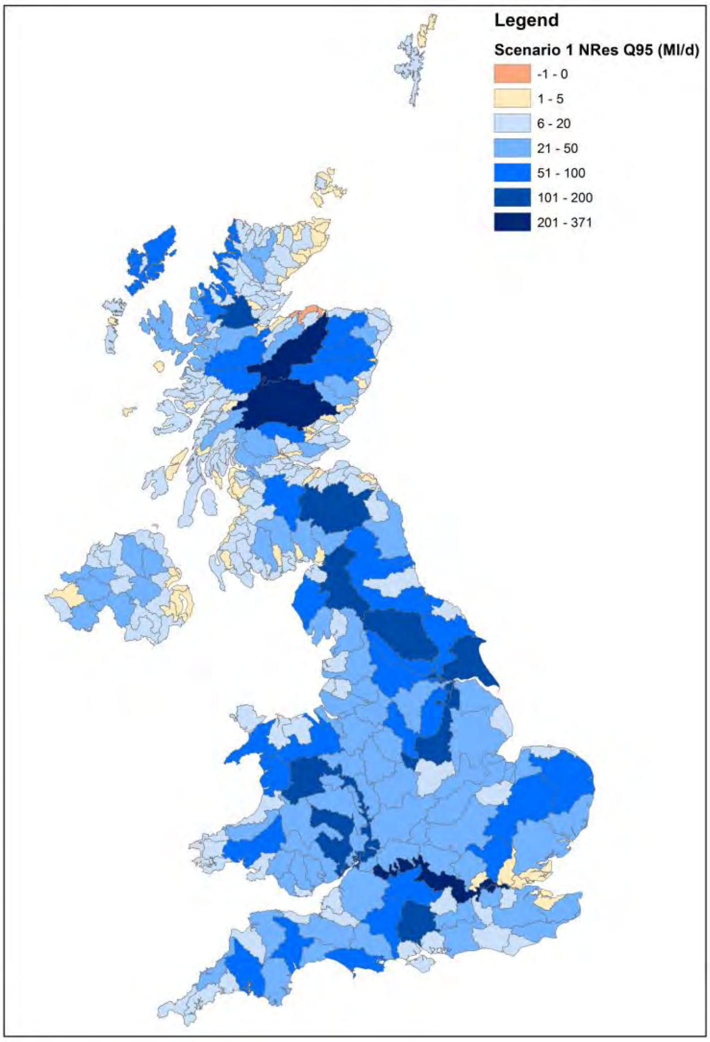

Figure 3.9: Baseline (~2015) natural available resource at Q95 (the catchment accumulation of natural flows minus the current environmental flows set according to the regulator's rules, in Ml/d) (Scenario 1).

Notes: Baseline natural flow values varied within the constituent datasets between England, Wales, Scotland and Northern Ireland. Those data with 1961-1990 baseline have been factored (by 0.8) to estimate a present day baseline in line with the latest information in the WRGIS.

Available Resource

The water resource available in rivers today is not only driven by the **natural available resource**. Discharges, mainly effluent returns from public water supply, have a large influence over low flows in catchments across the UK, see Figure 3.10. The presence of discharges means that in the present day, no catchments have less than zero total available resource at Q95 although a few catchments in Scotland have close to zero available resource. Those catchments with the least **available resource** tend to be smaller, coastal catchments with less water present in the catchment overall. They may also be largely uninhabited and so will benefit little from discharges from effluent returns.

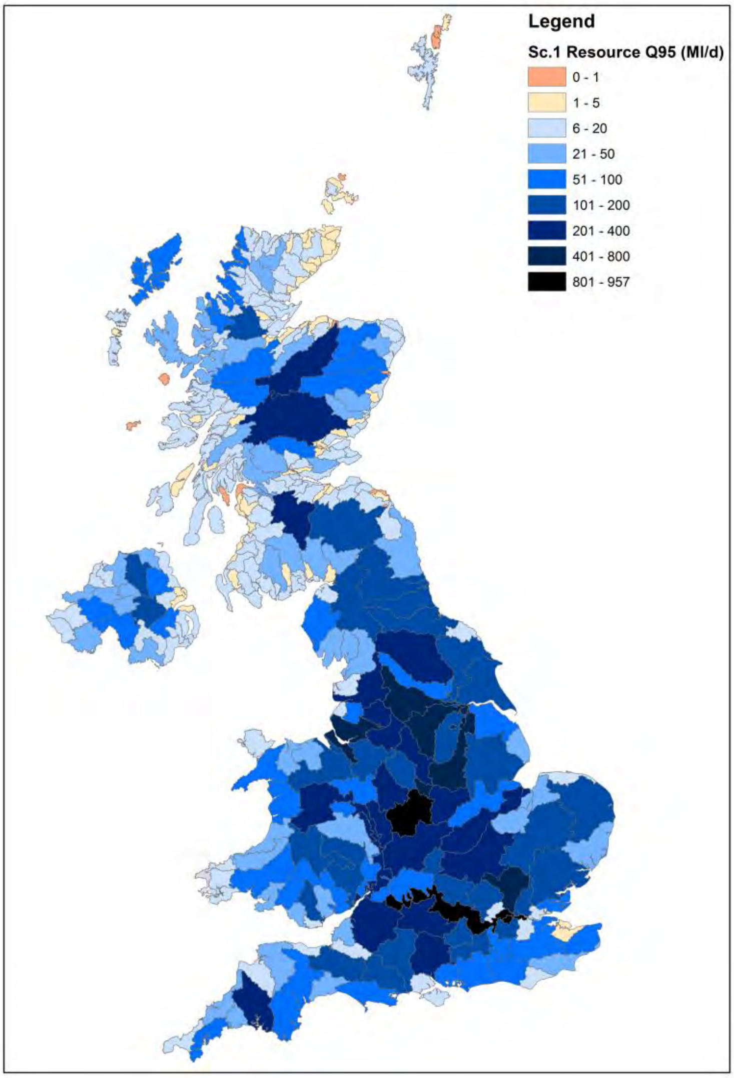

Figure 3.10: Baseline (~2015 for natural flows and 2007-2013 for discharges) available resource at Q95 (the catchment accumulation of natural flows minus environmental flows, plus discharges, in Ml/d) (Scenario 1).

Notes: Baseline natural flow values varied within the constituent datasets between England, Wales, Scotland and Northern Ireland. Those data with 1961-1990 baseline have been factored (by 0.8) to estimate a present day baseline in line with the latest information in the WRGIS.

Discharges

Discharges, at Q95, are shown in Figure 3.11. The majority of discharges are provided by effluent returns from Sewage Treatment Works. Therefore, the largest returns tend to be found in those areas with a high population; around urban centres.

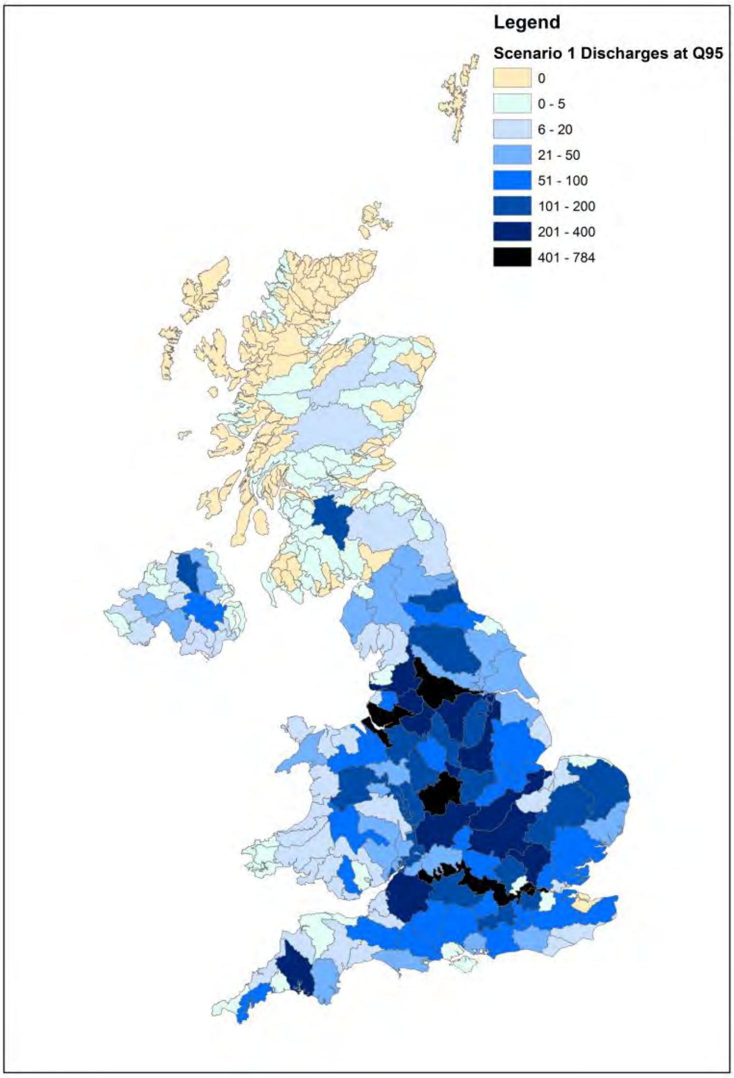

Figure 3.11: Baseline (2007-2013) discharges at Q95 (Ml/d) (Scenario 1).

Notes: n/a

Demand for abstraction

Figure 3.12 shows the baseline (2007-2013) consumptive abstraction demand at Q95 (the catchment accumulation of actual abstractions from surface and groundwater sources, excluding transitional zones and ignoring 'hands-off flow' requirements, in Ml/d). Whilst transitional water bodies may contain large discharges that are theoretically available for abstraction, these generally discharge almost immediately into the sea, so could only be accessed by making virtually direct re-use of effluent. The pattern of abstraction demand between catchments loosely correlates with natural resource availability (shown in Figure 3.9) and population centres in the UK.

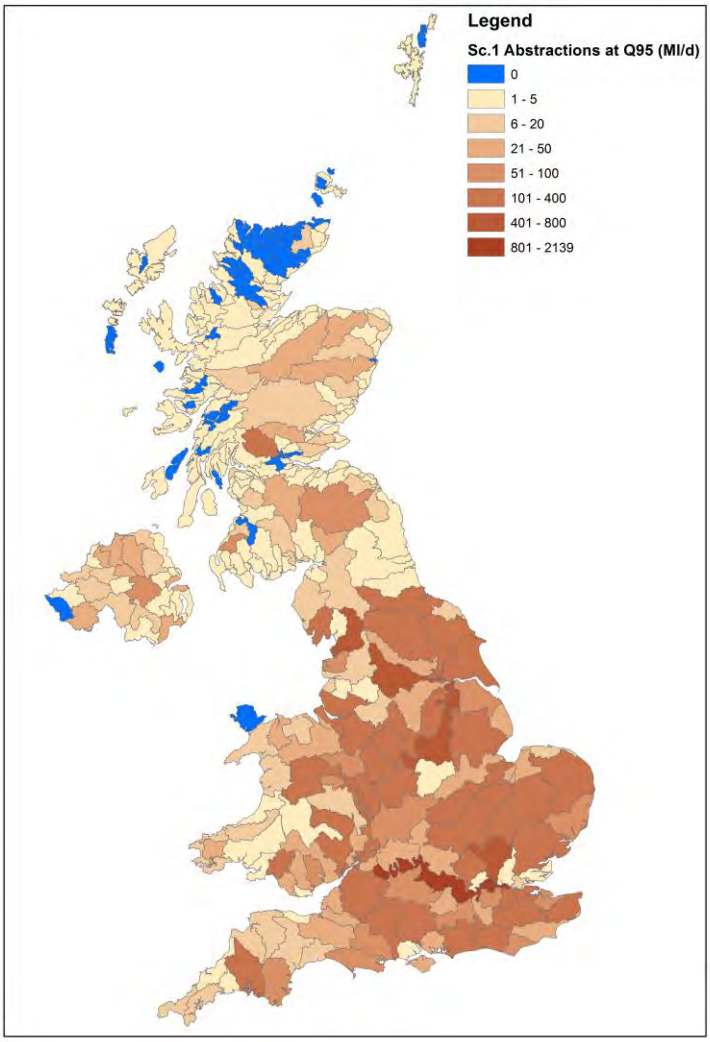

Figure 3.12: Baseline (2007-2013) average consumptive abstraction demand at Q95 (the catchment accumulation of actual abstractions from surface and groundwater sources, excluding transitional zones and ignoring hands-off flow requirements, in Ml/d) (Scenario 1).

Notes: n/a

4. Results: Future vulnerabilities, sensitivities and risks

4.1. Public Water Supply

Summary

Overview: Under the upper bound scenario (high population growth and a high climate change impact) for the 2050s, without any additional adaptation, there is a widespread pattern of large deficits in the provision of public water supplies. In particular, large deficits are projected in the south-east of England and the large conjunctive use zones in the north of England, but significant deficits are also prevalent in other parts of the UK. On a national scale, all countries are in deficit except for Scotland, although this masks more localised projected deficits in places such as Edinburgh and Lothian.

By the 2080s under the same scenario, these projected deficits become more acute and widespread and would present significant challenges in most parts of the UK but particularly across England. All countries would be in deficit when considered at a national scale. Under this scenario, the total deficits across the UK would equate to over 3,200 and over 6,000 Ml/d by the 2050s and 2080s respectively, equivalent to shortfalls of 16% and 29% of the projected demand for water at that time.

When considering the lower bound scenario (a low population and medium climate change projection), significant deficits are still estimated in parts of the south-east and elsewhere in the UK by the 2050s, suggesting that additional adaptation in some parts of the UK over and above the ‘no additional action’ scenarios would be necessary under almost all possible future conditions. Under this future scenario, the projected deficits across the UK equate to over 800 and 1,400 Ml/d by the 2050s and 2080s respectively, equivalent to shortfalls of 5% and 8% of the required demand for water at that time. At a national scale only England is projected to be in deficit under this scenario. However, whilst Wales, Scotland and Northern Ireland are in surplus at a national scale, there are deficits projected at a more local scale.

Climate: Under both a medium and high climate change scenario there are significant reductions projected in the availability of public water supplies by the 2050s and the 2080s. Under a medium emissions, ‘no additional action’ scenario, a projected loss of Deployable Output (compared to the baseline condition) across the UK equates to 6% and 8% for the 2050s and 2080s respectively. Under a high climate change, ‘no additional action’ scenario these projected losses equate to 11% and 15%, although much greater impacts may be realised at a more local scale in those WRZs particularly vulnerable to climate change. Groundwater sources are projected to be largely resilient to climate change, although analysis of modelling outputs suggest parts of the chalk aquifer in the south-east may be particularly sensitive by the 2080s.

Population and the demand for water: Under a low population growth future, significant population increases are projected to occur across most of the UK, but particularly in the south-east of England. In total, in a ‘no additional action’ scenario, the demand for water across the UK as a whole under this scenario is projected to increase by 2% and 4% (from the baseline condition) for the 2050s and 2080s respectively. Under a high population growth future these increases are notably higher, particularly around already densely populated areas, potentially placing severe additional demands for water. Under a high population scenario, the demand for water across the UK as whole is projected to increase by 9% and

18% (from the baseline condition) for the 2050s and 2080s respectively, but at a local scale much higher increases may be projected.

4.1.1. Introduction

This assessment of public water supply availability has analysed different future scenarios made up of combinations of:

- **Time:** Baseline, 30-year averages for the 2030s (End of water company resource plans), 2050s and 2080s.
- **Climate change:** 09-Hydrology metrics for low (UKCP09 – low emissions - p10), medium (UKCP09 – medium emissions - p50) and high (UKCP09 – high emissions – p90) emissions scenarios from Tasks 1 and 2.
- **Abstraction growth:** incorporating:
  - Low, principal and high population growth through public water supply growth trajectories from Task 3.1.
  - Adaptation assumptions considering other sector growth and levels of adaptation from the Case for Change analysis (see Table 2.3), categorised as "No additional action", "Current objectives" and "Current objectives+", along with an assessment of the potential mitigation offered by options listed by the latest water company resource plans.

For the 2030s, the impacts reported in this section are based on the evidence presented in the water company resource plans, and the situation at the end of their respective planning horizons for the baseline water resource systems (i.e. without considering the intervention measures proposed during the planning horizon to maintain a supply-demand balance). The end dates for the respective planning horizons are 2040 for England and Wales, 2032 for Scotland and 2035 for Northern Ireland. For the 2050s and 2080s, the impacts reported in this study are also based on the present-day water resources system but consider multiple population and climate change scenarios, as set-out in Table 4.1 and Table 4.2, to explore both demand and supply-side uncertainties. Future adaptation, including those intervention measures programmed within the water company resource plans in England and Wales, is considered in Section 5.

For population, the three scenarios presented in Table 4.1 are evaluated. These reflect a plausible central, principal estimate of future population along with upper and lower bound estimates, taken as the Office of National Statistics' (ONS) high and low fertility storylines (refer to Table 2.5 and Table 4.1 for details).

The ONS population projections are provided as local authority area projections to 2037 and national projections to 2100. For this study, WRZ population projections for the 2050s and 2080s under the selected ONS variants have been developed as follows:

- Calculate local authority scale projections for the 2050s and 2080s, for selected ONS variants, assuming that regional patterns of population change are assumed to continue as suggested by the local authority projections to 2037;
- Calculate WRZ population projections for 2030s (2040 in England and Wales, 2032 in Scotland and 2035 in Northern Ireland) from the Local Authority area ONS principal projection;
- Calculate scale factors for each WRZ based on the population projections reported in the water company resource plans for 2030s with the ONS-based projections calculated in the previous step;
- Develop WRZ population projections for 2050s and 2080s, for the selected ONS variants;

- Apply appropriate scale factors to convert the ONS projections to water company resource plans equivalent population projections.

Table 4.1: Population projections.

Population Scenario	Description
Principal population projection	ONS principal projection
Low population projection	ONS Low Fertility variant
High population projection	ONS High Fertility variant

Source: Population projections adapted from ONS (2014, 2013a-l); National Records of Scotland (2014); Welsh Government (2013); and, Northern Ireland Statistics and Research Agency (2013). For more details see Table 2.5.

For climate change, the three scenarios presented in Table 4.2 have been selected from the UKCP09 projections (Murphy *et al.* 2009) to provide a central estimate along with upper and lower bound estimates. The hydrological modelling work described in Section 2.1 provides the change factors required for each climate change scenario. Details of how climate change impacts have been translated to estimated impacts on Deployable Output for a specific WRZ are provided in Appendix A.

Table 4.2: Climate change projections.

Climate change projection	Description
Low climate change	Taken as a reasonable 'lower bound' estimate (low emissions, 10th percentile) from the 10,000 UKCP09 ensemble scenarios
Medium climate change	Taken as a reasonable 'central' estimate (medium emissions, 50th percentile) from the 10,000 UKCP09 ensemble scenarios
High climate change	Taken as a reasonable 'upper bound' estimate (high emissions, 90th percentile) from the 10,000 UKCP09 ensemble scenarios

Source: n/a

There is a medium level of confidence in this assessment with respect to the 2050s and 2080s estimates.

4.1.2. Short-term projection (2030s)

Where in the UK faces the greatest level of PWS deficit by the 2030s?

Figure 4.1 presents the supply-demand balance at the end of the water company resource planning horizon, based on the water resource system for the baseline period (i.e. does not include for planned interventions set-out in the water company resource plans). For England and Wales this reflects the position in 2040, for Scotland the position in 2032 and for Northern Ireland the position in 2035. National summary information is provided in Table 4.3. These national figures should be interpreted with care as aggregating the results to such a high level may mask any local deficits and surpluses.

Table 4.3: Summary of overall supply-demand balance for the 2030s (in Ml/d and as a % of baseline total Distribution Input) by country, with positive numbers indicating a surplus.

Country	2030s water company resource plans supply-demand balance
England	-190 (-1%)
Wales*	+ 79 (+9%)
Scotland	+415 (+22%)
Northern Ireland	-26 (-4%)

*Source: Water company resource plan, planning tables. Climate change and population projection as per water company resource plans (assumed to be medium emissions p50 and principal population projections). * A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

A total of 27 WRZs report a supply-demand deficit of greater than 5 Ml/d in their water company resource plans in the 2030s. These comprise one WRZ in Wales, two in Northern Ireland and 24 in England. The largest deficit reported is for the London WRZ with a supply-demand shortfall of 350 Ml/d. A deficit of 95 Ml/d is reported in the Yorkshire Grid Zone which is the next most affected WRZ. The magnitude of these deficits should be considered alongside the relative scale of the WRZ's respective total demand for water, with the example values provided here intended to indicate the overall scale of deficits projected at a regional and national scale. The water companies that report a deficit during the water company resource planning horizon then set-out a programme of *preferred* measures to mitigate this deficit in their Final Plans (see later in this Section, 4.1, for a discussion of future adaptation, including water company preferred options).

Figure 4.2 presents the corresponding end of plan target headroom values adopted in each WRZ, as a percentage of total Distribution Input (a measure of total demand). The target headroom values highlight that the majority of water companies adopt values of less than 10%, but some report values up to almost 30%. A number of WRZs report similar percentages to the baseline position but some also report significant changes, sometimes increasing their target headroom whilst others reduce it. Increases are often associated with WRZs reporting significant climate change impacts thus reflecting the uncertainty associated with this component of the supply demand balance.

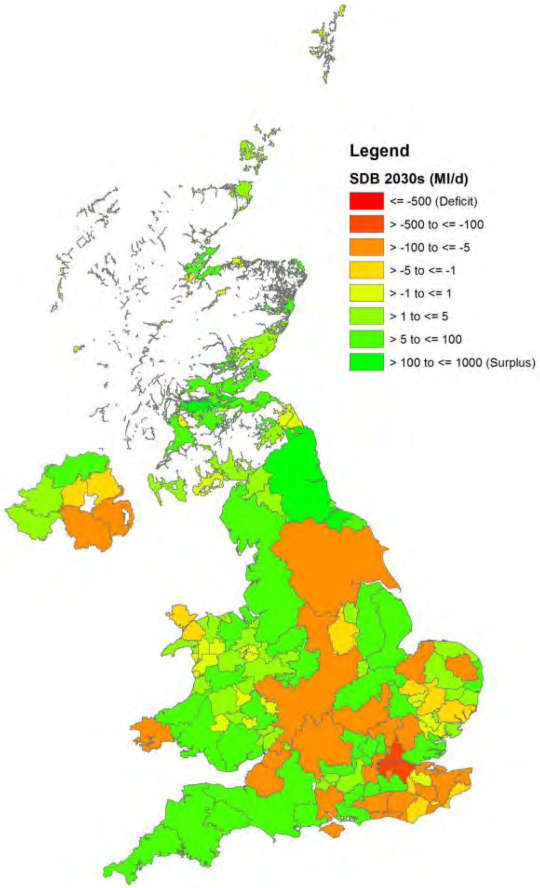

Figure 4.1: Plot of projected supply-demand balance for current water resource zones in the 2030s (end of water company resource planning horizon) (Ml/d). Climate scenario(s) as per water company resource plan, planning tables. 'No additional action' adaptation.

Source: Water company resource plan, planning tables

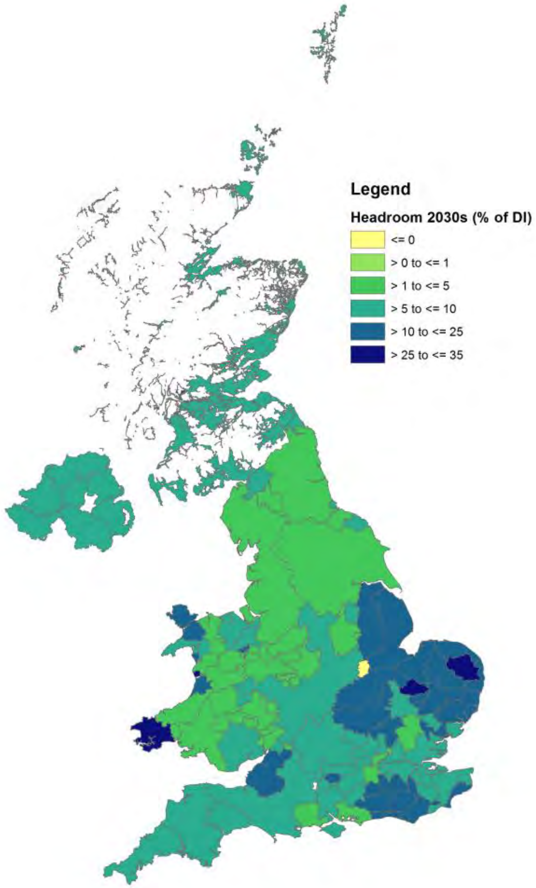

Figure 4.2: Plot of projected target headroom values for current water resource systems in the 2030s (end of water company resource planning horizon), as a % of Distribution Input. Climate scenario(s) as per water company resource plan, planning tables. 'No additional action' adaptation.

Source: Water company resource plan, planning tables

Effects of population change on demand for public water supplies

Figure 4.3 and Figure 4.4 present the percentage change in population from the baseline to this 'end-of-plan' date and the corresponding demand for public water supplies (total Distribution Input) respectively – noting that this end of plan date is 2040 in England and Wales, 2032 for Scotland and 2035 for Northern Ireland. These figures highlight that changes in population and the corresponding demand for public water supplies vary significantly across the UK. The total demand for public water supplies increases by the greatest extent, in general, in the south-east of England and Northern Ireland (noting that in Northern Ireland, the changes shown are relative to 2009). In Wales, northern, central and south west England and some WRZ's in Scotland, Distribution Input is projected to decrease by the 2030s. This is primarily due to PCC reductions and improvements in leakage rates. A summary of the change in Distribution Input is shown in Table 4.4.

Table 4.4: Summary of change in Distribution Input (in Ml/d and as a % of baseline Demand) by country.

Country	2030s total Distribution Input
England	+ 55 (0%)
Wales*	-60 (-7%)
Scotland	-18 (-1%)
Northern Ireland	+ 64 (+9%)

Source: Water company resource plan, planning tables. Population projection as per water company resource plans (assumed to be principal population projections).

**A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

The maps in Figure 4.5 show the proportion of demand from household, non-household and leakage respectively at this 'end-of-plan' date and highlight those areas where non-household demand and leakage are particularly significant components of the demand for water. Note that this is for the water resource systems prior to the implementation of any measures proposed by the water companies during the water company resource planning horizon, including leakage reductions.

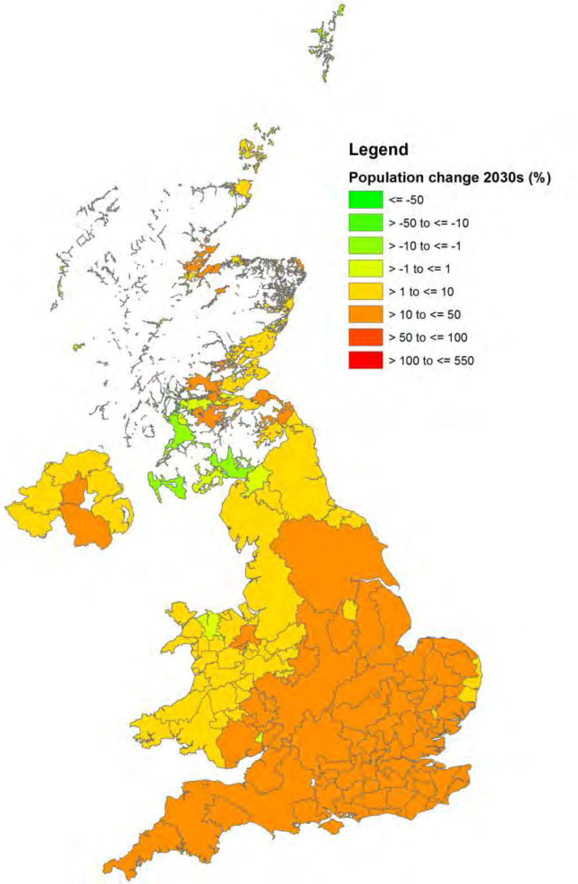

Figure 4.3: Plot of 2030s change in population from baseline (%).

Source: Water company resource plan, planning tables

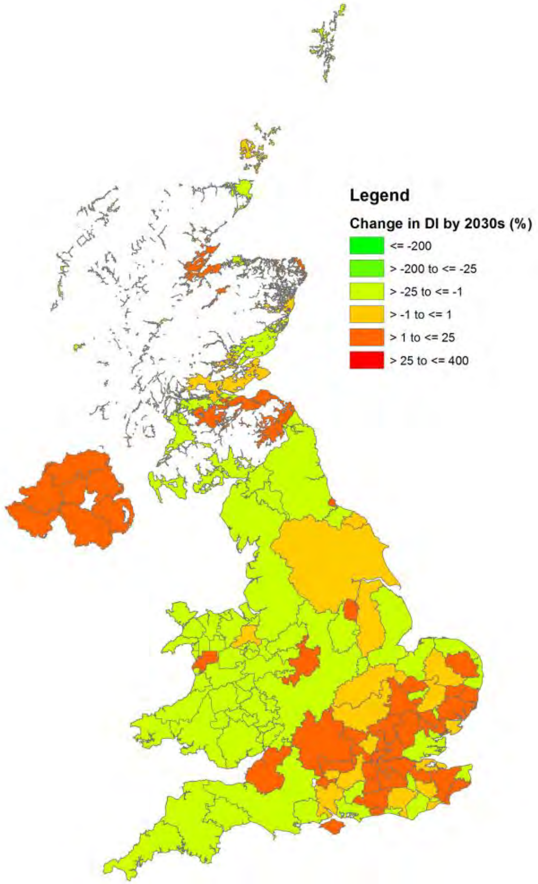

Figure 4.4: Plot of 2030s change in Distribution Input for public water supplies from baseline (%). Climate scenario(s) as per water company resource plan, planning tables. ‘no additional action’ adaptation.

Source: Water company resource plan, planning tables

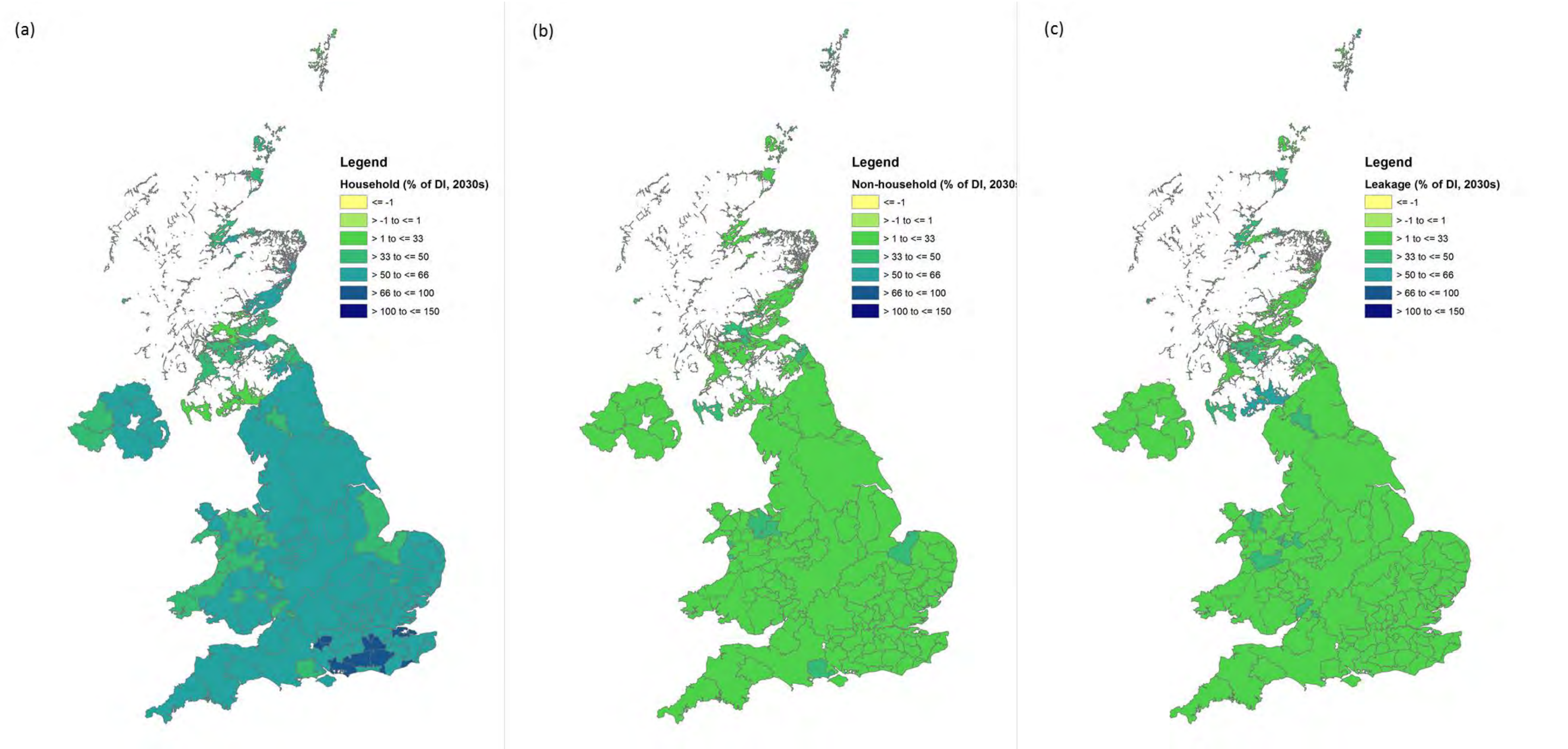

Figure 4.5: From left to right: (a) Plot of 2030s percentage of demand for Household consumption (% of total Distribution Input); (b) Plot of 2030s percentage of demand for Non-Household consumption (%); and, (c) plot of 2030s percentage of demand lost to leakage (%). Climate scenario(s) as per water company resource plan, planning tables. A 'No additional action' adaptation scenario is assumed for all three maps.

Source: Water company resource plan, planning tables

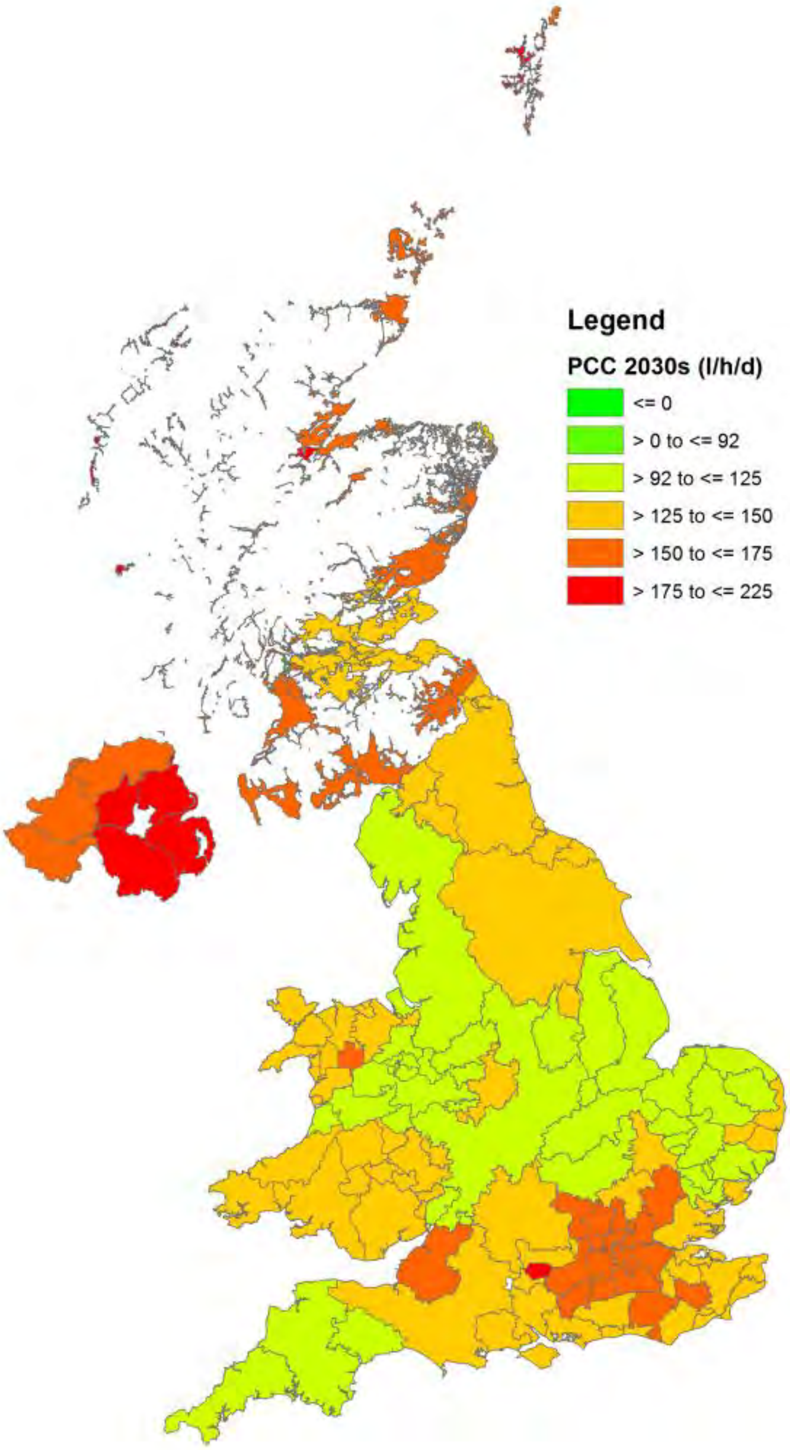

Figure 4.6: Plot of weighted (measured and unmeasured) PCC (l/h/d) for the 2030s under a 'no additional action' adaptation scenario.

Source: Water company resource plan, planning tables

The values adopted for PCC in the 2030s for each WRZ are presented in Figure 4.6. This figure, when compared to that presented in Figure 3.6 for the base year, highlights the significant reductions in PCC anticipated by the water companies to be achieved by the 2030s.

Effects of climate change on Deployable Output

Figure 4.7 presents the reported Deployable Output values for each WRZ. Figure 4.8 reports the impact of climate change, as a percentage of Deployable Output.

In this analysis, the magnitude of Deployable Output may be limited by:

- The yield of the river (a measure of the unconstrained water output of a *source* that can be sustained by the catchment or aquifer feeding the source);
- Licensing constraints; and/or
- The capacity of treatment works to process the water.

Where the yield, including any climate change impacts, of a water source remains above the value of the abstraction licence and/or the capacity of the treatment works, the Deployable Output will be considered to be unaffected by climate change. This means that climate change impacts on Deployable Output are only realised when the revised yield for a WRZ becomes the limiting factor on Deployable Output.

For England, Wales and Northern Ireland, climate change impacts on Deployable Output are reported explicitly as part of their water company resource plans. These are typically calculated using hydrological and water resources models. For Scotland, the planning tables do not currently report climate change impacts. Consequently, for this study, Scottish Water made available the outputs from their separate climate change impact assessment. In this study, Scottish Water used outputs from the Future Flows project (Prudhomme *et al.* 2012) to derive projected climate change impacts on yield for the 2040s for their WRZs. For deriving impacts on Deployable Output, rather than yield (yield ignores any infrastructure or licence constraints), the analysis presented here used the central estimate of climate change impact on yield, along with information on licensing constraints and treatment works capacity to estimate the impact on Deployable Output to the end of Scottish Water's final plan (2032).

The results presented in Figure 4.8 across the UK highlight that the climate change impacts reported at the end of the water company resource plans vary significantly across the different WRZs:

Absolute impacts by the 2030s:

- The highest impacts, in absolute terms are reported in the Grid WRZ for Yorkshire Water and the Integrated WRZ in United Utilities, reporting losses of 131 and 121 Ml/d respectively;
- London WRZ reports a loss of 72 Ml/d;
- Severn Trent Water's Strategic Grid WRZ is the only other zone reporting a loss of over 50 Ml/d.

Proportional impacts by the 2030s:

- In north-west Wales in the Tywyn/Aberdyfi WRZ, there is a reported loss in Deployable Output of 24%, much larger than elsewhere;
- Four other WRZs report impacts of around 10%:
  - Nottinghamshire, NEYM (Welsh Water);
  - Parts of Essex and Suffolk Water; and
  - Affinity Water.

- Sixteen WRZs report impacts of 5% or more (three WRZs in Scotland, four of Welsh Water and nine in England); and
- 17 WRZs record an increase in Deployable Output due to climate change (16 of these WRZs in Scotland and the other being the Essex WRZ).

Of the rest, 203 WRZs report no impact due to climate change (146 WRZs in Scotland, 11 of Welsh Water, two in Northern Ireland and 44 in England). These are typically WRZs where Deployable Output is not considered, by the end of the planning horizon, to be yield constrained (i.e. sources which may be constrained by license conditions or infrastructure capacity), and/or WRZs with significant groundwater resources that are considered largely resilient to climate change.

Whether a WRZ is reported as being vulnerable to climate change is therefore not only related to whether the flows in the river(s) are projected to change, but also other characteristics of the supplies that may affect the amount of water a company can abstract. This may include the availability of above and below ground storage and licence constraints such as thresholds at which abstractions must be suspended. The large absolute impacts projected for the Grid WRZ in Yorkshire Water, the Integrated WRZ in United Utilities, London and Severn Trent Water's Strategic Grid WRZ are also a function of the volume of water being provided to customers in such large and/or heavily populated zones.

Table 4.5 provides a summary of the total losses, in absolute and percentage terms for each country and highlight that the majority of climate change impacts reported in the water company resource plans are in England, with Deployable Output considered to be reduced by over 500 Ml/d across England as a whole by the end of the planning horizon without the introduction of any new measures.

Table 4.5: Summary of climate change impacts on Deployable Output Ml/d (Ml/d and % of baseline Deployable Output) by country, as reported at the end of the water company resource planning horizons (2030s). Climate scenario(s) as per water company resource plan, planning tables. 'no additional action' adaptation.

Country	Change in Deployable Output due to climate change (Ml/d)
England	-544 (-3%)
Wales*	-19 (-2%)
Scotland	-14 (-1%)
Northern Ireland	-2.6 (-1%)

Source: Water company resource plan, planning tables. Climate change projection as per water company resource plans (assumed to be medium emissions p50) and under a 'no additional action' adaptation scenario.

**A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

The example values provided here are intended to indicate the overall scale of impacts projected to help inform the Climate Change Risk Assessment at a regional and national scale as opposed to providing specific estimates of impacts on WRZs which would be more suitable to assisting WRZ and/or water company level risk assessment.

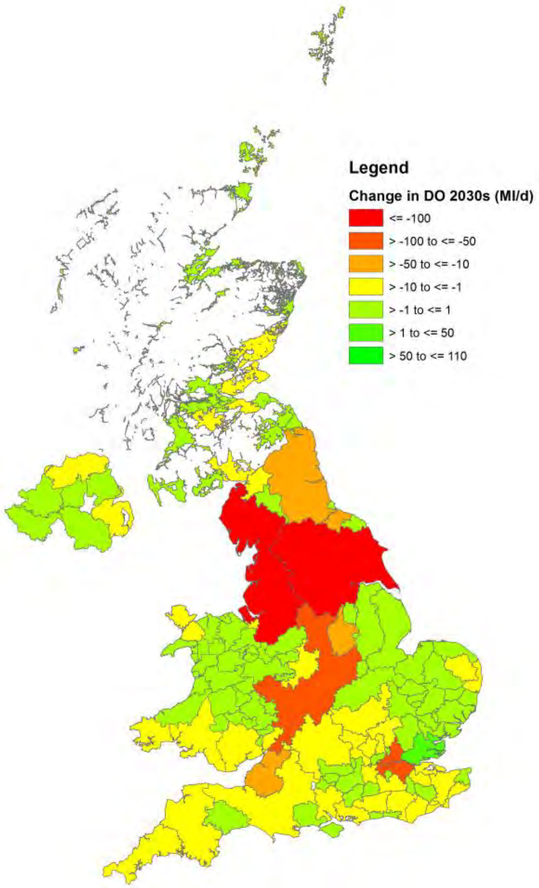

Figure 4.7: Plot of Change in Deployable Output due to climate change by 2030s, from baseline (Ml/d). Climate scenario(s) as per water company resource plan, planning tables. 'No additional action' adaptation.

Source: Water company resource plan, planning tables

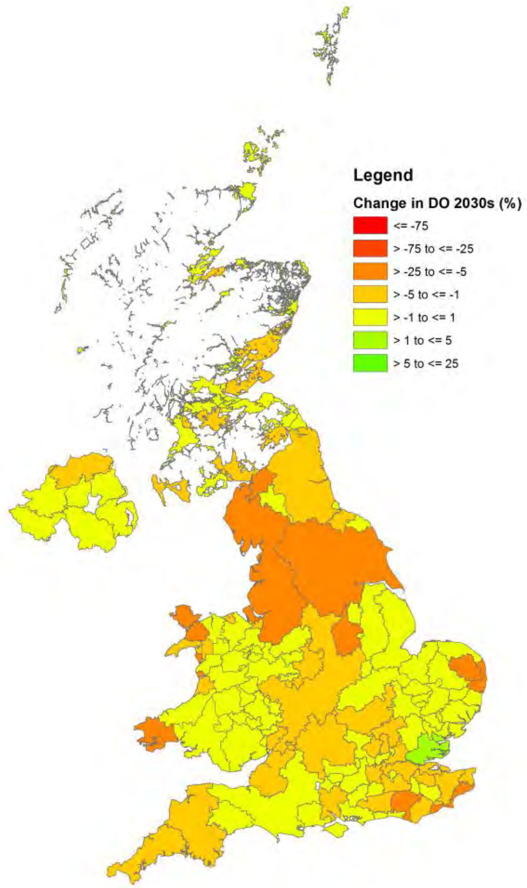

Figure 4.8: Plot of 2030s climate change Impact on Deployable Output (as a % of baseline Deployable Output). Climate scenario(s) as per water company resource plan, planning tables. 'No additional action' adaptation.

Source: Water company resource plan, planning tables

4.1.3. Medium and long-term projections (2050s and 2080s)

The method used to develop projections of supply-demand balances for the 2050s and 2080s under the range of scenarios considered has been based on extrapolation of the water company resource planning tables, as described in Appendix A. The method has not involved detailed water resources system modelling and therefore the results presented in this section, particular for the 2080s, should be seen as being indicative and highlighting potential areas of concern rather than precise estimates of future impacts.

Figure 4.9 to Figure 4.12 present the range of estimates used in this assessment of the supply demand balance for the 2050s and 2080s, based on the present-day water resources systems. The lowest estimates made for the 2050s and 2080s are represented by a medium climate change projection (p50 probability level and medium emission climate change scenario), a low population and 'no additional action' adaptation future. **Additional scenarios for the 2080s for a lower scenario are provided in an annex accompanying this report.** The upper bound estimates for the 2050s and 2080s are represented by a high climate change projection (90th percentile and high emission climate change scenario) and a high population future. In generating these supply-demand balances, target headroom has been fixed at the absolute values used in the final year of the water company resource plans.

Where in the UK faces the greatest level of PWS deficit by the 2050s and 2080s under the lower bound projections assessed?

Figure 4.9 highlights that, by the 2050s, under a low population, no additional adaptation and medium climate change projection a total of 39 WRZs are projected to have a supply-demand deficit of greater than 5 Ml/d. This would comprise one WRZ in Scotland, three WRZs in Wales, two in Northern Ireland and 33 in England. The largest deficit is projected for the London WRZ with a supply-demand shortfall of 590 Ml/d. A deficit of 193 Ml/d is projected in Yorkshire Grid Zone, and both Severn Trent Water's Strategic Grid and Bristol WRZs have projected deficits in excess of 100 Ml/d.

By the 2080s, under a low population, no additional adaptation and medium climate change projection, the number of WRZs with a deficit greater than 5 Ml/d increases to 41 WRZs: one in Northern Ireland, three in Wales, one in Scotland and 36 in England, see Figure 4.10. Five WRZs are projected to have more than 100 Ml/d deficit with United Utilities' Integrated Zone joining the four WRZs[14] with deficits greater than 100 Ml/d estimated for the 2050s under a low population, medium climate change impact future. London WRZ's deficit is projected to reach 770 Ml/d under this scenario by the 2080s.

Where in the UK faces the greatest level of PWS deficit by the 2050s and 2080s under the upper bound projections assessed?

Under a high population, no additional adaptation, high climate change projection for the 2050s, 56 WRZs exhibit deficits of more than 5 Ml/d. Six WRZs are projected to have deficits of more than 100 Ml/d which include the five WRZs listed above[15] along with the Nottinghamshire WRZ. Overall, a large number of the WRZs in England are demonstrating significant deficits under such a future scenario with only the south-west largely unaffected; all of South West Water's, Wessex Water's and Sembcorp (Bournemouth) Water's WRZs

[14] London WRZ; Yorkshire Grid Zone; and, Severn Trent Water's Strategic Grid and Bristol WRZs.

[15] London WRZ; Yorkshire Grid Zone; Severn Trent Water's Strategic Grid and Bristol WRZs; and, United Utilities' Integrated Zone.

are projected to have surpluses. The deficit in the London WRZ is projected to reach 750 Ml/d under this scenario.

In Scotland, under a high population, no additional adaptation, high climate change projection, six WRZs are projected to have a deficit of greater than 5 Ml/d by the 2050s, including the Fife WRZ, Afton and Bradan WRZ, Clatto & Lintrathen & Whitehillocks WRZ, Edinburgh and Lothian WRZ and Lanarkshire WRZ which are five of the largest Scottish WRZs. In Northern Ireland, four WRZs are projected to exhibit deficits greater than 5 Ml/d and Northern Ireland Water overall, across the seven WRZs considered, demonstrates an overall deficit of nearly 90 Ml/d.

By the 2080s, under a high population, high climate change, 'no additional action' projection, the number of WRZs projected to have deficits of more than 5 Ml/d increases to 75. Ten WRZs are projected to show a deficit of more than 100 Ml/d, with three of Affinity Water's WRZs and Southern Water's Hampshire South WRZ joining the six WRZs[16] projected to have deficits of more than 100 Ml/d under such a future by the 2050s. Overall, the majority of England is impacted by the 2080s, including the south-west of England, which up to this point, has been estimated to be largely resilient to future pressures. The London WRZ deficit is estimated to be over 1,350 Ml/d and both Yorkshire Water's Grid WRZ and United Utilities' Integrated WRZs are estimated to have deficits in excess of 650 Ml/d. Northumbrian Water's Kielder WRZ remains in surplus throughout all the scenarios assessed and still has a projected surplus of over 75 Ml/d under this upper bound scenario. At a national scale, England has a projected deficit of over 3,000 Ml/d by 2050s and over 5,500 Ml/d by the 2080s, equivalent to 19% and 33% of the corresponding demands under this projection (refer to Table 4.6).

In Wales, the majority of Welsh Water's WRZs are projected to remain in surplus by the 2080s, under a high population high climate change projection, with only three out of their 24 WRZs reporting deficits of more than 5 Ml/d, which are NEYM, SEWCUS and Pembrokeshire. Overall, Welsh Water has a projected deficit of 69 Ml/d by 2050s and 136 Ml/d by the 2080s, equivalent to 8% and 15% of the corresponding demands under such projections (refer to Table 4.6).

For Scotland, nine of the 189 WRZs considered in this study have projected deficits of more than 5 Ml/d, with the additional WRZs affected (compared to the 2050s) including the large WRZ of Invercannie & Mannofield. However, due to its very large projected yields in relation to demands, a significant surplus of over 80 Ml/d is estimated for Glasgow under this scenario. For Northern Ireland, all WRZs are projected to be in deficit although the west and south-west WRZs have estimated deficits of less than 5 Ml/d. In terms of national figures, Scotland would remain in surplus by 96 Ml/d in the 2050s and a deficit of 88 Ml/d by the 2080s under a high population, high climate change impact future scenario. Under the same projections, Northern Ireland has projected deficits of 89 and 145 Ml/d in the 2050s and 2080s respectively (refer to Table 4.6).

When interpreting all the projected deficits highlighted above, the magnitude of these should be considered alongside the relative scale of the WRZ's with respect to the total demand for water. The values provided are intended to indicate the overall scale of deficits projected to help inform the Climate Change Risk Assessment at a regional and national scale as opposed to providing specific estimates of impacts on WRZs which, would be more suitable to assisting WRZ and/or water company level risk assessment.

[16] London WRZ; Yorkshire Grid Zone; Severn Trent Water's Strategic Grid and Bristol WRZs; United Utilities' Integrated Zone; and, the Nottinghamshire WRZ.

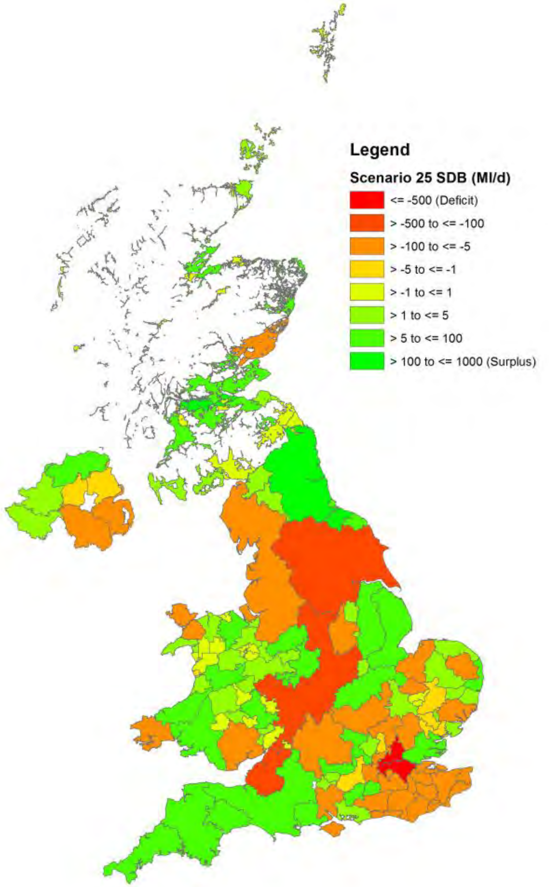

Figure 4.9: Plot of supply-demand balance for current water resource systems for 2050s under low population, medium climate change projections and a 'no additional action' adaptation scenario.

Source: n/a

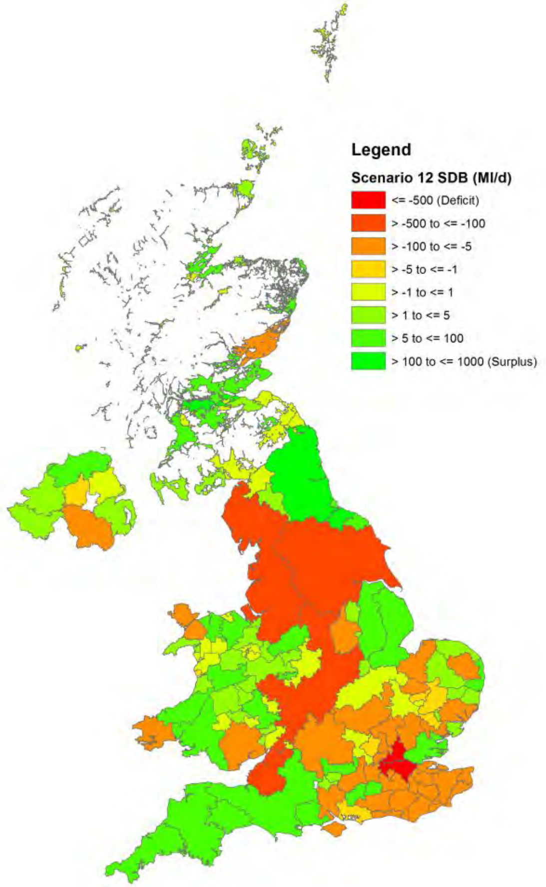

Figure 4.10: Plot of supply-demand balance for current water resource systems for 2080s under low population, medium climate change projections and a 'no additional action' adaptation scenario.

Source: n/a

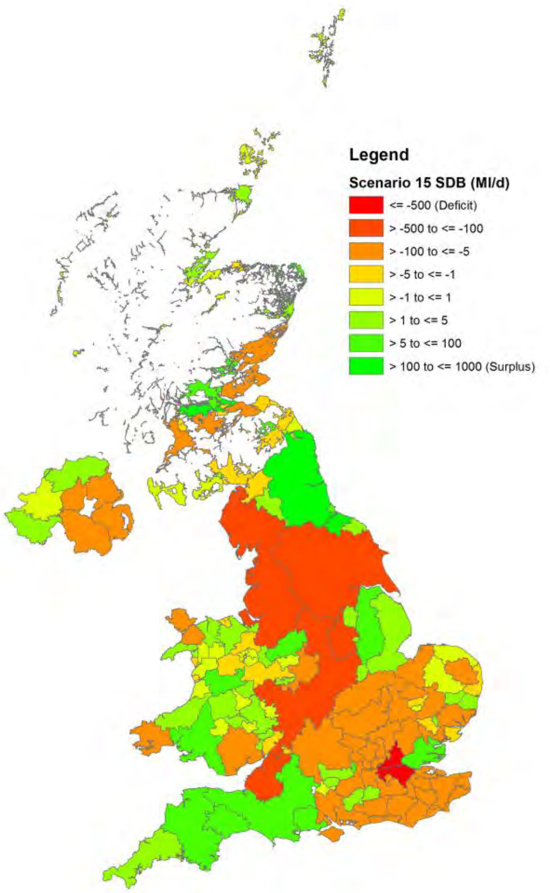

Figure 4.11: Plot of supply-demand balance for current water resource systems for 2050s under high population, high climate change projections and a ‘no additional action’ adaptation scenario.

Source: n/a

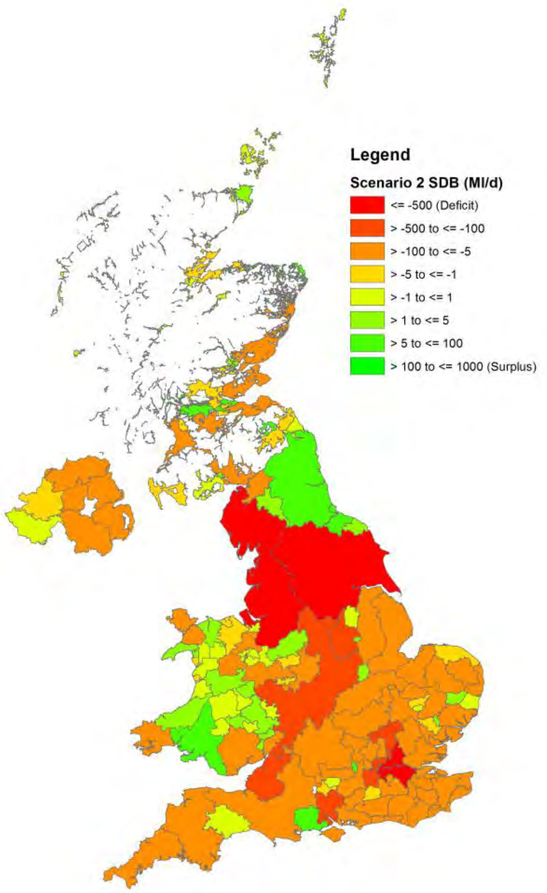

Figure 4.12: Plot of supply-demand balance for current water resource systems for 2080s under high population, high climate change projections and a ‘no additional action’ adaptation scenario.

Source: n/a

Table 4.6: Summary of overall supply-demand balance (in Ml/d and as a % of total Distribution Input) by country for different projections for the 2050s and 2080s, with positive numbers indicating a surplus. All scenarios assume no additional adaptation.

	2050s		2080s	
Country	Low Population, Medium Climate Change	High Population, High Climate Change	Low Population, Medium Climate Change	High Population, High Climate Change
England	-1,173 (-8%)	-3,006 (-22%)	-1,862 (-13%)	-5,657 (-41%)
Wales*	+26 (+3%)	-69 (-8%)	+39 (+4%)	-136 (-15%)
Scotland	+321 (+17%)	+96(+5%)	+334 (+18%)	-88 (-4%)
Northern Ireland	-15 (-2%)	-89 (-11%)	+14 (+2%)**	-145 (-17%)

Source: **A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

***Under a low population projection the population in Northern Ireland is projected to fall below the baseline population which results in a supply-demand surplus for this time period under a medium climate change scenario.*

The supply-demand deficits presented above are a manifestation of both supply-side and demand side impacts. The respective contributions from these impacts are examined in more detail in the following sections.

4.1.4. What are the effects of population change on demand for public water supplies?

Figure 4.13 to Figure 4.16 present the percentage change in population from the baseline for the future scenarios presented in Table 4.6.

These results highlight that population increases vary significantly spatially but that most areas see large increases by the 2080s under a high population future and that already densely populated areas receive the greatest population increases. It should be noted that, beyond 2037, population increases have been distributed based on the projected spatial patterns of growth suggested by the regional population forecasts to 2037 as described by ONS and each Devolved Government. Future population growth and the distribution of such growth is highly uncertain.

The population in a number of WRZs in the south-east of England are projected to increase by over 80% by the 2080s under a high population scenario. In Welsh Water's and Northern Ireland Water's WRZs, increases vary from between 10 and 45%. In Scotland, in the more populated WRZs, increases are between 25% and 60% under the same scenario. It should be noted that in some WRZs, population increases may be larger in the 2050s than the 2080s. In some WRZs and in particular for Northern Ireland as a whole under a low population medium climate change scenario, this may lead to a more negative impact on supply-demand balance in the 2050s than in the 2080s, note Table 4.6.

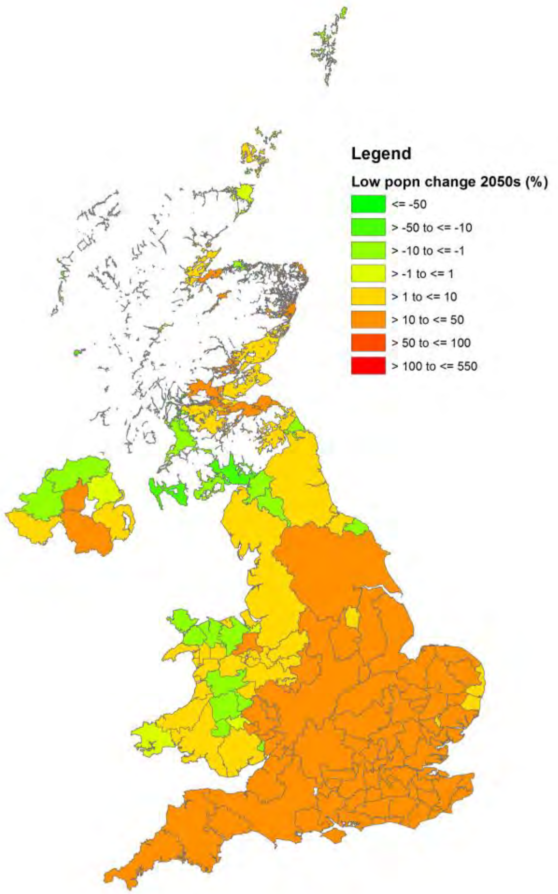

Figure 4.13: Plot of population change for 2050s under a low population projection (%).

Source: n/a

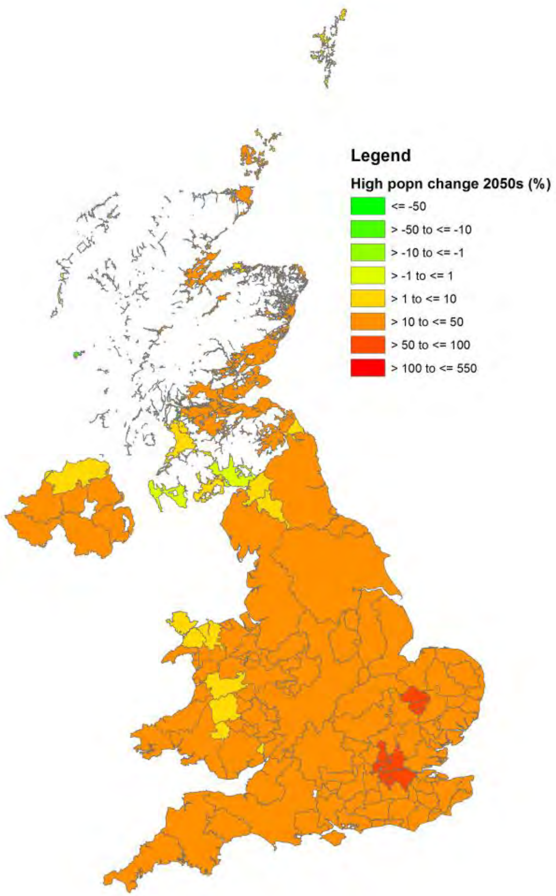

Figure 4.14: Plot of population change for 2050s under a high population projection (%).

Source: n/a

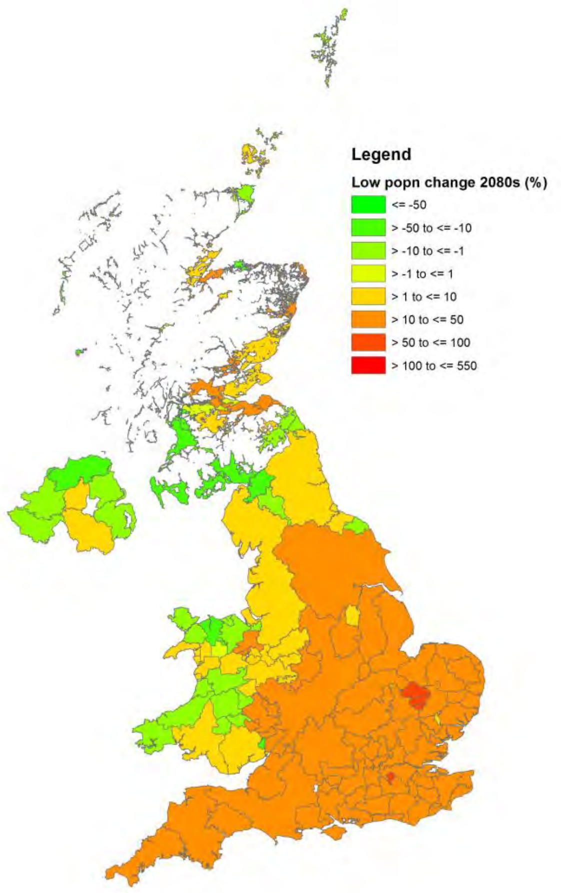

Figure 4.15: Plot of population change for 2080s under a low population projection (%).

Source: n/a

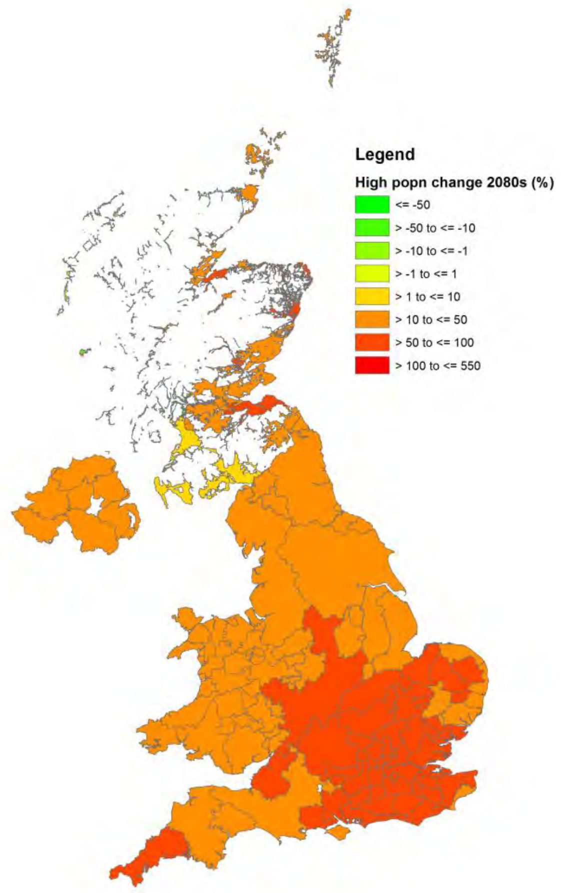

Figure 4.16: Plot of population change for 2080s under a high population projection (%).

Source: n/a

Equivalent plots for the corresponding change in the demand for public water supplies (in terms of total Distribution Input) under the future projections described in Table 4.7 are presented in Figure 4.17 to Figure 4.20. These confirm that the increases correspond to the population changes projected in Figure 4.13 to Figure 4.16, with significant impacts in the south-east of England in particular, even under a low population projection.

Table 4.7: Summary of change in total Distribution Input (in Ml/d and as a % of baseline demand) by country for the 2050s and 2080s.

Country	2050s		2080s	
	Low Population	High Population	Low Population	High Population
England	+430 (+3%)	+1,476 (+11%)	+792 (+6%)	+3,269 (+24%)
Wales*	-64 (-7%)	-9 (-1%)	+74 (+8%)	+52 (+6%)
Scotland	-26 (-1%)	+88 (+5%)	-47 (-3%)	+208 (+10%)
Northern Ireland	+51 (+7%)	+118 (+15%)	+22 (+3%)	+166 (+20%)

*Source: *A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

Table 4.7 presents a summary of the change in total Distribution Input by country. Changes to demand are primarily driven by population growth but also changes in PCC, leakage and non-household consumption. In generating these demand projections, the following assumptions have been made:

- Metered and unmetered PCC values remain at the levels reported at the end of the water company resource planning horizon. All additional population (beyond the end of water company resource plan population) is assumed to be in metered properties in England and Wales but in Scotland and Northern Ireland the split between measured and unmeasured is assumed to remain at the same proportions as at the end of the planning horizon. No further change in PCC, beyond the end of the water company resource planning horizon, is taken into account for the 2050s and 2080s;
- For non-household consumption, the relationship between population change and non-household consumption change to the end of the water company resource planning horizon is derived and the trend is applied to the projection for the 2050s and 2080s; and
- Per capita leakage rates remain at the levels implied for new properties during the resource planning horizon (i.e. so that the rate of change in leakage with population follows the same trend as implied by the trajectory through the resource plans).

These figures highlight a number of differences across the four countries with the largest changes primarily in the south-east of England, matching those areas projected to have the largest increases in population. These plots also highlight the significant increases from the 2050s to the 2080s and also the differences between the principal and high population projections. This underlines the large uncertainty associated with population, and hence demand projections. The lower impacts on demand shown for England and Wales compared to Scotland and Northern Ireland, relative to their respective projected rates of population growth, is due, at least in part, to the assumption that all new population in England and Wales would be metered and adopt the PCC values for metered population. This assumption is not made for Scotland or Northern Ireland as their current metering policies are not the same as England and Wales.

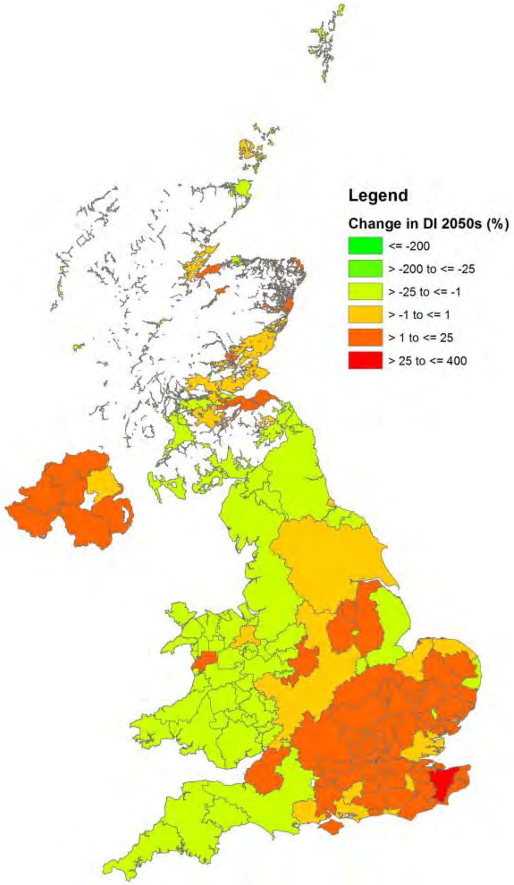

Figure 4.17: Plot of 2050s change (as a percentage relative to baseline) in Distribution Input under a low population projection and a ‘no additional action’ adaptation scenario.

Source: n/a

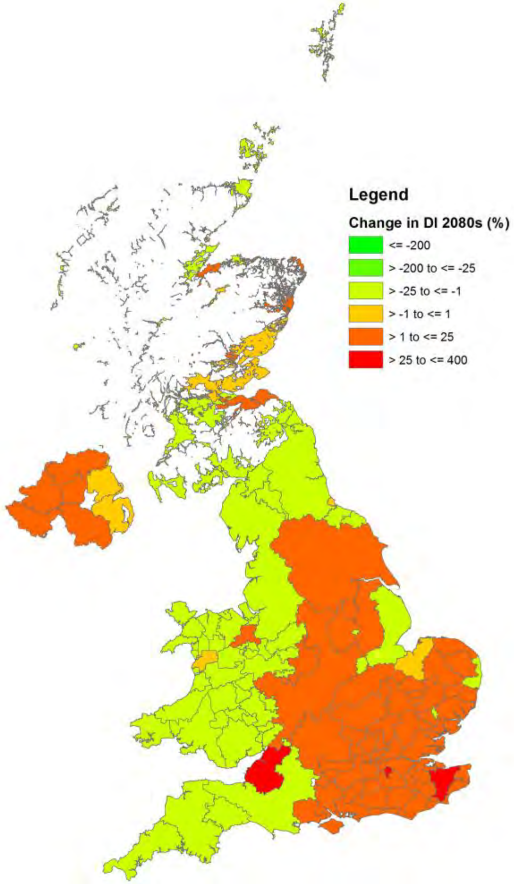

Figure 4.18: Plot of 2080s change (as a percentage relative to baseline) in Distribution Input under a low population projection and a ‘no additional action’ adaptation scenario.

Source: n/a

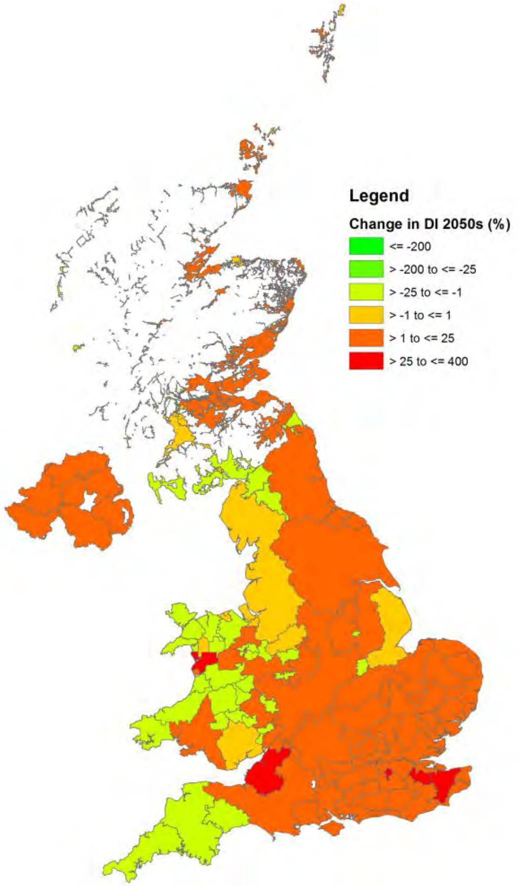

Figure 4.19: Plot of 2050s change (as a percentage relative to baseline) in Distribution Input under a high population projection and a 'no additional action' adaptation scenario.

Source: n/a

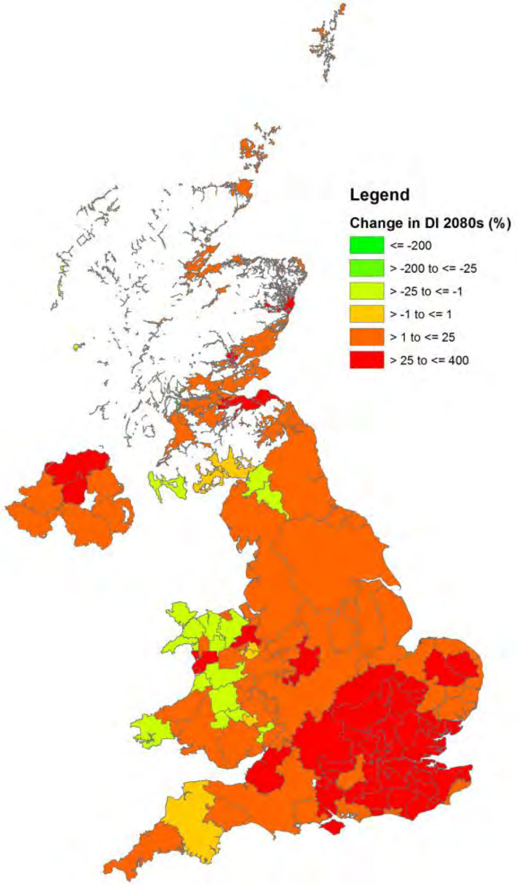

Figure 4.20: Plot of 2080s change (as a percentage relative to baseline) in Distribution Input under a high population projection and a 'no additional action' adaptation scenario.

Source: n/a

4.1.5. What are the effects of climate scenarios on Deployable Output?

Typically, hydrological and water resources modelling is undertaken by water companies for their water company resource plans. Such modelling has not been undertaken for this study and instead, the outputs from the water company resource plans have been extrapolated to the 2050s and 2080s using a simple ‘emulator method’ described in Appendix A. When interpreting these results, the following points in particular should be noted:

- The method has not involved the direct use of water resources models and hydrological/groundwater models at specific abstraction sites. Therefore, the approach has not included all the details of infrastructure and licence constraints, complex operating rules (e.g. reservoir control curves) or the detailed modelling of design events.
- The method has been based on the relationship between the impacts reported by the water company resource plans and the change in hydrological indicators due to climate change using the UKCP09 climate change projections described in Section 2. Therefore, this approach is not able to capture non-linearities (or “tipping points”) in the system beyond those already reflected in the estimates produced by the water companies as part of their plans. **This also means that those WRZs that report no climate change impacts at the end of their plan will not be shown to have any impacts projected by the 2050s and 2080s.**
- The method is considered by the authors to be an improvement on the method adopted for CCRA1 (where future projections were largely based upon a simple, defined relationship between relative aridity and Deployable Output, see Section 1.2 for more details) but it will still not be able to capture critical threshold values such as, for example, capturing the impacts from those sources which may not be considered drought susceptible at the end of the water resource plans but could become so by the 2080s.
- Different water companies may have adopted different assumptions and approaches to estimating the components of their supply-demand balance and, whilst the plans themselves may be considered to be broadly consistent given the regulatory process to which they are subjected, such differences may become more significant when projecting future impacts.

Consequently, there is potentially significant uncertainty associated with these estimates, particularly by the 2080s under a high climate change impacts future which is a significant ‘extension’ of the water company resource plan outputs. To assess the potential significance of adopting this ‘emulator’ approach compared to a more detailed simulation modelling method, four case studies have been modelled and examined in more detail as described in Appendix E. Based on this comparison, the emulator method used to estimate climate change impacts is considered appropriate to provide a reasonable first estimate of climate change impacts on Deployable Output for regional and national level climate change risk assessments, such as the CCRA. However it is not a substitute for the detailed modelling, at a more localised scale, typically undertaken by water companies as part of their resource planning.

Figure 4.21 to Figure 4.24 present the projected loss in Deployable Output for each WRZ under both a medium and high climate change future for the 2050s and 2080s. For each of the four countries the losses in absolute and percentage terms, for each scenario, are presented in Table 4.8. Within these figures, the largest absolute loss projections are related to the largest and/or most densely populated WRZs, with losses in the Grid WRZ in Yorkshire Water’s area and the Integrated WRZ of United Utilities, projected to be 350 and 460 Ml/d respectively by 2050s under a High Climate Change impact future, equivalent to losses of 25 and 21% of the baseline Deployable Output respectively. By the 2080s, these losses are projected to reach

480 and 680 (34 and 32%) Ml/d respectively. In the south of England, London has a projected loss of 280 and 410 Ml/d (13 and 19%) under a high climate change impact future, by the 2050s and 2080s respectively. For Severn Trent Water's large Strategic Grid WRZ, the equivalent losses are projected to be 140 and 190 Ml/d (10 and 13%). The large absolute impacts projected are for a couple of reasons:

- Thames Water's London zone:
  - The population is high and therefore the absolute water requirement is also high. Even small percentage changes equate to relatively large volumes.
  - Abstraction from the Thames River supplies more than one WRZ. However, the licence restrictions on abstractions from the Thames river are not equally spread between the receiving zones. Therefore, the London WRZ carries proportionally more risk, with respect to climate change, based on the licence conditions than the other WRZs served.
- Severn Trent Water's large Strategic Grid WRZ, Yorkshire Water's Grid zone and United Utilities Integrated WRZ:
  - The large geographical area means that the population is high and therefore the absolute water requirements are also high. Similar to the London zone, even small percentage changes equate to relatively large volumes.
  - Abstractions are largely from surface water sources that are relatively severely impacted by climate change, especially when compared to zones that have greater groundwater resources.

In Scotland, the largest estimated losses by the 2050s and 2080s under the high climate change impact scenario are for the Edinburgh and Lothian WRZ with losses of 40 and 50 Ml/d (17 and 22%) respectively. For other parts of Scotland, some areas such as Glasgow, appear to be particularly resilient to climate change because the projected yield, even under a high emissions climate future, is not the constraint on Deployable Output.

For Northern Ireland, the projected losses are generally lower with the greatest impact equal to 5 Ml/d by the 2080s under a high climate change scenario, for both the east and north WRZs (losses of 4 and 9% respectively). Out of all of Welsh Water's WRZs, SEWCUS is projected to have the largest losses with a 30 Ml/d (around 7%) reduction in Deployable Output in the 2080s.

Table 4.8 provides a summary of the projected total losses, in absolute (and percentage of baseline Deployable Output) terms for each country. The reduction in Deployable Output in England is 2,724 Ml/d under a high climate change projection for the 2080s, equivalent to a reduction of 16% from the baseline Deployable Output total. For the same projection, the losses for Wales, Scotland and Northern Ireland are 113 (-11%), 289 (-12%) and 14(-4%) Ml/d respectively, demonstrating that Northern Ireland is projected to be impacted to a much lower extent than the other countries in the UK.

Table 4.8: Summary of climate change reductions (shown as negative values) to Deployable Output (in Ml/d and as a % of baseline Deployable Output) by country for different climate projections for the 2050s and 2080s.

Country	2050s		2080s	
	Medium climate change projection	**High climate change projection**	**Medium climate change projection**	**High climate change projection**
England	-1,079 (-6%)	-1,866 (-11%)	-1,406 (-8%)	-2,724 (-16%)
Wales*	-67 (-6%)	-107 (-10%)	-64 (-6%)	-113 (-11%)
Scotland	-111 (-4%)	-224 (-9%)	-119 (-5%)	-289 (-12%)
Northern Ireland	-5 (-1%)	-9 (-2%)	-7 (-2%)	-14 (-4%)

Source: **A few WRZs cross the political border between Wales and England. All Welsh Water WRZs are included in the Wales national figure. Wrexham WRZ is included in the Wales national figure as the majority of the demand lies within Wales. Shelton and Chester are included in the England national figure as the majority of the demand lies within England.*

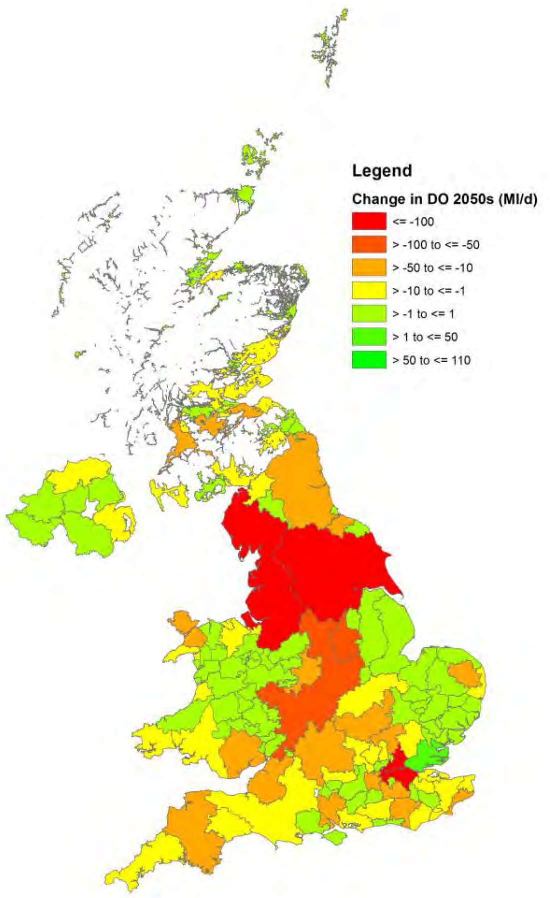

Figure 4.21: Plot of Change in Deployable Output by 2050s due to climate change under a medium climate change projection (Ml/d).

Source: n/a

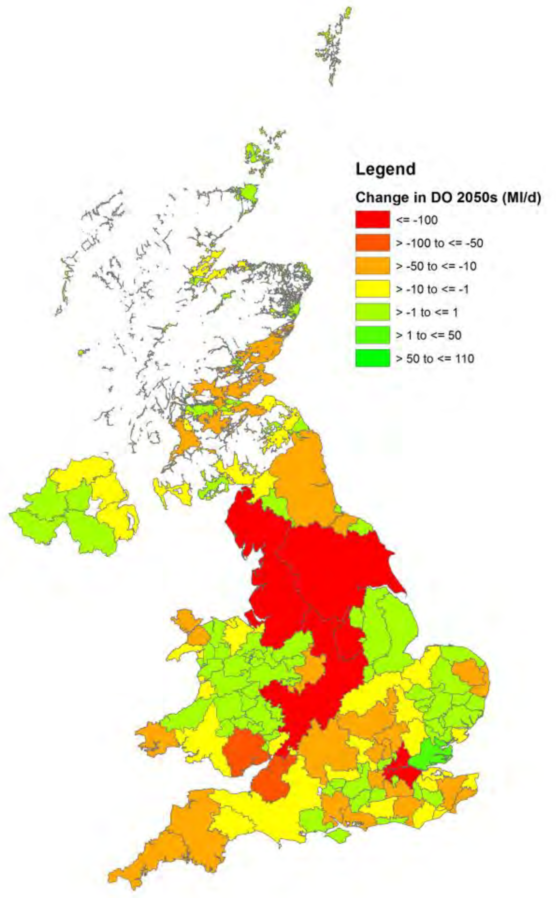

Figure 4.22: Plot of Change in Deployable Output by 2050s due to climate change under a high climate change projection (Ml/d).

Source: n/a

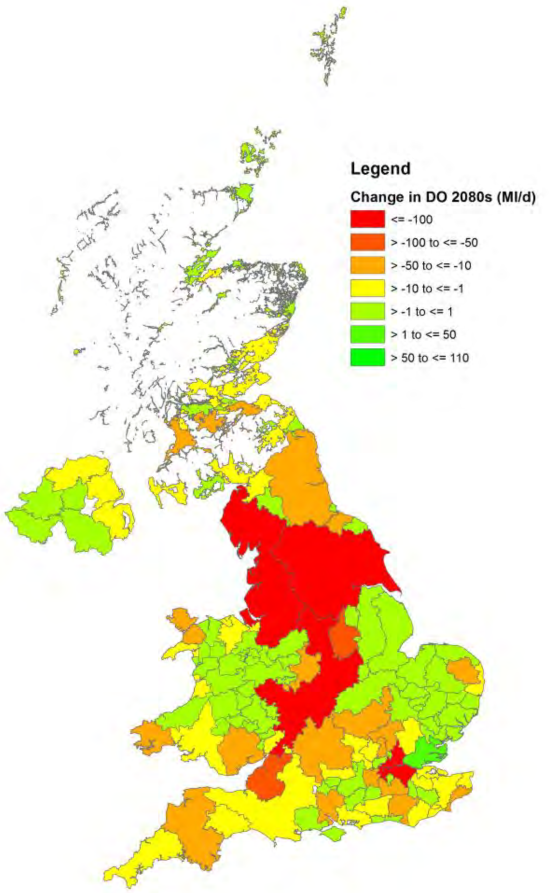

Figure 4.23: Plot of 2080s Deployable Output (Ml/d) under a medium climate change projection.

Source: n/a

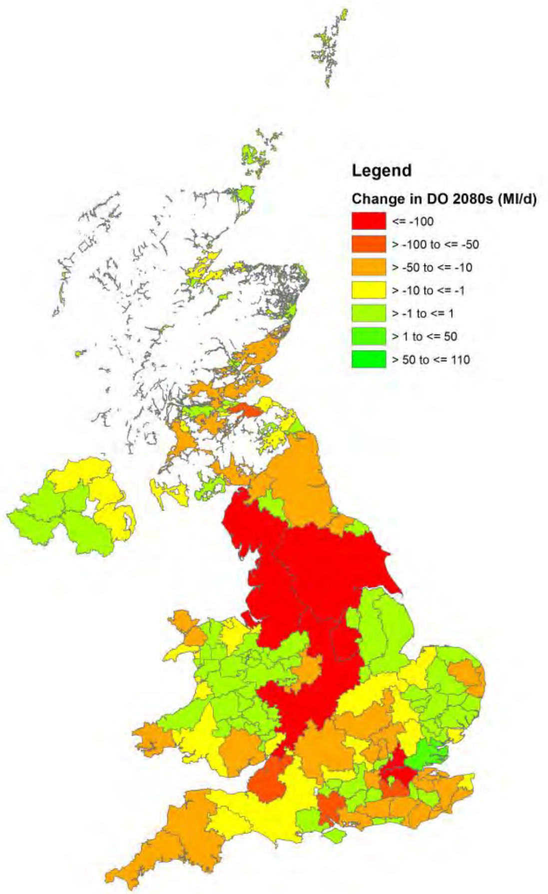

Figure 4.24: Plot of 2080s Deployable Output (Ml/d) under a high climate change projection.

Source: n/a

4.1.6. Groundwater, climate change and public water supply sources

Groundwater sustains environmentally important flows to our rivers and wetlands but is also a significant component of public water supply and water use in the UK. Groundwater resources are important to the UK's economy and in 2005 were valued at about £8 billion (Environment Agency, 2005). Most of the groundwater abstracted is in southern, eastern and central England from the major aquifers: the Chalk; Permo-Triassic sandstone; Jurassic limestone; and Lower Greensand (Allen *et al.*, 1997). The method used in the above sections has included analysis of WRZs particularly reliant on groundwater sources. Assessing the impacts of climate change on groundwater is challenging, particularly when assessing potential impacts at groundwater levels much lower than in the historical record.

In the latest water company resource plans, a number of water companies have made an assessment of the potential losses in groundwater yield based on either the outputs from detailed regional models or more simplified approaches (and therefore these will have informed the analysis presented in Section 4.1). These typically only considered the water company resource plan 25-year planning horizon and may not necessarily identify those aquifers that may become more vulnerable beyond this date.

As part of this project, the outputs from 24 Future Flows groundwater sources (Prudhomme *et al.*, 2012), 'driven' by the UKCP09 climate projections, have been assessed in the context of those WRZs that overlay related hydrogeological features within relatively close proximity. The location of the 24 Future Flows groundwater sources are shown in Figure 4.25.

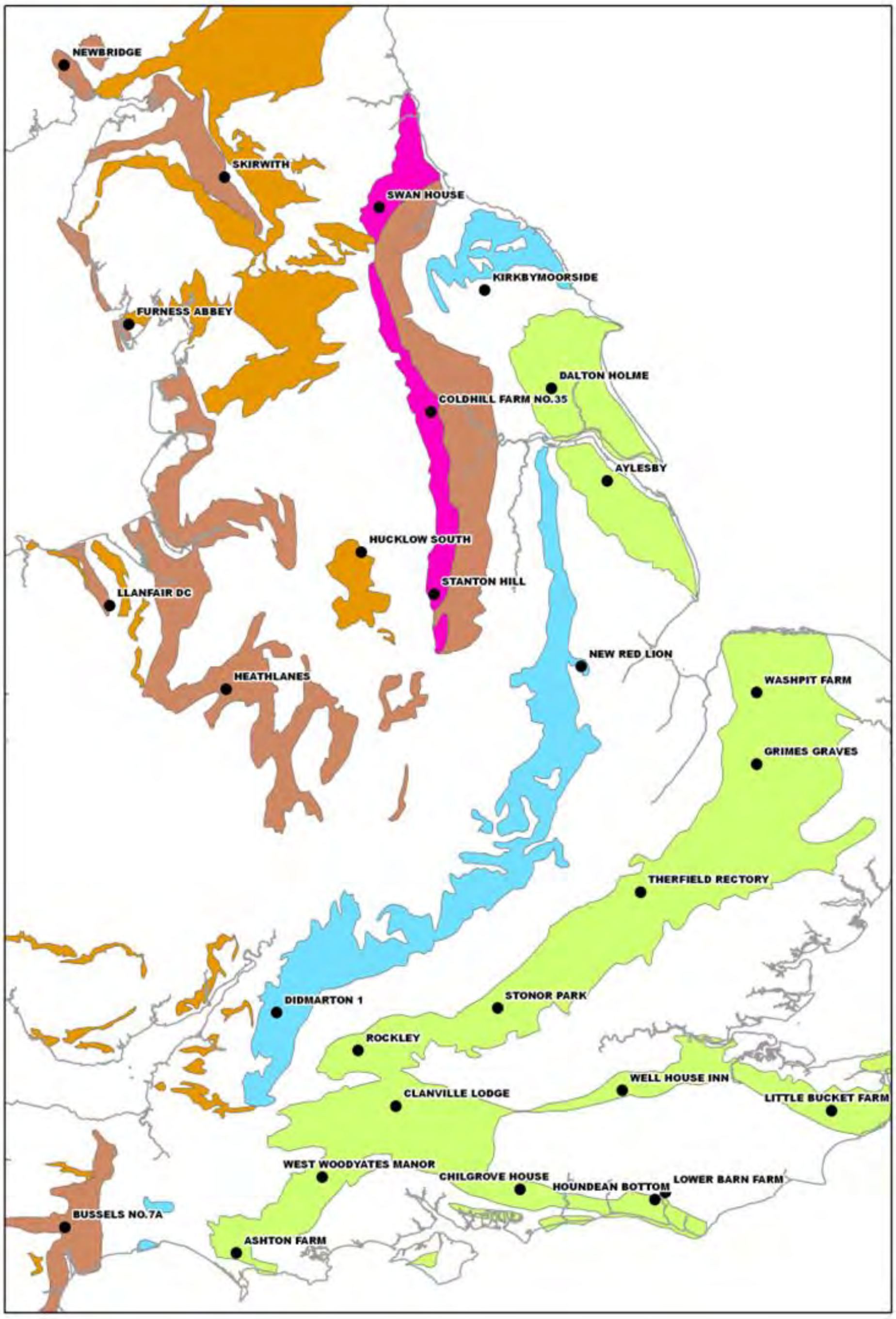

Figure 4.25: Location of Future Flows groundwater sites. Coloured areas indicate major aquifer extents.

Source: Prudhomme et al. (2012)

Figure 4.26 provides an overview of the projected impacts of climate change (using the change in mean summer level as the indicator) for the 2080s, medium emissions scenario, p50 probability level, across the 24 sites, with each 'box' focussing on each of the different hydrogeological classifications considered in the Future Flows project. To provide context, in terms of public water supplies, the WRZs have also been shaded according to the impacts of climate change reported in the water company resource plans for the 2030s.

Apart from the chalk aquifers in the very south-east, mean summer groundwater levels under this medium emissions scenario are projected to remain at current levels or slightly increase by the 2080s, with winter recharge offsetting increased evaporative losses during the summer likely to be the cause (as indicated by white-red dots for future flows groundwater level change).

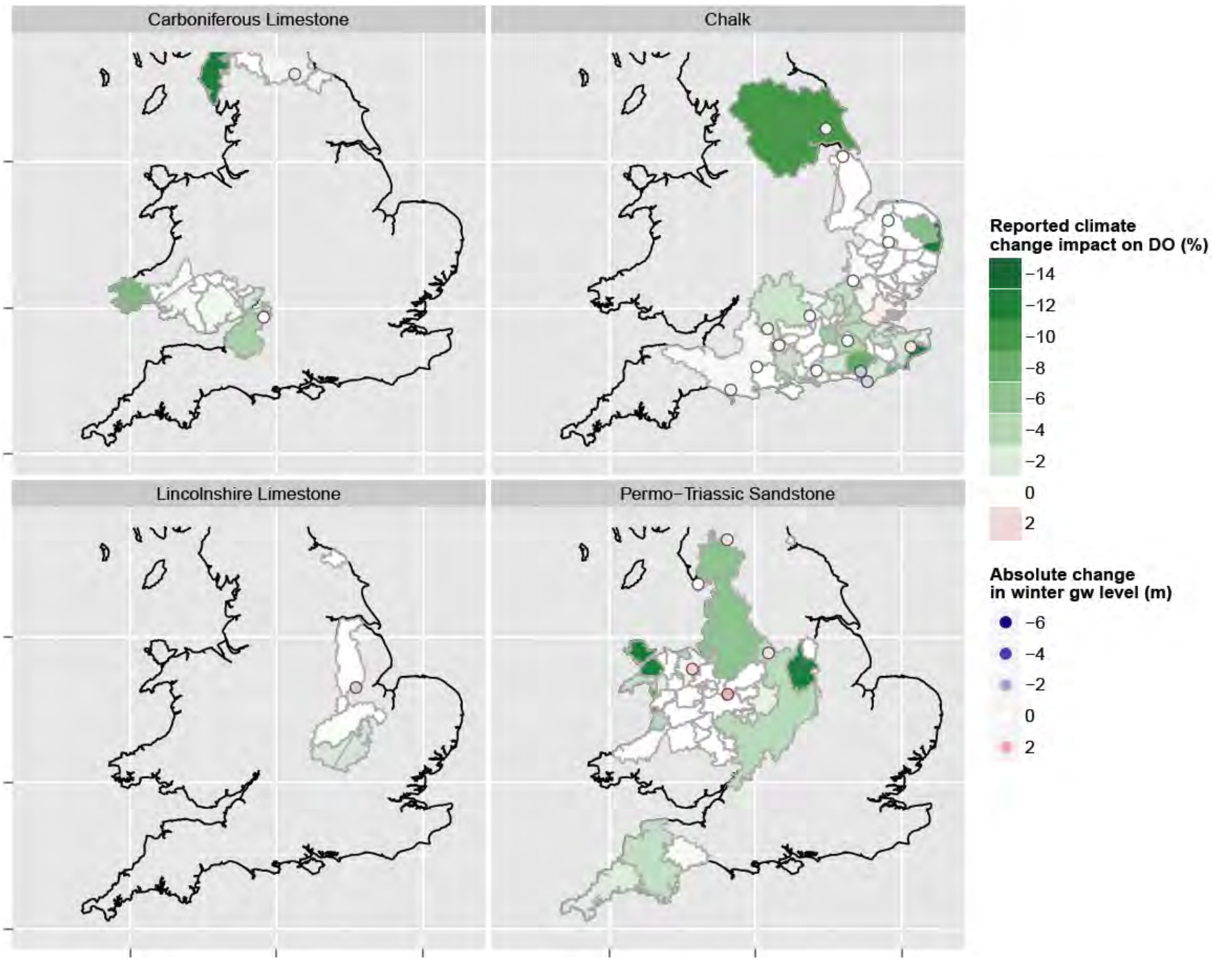

Figure 4.26: Projected change in mean summer groundwater levels for 24 Future Flows sites for the 2080s under a medium emission scenario and p50 probability level.

Source: n/a

Figure 4.27 shows just the chalk aquifers that are critical to water supplies in the south-east. The WRZs are split into the four plots depending on how reliant they are on groundwater resources ('gwprop' is the proportion of each WRZ's resource provided by groundwater sources as reported in the water company resource planning tables). Each plot is overlaid by the dots showing all of the projected impacts of climate change on groundwater levels in chalk aquifers for the 2080s, under the medium emissions scenario (p50).

These four figures in Figure 4.27 show that the Future Flows sites projecting the largest reductions in mean summer groundwater levels (light blue dots) are located in the south-east of England. These dots are close to WRZs that are particularly reliant on groundwater (see the increasingly green areas in the plots “Gwprop > 0.75” and “0.50 < GwProp < 0.75”). These WRZs typically report relatively significant impacts of climate change for the 2030s, further analysis beyond the 25-year water company resource planning horizon may be warranted to better understand the potential risks beyond this time horizon.

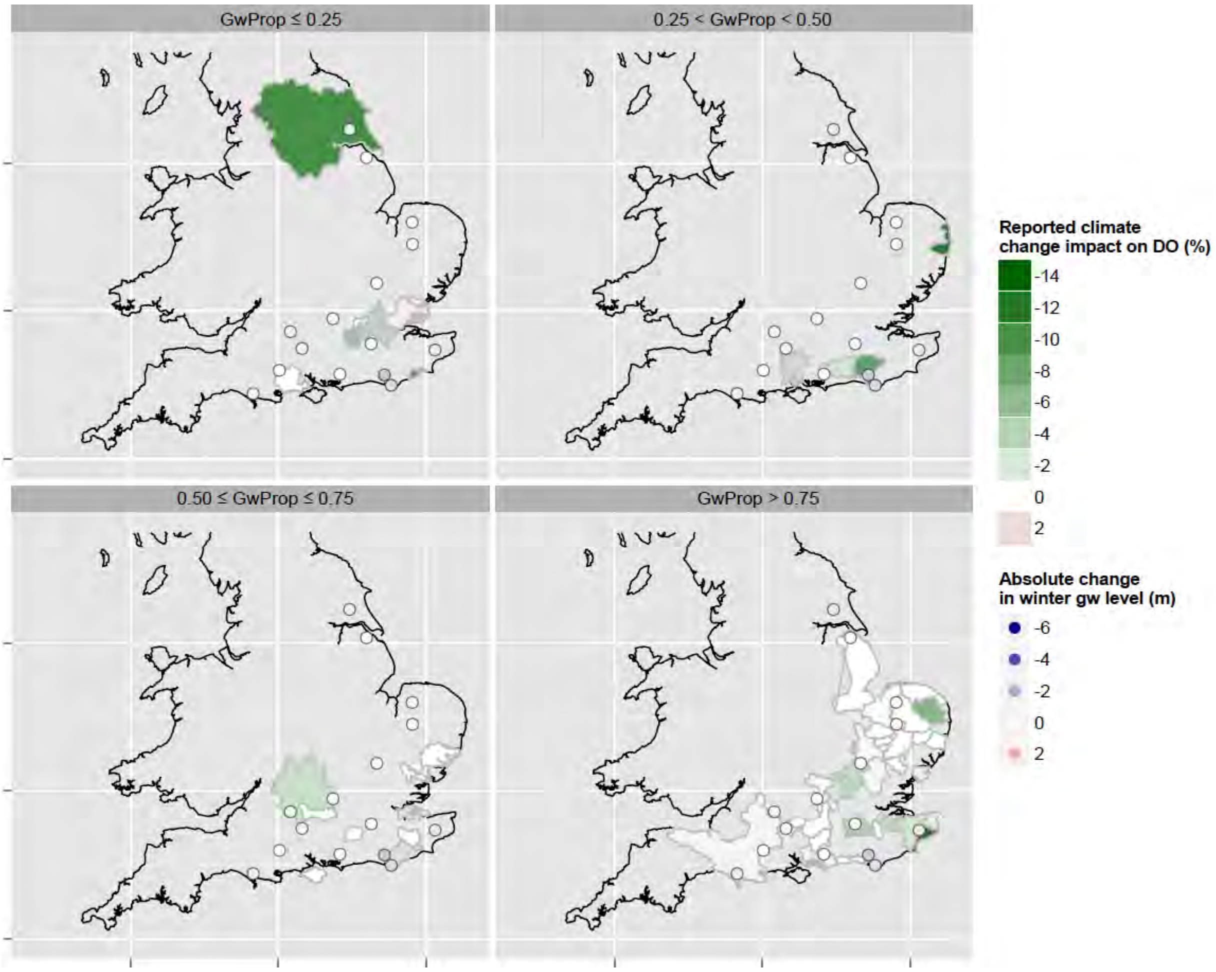

Figure 4.27: Projected change in mean summer groundwater levels for Future Flows sites located in chalk aquifers for the 2080s under a medium emission scenario, p50 probability level. The reliance on groundwater (gwprop) of each water resource zone also shown.

Source: n/a

4.1.7. Uncertainties in Public Water Supply

Assessing the relative significance of the different sources of uncertainty

It is recognised that developing the trajectories of supply and demand to 2050 and 2080 is based on a number of assumptions, particularly beyond 2040 (and the end of the water company resource planning horizon). The supply-demand trajectories presented in the previous section highlight that a number of components influence the adequacy of public water supplies in the future including climate change, population change as well as the degree of adaptation that might be achieved (refer to Section 5 for details).

The relative influence of the uncertainty associated with each of the different constituent elements varies from area to area. To provide an idea of the relative significance of these different sources of uncertainty, the four case studies described in Appendix E (for which the emulator approach for projecting the impacts of climate change beyond the 25-year water company resource planning horizon was reviewed) have been considered in more detail in terms of the contribution made by the different components considered in the supply-demand balances presented in this report.

In the method presented here, the relative contribution of each component (e.g. population projection, climate projection) can be expressed as a proportion of the total range of the overall projections to highlight the degree of uncertainty associated with it. This is undertaken by sequentially stepping through the method in a "top down" approach (e.g. population projection, emissions scenarios, climate projection, adaptation scenario) and isolating each component individually. For a given component all the other components are fixed with just the isolated component allowed to vary, from which the total range of possible trajectories is then calculated. This is undertaken for each component in turn to identify their respective ranges; the larger the range the greater the contribution of uncertainty. The ranges for all the components are then standardised to allow a comparison between time horizons and WRZs.

The specific components that have been included in this assessment are presented in Table 4.9 and are based on the different combinations of scenarios considered in this study (see Section 2). Other sources of uncertainty relevant to future water availability, such as natural climate variability and changes in environmental policy have not been included.

Table 4.9: Components considered in the assessment of uncertainty.

Component	Description
Emission Scenario	The relative influence of different emission projections on the supply –demand balance is considered by considering Low, Medium and High emission scenarios.
Climate Projection	This work is only considering the outputs from UKCP09 climate projections but assess the uncertainty associated with the range of these projections relative to the other sources of uncertainty considered.
Population	The relative influence of different population projections on the supply –demand balance is considered using Low, Principal and High population forecasts.
Adaptation	The relative influence of adopting the different adaptation pathways assessed ('No Additional Action', 'Current objectives', 'Current objectives+') – note this does not consider the water company resource plan feasible options remaining beyond the end of the Final water company resource plans (see Section 5 for further details).

Source: n/a

The four case studies considered are listed below, and a description of each WRZ can be found in Appendix E:

- Ruthamford South in East Anglia;
- Barmouth in Wales;
- Wimbleball in south-west England;
- Carlisle in the north-west of England.

The results from this assessment are shown in Figure 4.28, and show the large range of uncertainty associated with the projected supply-demand balances from adopting different scenarios. The individual plots highlight which of the assumptions considered in this study contribute the largest uncertainty to the supply-demand balance in each of the WRZs. For Ruthamford South and, to a slightly lesser extent

Wimbleball, the uncertainty associated with population growth has the greatest influence on the supply-demand balance. Conversely, for Carlisle, climate change is shown to be the most significant factor with population change having a modest impact relatively. Across all four case studies, climate model uncertainty is much greater than emission uncertainty. Finally, the choice of adaptation pathway (refer to Section 5 for more details) is also shown to be significant in each of the case studies although its relative influence reduces from the 2050s to the 2080s as the other factors become increasingly uncertain, particularly population whose relative influence increases significantly from the 2050s to the 2080s for all four case studies. Figures similar to these have been calculated for all of the WRZs included in this assessment and are included in accompanying documents, see Appendix F.

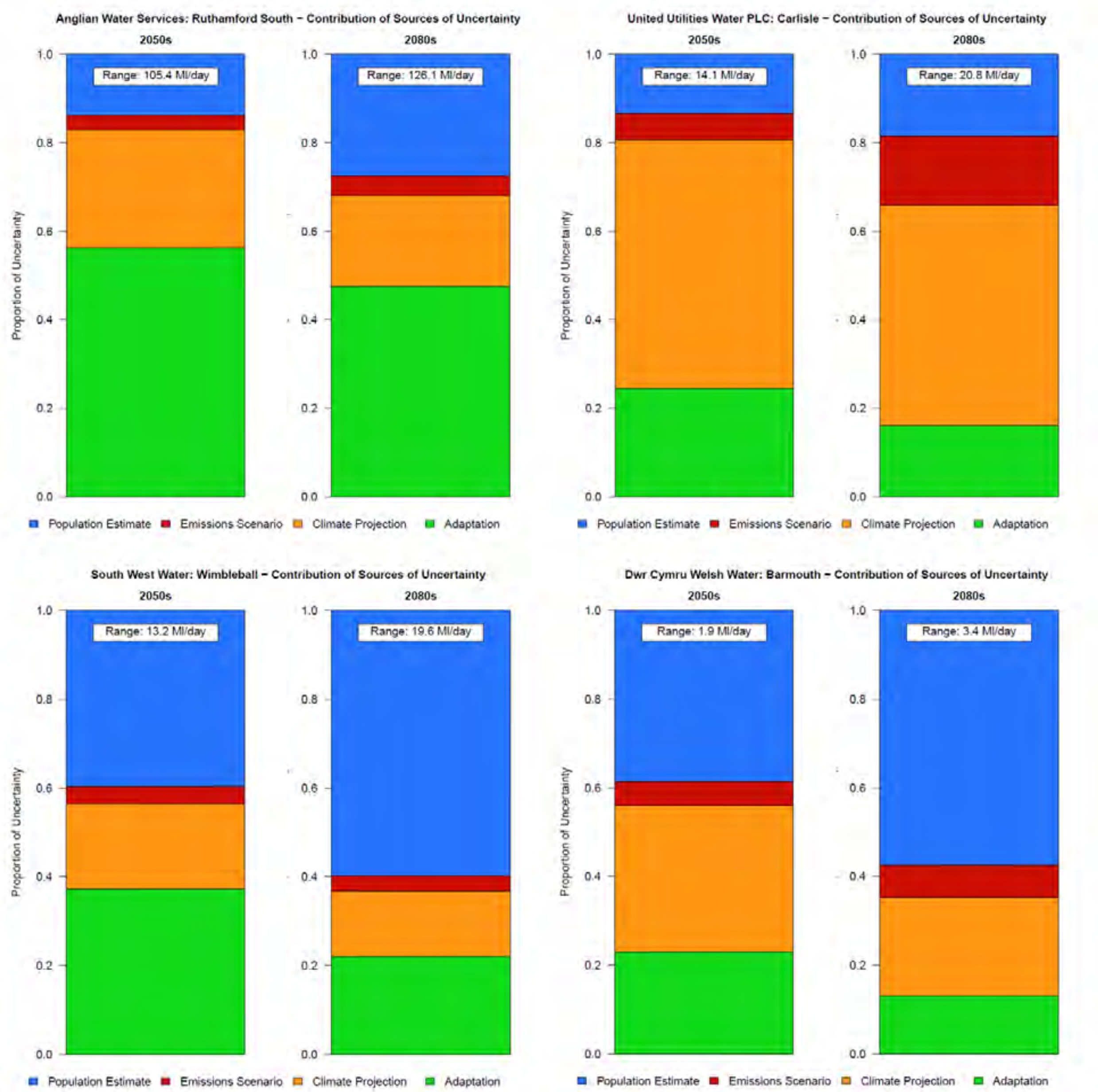

Figure 4.28: A representation of the relative significance of different sources of uncertainty associated with the projections of supply-demand balance for the 2050s and 2080s for four case study sites.

Source: n/a

In Figure 4.29 and Figure 4.30, the results of the uncertainty analysis are shown for each WRZ for the 2050s and 2080s. The proportional contribution of each of the four parameters, population estimate, emissions scenario, climate projection and adaptation scenario, to the variation in the projected results is shown by the level of transparency in the colour on the map. As per Figure 4.28, the contribution of population estimates is shown in blue, emissions scenario in red, climate projections in orange and adaptation scenario in green.

For the 2050s, Figure 4.29 shows that the contribution of emissions scenario is relatively low in the projections in this analysis across all WRZs. For the majority of WRZs, the contribution is less than 10%. The contribution of the climate projection is a lot more variable between WRZs and in some WRZs may account for more than 25% of the variation shown between the projections. The contribution of population estimate similarly varies between WRZ; the contribution is large in some and low in others. In general, the contribution of the population estimate to variability is slightly larger than the contribution of emissions scenario and slightly less variable between WRZs than the climate projections. The choice of adaptation scenario makes a large contribution to the variability in the projections analysed. In the majority of WRZ, the contribution is more than 50% in the 2050s.

For the 2080s, Figure 4.30 shows the contribution of emissions scenario is still relatively low, although there are a few WRZs where the contribution falls into the 11-25% category that were previously in the 2-10% category in the 2080s. The contribution of the climate projections shows a similar level of variability between WRZs in the 2080s as the 2050s. However, there are a few WRZ that show a slightly lower contribution of the climate projections to the overall projection results assessed. The contribution of the population estimate to the variability increases across many WRZs in the UK between the 2050s and 2080s. This reflects the increasing difference between the highest and lowest population projections used in this assessment. The opposite pattern is shown by the contribution of adaptation scenario choice. Between the 2050s and the 2080s, the contribution to the variation that the adaptation scenario choice provides reduces in many WRZs.

Across the different maps, in Figure 4.29 and Figure 4.30, there is no apparent geographical pattern across the UK. This highlights the importance of considering water resources at the WRZ scale as a coarser resolution would mask the differences and sources of uncertainty seen here.

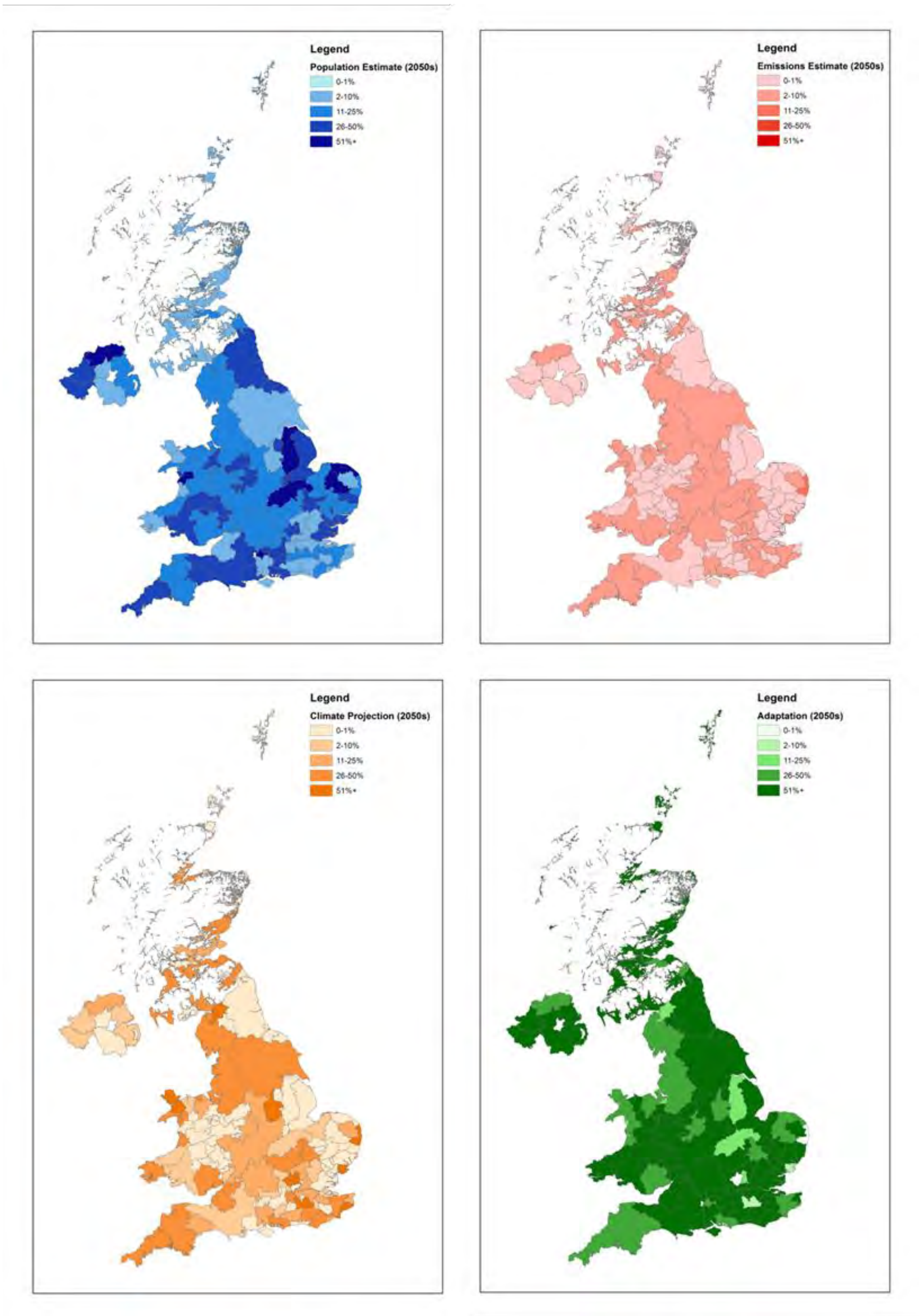

Figure 4.29: Relative drivers of uncertainty in the 2050s including population estimate, emissions scenario, climate projection and adaptation scenarios.

Source: n/a

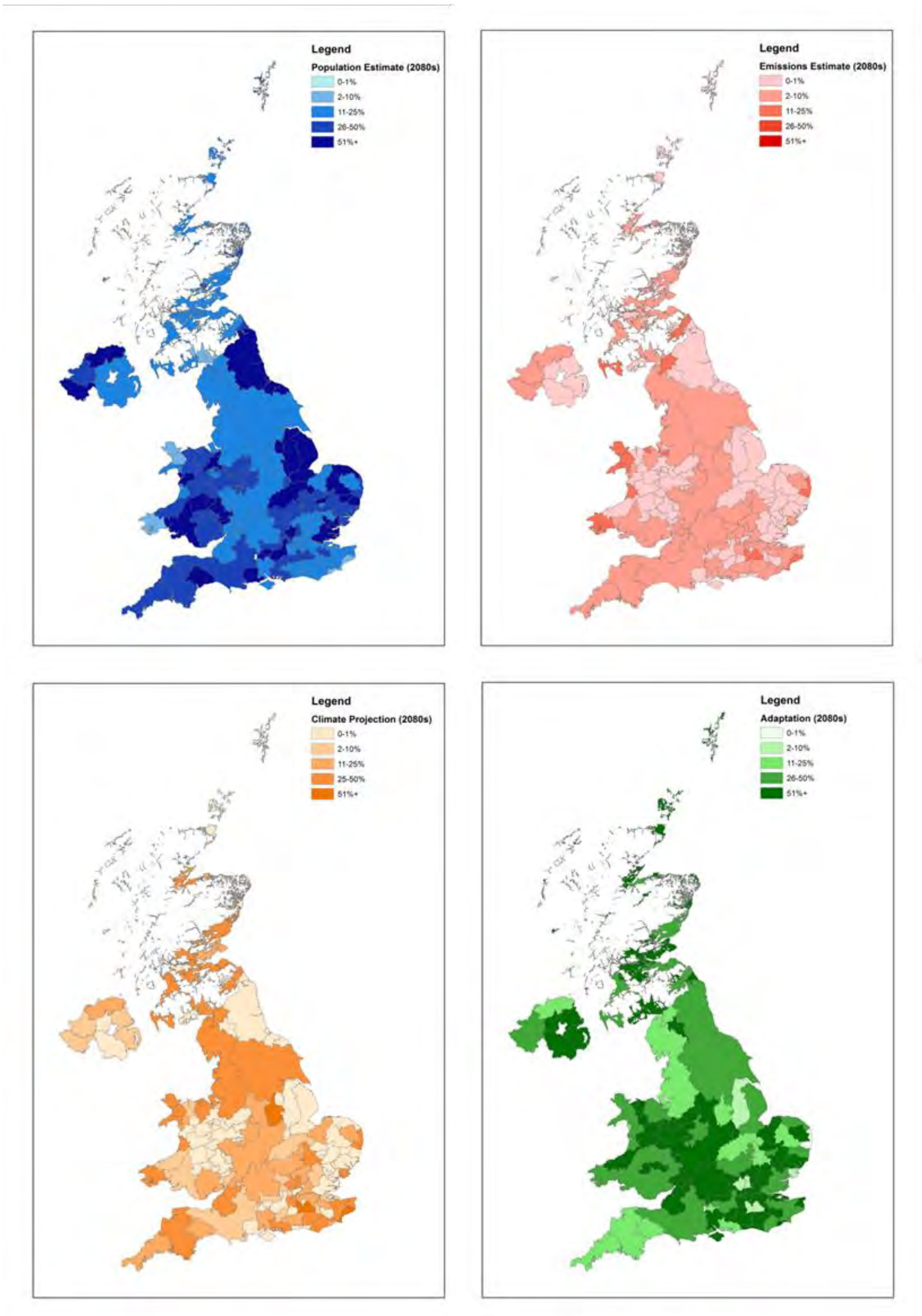

Figure 4.30: Relative drivers of uncertainty in the 2080s including population estimate, emissions scenario, climate projection and adaptation scenarios.

Source: n/a

4.2. 'All sectors'

Summary

Overview: Under the most extreme upper bound scenarios for the 2050s and 2080s, there is a general pattern of a lack of available resource in the west of the UK and severe impacts from abstraction demand in the east and south of the UK and across central Scotland. Only the northern most catchments of Scotland and some central and west midlands catchments in England are projected to maintain a high level of water available under all future scenarios.

Climate: There is a negligible difference between the baseline and the lower bound climate projections of natural flows to the end of this century. There is a large reduction in natural available resource under the upper bound climate projections in the 2050s and 2080s.

Population: The influence of population is complex as increasing consumptive demand also increases discharges into rivers, supporting flows (although often downstream of the abstraction impacts). Projections may indicate an increase or decrease in the proportion of available resource used, depending upon the characteristics of the catchment in question.

Adaptation approach: The approach taken to adaptation influences the severity of the impact of the proportion of the available resource used. Influence is most notable in the west where in a number of catchments the approach may make the difference between a projection of surplus or deficit.

EFI approach: The approach taken to environmental flows has a very large influence on whether there is any natural available resource for human uses available at all, particularly in the west of the UK. Upland catchments tend to be most affected although lowland catchments are also affected under the most extreme upper scenario. Only a 'proportional' approach to setting EFI targets allows water to be available for human uses into the 2080s. The effect that this may have on the environment was not tested in this assessment.

4.2.1. Introduction

As described in Section 3.2, the results from the analysis undertaken by the WRGIS and WRGIS-lite tools can be mapped to create an overall snapshot view of the order of magnitude of results under each of the 27 scenarios tested. The variables that make up the 26 future scenarios are shown in Table 2.2 and incorporate future projections of climate, abstraction growth for the public water supply, industry and commerce, energy and agriculture sectors; and, test a range of Environmental Flow Indicator options.

The results of the water body level analysis are aggregated to 296 catchments for the UK and are presented in the subsequent sections to provide evidence to explore the questions:

- Where in the UK faces the greatest level of deficit?
- What are the effects of climate scenarios on natural available resource?
- What are the effects of population change on catchment level deficits?
- What are the effects of adaptation scenarios on catchment level deficits?
- What are the effects of Environment Flow Indicator (EFI) approaches on catchment level deficits?

This section presents the results of the future projections at a catchment level. They should be viewed as broad estimates of impacts at a catchment level although the underlying analysis has been undertaken at a water body level. Individual water bodies may be projected to be in more or less deficit or surplus than the catchment as a whole.

There is a medium level of confidence in this assessment with respect to the 2050s and a low level of confidence with respect to the 2080s estimates.

4.2.2. Where in the UK faces the greatest level of deficit?

Figure 4.31 and Figure 4.32 show the abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 (average low flow conditions) for scenarios 27 and 15:

- Scenario 27 presents the low climate change projection, low population growth projection, 'Current objectives+' adaptation approach and 'Proportionate' EFI option for the 2050s.
- Scenario 15 presents the high climate change projection, high population growth projection, the 'No additional action' adaptation approach and the 'Fixed' EFI option for the 2050s.

These two scenarios therefore present the full range of impacts that have been assessed in this analysis for average low flows in the 2050s.

Scenario 27 (Figure 4.31), projects that the most severe projected impacts of consumptive abstraction demand (i.e. defined here as more than 150% of the available resource) are mostly restricted to a small number of catchments (16 catchments in total) in the south and east of England. However, there are some catchments in Scotland, for example, the River Leven (Fife), Allan Water and Dundee Coastal; Northern Ireland, Faughan, Belfast Lough; and, northern England, the Lune and Wyre that are also projected to have similar severe impacts. In this projection, there are no catchments with negative resource availability.

Scenario 15 (Figure 4.32), projects that there are severe potential impacts of consumptive abstraction demand (of more than 150% of the available resource in the catchment) in all areas of the country (62 catchments in total), including a few catchments in northern Scotland, Northern Ireland and Wales. Across the west of Scotland, England and Wales, and in a few catchments in Northern Ireland, the results show that numerous catchments have negative resource availability i.e. there is not enough natural resource to service the fixed EFI requirement and therefore no resource available for human uses.

Figure 4.33 and Figure 4.34 shows the results of scenarios 14 and 2 (for the average of Q95 and Q70) and therefore present the full range of impacts assessed in this analysis for average low flows in the 2080s:

- Scenario 14 presents the low climate change projection, low population growth projection, 'Current objective+' adaptation approach and 'Proportionate' EFI option for the 2080s.
- Scenario 2 presents the high climate change projection, high population growth projection, the 'No additional action' adaptation approach and the 'Fixed' EFI option for the 2080s.

The results of Scenario 14 (Figure 4.33), are very similar to the projection for the 2050s; impacts are restricted primarily to the south and east of England and across central Scotland and there are no instances of negative resources.

The results of Scenario 2 (Figure 4.34), follow a general pattern of the most extreme impacts of abstraction in the east of the UK; and, the most extreme impacts of negative available resource in the west of the UK. Consumptive abstraction of more than 150% of the available resources occurs in 38 catchments in total and negative available resource occurs in the west in 142 catchments in total. According to this projection, only the central-west area of England and northern most catchments in Scotland have lower impacts and therefore, potential water resources available in the catchment for human uses. In Northern Ireland, there is less of a spatial pattern to the impacts. However, of the 26 catchments, 18 face negative available resource and two have projected consumptive abstraction impacts of more than 150% of the available resources in the 2080s scenario. Between the 2050s and the 2080s, under the most extreme upper bound scenarios tested in this analysis (Figure 4.32 and Figure 4.34), there are 38 WRZs that switch from having projected consumptive abstraction impacts of more than 100% of the available resources to having projections of negative resource availability. This corroborates with the reduction in catchments with severe impacts of consumptive abstraction between the 2050s and 2080s under the most extreme upper bound scenario.

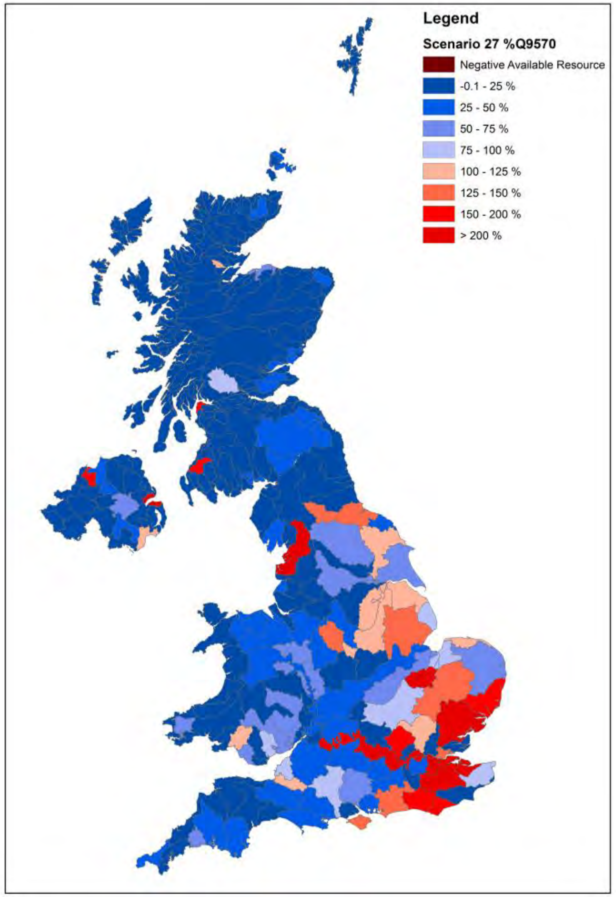

Figure 4.31: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 27).

Notes: Scenario 27: 2050s; UKCP09-Low-p10; Low population growth; 'Current objectives+' adaptation approach; and, 'Proportionate' EFI.

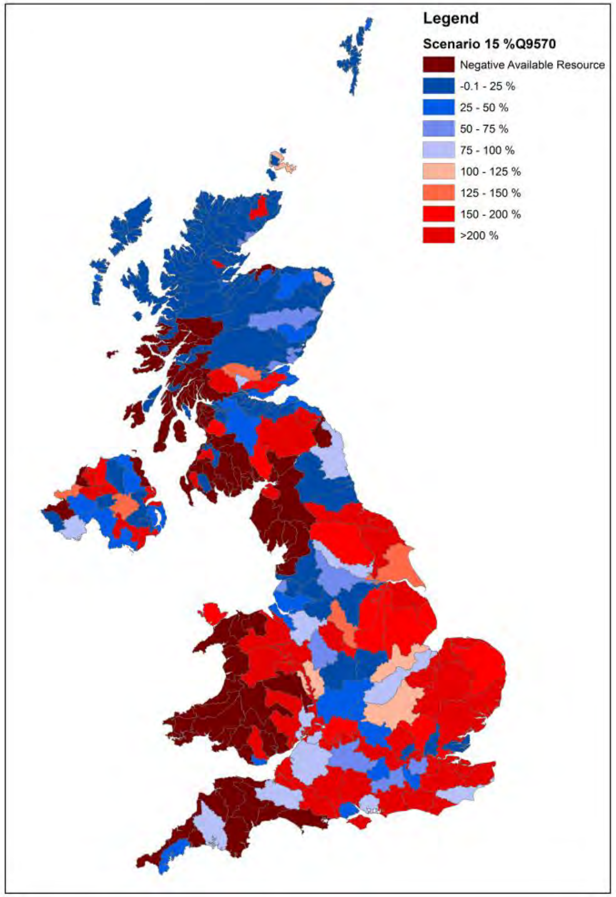

Figure 4.32: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 15).

Notes: Scenario 15: 2050s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Fixed' EFI.

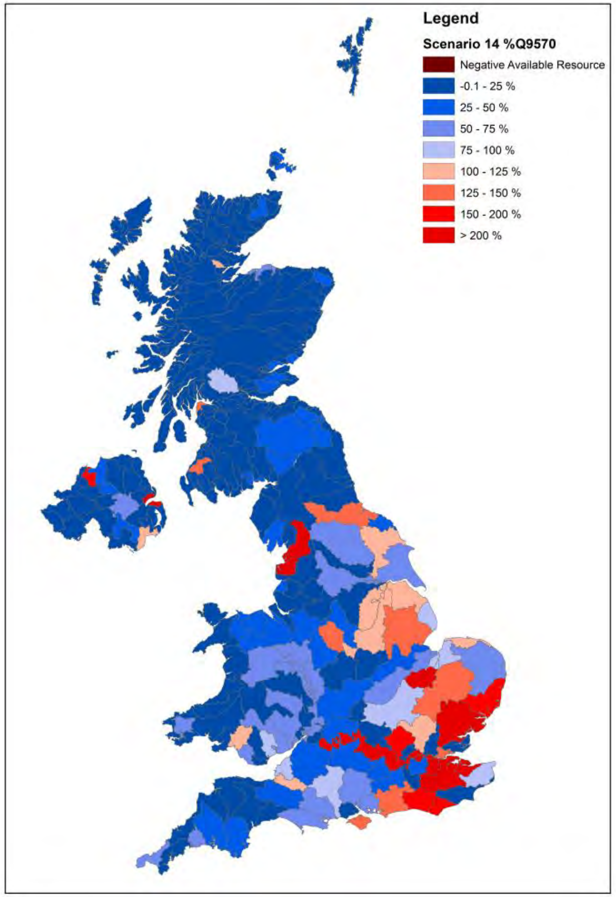

Figure 4.33: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 14).

Notes: Scenario 14: 2080s; UKCP09-Low-p10; Low population growth; 'Current objectives+' adaptation approach; and, 'Proportionate' EFI.

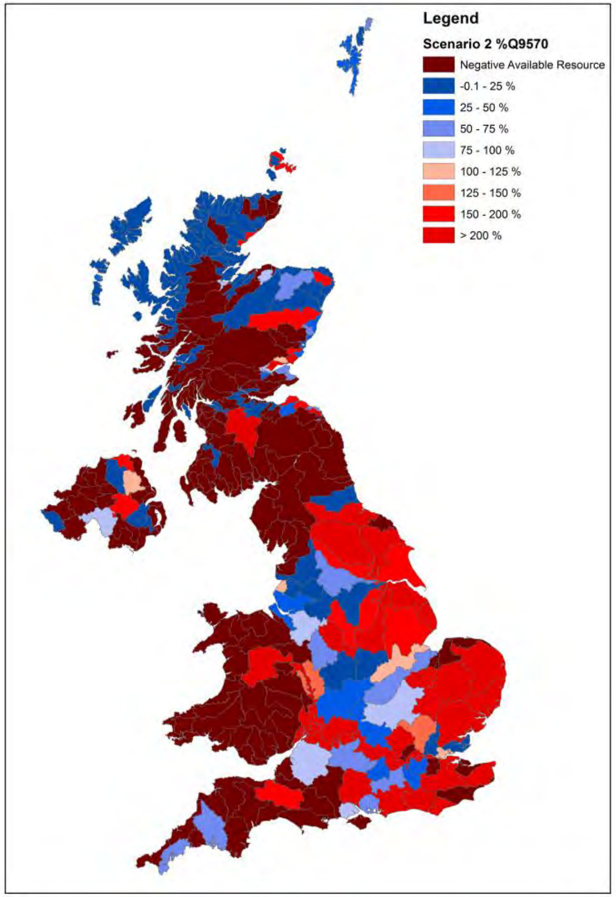

Figure 4.34: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 2).

Notes: Scenario 2: 2080s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Fixed' EFI.

4.2.3. What are the effects of climate scenarios on natural available resource

There are two principal components of importance in the metric described in this sub-section: (1) the projected influence of climate change on river flows in different catchments; and, (2) the sensitivity of water bodies, which helps determine the flow rate required under the EFI conditions.

Upland catchments with impermeable geology, such as in the north and west of England, are more susceptible to short periods of below average rainfall. These catchments have little groundwater base flow to support the river flows. By contrast, lowland catchments (in the south and east of England, for example) that are supported by groundwater baseflow are more susceptible to longer periods of below average rainfall, particularly if it occurs over successive winters, when groundwater recharge usually occurs (Environment Agency, 2015). Therefore, if climate change brings changes in the seasonality of rainfall, but not in the overall annual average rainfall, then upland catchments could be disproportionately affected by climate change compared to lowland catchments. In this type of future, upland catchments would typically experience a greater reduction in annual average Q95 compared to lowland catchments where the Q95 in summer would be supported to a much larger degree by the recharge in the previous winter(s).

In addition to the sensitivity of uplands to short periods of below average rainfall, uplands also are classified as more sensitive water bodies with respect to calculating their EFIs. By contrast, low gradient, lowland, clay catchments are much less sensitive with respect to the EFIs (Acreman *et al.*, 2006).

Figure 4.35 and Figure 4.36 show the projected natural available resource, at Q95, for catchments across the UK in the 2050s:

- Scenario 26, presents the low climate change projection influence on natural available resource at Q95 for the 2050s.
- Scenario 15, presents the high climate change projection influence on natural available resource at Q95 for the 2050s.

These scenarios may be compared to the baseline natural available resource (i.e. the projected natural flow minus EFI) shown in Figure 3.9. A negligible difference is projected between the baseline and lower bound projection of natural available resource. A significant difference can be seen between the baseline or lower and the upper bounds of the projection of natural available resource for the 2050s indicating a wide range of future possibilities for the natural resource availability. Impacts are greater towards the west of the UK, relative to the east, following the expected pattern of greater sensitivity in upland catchments.

Figure 4.37 and Figure 4.38 show the projected natural available resource, at Q95, for catchments across the UK in the 2080s:

- Scenario 13 Figure 4.37 presents the low climate change projection influence on natural available resource at Q95 for the 2080s.
- Scenario 2 presents the high climate change projection influence on natural available resource at Q95 for the 2080s.

In the 2080s lower bound projections, tested using Scenario 13, a similar spatial pattern to the 2050s and the present day is projected, see Figure 4.37. In the 2080s upper bound projection, tested using Scenario 2, shown in Figure 4.38, the majority of catchments are projected to have negative available resource.

It should be noted that for the projections shown, the EFI condition is set to 'Fixed' i.e. the same absolute flow rate as today. The effect of the climate scenarios follows the same geographical pattern across the UK under similar scenarios that use the proportional EFI condition, although the absolute results are less extreme because the EFI conditions are less in the latter.

4.2.4. What are the effects of population change on catchment level deficits?

Figure 4.39 and Figure 4.40 show scenarios 24 and 19 respectively. Both of these scenarios incorporate hydrology associated with UKCP09 medium emissions scenario p50 probability; 'Current objective+' adaptation and maintaining EFI at their current fixed flow rate. They differ such that Scenario 24 incorporates lower population and Scenario 19, higher population:

- Scenario 24 presents the medium climate change projection, low population growth projection, 'Current objective+' adaptation approach and 'Fixed' EFI option for the 2050s.
- Scenario 19 presents the medium climate change projection, high population growth projection, the 'Current objective+' adaptation approach and the 'Fixed' EFI option for the 2050s.

These scenarios present very similar projections. However, there are some important differences between the catchments in the two scenarios. For example, in a catchment such as the Clywd, increases in population are translated into increases in groundwater abstraction and discharges. Intuitively, the abstraction demand[17] in the 2050s under a high population growth scenario is greater than the same metric under a low population growth scenario i.e. more people equates to more resource used. Population increases have a different influence in some catchments, such as the Dorset Stour. Surface water abstraction, groundwater abstraction and discharges in the Dorset Stour catchment are higher under the higher population growth projection in Scenario 19, compared to low population growth projection in Scenario 24. However, the net result in this catchment is that the abstraction demand[18] in the 2050s under a high population growth scenario is less than the same metric under a low population growth scenario.

The reason for the counter-intuitive results described above is that where abstraction demands increases, so too do discharges. Depending upon the magnitude of the population increase and the natural available resource in the catchment, the available resource may be increased (albeit with mostly effluent discharge that has the potential to negatively influence water quality).

Whilst discharges may help to support river flows, it may be hypothesised that the headwaters of rivers would disproportionately suffer the effects of lowered flows as discharges are likely to occur, on average, further downstream from the abstraction points. Where groundwater, rather than surface water (especially river) sources are used, there may be further protection of average lower flows from increased abstractions. However, it should be noted that different rivers have different levels of connectivity with local groundwater sources and so at a local scale, increasing groundwater abstractions may still negatively influence local rivers (and wetlands).

The same patterns are reflected in the 2080s, as indicated by projections from Scenarios 11 and 6 in Figure 4.41 and Figure 4.42 respectively:

- Scenario 11 presents the medium climate change projection, low population growth projection, 'Current objective+' adaptation approach and 'Fixed' EFI option for the 2080s.
- Scenario 6 presents the medium climate change projection, high population growth projection, the 'Current objective+' adaptation approach and the 'Fixed' EFI option for the 2080s.

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[17] i.e. as a percentage of the available resource at the average of Q95 and Q70 low flow conditions.

[18] i.e. as a percentage of the available resource at the average of Q95 and Q70 low flow conditions.

4.2.5. What are the effects of adaptation scenarios on catchment level deficits?

Figure 4.43 and Figure 4.44 show scenarios 16 and 18. These scenarios incorporate hydrology associated with UKCP09 high emissions scenarios p90 probability; high population growth and a 'proportionate' EFI approach. They differ such that Scenario 16 assumes 'no additional action' adaptation, and Scenario 18 includes a 'Current objectives+' adaptation approach:

- Scenario 16 presents the high climate change projection, the high population growth projection, the 'No additional action' adaptation approach and the 'Proportionate' EFI option for the 2050s.
- Scenario 18 presents the high climate change projection, the high population growth projection, the 'Current objectives+' adaptation approach and the 'Proportionate' EFI option for the 2050s.

Overall, the influence of the different conceptual approaches to adaptation serves to reduce the severity of any deficits that may exist and so have greatest influence in the east and south of England. However, in the Leven, Crake and Duddon catchment, for example, the projection switches from a deficit under 'no additional action' and surplus under a 'Current objectives+' approach. Figure 4.45 and Figure 4.46 show the same scenario in the 2080s (Scenarios 5 and 3):

- Scenario 3 presents the high climate change projection, the high population growth projection, the 'No additional action' adaptation approach and the 'Proportionate' EFI option for the 2080s.
- Scenario 5 presents the high climate change projection, the high population growth projection, the 'Current objectives+' adaptation approach and the 'Proportionate' EFI option for the 2080s.

Under the future presented in Scenario 3, a deficit of available water is projected in a number of catchments in the west of the UK, particularly in Wales. Under Scenario 5, where the same parameters are tested except the adaptation approach is 'Current Objective+', the pattern of any deficits is kept more similar to the 2050s i.e. in the east. A number of the catchments in Wales are projected to have available water again under this scenario.

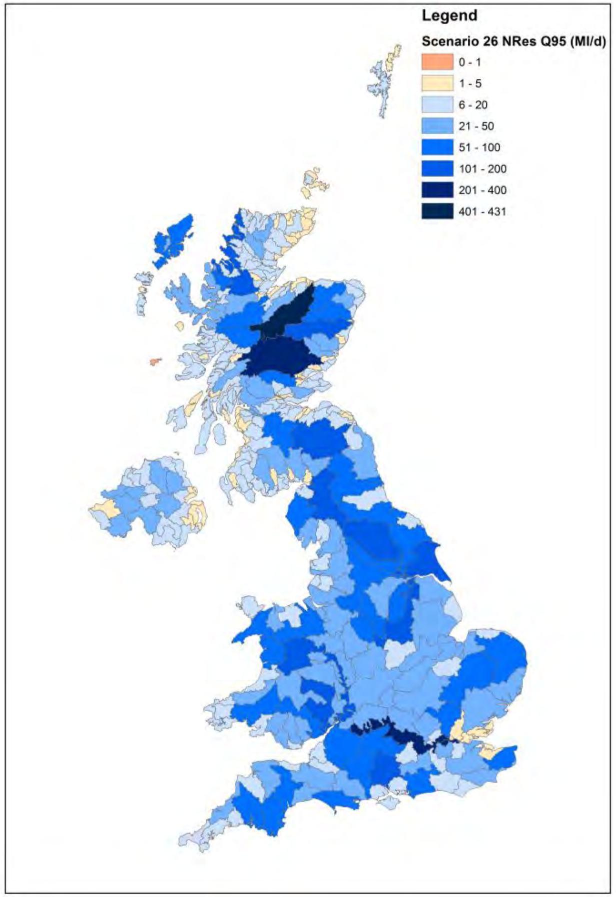

Figure 4.35: Projected natural available resource at Q95 for the 2050s (the catchment accumulation of natural flows minus environmental flows set according to the regulator's rules, in Ml/d) (Scenario 26).

Source: Scenario 26: 2050s; UKCP09-Low-p10 climate change projection and 'Fixed' EFI option.

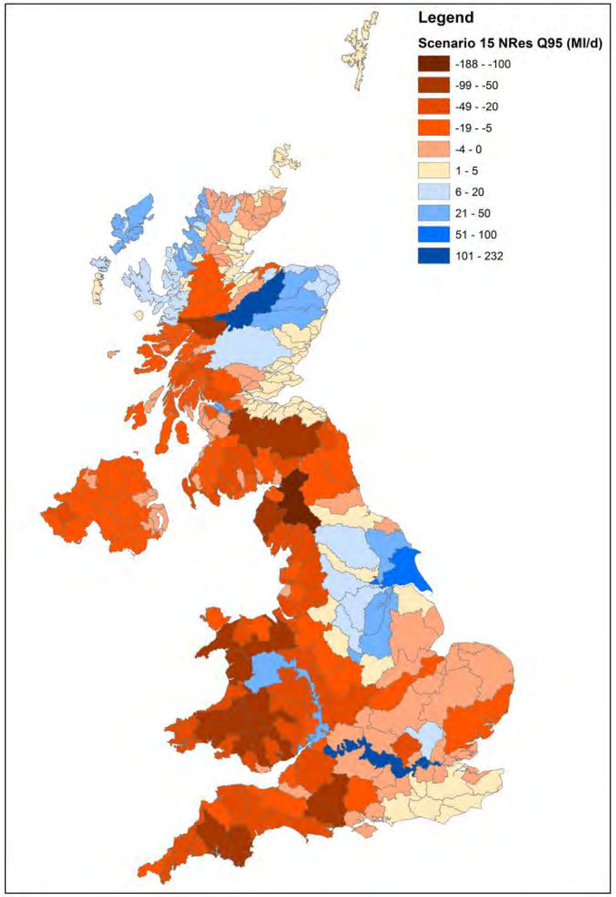

Figure 4.36: Projected natural available resource at Q95 for the 2050s (the catchment accumulation of natural flows minus environmental flows set according to the regulator's rules, in Ml/d) (Scenario 15).

Source: Scenario 15: 2050s; UKCP09-High-p90 climate change projection and 'Fixed' EFI option.

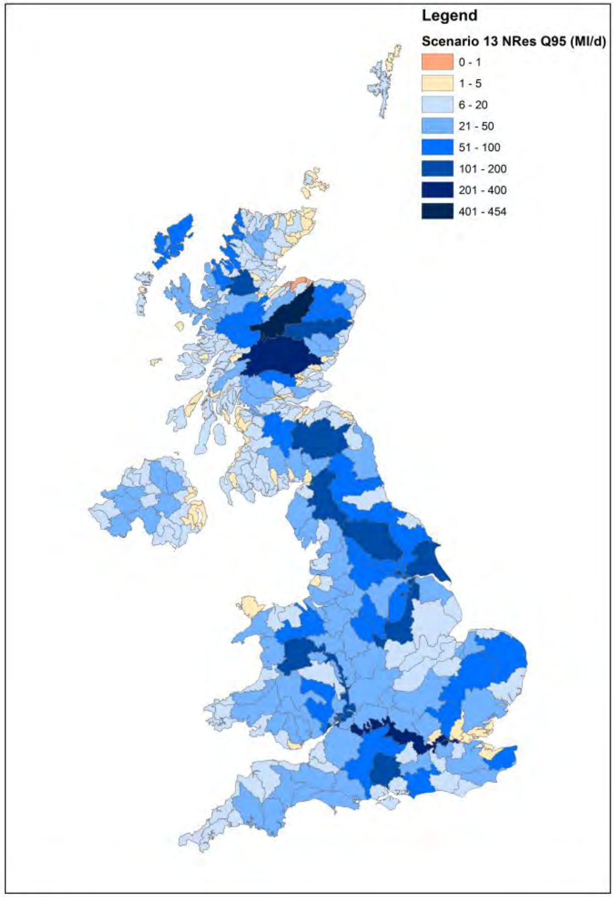

Figure 4.37: Projected natural available resource at Q95 for the 2080s (the catchment accumulation of natural flows minus environmental flows set according to the regulator's rules, in Ml/d) (Scenario 13).

Source: Scenario 13: 2080s; UKCP09-Low-p10 climate change projection and 'Fixed' EFI option.

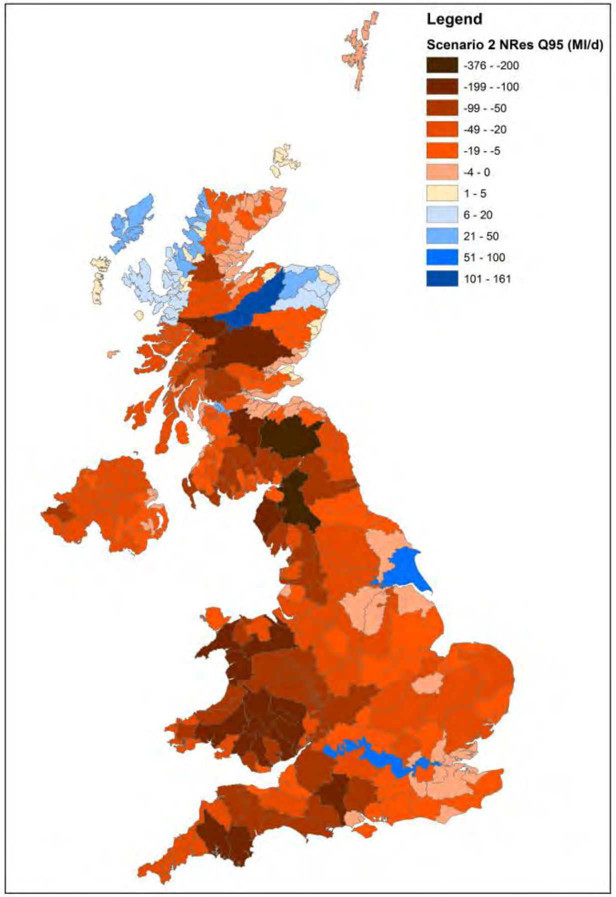

Figure 4.38: Projected natural available resource at Q95 for the 2080s (the catchment accumulation of natural flows minus environmental flows set according to the regulator's rules, in Ml/d) (Scenario 2).

Source: Scenario 2: 2080s; UKCP09-High-p90 climate change projection and 'Fixed' EFI option.

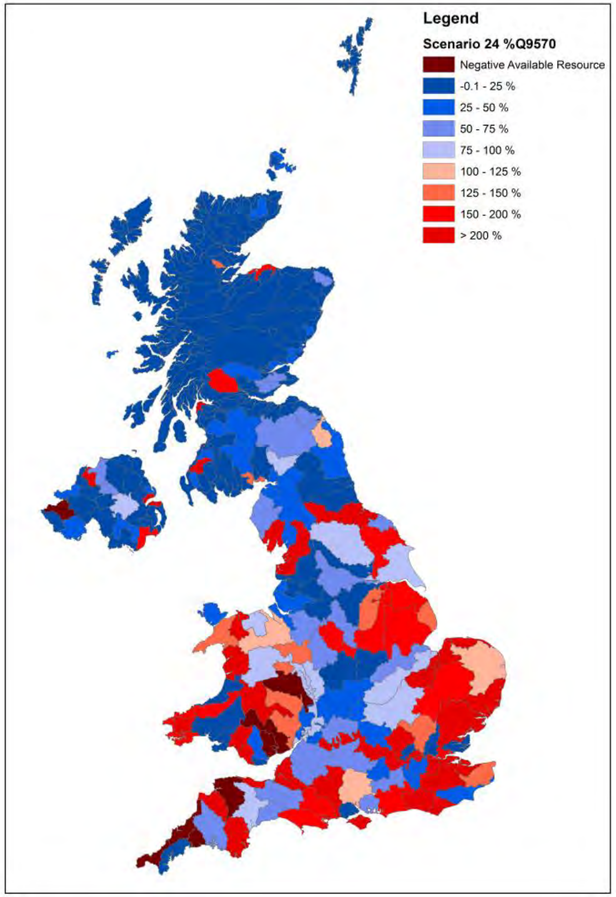

Figure 4.39: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 24).

Source: Scenario 24: 2050s; UKCP09-Medium-p50; Low population growth; 'Current objectives+' adaptation approach; and, 'Fixed' EFI.

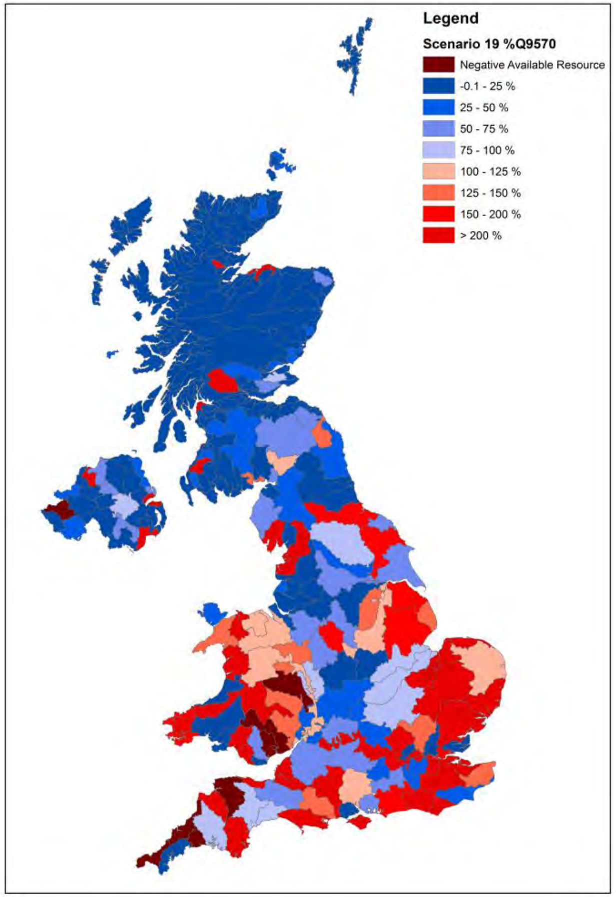

Figure 4.40: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 19).

Source: Scenario 19: 2050s; UKCP09-Medium-p50; High population growth; 'Current objectives+' adaptation approach; and, 'Fixed' EFI.

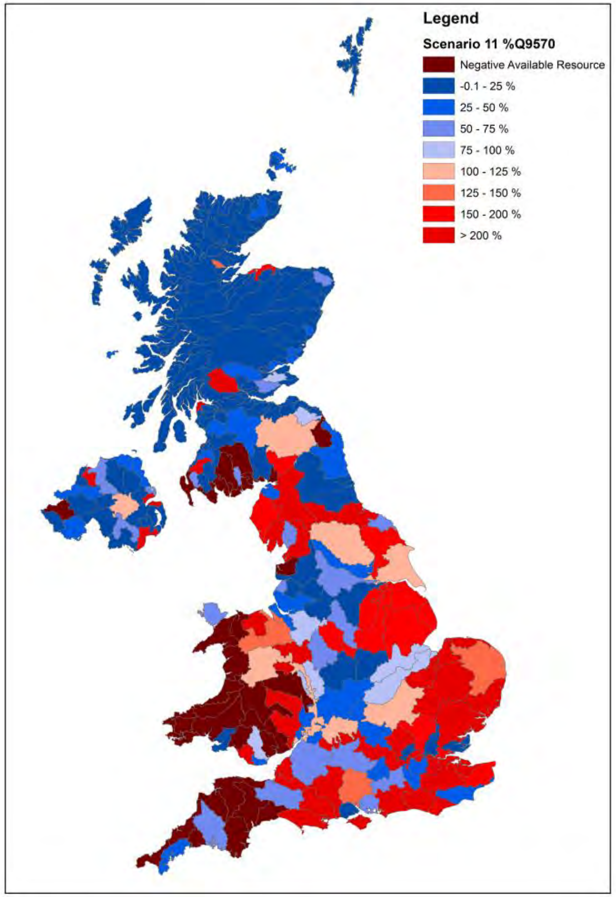

Figure 4.41: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 11).

Source: Scenario 11: 2080s; UKCP09-Medium-p50; Low population growth; 'Current objectives+' adaptation approach; and, 'Fixed' EFI.

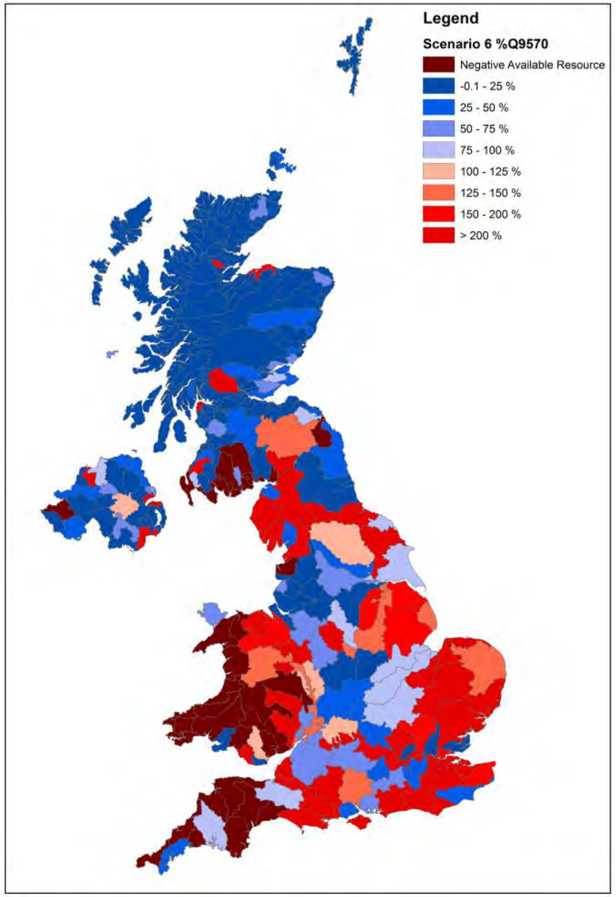

Figure 4.42: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 6).

Source: Scenario 6: 2080s; UKCP09-Medium-p50; High population growth; 'Current objectives+' adaptation approach; and, 'Fixed' EFI.

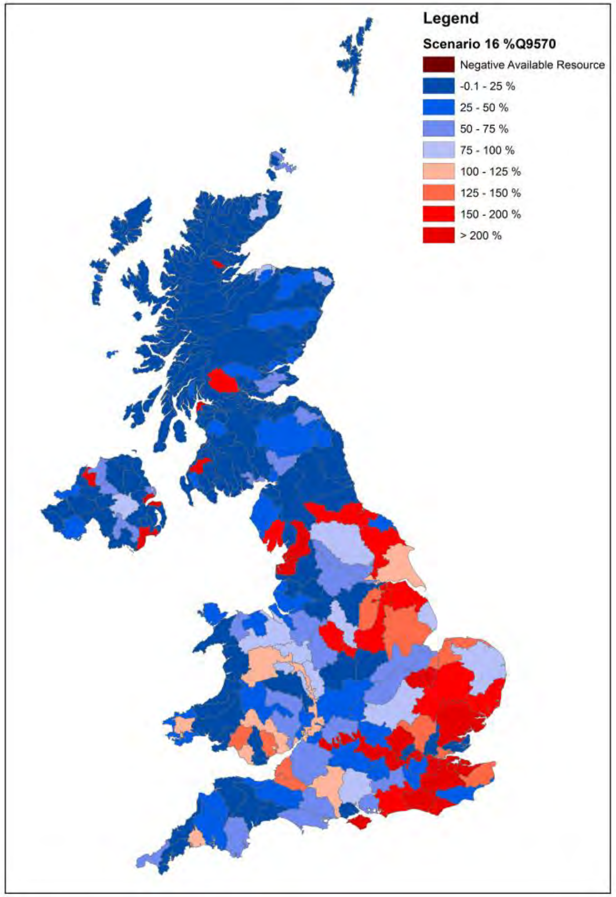

Figure 4.43: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 16).

Source: Scenario 16: 2050s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Proportionate' EFI.

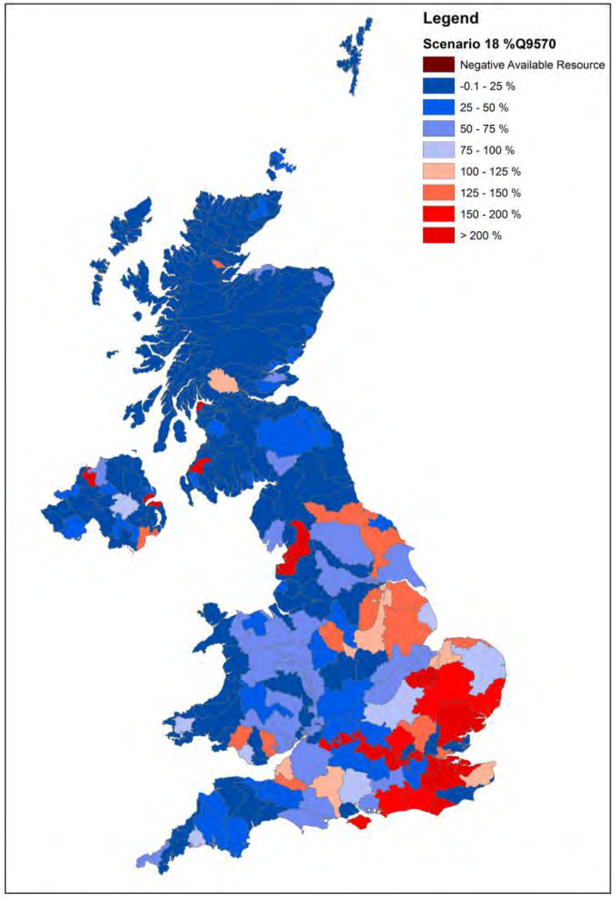

Figure 4.44: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 18).

Source: Scenario 18: 2050s; UKCP09-High-p90; High population growth; 'Current objectives+' adaptation approach; and, 'Proportionate' EFI.

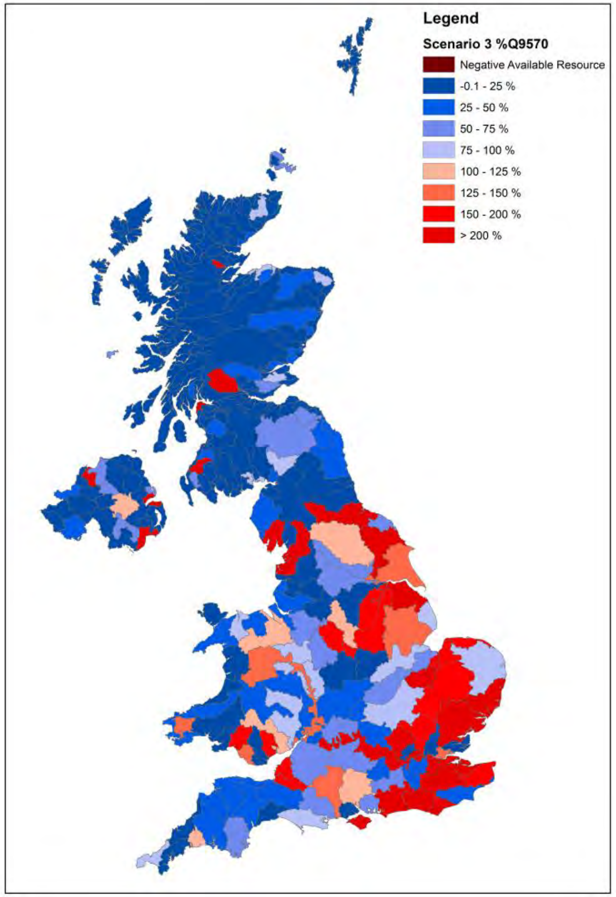

Figure 4.45: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 3).

Source: Scenario 3: 2080s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Proportionate' EFI.

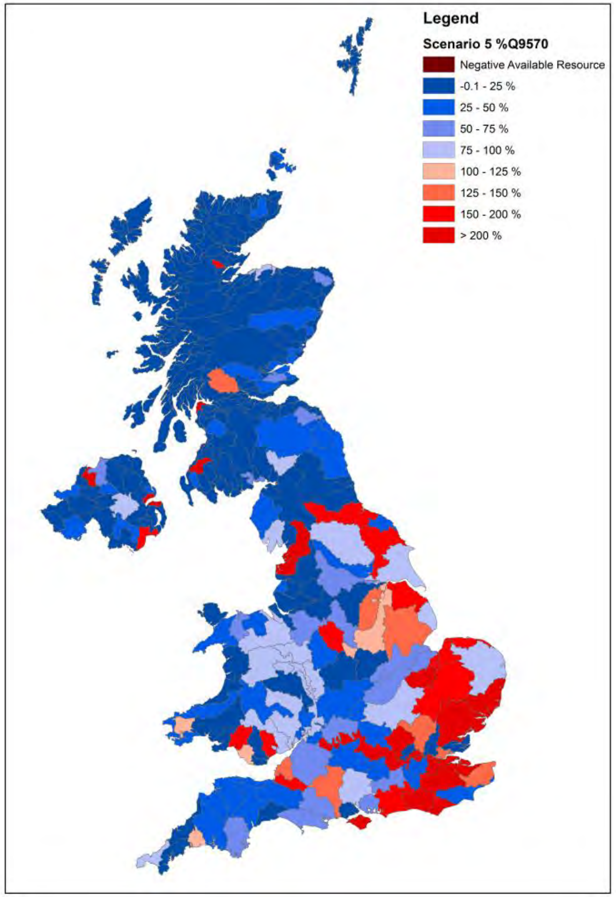

Figure 4.46: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 5).

Source: Scenario 5: 2080s; UKCP09-High-p90; High population growth; 'Current objectives+' approach; and, 'Proportionate' EFI.

4.2.6. What are the effects of Environment Flow Indicator (EFI) approaches on catchment level deficits?

Scenarios 21, 22 and 23, shown in Figure 4.47 and Scenarios 8, 9 and 10 shown in Figure 4.48 incorporate the following specifications in the projections:

- 2050s:
  - Scenario 21 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘Fixed’ EFI option.
  - Scenario 22 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘no deterioration’ EFI option.
  - Scenario 23 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘Proportional’ EFI option.
- 2080s:
  - Scenario 8 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘Fixed’ EFI option.
  - Scenario 9 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘no deterioration’ EFI option.
  - Scenario 10 presents the medium climate change projection, the principal population growth projection, the ‘Current objectives’ adaptation approach and the ‘Proportional’ EFI option.

The scenarios differ such that Scenarios 21 and 8 apply ‘Fixed’ EFIs meaning that the flows set aside for the environment are maintained at their current absolute flow rate. Scenarios 22 and 9 apply a ‘no deterioration’ approach whereby the flows set aside for the environment are maintained at either their current EFI threshold or level of recent actual (observed) flow rate, whichever is less. Scenarios 23 and 10 apply ‘proportional’ EFIs meaning that the flows set aside for the environment are maintained at their current proportion. Under this approach, the actual flow rate that the environment is allowed will reduce if natural flows also reduce in the future.

The choice of EFI approach appears to have a large influence on the availability of water per catchment, in the future projections. The influence is greatest in Wales, eastern and southern England, central and southern Scotland. Under Fixed EFI and ‘no deterioration’ scenarios there are also catchments without enough water to service the EFI approach. In the 2050s this begins to occur in Wales and the south-west of England. By the 2080s, there are many more catchments displaying this behaviour in Wales, south-west England, southern Scotland and also in Northern Ireland.

In Figure 4.49 to Figure 4.52 the influence of the range of EFI approach options tested can be seen using Scenarios 16 and 15:

- Scenario 16 in Figure 4.49, presents the high climate change projection, the high population growth projection, the ‘No additional action’ adaptation approach and the ‘Proportionate’ EFI option for the 2050s.
- Scenario 15 in Figure 4.50, presents the high climate change projection, the high population growth projection, the ‘No additional action’ adaptation approach and the ‘Fixed’ EFI option for the 2050s.

Scenarios 15 and 16 only differ in the EFI approach taken. Scenario 15 adopts a ‘Fixed’ EFI approach and Scenario 16 adopts a ‘Proportional’ EFI approach. Whilst there are a number of catchments in all four countries that are projected to experience a deficit of water in the 2050s under Scenario 16, the potential impacts are far more severe in Scenario 15. In particular, this is with respect to those catchments in the west that are projected to experience negative available resource, an eventuality that does not occur under the Scenario 15 projection.

Figure 4.51 and Figure 4.52 show the same projections for the 2080s, Scenarios 3 and 2 respectively where a similar pattern of impact is shown:

- Scenario 3 in Figure 4.52, presents the high climate change projection, high population growth projection, the 'No additional action' adaptation approach and the 'Proportional' EFI option for the 2080s.
- Scenario 2 in Figure 4.51, presents the high climate change projection, high population growth projection, the 'No additional action' adaptation approach and the 'Fixed' EFI option for the 2080s.

Under Scenario 2, the extent of catchments with negative available resource is notable in Northern Ireland, Wales and Scotland in particular.

The influence of the EFI approaches on the environment, as opposed to water resources, is out of scope for this assessment but one of the sister projects to this one, Project C "Aggregated assessment of climate change risks to natural capital" will contain a literature review of the evidence of the impacts of climate change on water quality, including impacts on low flows and subsequently the environment.

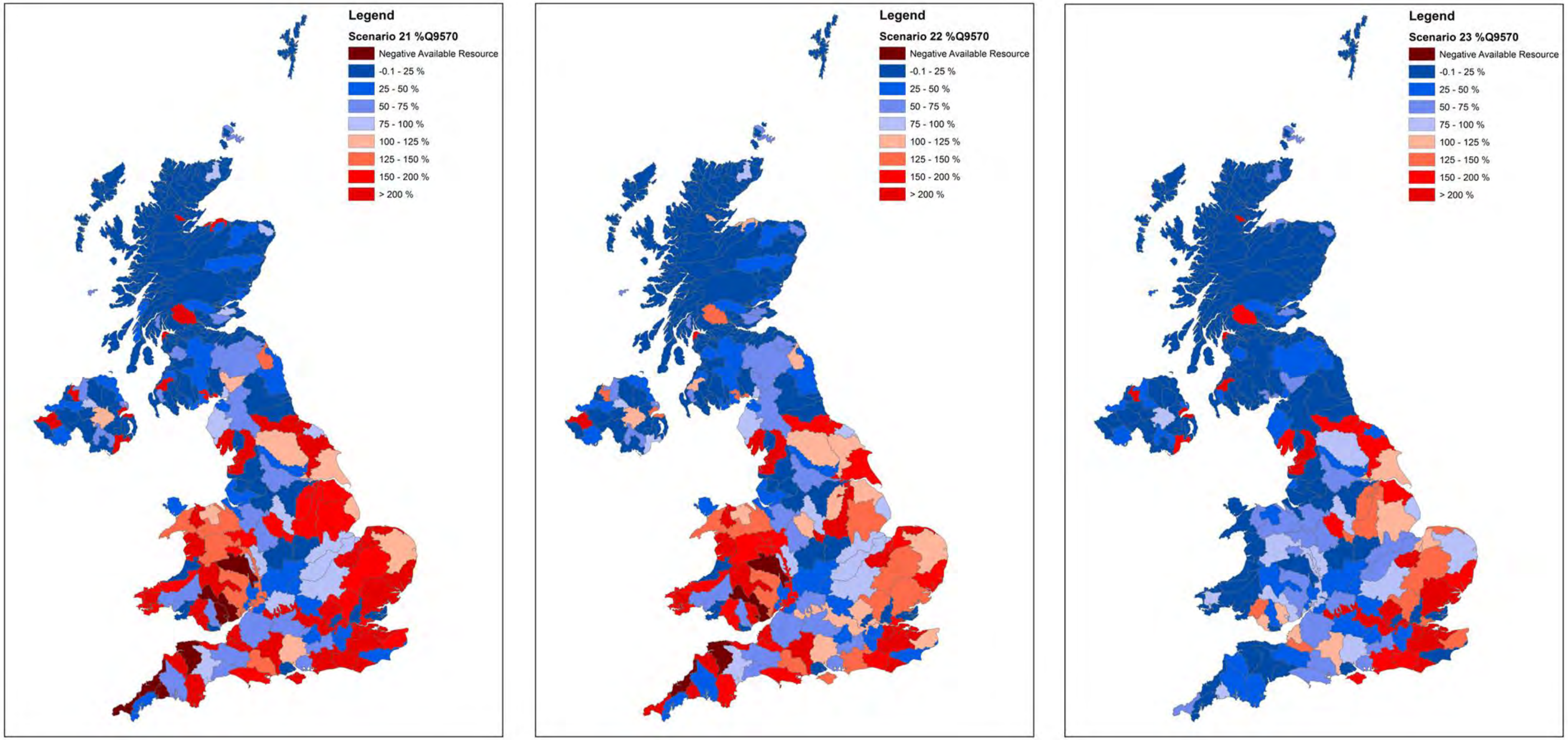

Figure 4.47: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions and three approaches to setting EFIs (Scenarios 21, 22 and 23).

Source: Scenario 21: 2050s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'Fixed' EFI; Scenario 22: 2050s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'No deterioration' EFI; Scenario 23: 2050s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'Proportionate' EFI.

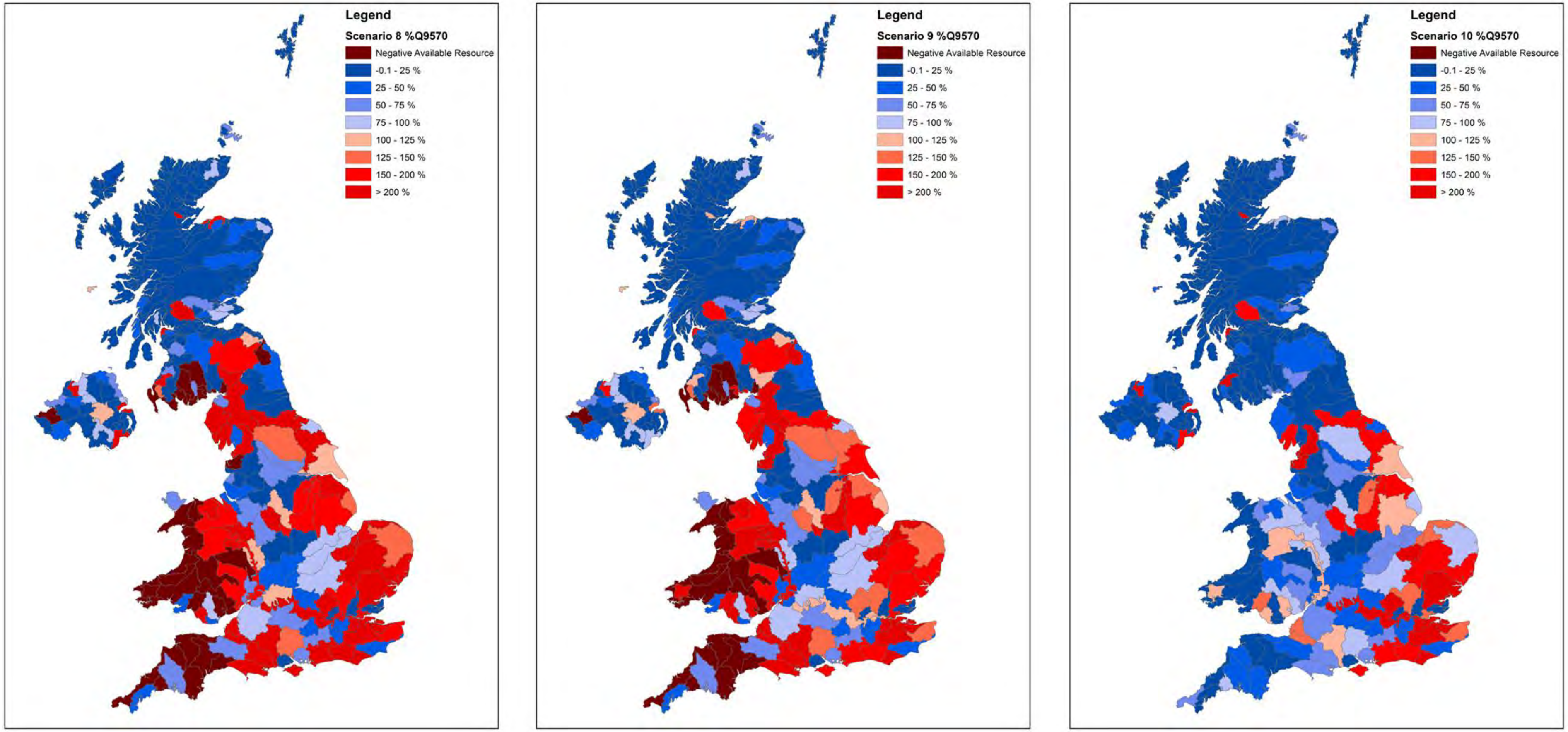

Figure 4.48: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions and three approaches to setting EFIs (Scenarios 8, 9 and 10).

Source: Scenario 8: 2080s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'Fixed' EFI; Scenario 9: 2080s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'No deterioration' EFI; Scenario 10: 2080s; UKCP09-Medium-p50; Principal population growth; 'Current objectives' adaptation approach; and, 'Proportionate' EFI.

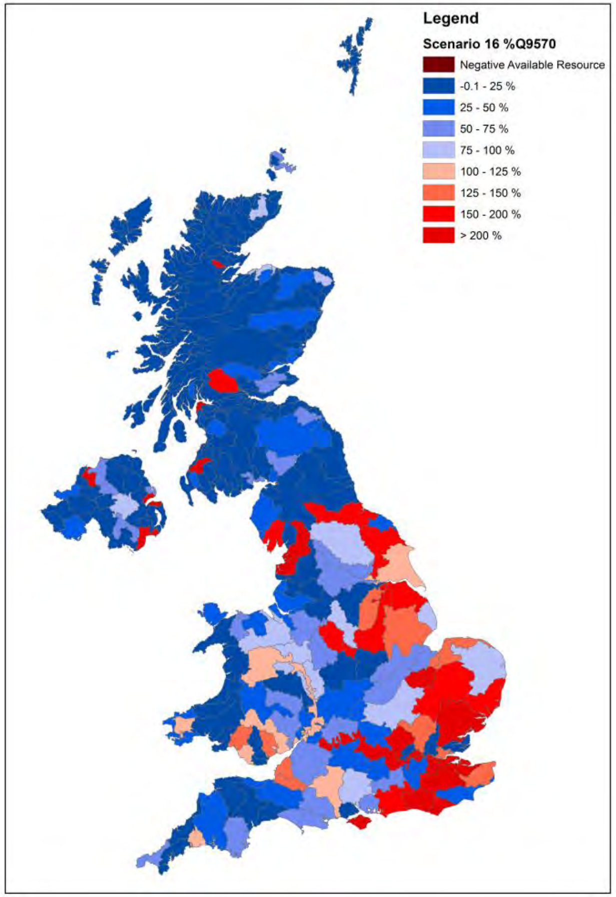

Figure 4.49: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 16).

Source: Scenario 16: 2050s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Proportionate' EFI.

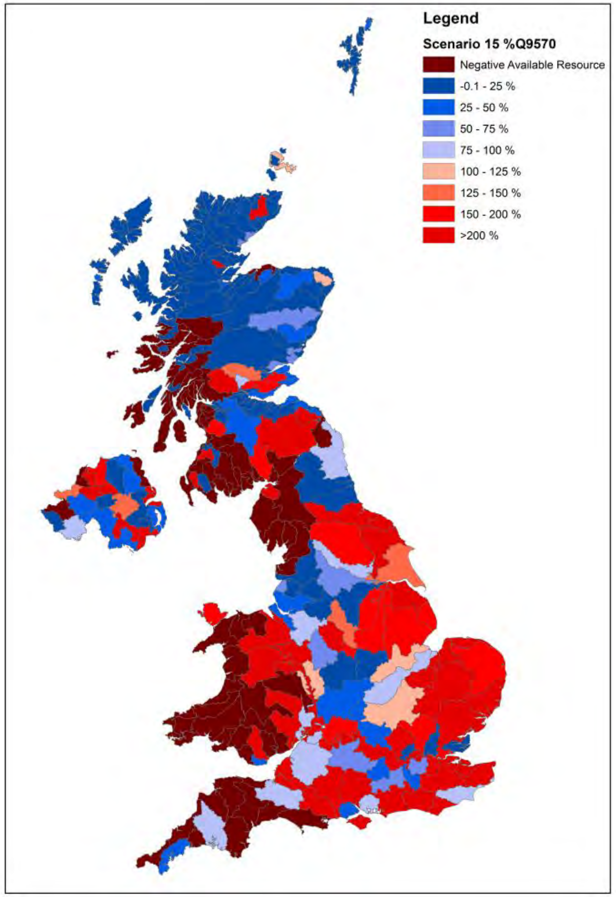

Figure 4.50: Abstraction demand in the 2050s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 15).

Source: Scenario 15: 2050s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Fixed' EFI.

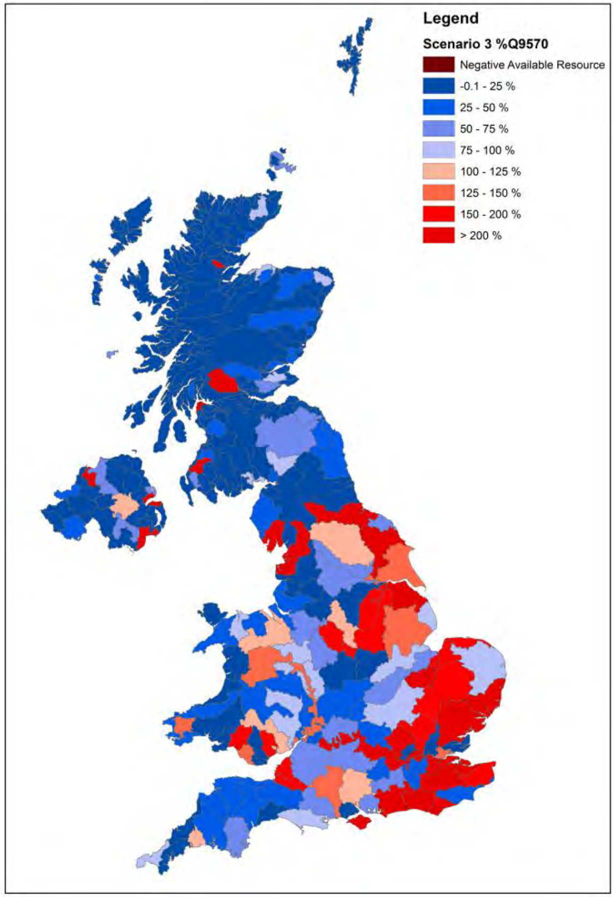

Figure 4.51: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 3).

Source: Scenario 3: 2080s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Proportionate' EFI.

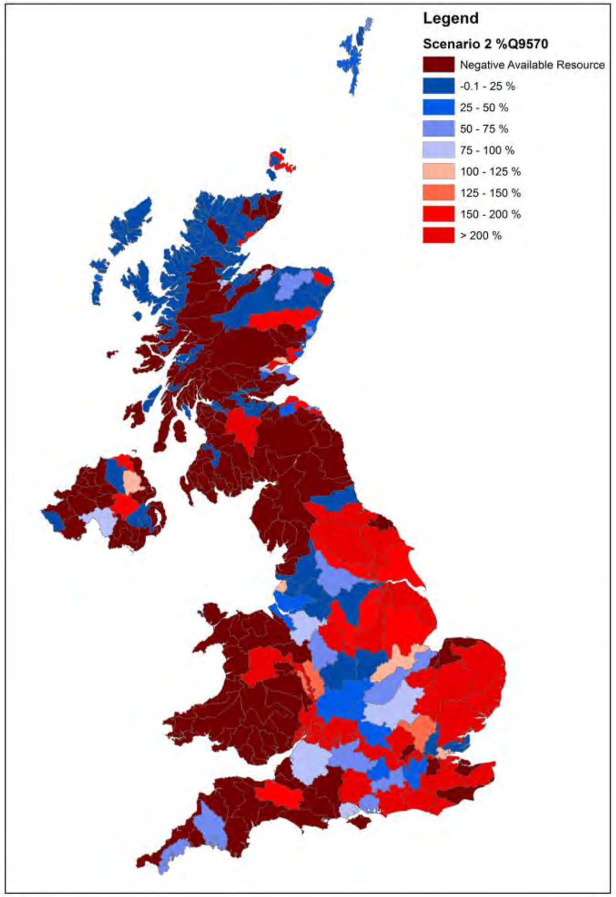

Figure 4.52: Abstraction demand in the 2080s as a percentage of the available resource at the average of Q95 and Q70 low flow conditions (Scenario 2).

Source: Scenario 2: 2080s; UKCP09-High-p90; High population growth; 'no additional action' adaptation approach; and, 'Fixed' EFI.

5. Results: Public Water Supply adaptation options

Summary

The approach taken to adaptation, in the form of reductions in household consumption, leakage and the implementation of additional feasible options identified by water company resource plans, is projected to have the potential to substantially alleviate the supply-demand deficits that may occur in the future. However, the projected reductions in leakage and household consumption (and the associated behavioural changes that would be necessary) under the 'Current objectives+' adaptation pathway in particular, may be extremely difficult and prohibitively expensive to achieve in practice in all areas. Their feasibility at more local scales should be evaluated. Further to this, it should be noted that water companies only consider a 25-year planning horizon and, therefore, there are potentially additional options available, above and beyond those reported in the latest WRMP process and considered here. These could include increased sharing of water, effluent re-use and the potential to provide additional above ground (reservoirs) or below ground storage (i.e. aquifer recharge) to capture increased winter flows.

The supply-demand balance projections presented in Section 4.1 do not consider any adaptation and are based on the water resource systems as defined for the water company resource plan baseline condition. For this report, this adaptation pathway is known as 'no additional action'.

There is a low level of confidence in this assessment with respect to the estimates in this section.

5.1.1. Scale of success of currently available adaptation options

The approach taken to evaluate adaptation in this research has sought to assess the potential scale of options already considered potentially available (through WRMP options and the Case for Change scenarios) in relation to the projected deficits under different climate and population projections and to convey the scale of the challenge that might be faced in the future. It should be noted that, for this study, it has not been possible to undertake a detailed assessment of the potential options for closing the gap for which evidence does not already exist (e.g. resource developments not already considered by water companies as part of their plans) given the complexities involved in evaluating their viability and yield.

To explore the potential adaptation potential, two alternative adaptation pathways have been considered as set out in Table 5.1.

Table 5.1: Adaptation pathways.

Adaptation Pathway	PWS interventions	Household consumption	Leakage
Current objectives	Implementation of all preferred* measures selected in the water company resource Final Plan.	For 2050s and 2080s, for all WRZs adopt the lower of the metered PCC rate as at the end of the planning horizon or a PCC of 125 l/h/d.	As for 'No additional action' adaptation pathway but with an additional constraint that absolute leakage cannot increase beyond water company resource plan reported values.
Current objectives+	Implementation of all preferred* measures selected in the water company resource Final Plan.	For 2050s and 2080s, adopt the Case for Change "Sustainable Behaviour" scenario (Environment Agency, 2011) PCC value of 92 l/h/d for all WRZs.	For 2050s and 2080s, adopt the reductions in per capita leakage, in percentage terms, suggested by the Case for Change "Innovation" scenario (Environment Agency, 2011), along with absolute leakage not greater than water company resource plan values.”

*Source: *Preferred measures are those options identified by a water company to be implemented over the course of the planning horizon to mitigate emerging supply-demand deficits.*

The Case for Change scenarios are presented in Figure 5.1 for reference, and of particular relevance to this component of the project are the “Sustainable Behaviour” scenario for household consumption and the “Innovation” scenario for leakage.

	Baseline[a]	Innovation	Uncontrolled demand	Sustainable behaviour	Local resilience
Population	55,250,000	72,770,000	78,340,000	66,600,000	64,930,000
Household (Ml/d)	8,628	8,038	11,812	6,101	9,201
		High rates of retrofitting and use of grey/rainwater. Significant innovation in self-cleaning / waterless materials and appliances.	Poor attitude to water efficiency increases use, but some gains through improved flushing technology and efficient appliances.	Reductions due to strong belief in water efficiency. High rate of waterless appliances and easy fit water efficiency devices.	Shift in attitude to saving water, but lack of innovation.
Leakage (Ml/d)	3,135	940	7,524	1,881	3,762
		Strong regulation, central network management and well-maintained infrastructure leads to large reductions. High levels of innovation and technology.	Very weak regulation and poor attitude to leakage, leakage up to levels similar to the 1980's. Little investment, repairing leaks seen as expensive.	Strong reduction as result of significant technological improvements. Company & Government willingness to invest.	Weak regulation and limited maintenance.
Industry & Commerce (Ml/d)	7,160	8,696	8,369	5,682	7,197
		Despite innovation, significant shift in water replacing chemicals in manufacturing processes as a cleaner resource. Greater reliance on UK focussed food production.	Drive to produce more and quickly. Less focus on water efficiency and innovation across the sector. Potential for water to be used as substitute for chemicals.	Significant shift to greater reliance on UK focussed food growing and production to mitigate unsustainable transportation of food. Shift away from fuels that require refining.	Despite potential reduced demand, greater focus on UK / local production. Potential for greater demand from local industries, i.e. greater mineral extraction at local scale drives up demand.
Agriculture (Ml/d)	192	492	513	272	269
		Increase due to population growth, but mitigated by greater choice in technology, increased yield, and focus on efficient application of water.	Increase in population drives up demand and farming intensity. Higher expectation of horticultural goods.	Greater reliance on UK grown produce, but efficiencies found in technology and improved yield. Acceptance to grow crop where climate allows.	Increase in area under cereal and vegetable crops to meet demand from population growth. Marginal reduction in demand from innovation.
Energy Generation (Ml/d)	585	559	1129	176	355
		Greatest increase in demand for electricity, mitigated by greatest share of non water using renewables and all nuclear generation on the coast.	Increase in nuclear generation, with 10% inland, greatest biomass generation and lowest share of non-water using renewables.	Shift in thermal generation to the coast with uptake of CCS using coastal water, a large share of non water using renewables and nuclear generation on the coast.	Low levels of generation and lowest uptake of carbon capture and storage technologies.
Total demand	19,699	18,726	29,347	14,112	20,783
% change from baseline		-5	49	-28	6

Figure 5.1: Case for Change Socio-Economic demand scenario assumptions [to 2050].

Source: Environment Agency and Natural Resources Wales, 2013.

Supply-demand balance under the ‘Current objectives’ adaptation pathway

Figure 5.2 and Figure 5.3 present the supply demand balance projections for the 2050s and 2080s under a Medium Emissions, Principal Population future and a ‘Current objectives’ adaptation pathway.

These results suggest that, by the 2050s, a total of 16 WRZs are projected to have a supply-demand deficit of greater than 5 Ml/d, with all but one of these WRZs in England with the other in Wales. The largest deficit is again projected for the United Utilities’ Integrated Zone with a supply-demand shortfall of 118 Ml/d, followed by a deficit of 79Ml/d projected in the London WRZ. By the 2080s, the number of WRZs with a deficit of more than 5 Ml/d increases to 35, with three in Wales and the remainder in England. The largest of these are the London WRZ, with a of 327 Ml/d, the United Utilities’ Integrated Zone projecting a deficit of 250 Ml/d, the Grid zone in Yorkshire is projected to have a shortfall of 150 Ml/d.

Supply-demand balance under the ‘Current objectives+’ adaptation pathway

Figure 5.4 and Figure 5.5 present the supply demand balance projections for the 2050s and 2080s under a High Emissions, High Population and a ‘Current objectives+’ adaptation pathway. Eight WRZs are projected to exhibit deficits of more than 5 Ml/d, six in England and two in Wales. Of these, the Nottingham WRZ is projected to have the highest deficit of 46 Ml/d and the East Surrey WRZ a deficit of 30 Ml/d by the 2050s. In general those WRZs projected to be in deficit, have neighbouring WRZs with surpluses and therefore sharing of water may mitigate these localised deficits.

By the 2080s, the number of WRZs with projected deficits of more than 5 Ml/d increases to 31, with three WRZs projected to have a deficit of more than 100 Ml/d: these are the United Utilities’ Integrated Zone (a deficit of 368 Ml/d), the Nottingham WRZ (a deficit of 139 Ml/d) and the Grid zone in Yorkshire (a deficit of 137 Ml/d). Three WRZs in Wales are projected to be in deficit by more than 5 Ml/d, with the North Eryri/Ynys Mon WRZ the most affected zone with a deficit of 19 Ml/d.

When interpreting all the projected deficits highlighted above, the magnitude of these should be considered alongside the relative scale of the WRZ’s with respect to the total demand for water. The values provided are intended to indicate the overall scale of deficits projected, to inform the Climate Change Risk Assessment at a regional and national scale as opposed to providing specific estimates of impacts on WRZs which, would be more suitable to assisting WRZ and/or water company level risk assessment. In addition, significant caution must be exercised when interpreting these results at such a local scale. The reductions in PCC and leakage suggested by the Case for Change analysis adopted for this project may be difficult to achieve universally in practice. For example, achieving the dramatic reductions in leakage in London may be considered prohibitively expensive to implement in comparison to other solutions.

Demand projections under ‘Current objectives’ and ‘Current objectives+’ adaptation pathways

The ‘Current objectives’ and ‘Current objectives+’ adaptation pathways mitigate the supply-demand deficits through reductions in the consumption of water and losses through leakage and through implementation of the water company preferred options as set out in the water company resource plans.

Figure 5.6 to Figure 5.9 present the projected change in the Distribution Input for the 2050s and 2080s corresponding to the supply-demand balances presented previously in Section 4.1. These projections demonstrate the large mitigation in the demand for public water supplies that could potentially be achieved under these adaptation pathways. However, as highlighted above, achieving such reductions across all areas may be difficult to achieve in practice.

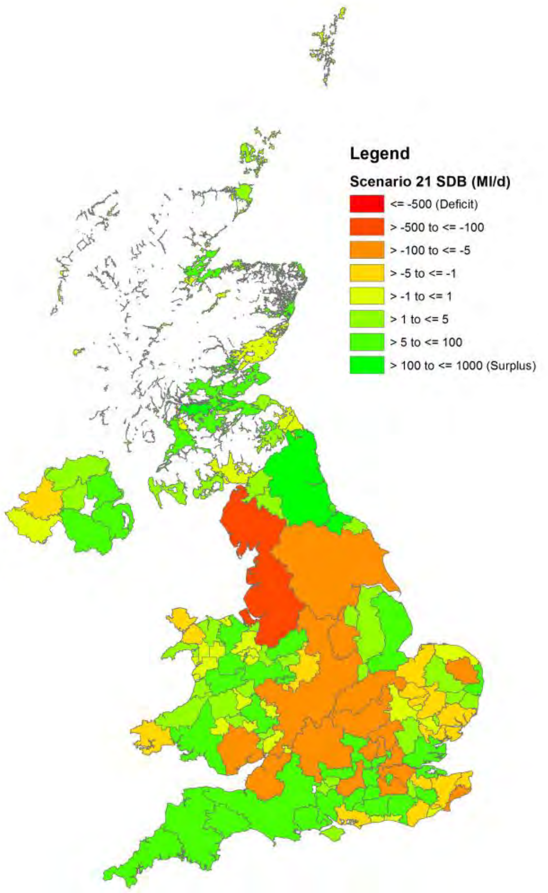

Figure 5.2: Plot of supply-demand balance for 2050s under a principal population projection, medium climate change projection and a ‘Current objectives’ adaptation pathway.

Source: n/a

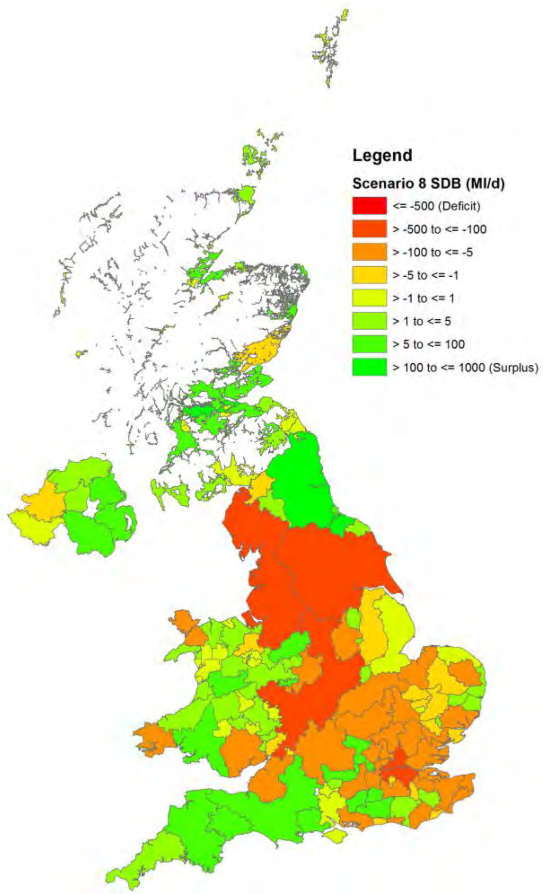

Figure 5.3: Plot of supply-demand balance for 2080s under a principal population projection, medium climate change projection and a ‘Current objectives’ adaptation pathway.

Source: n/a

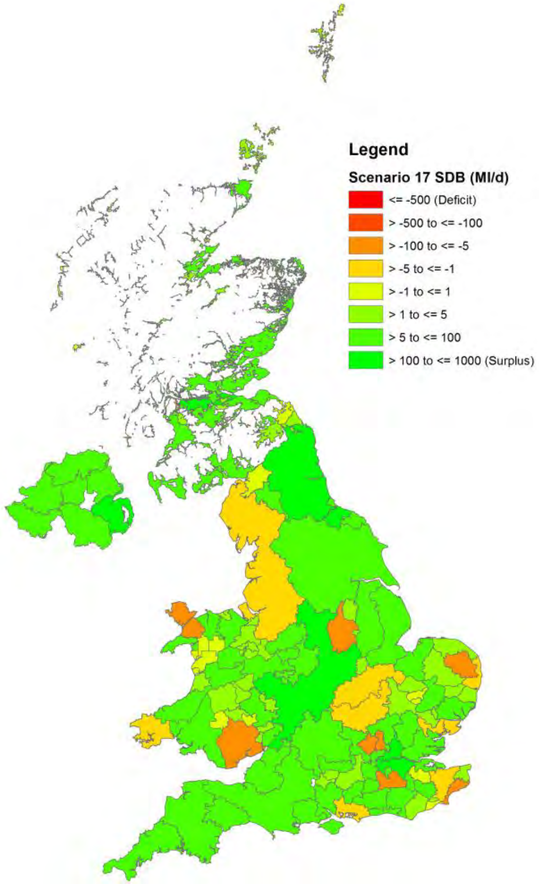

Figure 5.4: Plot of supply-demand balance for 2050s under a high population projection and a ‘Current objectives+’ adaptation pathway.

Source: n/a

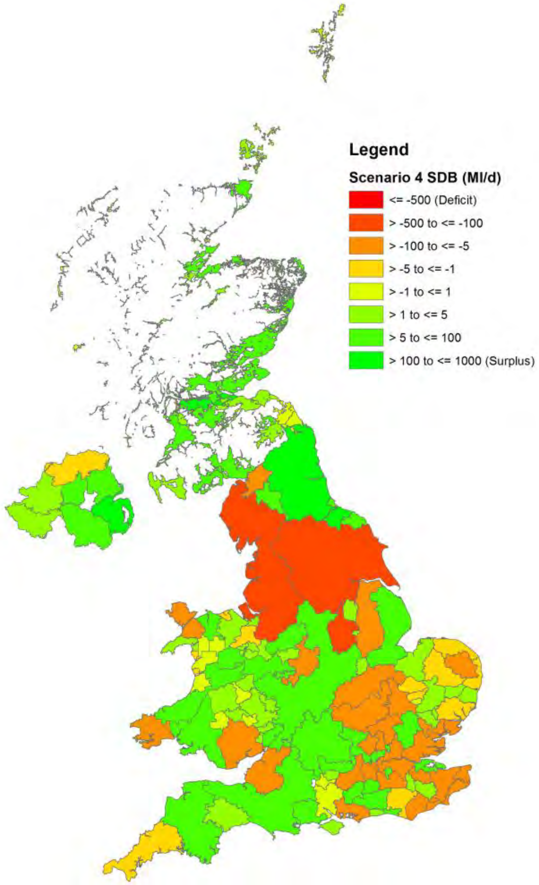

Figure 5.5: Plot of supply-demand balance for 2080s under a high population projection and a ‘Current objectives+’ adaptation pathway.

Source: n/a

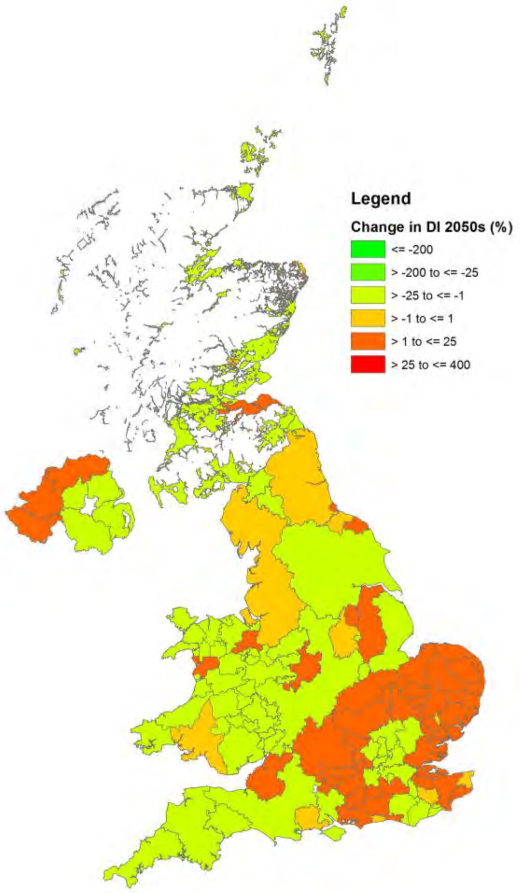

Figure 5.6: Plot of 2050s change (% change from baseline) in Distribution Input under a Principal Population future and a 'Current objectives' adaptation pathway.

Source: n/a

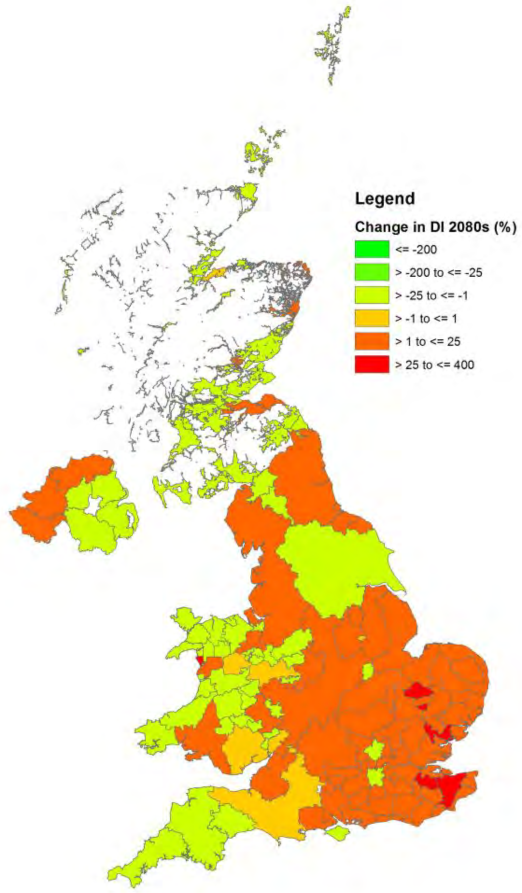

Figure 5.7: Plot of 2080s change (% change from baseline) in Distribution Input under a Principal Population future and a 'Current objectives' adaptation pathway.

Source: n/a

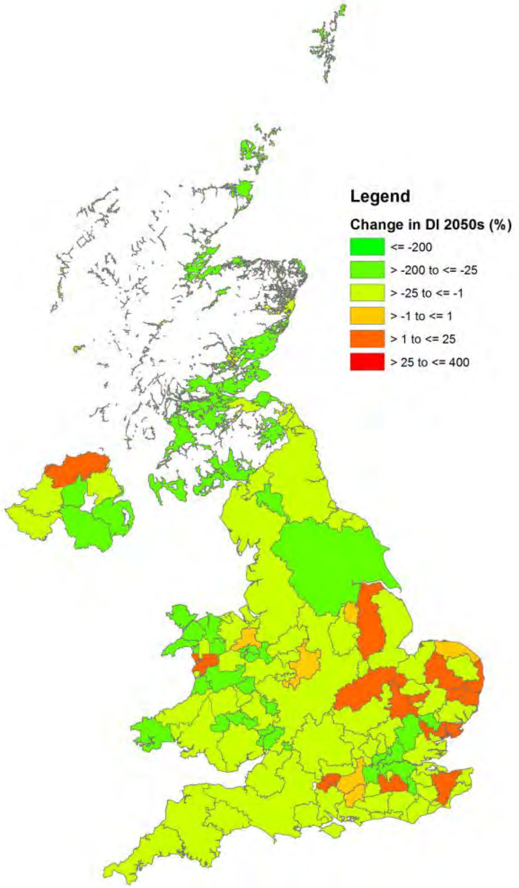

Figure 5.8: Plot of 2050s change (% change from baseline) in Distribution Input 2050s under a high population projection and a 'Current objectives+' adaptation pathway.

Source: n/a

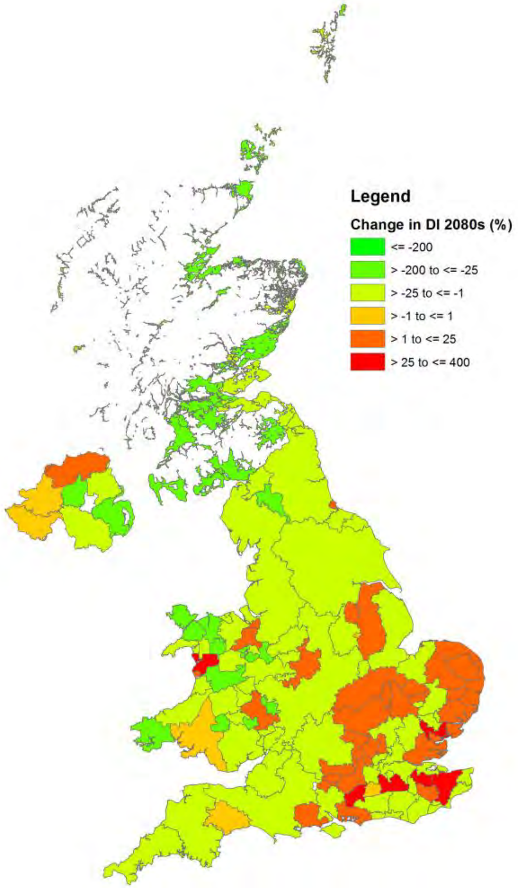

Figure 5.9: Plot of 2080s change (% change from baseline) in Distribution Input 2080s under a high population projection and a 'Current objectives+' adaptation pathway.

Source: n/a

5.1.2. Adaptation through water company options beyond the WRMP planning horizon

As can be seen from the results presented in Section 5.1.1, supply-demand deficits may be significantly mitigated under a ‘Current objectives+’ adaptation pathway but supply deficits are still projected to exist in some WRZs under a high population, high climate change projection.

As part of the WRMP process, water companies with a projected supply-demand deficit at some point during the 25-year planning horizon consider what options might be available to mitigate such deficits. These are evaluated to form a *feasible* list (options considered potentially viable) and ultimately a *preferred* list (all options that the company promotes for implementation during their WRMP planning horizon). This list of *feasible* and *preferred* options, for WRZs in England and Wales only, has been based on outputs provided from the Environment Agency’s Strategic Water Infrastructure and Resilience project and a review of the WRMP tables provided by the water companies as part of this project. For the purposes of this evaluation, all feasible options are considered to be available in the 2050s and 2080s. The potential Water Available For Use (WAFU) listed for each option in the WRMP tables is also assumed to be fully available at those times.

The ‘Current objectives+’ adaptation pathway includes all the *preferred* options from the WRMPs. It also includes large reductions in household consumption and leakage and is therefore assumed to include all the demand-side feasible options around household consumption and leakage (water company planning table option ‘types’ 59.1a, 61.1a, 61.2a, 61.8a, 61.9a in Figure 5.10) specified in the WRMP tables.

This part of the Public Water Supply analysis aims to establish the extent to which the remaining options, such as supply-side resource development and reductions in non-household consumption, may be able to provide further deficit alleviation above and beyond the ‘Current objectives+’ adaptation pathway.

58a	RESOURCE SIDE
58.1a	Options to increase raw water abstractions
58.2a	Options to increase raw imports
58.3a	Options to increase potable imports
58.4a	Options to reduce raw water losses and operational use
58.5a	Options to reduce raw water exports
58.6a	Options to reduce potable water exports
58.7a	Other options to increase Deployable Output
59a	**DISTRIBUTION SIDE**
59.1a	Options to reduce Distribution Losses
59.2a	Options to reduce Distribution System Operating Use (DSOU) losses
60a	**PRODUCTION SIDE**
60.1a	Options to reduce treatment works losses
60.2a	Options to reduce outage
61a	**CUSTOMER SIDE**
61.1a	Options to change volume delivered to measured households
61.2a	Options to change volume delivered to unmeasured households
61.3a	Options to change volume delivered to measured non households
61.4a	Options to change volume delivered to unmeasured non households
61.5a	Options to reduce water taken unbilled
61.6a	Options impacting on measured Non Household - USPL
61.7a	Options impacting on unmeasured Non Household - USPL
61.8a	Options impacting on measured Household - USPL
61.9a	Options impacting on unmeasured Household - USPL
61.10a	Options impacting on Void properties - USPL

Figure 5.10: Summary of option types considered as part of the WRMP process.

Source: Water Resources Planning Guidance (Environment Agency et al. 2011)

Figure 5.11 and Figure 5.12 present the projected supply-demand deficits for England and Wales for the 2050s and 2080s under a high population and a high climate change projection, adopting a 'Current objectives+' adaptation pathway and the implementation of all remaining WRMP options. For the 2050s, relatively modest deficits still exist in some WRZs, which increase by the 2080s, with the largest deficit projected for the Nottingham WRZ at just over 100 Ml/d by the 2080s. This deficit is due to significant impacts from population growth and climate change, along with only a limited resource available from the remaining feasible options considered during the 25-year WRMP planning horizon.

Figure 5.13 and Figure 5.14 convert the above values for the 2050s and 2080s into the additional reductions in PCC that would be necessary to achieve a supply-demand balance within each WRZ, noting that a 'Current objectives+' adaptation pathway already assumes a PCC of 92 l/h/d. The relatively large reductions shown for a small number of WRZs typically reflect those WRZs with significant climate and/or population impacts, a limited volume of resource potentially available under the feasible options considered in the WRMPs and zones with relatively significant non-household consumption not significantly affected by the adaptation pathways considered as part of this study.

Whilst Figure 5.11 and Figure 5.12 show localised supply-demand deficits for the 2050s and 2080s, overall England and Wales both have significant surpluses when considered as a whole. It should be noted that water companies only consider a 25-year planning horizon and therefore there are potentially still options available, above and beyond those considered as part of the latest WRMP process, to alleviate the deficits estimated. These options might include the potential to provide additional above ground (reservoirs) or below ground storage (i.e. aquifer recharge) to capture increased winter flows and effluent re-use. This is likely to be of most significance to those WRZs, such as South Staffordshire, which don't project deficits during the WRMP planning horizon and therefore may not have considered what mitigation options may be feasible. It is also worth noting that where such deficits exist, such as in the Nottingham WRZ, there are neighbouring WRZs within the regions that are in surplus which suggests that further sharing of water through transfers may be able to provide further alleviation of the projected deficits.

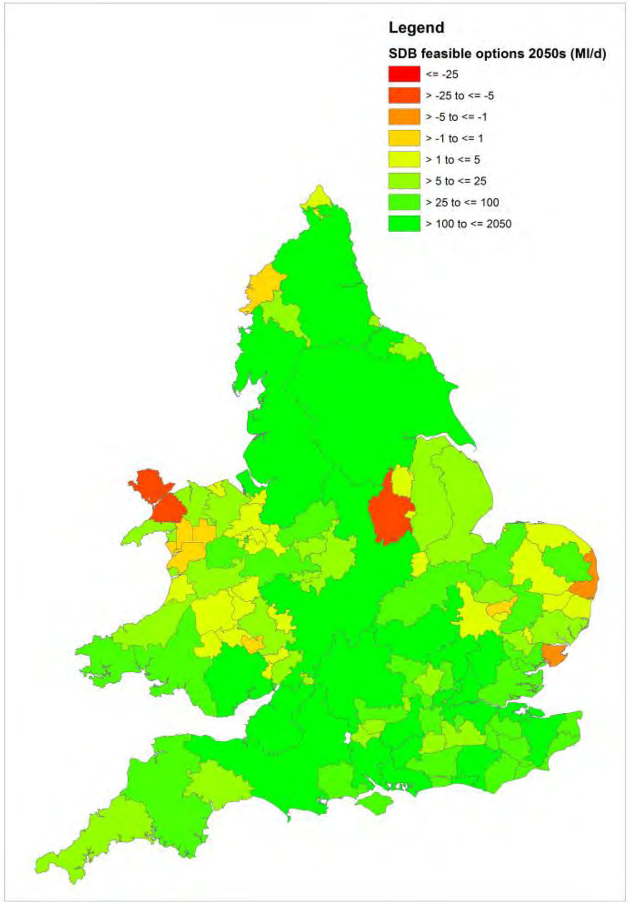

Figure 5.11: Plot of supply-demand balance for the 2050s under a high population projection, high climate change projection and a 'Current objectives+' adaptation pathway and implementation of all remaining WRMP feasible options.

Source: n/a

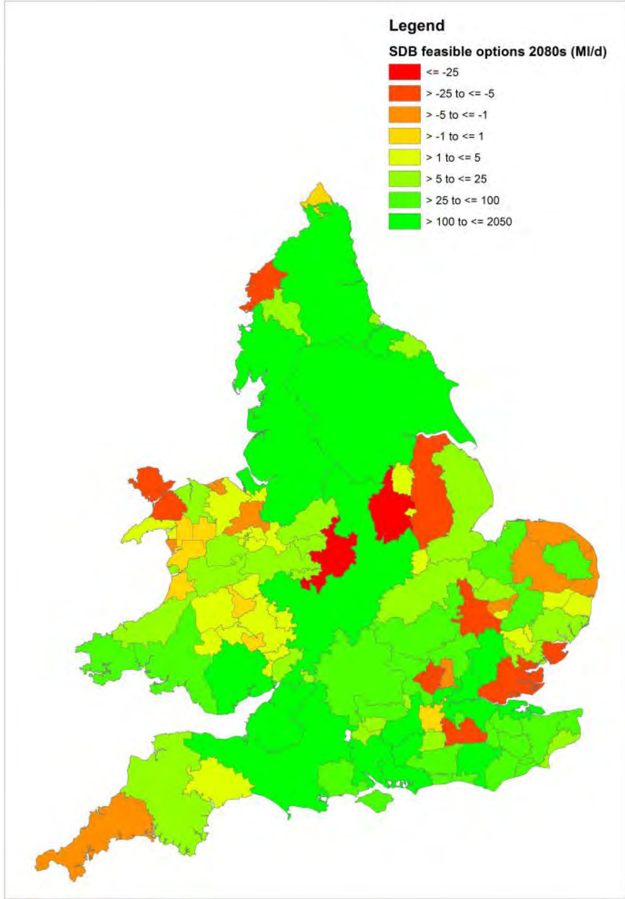

Figure 5.12: Plot of supply-demand balance for the 2080s under a high population projection, high climate change projection and a 'Current objectives+' adaptation pathway and implementation of all remaining WRMP feasible options.

Source: n/a

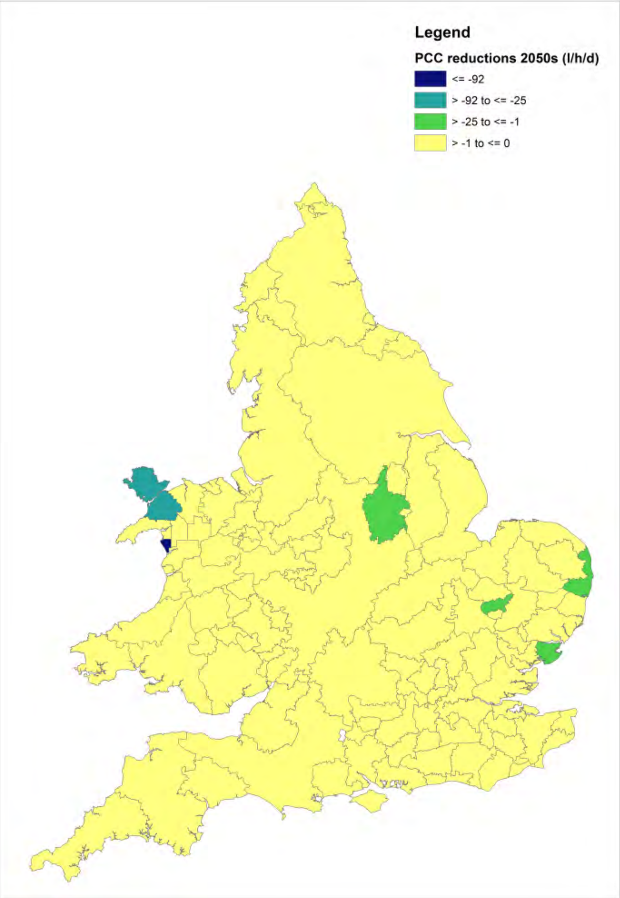

Figure 5.13: Plot of additional PCC reductions that would be required to achieve a supply-demand balance for the 2050s under a high population projection, high climate change projection and a 'Current objectives+' adaptation pathway and implementation of all remaining WRMP feasible options.

Source: n/a

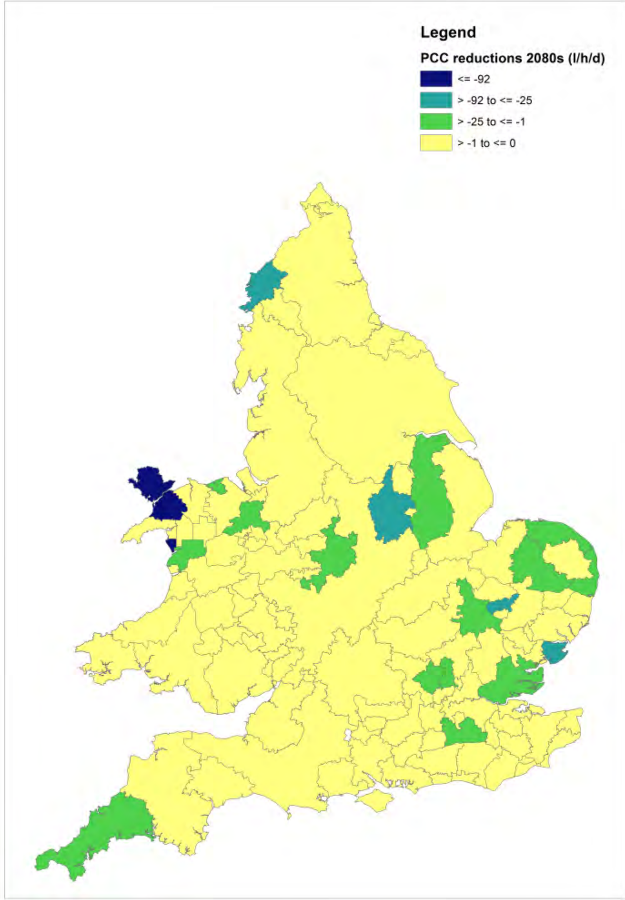

Figure 5.14: Plot of additional PCC reductions that would be required to achieve a supply-demand balance for the 2080s under a high population projection, high climate change projection and a 'Current objectives+' adaptation pathway and implementation of all remaining WRMP feasible options.

Source: n/a

6. Results: Droughts

Summary

This assessment has used an index for normalising and comparing time-series for groundwater levels and river flows to assess the change in severity of extreme levels and flows under climate change using the simulations from Future Flows sites.

Overall, there is not a clear picture of the instances of extreme wet or extreme dry events projected into the future and any trends appear to be location specific.

Additional information on droughts can be found in Project D "*Consideration of new extreme "high++" scenarios for extreme events".*

6.1. How do the Future Flows Hydrology (FFH) projections of extreme river flows and groundwater levels change during the 21st century?

Whilst it is generally considered that the global climate models (GCMs) that underpin the Future Flows and UKCP09 projections have limited skill in reproducing the key physical process which lead to droughts, there has been little attention paid to the drought characteristics obtained from the derived hydrological products to confirm this view.

This assessment has used an index for normalising and comparing groundwater level time-series, the Standardised Groundwater Level Index (SGI) (Bloomfield and Marchant, 2013) to assess the change in severity of extreme groundwater levels under climate change using the simulations from Future Flows sites. This approach has been applied to groundwater with a similar approach also applied to river flows. The assessment produces a series of "heat maps" for each member of the 11 member ensemble used in Future Flows. An example of a heat map is shown in Figure 6.1 and Figure 6.2 and the rest of the results are presented in Appendix D. Each map displays the index series for the 24 boreholes or 57 flow gauges used in the assessment, along the y-axis, with the date through the projection, from 1950 to 2100, shown on the x-axis. The colour refers to the SGI index value, a key to these indices is provided in the scale to the right-hand side of each heat map. The index provides a standardised measure of groundwater levels or river flows using the Future Flows model outputs to highlight whether a discernible climate change signal within an ensemble member is evident or not (e.g. an increased frequency in extremely wet or dry periods) which may in turn suggest an increased tendency for such events in the future due to climate change.

It is difficult to see any clear patterns over time for either the groundwater or river sites assessed. Occasionally, over a short period of a few years there is an apparent red or blue stripe; indicating either a wetter or drier period across all or at least most of the sites. As described in Project D's main report, there appears to be an almost regularity or cyclical nature to the instance of generally wetter and generally drier periods over time in the past. The heat maps provided in Figure 6.1 and Figure 6.2 and Appendix D suggest that a similar sort of process may be projected by these models in the future. No obvious change in the frequency of extremely wet or extremely dry periods in the future is apparent.

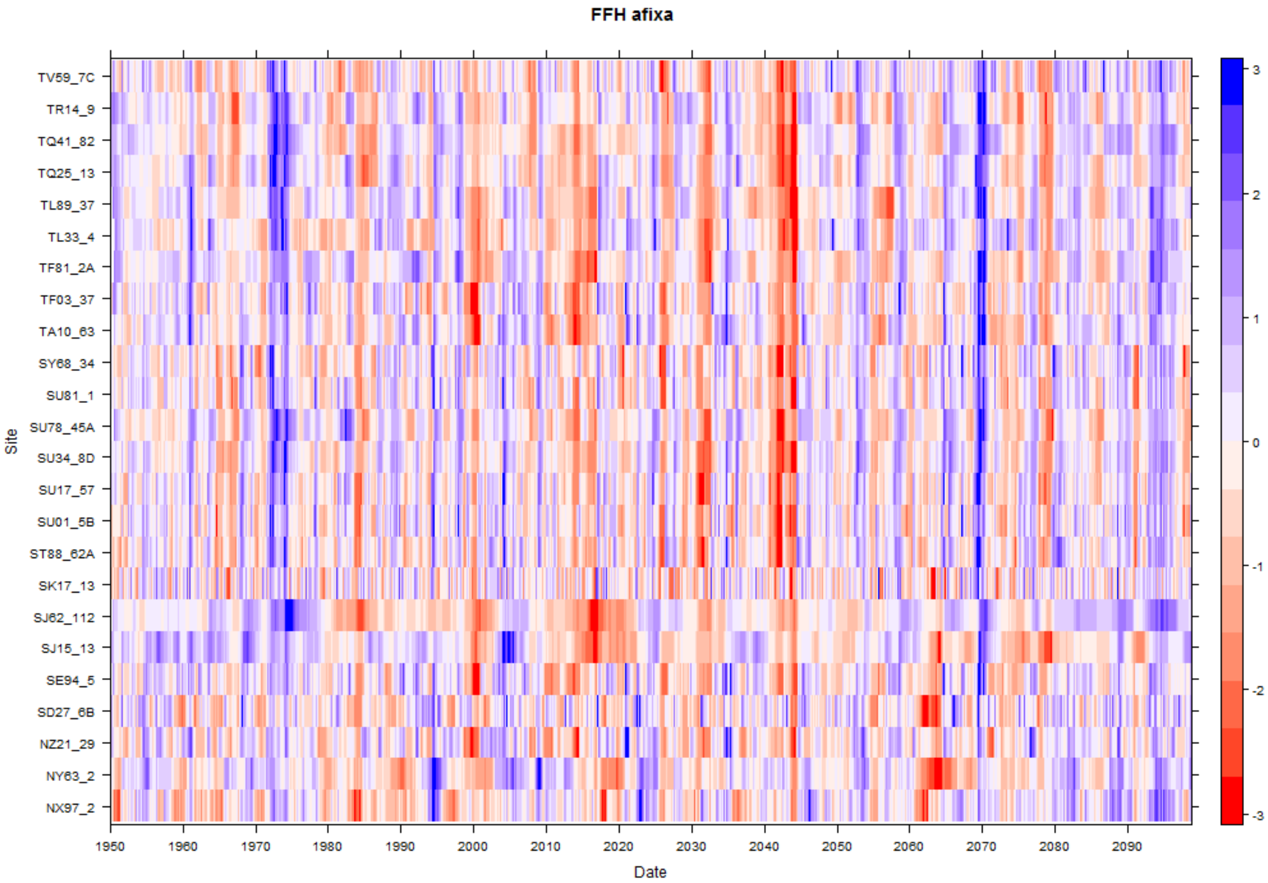

Figure 6.1: An example heat map for groundwater levels using a standardised index using the FFH afixa simulation between 1950 – 2099.

Notes: *The heat map shows the 24 boreholes used in the Future Flows assessment on the y-axis. Time is shown on the x-axis. The colours represent the standardised index value of the groundwater levels. Values of the colours are shown in the key to the index on the right-hand side of the heat map. Values less than -2 are considered to be an extremely dry event. Values greater than +2 are considered to be an extremely wet event. The heat map will show any relative change in the frequency of such events over time. A heat map has been produced for all 11 members of the ensemble used in Future Flows. The FFH-afixa member is shown here as an example of the results.*

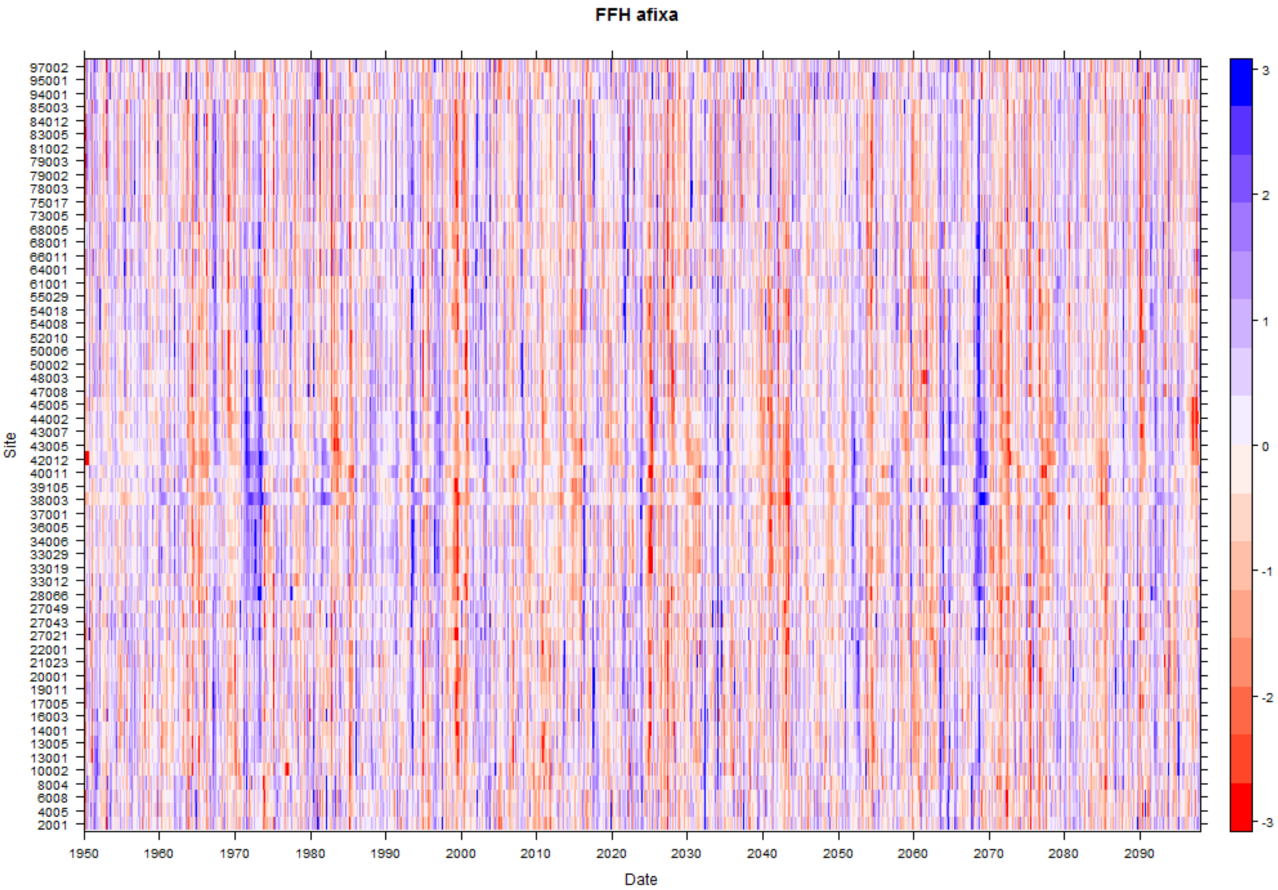

Figure 6.2: An example heat map for river flows using a standardised index using the FFH afixa simulation between 1950 – 2099.

Notes: The heat map shows the 57 flow gauges used in the Future Flows assessment on the y-axis. Time is shown on the x-axis. The colours represent the standardised index value of the river flows. Values of the colours are shown in the key to the index on the right-hand side of the heat map. Values less than -2 are considered to be an extremely dry event. Values greater than +2 are considered to be an extremely wet event. The heat map will show any relative change in the frequency of such events over time. A heat map has been produced for all 11 members of the ensemble used in Future Flows. The FFH-afixa member is shown here as an example of the results.

The number of months in moving 30-year windows with an index <-2 and >2 i.e. extreme dry months and extreme wet months (defined by McKee, Doesken, and Kleist, 1993) is then counted. These data are plotted on two graphs for each site, plus the mean for the ensemble, see the examples in Figure 6.3 and Figure 6.4. The rest of the results are presented in Appendix D. For both groundwater and river flows there are often highly variable results from the different simulations assessed. Changes in extreme low groundwater conditions appear to be generally minimal, although this varies by location and both positive and negative changes are apparent in the projections. For river flows, projected changes are for an increasing frequency of extremely dry events, although not for all sites and the range of potential outcomes is wide, similar to the groundwater projections. Overall, there is not a clear picture of the instances of extreme dry events projected into the future and any trends appear to be location specific.

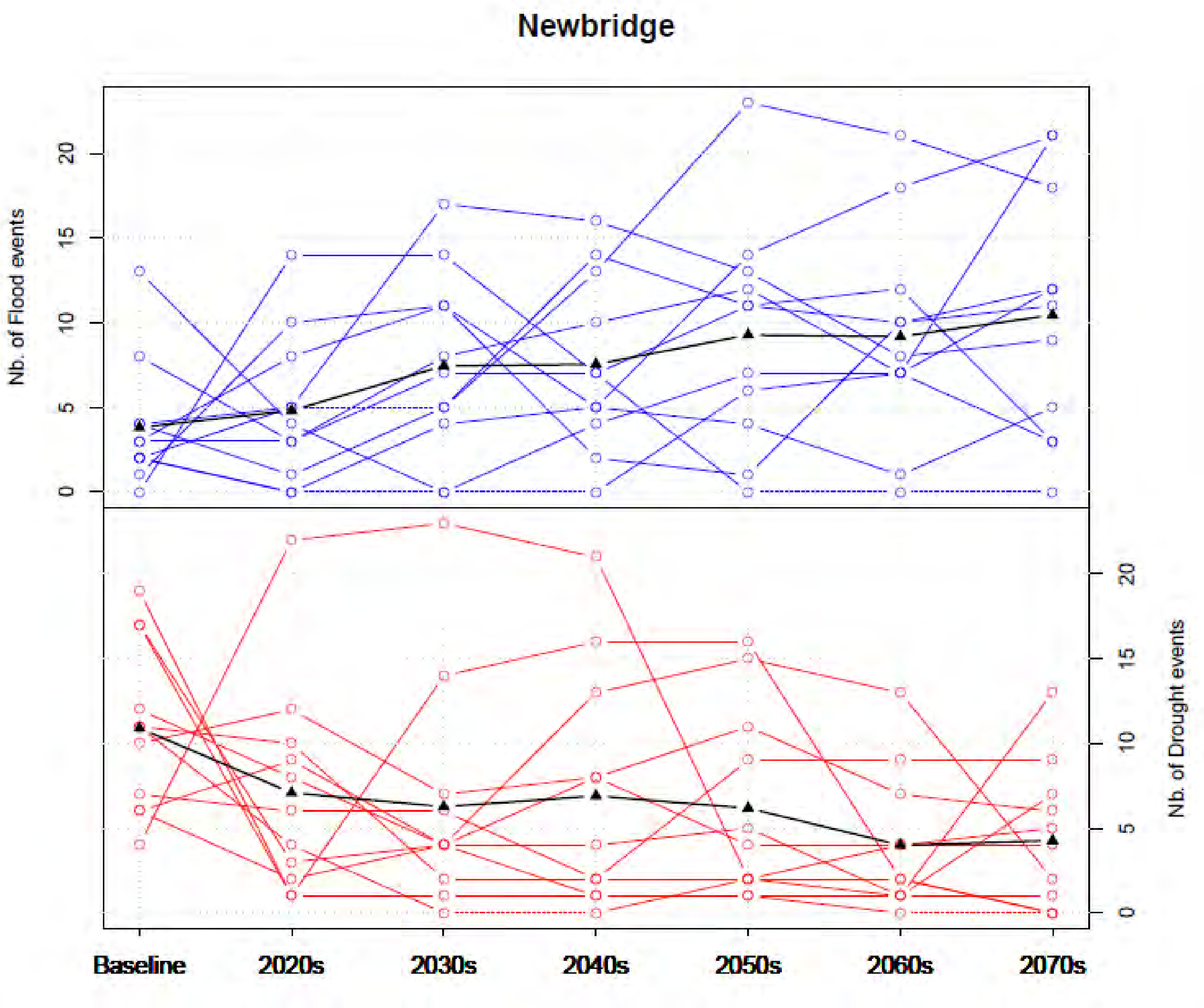

Figure 6.3: Changes in number of extreme wet and dry groundwater level events at the Newbridge borehole over time, present-day to 2070s.

Notes: Each red or blue line reflects a different FFH climate simulation. The black line displays the mean of the simulations. Decadal time-steps are presented along the x-axis.

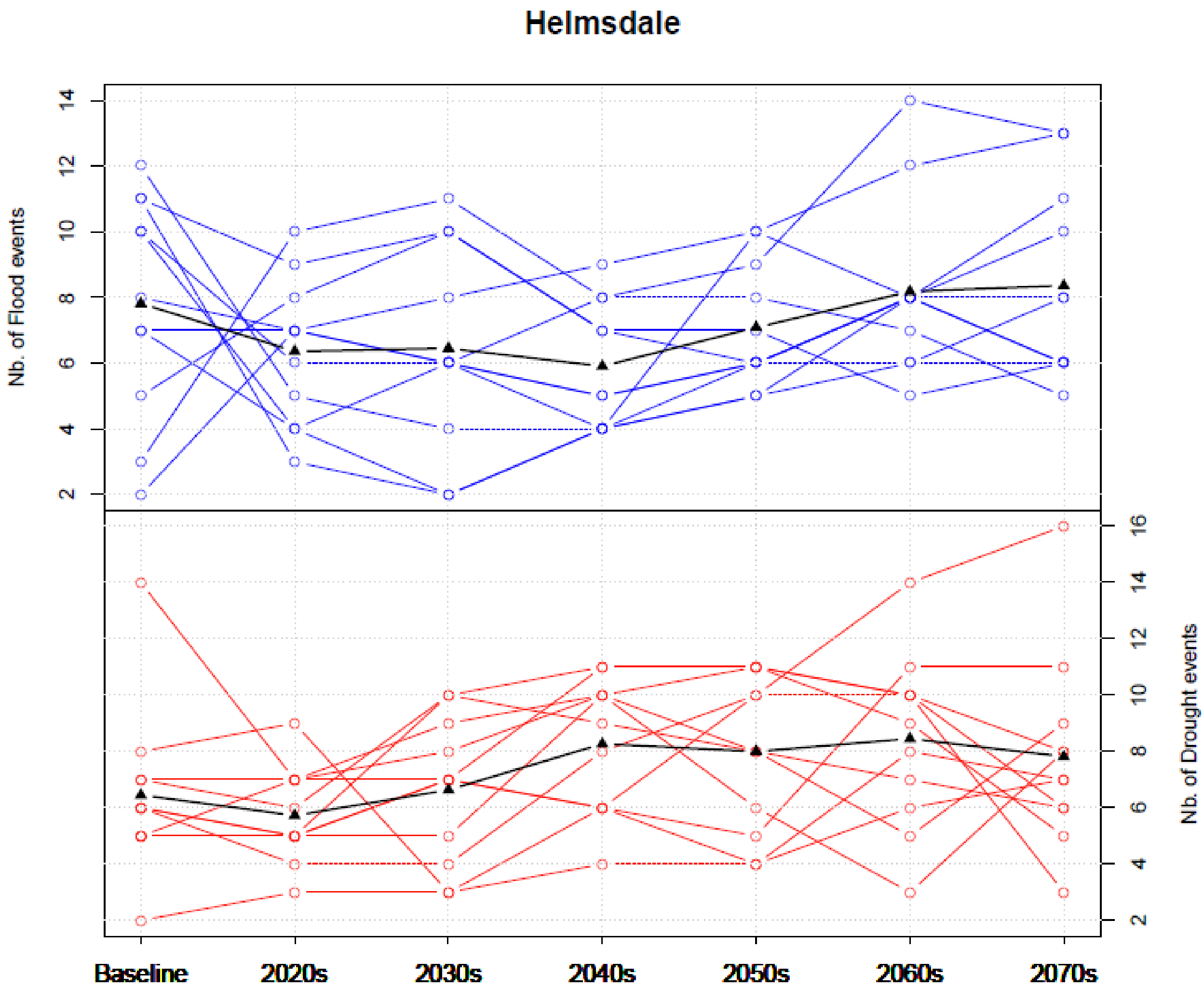

Figure 6.4: Changes in number of extreme wet and dry river flow events at the Helmsdale gauge over time, present-day to 2070s.

Notes: Each red or blue line reflects a different FFH climate simulation. The black line displays the mean of the simulations. Decadal time-steps are presented along the x-axis.

7. Discussion and conclusions

7.1. What does all this mean?

7.1.1. Implications for Public Water Supplies

Total supply-demand balance

Short-term: 2030s

The supply demand balance at the end of the water company resource planning horizon, based on the water resource system as at the baseline period (i.e. does not include for planned interventions set-out in the water company resource plans, so is in effect a ‘no action’ scenario) reports that a total of 27 WRZs exhibit a supply-demand deficit of greater than 5 Ml/d in the water company resource plans in the 2030s. These comprise one WRZ in Wales, two in Northern Ireland and 24 in England. The largest reported deficit is in London, followed by Yorkshire Water’s Grid Zone.

At a national level, England and Northern Ireland are reported to be in deficit at the end of the planning period (-1% and -4% respectively). By contrast, Wales and Scotland report surpluses overall at this time (10% and 22% respectively).Population changes by the 2030s are projected to vary significantly across the UK. The total demand for public water supplies increases by the greatest extent, in general, in the South-East of England and Northern Ireland. In Wales, northern, central and south-west England and some WRZ’s in Scotland, Distribution Input is projected to decrease by the 2030s. This is primarily due to PCC reductions and improvements in leakage rates.

Climate change impacts on Deployable Output reported at the end of the water company resource plans varies significantly across the different WRZs. Thirty-five percent of the WRZs included in this analysis report impacts from climate change (51% in England; 54% in Wales; 23% in Scotland; and, 71% in Northern Ireland). In absolute terms, the greatest impacts are reported to be in England (in London and the north of England). The large absolute impacts projected are for a couple of reasons:

- Thames Water’s London zone:
  - The population is high and therefore the absolute water requirement is also high. Even small percentage changes equate to relatively large volumes.
  - Abstraction from the Thames River supplies more than one WRZ. However, the licence restrictions on abstractions from the Thames river are not equally spread between the receiving zones. Therefore, the London WRZ carries proportionally more risk, with respect to climate change, based on the licence conditions than the other WRZs served.
- Severn Trent Water’s large Strategic Grid WRZ, Yorkshire Water’s Grid zone and United Utilities Integrated WRZ:
  - The large geographical area means that the population is high and therefore the absolute water requirements are also high. Similar to the London zone, even small percentage changes equate to relatively large volumes.
  - Abstractions are largely from surface water sources that are relatively severely impacted by climate change, especially when compared to zones that have greater groundwater resources.

In relative terms, WRZs in Wales, the south-east and east of England and Scotland report impacts of 5% or more. Sixteen WRZs in Scotland report an increase in Deployable Output due to climate change. The vulnerability of each zone to climate change is related to the specific characteristics of its supplies, including the availability of above and below ground storage, specific licence constraints and the volume of resources exploited to meet the local demand for water.

Medium and long-term: 2050s and 2080s

Under the upper bound scenario (high population growth and a high climate change projection) for the 2050s, under a 'no additional action' adaptation scenario, there is a pattern of large deficits in the provision of public water supplies; particularly in the south-east of England and the large conjunctive use zones in the north of England, but also in other parts of the UK. Such deficits are projected to become more acute and widespread in the 2080s and would present significant challenges in most parts of the UK but particularly across England. All countries are projected to be in deficit when considered at a national scale. Under this scenario, the projected total deficits across the UK equate to over 3,200 and over 6,000 Ml/d by the 2050s and 2080s respectively, equivalent to shortfalls of 16% and 29% of the required demand for water at that time.

At a more local scale deficits under the upper bound scenario could be particularly large, for example, London's deficit is projected to reach 1,360 Ml/d by the 2080s. Other significant deficits are in the large conjunctive use zones in the north of England and in the Severn basin, and smaller zones serving large cities such as Bristol and Nottingham. In Wales, SEWCUS projects a deficit of 75 Ml/d by the 2080s, and the most impacted zone in Scotland would be Edinburgh, with a deficit of over 60 Ml/d. A similar deficit is projected in Northern Ireland Water's most affected zone, the East WRZ. In interpreting these results, the magnitude of these deficits should be considered alongside the relative scale of the WRZ's respective total demand for water. The values provided here are intended to indicate the overall scale of deficits projected to help inform the Climate Change Risk Assessment at a regional and national scale as opposed to providing specific estimates of impacts on WRZs which, would be more suitable to assisting WRZ and/or water company level risk assessment.

The results highlight the variability in climate change sensitivity between WRZs within the same region that are subject to similar changes in climate. Such variability is related to the specific characteristics of each zone's supplies; in particular the availability of above and below ground storage for capturing winter rainfall and the specific attributes of abstraction licences such as flow thresholds at which abstraction is required to stop. It is also worth highlighting that these are deficits in the absence of any adaptation through demand or leakage reductions or the implementation of other options set-out in the water company plans which are considered separately.

When considering a lower bound scenario, of low population growth and a medium climate change projection, significant deficits are still evident in parts of the south-east and elsewhere in the UK by the 2050s. This suggests that adaptation in some parts of the UK may be necessary under almost all possible future scenarios. Under this lower scenario, deficits across the UK equate to over 800 and over 1,400 Ml/d by the 2050s and 2080s respectively, equivalent to shortfalls of 5% and 8% of the required demand for water at that time. At a national scale, only England is projected to be in deficit under this scenario. Whilst Wales, Scotland and Northern Ireland are projected to be in surplus at a national scale, there are deficits evident at a more local scale.

These lower supply-demand balance scenario projections are driven by a combination of climate change impacts and increased demand for public water supplies, itself driven by potentially high rates of population growth in already densely populated areas. Charlton *et al.* (2011) in their review of climate change impacts on water resource in England and Wales, based on an analysis of the outputs of water company WRMPs in 2009, suggested that climate change and supply side measures are likely to be "dwarfed" by increasing demand side pressures. Concluding that, for adaptation decision-making, climate change is rarely the sole driver with decisions made to mitigate a range of pressures. However, in the detailed analysis presented here both of these components, climate change and demand-side pressures, are significant, with their relative importance varying depending on which area is being assessed.

Under both a medium and high climate change impact future there are significant reductions projected in the availability of public water supplies by the 2050s and the 2080s. Under a medium emission scenario, projected loss of Deployable Output (compared to the baseline condition) across the UK equates to 6% and 8% for the 2050s and 2080s respectively. Under a high climate change impact future these projected losses equate to 11% and 15%, although much greater impacts may be realised at a more local scale in those WRZs particularly vulnerable to climate change. Locally, some WRZs project significant reductions in availability of public water supplies with, for example, losses of 480 and 680 Ml/d (34 and 32%) in the Grid WRZ for Yorkshire Water and the Integrated WRZ of United Utilities. Whilst Scotland, Wales and Northern Ireland are generally less affected than England, some WRZs project large impacts, for example, Lothian, SEWCUS and Northern Ireland Water's North WRZ projected to have reductions of 50 Ml/d (22%), 30 Ml/d (7%) and 5 Ml/d (9%) respectively. However, in comparison with CCRA1, the projected impacts of climate change on public water supplies reported in this study are generally lower, noting that very different methodological approaches have been used along with the new information now available in the latest water company resource plans.

With regards to population and the demand for water, under a low population growth future, significant population increases are projected to occur, particularly in the south-east of England but also across most areas of the UK. It is worth noting that reductions (from baseline) in population at a national scale are projected to occur in Northern Ireland in the 2080s and are also evident in some other WRZs across the UK for both the 2050s and 2080s. In total, the demand for water across the UK as a whole under this scenario is projected to increase by 2% and 4% (from the baseline condition) for the 2050s and 2080s respectively. Under a high population growth future the projected increases are very significant, particularly around already densely populated areas potentially placing severe additional demands for water. Under a high population scenario, the demand for water across the UK as a whole is projected to increase by 9% and 18% (from the baseline condition) for the 2050s and 2080s respectively. At a more local scale, the population in some WRZs is projected to increase by over 80% by the 2080s in England under a high population scenario. For the same scenario, Welsh Water's and Northern Ireland Water's WRZs, population increases vary from between 10 and 45%. In Scotland, in the more populated WRZs, increases are between 25% and 60%.

Adaptation

Widening supply-demand deficits may have a range of consequences such as the reduced reliability of supplies (with more frequent or severe shortages during drought) through to increasing in the costs of supplying water. The actual consequences will depend on the size of the deficits and measures to manage these future risks but a study by NERA (2012) suggested that in London alone, the financial impact of emergency restrictions on water use – which involve rationing the amount of water available for public use – would be in the range of £236m - £329m every day. Despite these future pressures, the analysis presented in this report suggests that adaptation, in the form of reductions in household consumption and leakage, along with implementation of additional feasible options identified by the current water companies resource plans, could have the ability to alleviate much of the supply-demand deficits that may occur in the future. However, the projected reductions in leakage and household consumption (and the associated behavioural changes that would be necessary) under the 'Current objectives+' adaptation pathway in particular, may be extremely difficult and prohibitively expensive to achieve in practice in all areas. Their feasibility at more local scales should be evaluated. Further to this, it should be noted that water companies only consider a 25-year planning horizon and therefore there are potentially additional options available, above and beyond those reported in the latest resource planning process and considered here. These could including increased sharing of water, effluent re-use and the potential to provide additional above ground (reservoirs) or below ground storage (i.e. aquifer recharge) to capture increased winter flows.

The approach taken to adaptation should not be interpreted as necessarily promoting demand-side measures over supply-side measures. The approach adopted in this study has sought to assess the potential scale of mitigation options already considered potentially available (through WRMP options in England and Wales and, the Case for Change scenarios) in relation to the projected deficits under different climate and population projections and, convey the scale of the challenge that might be faced in the future. It should be noted that for this study it has not been possible to undertake a detailed assessment of potential options for closing the gap for which evidence does not already exist (e.g. resource developments not already considered by water companies as part of their plans) given the complexities involved in evaluating their viability and yield.

It is emphasised that the water company resource planning process requires water companies to prepare and update their resource plan every 5 years and the process is therefore adaptive by design. The industry is also looking to move towards more risk-based methods and explicitly consider multiple futures and deliver water company resource plans that can be shown to be both robust and resilient to a range of possible future conditions, with a number of water companies undertaking innovative work in this regard (including the WRSE and WREA regional studies and company specific studies such as Southern Water's use of stochastic methods in their latest WRMP). Based on the projections presented in this study, there may be an argument that water company resource plans should consider planning horizons much greater than the currently adopted 25-years, along with a range of possible scenarios encompassing uncertainties related to the future climate, demographic changes and alternative adaptation pathways in order to understand the scale of challenges that could be faced in the future.

7.1.2. Implications for 'all sectors'

Accounting for the requirements of freshwater ecosystems using existing regulatory approaches, current abstraction demand already exceeds the available water resource in some catchments in the UK today. This is particularly the case in the south and east of England, but also in a small number of catchments in the north west of England, Northern Ireland and Scotland. In reality, hands-off flow constraints restrict actual abstractions, often to the levels appropriate for the EFI thresholds. However, it is notable that in some catchments the EFI thresholds are not met.

There is currently natural available resource at Q95 in all, bar one, of the catchments in the UK. There is a wide range of natural available resource depending upon location. The catchments with the largest natural available resource are the Thames and Severn Corridors in England and Wales and the Rivers Tay and Spey in Scotland. Whilst coastal catchments, particularly in Scotland, south-east England and Northern Ireland may have very little available resource at Q95 today, discharges, mainly from effluent returns, currently provide the additional flow support required in these catchments.

Under the upper bound scenarios for the 2050s and 2080s, there is a general pattern of a lack of available resource projected in the west of the UK and severe impacts of abstraction in the east and south of the UK and across central Scotland. Only the northern most catchments of Scotland and some central and west midlands catchments in England are projected to maintain a high level of water available under all future scenarios.

Whilst there is a negligible difference between the baseline and the lower bound projections of natural flows at Q95 to the end of this century, there is a large reduction in natural available resource under the upper bound projections in the 2050s and 2080s. To an extent, increases in population may help to support lower flows as an increased population will be associated with increased effluent returns. However, these effluent returns are more likely to occur downstream of any abstraction impacts meaning the influence of population increases on river flows, available resource and abstraction impacts on river ecology is complex. Projections may indicate an increase or decrease in the proportion of the available resource used, depending upon the characteristics of the catchment in question.

The approach taken to adaptation influences the severity of the impact of the proportion of the available resource used. Influence is most notable in the west where in a number of catchments the difference between a ‘No additional action’ and ‘Current objectives+’ scenario may make the difference between a projection of surplus or deficit.

At a national level, the assumptions made about the future approach taken to environmental flows has a the largest influence on whether there is any available resource for human uses available at all, particularly in the west of the UK. The more sensitive, upland catchments tend to be the most affected although lowland catchments are also affected under the most extreme upper scenario. Only a ‘proportional’ approach to setting EFI targets allows water to be available for human uses into the 2080s. The effect that this may have on the environment was not tested in this assessment but it is clear that the decisions made on the balance between environment flows and allowable abstraction is critical in terms of both maintaining a secure and sustainable water supply for human use and maintaining a good status in the freshwater environment into the future. Unless climatic changes or population changes turn out to be particularly severe, the sensitivity testing undertaken by this analysis suggests that the characteristics of the policy decisions for adaptation and EFIs may have the greatest impact on both people and the environment.

7.1.3. Integrating implications for Public Water Supplies and all other sectors

In this assessment, the growth factors calculated for hydrological changes due to climate and for Public Water Supply demand were incorporated into the analysis for ‘all sectors’, discussed in Section 7.1.2. Therefore, the results of the assessment for ‘all sectors’ incorporates the same magnitude of projected climatic changes and the same magnitude of demand changes as the Public Water Supply assessment. The adaptation pathways assessed also used the same approach, although the Public Water Supply assessment didn’t include the changes for the direct abstractions from non-PWS sectors (i.e. industry and commerce, agriculture and energy).

A key outcome of the Public Water Supply assessment is presented in the evaluation of the factors that contribute to the uncertainties in the analysis. Across all WRZs, the relative contribution of the different factors changes, meaning that in different WRZs, there may be different primary drivers of change. Similarly, in the ‘all sectors’ analysis, there are differences in the projected sensitivity of a catchment to a particular component of the analysis, depending on location:

- The most impacted regions in the UK with respect to supply-demand balance for the 2050s and 2080s, are projected to be the north of England, London and the south-east of England, see Figure 4.9 to Figure 4.12. Under a similar range of scenarios, the south-east of England and London and some catchments in the north and particularly to the east of England are impacted the most. Under higher climate and population scenarios and from the 2050s and 2080s and without additional adaptation, as impacts become generally more severe, there is a pattern of severe potential impacts of abstraction demand (of more than 150% of the available resource in the catchment) in all areas of the country, particularly in the east. In the west of the UK, many catchments have negative available resource in the 2050s and 2080s if EFI thresholds are 'Fixed' at current absolute flow rates. The same western catchments may be either severely impacted or have some resource available under other EFI scenarios.

- With respect to sensitivity to climate, the largest projected impacts in the 'all sectors' analysis are in the west of the UK due to the increased sensitivity of upland catchments to changing seasonality of rainfall. In the PWS analysis, the pattern is slightly different, Deployable Output in England is projected to be most impacted, particularly in the north and London. The patterns of sensitivity to climate differ slightly. This reflects the different metrics used. Public Water Supply evaluates the potential climate impact on Deployable Output (i.e. during specific design drought events) taking into account available water supply infrastructure and the results are presented in absolute values to reflect where additional water may potentially be required. The 'all sectors' analysis focuses on river flows and groundwater levels for specific flow percentiles (related to recent records, typically the most recent 18-year period) and is expressed as a percentage of the available flow as the tools used to calculate these results are focussed on a more holistic overview of water balance across catchments, rather than specific public water supply requirements.
- In the 'all sectors' analysis, catchments with high population growth projections face either increased impacts on average low flows or decreased impacts on low flows, depending on the location and the specific characteristics of the catchment. As a result, the catchment level impacts do not follow the pattern of population increases and decreases in the projections quite as closely as can be seen in the PWS detailed analysis even though the PWS growth factors are incorporated into the 'all sectors' analysis.
- Under both sets of analyses, decision-making, with respect to adaptation and EFIs can have a significant influence over both the projected reliability of Public Water Supplies and the relationship between available resource and abstraction demand at a catchment scale. Adaptation actions are shown to potentially have a positive influence over Public Water Supply reliability and helping to maintain an equitable balance between environmental and human uses of freshwater in the UK.

The greatest driver in the 'all sectors' analysis was the choice of EFI option taken. It was not possible to explicitly evaluate the impact of EFIs choices or any future associated changes to abstraction licensing on Public Water Supplies for this assessment. However, as shown in Section 4.2.6, current EFI threshold flow rates, if maintained at their current level, may result in no natural available resource in many catchments at average low flows. Whilst there is uncertainty in this analysis, this result is clearly impractical. However, it should also be borne in mind that the current EFI threshold is designed to protect the freshwater environment with respect to the requirements of the WFD and, therefore, any reductions in these flow rates may lead to reduced ecological quality of the UK's freshwater environment. This highlights an important dichotomy with respect to how to maintain and improve the freshwater environment and how to maintain clean and sustainable water supplies for human use.

7.2. Comparison to CCRA1 and Case for Change

7.2.1. The first Climate Change Risk Assessment

The first CCRA was published in 2012 and comprised analysis in eleven sectors, including the water sector. The first CCRA water sector analysis analysed 10 risks, prioritised from a list of over 50. The analysis covered three themes: pressures on water availability, water quality, and the deterioration of water company assets. The analysis used a standard method, developed for all the sectors evaluated in the first CCRA. The method involved the use of metrics: measures that are sensitive to climate and provide an estimate of the changing probability or consequences relevant to a given baseline whilst also being relevant to government policy and suitable for presentation at a national and/or regional scale. Similar to this assessment, the data used to inform many of the metrics in the first CCRA were drawn from the Water Resource Management Plans of the time, and UKCP09 climate projections. A fundamental difference between the two assessments is that the first CCRA aggregated the WRMP data to UKCP09 river basins prior to their use in any of the metrics. The metrics used in the CCRA1 water sector analysis and relevant comparisons to this analysis are:

- **Relative aridity.** A basic hydrological measure of how warm and dry the climate is relative to 1961-1990. This indicator showed increased aridity for all emissions and time periods (2020s, 2050s and 2080s) for the 'mid' and 'dry' scenarios. Only the 'wet' scenario for the 2020s and the 2050s (Low emissions only) showed any decrease in aridity. Relative aridity was the climate variable used for subsequent metrics, including Change in Q95, Change in Deployable Output and Change in the demand for water. While it was convenient to use relative aridity in this way, there were some limitations, notably that:
  - Hydrological responses depend on catchment characteristics and have a much more non-linear responses to climatic change than relative aridity. At the time, data from the Future Flows project that have fed into some aspects of this latest assessment, were not available.
  - For scaling outside of the available data set (i.e. the data from the water companies and draft Water Resources Management Plans), the following limits were applied to the linear relationships in CCRA 2012:
    - -20% for the 'wet' scenario;
    - -30% for the 'mid' scenario;
    - -40% for the 'dry' scenario.

    This means that for the 'mid' scenario, for example, estimates for decreases in DO can be no greater than -30%. These limits were based upon expert judgement at the time, taking account of the assumptions and caveats in the analysis, in particular the use of an annual aridity measure that does not reflect seasonal changes. It has not been necessary to make similar assumptions in this assessment, due to the difference in methodological approach taken.
- **Change in Q95.** This metric was based upon changes in the annual Q95 of river flows, by UKCP09 River Basin. The changes were found to be geographically variable, with generally larger decreases in Q95 in the south and east of the UK. It was noted that the response of individual catchments would be different from the region averages presented.
- **Change in Deployable Outputs (Ml/d or %).** This metric was estimated by relating the published water company Deployable Output with the relative aridity values from the first metric. Deployable Output declines as aridity increases. Similar to this work, this metric did not account for changes in the seasonal pattern, or inter-annual variability of rainfall. The results from CCRA1 suggested that there could be a

reduction of 3% (8 to -14%) in average Deployable Output in the near term (2020s), and reductions of 23% (-4 to -35%) in the longer term (2080s). Similar results from this assessment suggest projected reductions between -2% and -16%. It should be noted that the lower bound climate projections differ between the two assessments and the results presented here from this assessment refer to the aggregated country level projections, presented in Table 4.8.

- **Change in the demand for water (Ml/d or %).** This metric evaluated changes in domestic demand. The results suggested that the climate effect could increase average demands from 2% (2 to 3%) by the 2020s, to 5% (3 to 8%) by the 2080s. CCRA1 estimated climate-driven changes would be small relative to possible changes in the demand for water from population growth, industrial water use, household occupancy rates, property types and social attitudes to water use. This assessment has come to a similar conclusion. Population changes, particularly in already highly populated areas, is projected to have a large impact on Public Water Supply demand. Projections using different adaptation options indicate that social attitudes to water and per capita consumption rates could have a significant influence on demand. Due to the smaller scale of this assessment, compared to CCRA1, these newer results indicate a greater geographical variation in demand changes than was evident in the previous analysis. As a result, the range of demand is wider in this analysis, see Table 4.7.
- **Supply-demand deficits (Dry Year Annual Average design condition) (Ml/d or %).** The pattern of projected supply-demand deficits is approximately the same between the original CCRA analysis and this assessment, the greatest deficits are shown to be in England, particularly the London area and the north east. The differences are in the volumes of deficit calculated. In general, this assessment projects slightly less severe deficits than the first CCRA analysis. Adaptation also appears to have a larger influence than it did in the CCRA1 analysis, however, it should be noted that the 'Current objectives+' per capita consumption values in this analysis are more than 30 l/h/d lower than those used in the CCRA analysis.
- **Population affected by a supply-demand deficit (No. or %).** This CCRA1 metric has not been repeated in this analysis.
- **Number of sites meeting WFD Environmental Flow Indicators (No. or %).** This CCRA1 metric has not been repeated in this analysis. However, the 'all sectors' analysis has produced similar information by highlighting where catchments have negative available resource. At Q95, under a high climate change scenario, without considering any abstractions or discharges, more than 60% of catchments in the 2050s and 80% of catchments in the 2080s are projected to have negative available resource if EFI threshold rates are kept at the absolute value that they are today.
- **Number of sites with unsustainable abstraction (total) (No. or %).** This CCRA1 metric has not been repeated in this analysis.
- **As above for agricultural and industrial abstractions (No. or %).** This CCRA1 metric has not been repeated in this analysis.
- **The percentage of rivers with a net decline in ecological status – sanitary determinands.** This CCRA1 metric has not been repeated in this analysis.
- **Diffuse pollution.** This CCRA1 metric has not been repeated in this analysis.
- **Change in CSO spill frequency.** This CCRA1 metric has not been repeated in this analysis.

7.2.2. Case for Change

The Environment Agency developed their Case for change: current and future water availability report in 2011 in support of the UK Government's Water White Paper, Water for Life and proposals to reform abstraction licensing. In 2013 a refresh of the Case for Change (C4C) analysis was undertaken to incorporate the water demand from the electricity generation sector and updated demand forecasts relating to agriculture, industry and commerce, households and leakage. The C4C analysis also incorporated a new EFI threshold scenario, 'no deterioration' (see Table 2.4 for more details).

Some of the parameters from the socio-economic scenarios that informed the C4C refresh analysis have been used in this assessment. The 'Current objectives+' adaptation scenario used in this assessment has drawn upon:

- Sustainable behaviour scenario:
  - Per capita consumption volume;
  - Water demand values for the agriculture, industry and commerce and, energy generation sectors.
- Innovation scenario:
  - Leakage volume.

The results are not exactly the same as the 'all sectors' results are also driven by the Public Water Supply analysis and the climate and hydrological projections developed specifically for this assessment. Furthermore, the C4C published work presents the results at Q70 rather than average low flows. However, as a result of using the C4C scenario information, the results of the 'all sectors' analysis presents similar spatial patterns of impact to that shown in the C4C analysis.

7.3. Key Assumptions, Uncertainties and Evidence Gaps

This section summarises the key assumptions, uncertainties and evidence gaps identified as part of this project.

7.3.1. Population projections

For population, three scenarios presented in Table 7.1 have been evaluated to reflect a central, principal estimate of future population along with upper and lower bound estimates, taken as the Office of National Statistics' (ONS) high and low fertility storylines (refer to Appendix B for details).

The ONS population projections are provided as local authority area projections to 2037 and national projections to 2100. The method used for this study to provide WRZ population projections for the 2050s and 2080s under the selected ONS variants is presented in Appendix B.

The underlying ONS population principal and variant projections should not be interpreted as forecasts but present plausible futures of population growth. In addition, the attribution of national population growth, beyond 2037 to the local scale has adopted the 'signal' of relative growth patterns suggested by the local authority principal projections and actual growth in specific areas may be significantly different.

Table 7.1: Population projections.

Population Scenario	Description
Principal population projection	ONS principal projection
Low population projection	ONS Low Fertility variant
High population projection	ONS High Fertility variant

Source: Population projections adapted from ONS (2014, 2013a-l); National Records of Scotland (2014); Welsh Government (2013); and, Northern Ireland Statistics and Research Agency (2013).

7.3.2. Projecting climate change impacts on water availability

For climate change, the three scenarios presented in Table 7.2 have been considered to provide a central estimate along with upper and lower bound estimates.

Table 7.2: Climate change projections.

Climate change Scenario	Description
Low climate change projection	Taken as a reasonable ‘lower bound’ estimate (low emissions, 10th percentile) from the 10,000 UKCP09 ensemble scenarios
Medium climate change projection	Taken as a reasonable ‘central’ estimate (medium emissions, 50th percentile) from the 10,000 UKCP09 ensemble scenarios
Low climate change projection	Taken as a reasonable ‘lower bound’ estimate (low emissions, 10th percentile) from the 10,000 UKCP09 ensemble scenarios

Source: n/a

Impacts on availability of Public Water Supplies

Typically, hydrological and water resources modelling is undertaken by the water companies for their resource management planning. This was not possible for this study. Instead, the outputs from the resource management plans have been extrapolated to the 2050s and 2080s using a simple ‘emulator method described in Appendix A. In interpreting these results, the following points should be noted:

- The method used has not involved the direct use of water resources models and hydrological/groundwater models at specific abstraction sites. Therefore, the approach has not included all the details of infrastructure and licence constrains, complex operating rules (e.g. reservoir control curves) or the detailed modelling of design events.
- The method used has been based on the relationship between the impacts reported by the water company resource plans and the change in hydrological indicators due to climate change using the UKCP09 climate change projections described in Section 2. Therefore, this approach is not able to capture non-linearities (or “tipping points”) in the system beyond those already reflected in the estimates produced by the water companies as part of their plans. This also means that those WRZs that report no climate change impacts at the end of their plan will not be shown to have any impacts projected by the 2050s and 2080s.
- The method is considered an improvement on the method adopted for CCRA1 (where future projections were largely based upon a defined relationship between relative aridity and Deployable Output) but it will still not be able to capture critical threshold values such as, for example, capturing the impacts from those sources which may not be considered drought susceptible at the end of the WRMPs but could become so by the 2080s.
- It is also worth emphasising that different water companies may have adopted different assumptions and approaches to estimating the components of their supply-demand balance and, whilst the plans themselves may be considered to be broadly consistent given the regulatory process to which they are subjected, such differences may become more significant when projecting future impacts.

Consequently, there is potentially significant uncertainty associated with these estimates, particularly by the 2080s under a high climate change impacts future which is a significant ‘extension’ of the water company resource plan outputs. To assess the potential significance of adopting this ‘emulator’ approach compared to a more detailed simulation modelling method, four case studies have been modelled and examined in more detail as described in Appendix E. Based on this comparison, the emulator method used to estimate climate change impacts is considered appropriate to provide a reasonable first estimate of climate change impacts on Deployable Output for regional and national level climate change risk assessments. However it is not a substitute for the detailed modelling, at the more localised scale, typically undertaken by water companies as part of their resource planning.

Assessment of 'all sectors'

The assessment of 'all sectors' is based upon the existing WRGIS tool, for England and Wales, and two new WRGIS-lite tools for Scotland and Northern Ireland. The tools are not hydrological or hydrogeological models. Instead, they calculate the balance of water at a catchment scale using input data on natural river flows and artificial influences such as abstractions and discharges. Whilst the input datasets used are nationally recognised and regularly updated and improved, the calculation of the impacts of abstraction and other flow pressures on natural flows is dependent on the quality of these input datasets.

Quantifying the balance between available resource and demand for abstraction is complex. Numerous assumptions and simplifications have been made in the calculations. These are listed in Table 2.6. Furthermore, the baseline data are not from the same years. Generally either 1961-1990 or 2007-2013, the values for 1961-1990 are factored to create a consistent baseline estimate. In addition, all of the caveats and assumptions made during the analysis of changes in climate and hydrology and assessment of public water supply in Tasks 1, 2, and 3.1, are also applicable as outputs from these tasks and feed into this part of the analysis.

Subsequently, the results of this task should be treated as sensitivity analysis i.e. the results provide a rough order of magnitude on the levels of surplus or deficit for different catchments given a particular future scenario rather than as an accurate or specific measure of currently available resource at a particular point in time.

7.3.3. Adaptation assumptions

In addition to the Adaptation Pathways presented in Table 5.1, adaptation has also been considered using the list of feasible and preferred options published by the water company resource plans. The list of *feasible* and *preferred* options, only available for WRZs in England and Wales, has been based on outputs provided from the Environment Agency's Strategic Water Infrastructure and Resilience project and a review of the water company resource plan tables provided by the water companies as part of this project. For the purposes of this evaluation, all options are considered to be available in the 2050s and 2080s and that the potential Water Available For Use (WAFU) listed for each option in the water company resource plan tables is considered to be fully available at those times. Further to this, it should be noted that water companies only consider a 25 year planning horizon and therefore there are potentially additional options available, above and beyond those reported in the latest WRMP process and considered here. These could including increased sharing of water, effluent re-use and the potential to provide additional above ground (reservoirs) or below ground storage (i.e. aquifer recharge) to capture increased winter flows.

It should also be noted that the analysis presented in this study has not been able, due to lack of readily available evidence, to consider how changes in competition and markets (trading etc.) might affect future risks nor the potential implications of the resilience duty.

The transitioning of public water supply licenses due to reform of the abstraction licensing system has also not been considered as part of the PWS analysis, as at the time of this study, it is anticipated that intention is that the reliability of public water supplies would be no worse due to transitioning process.

References

Acreman, M. C., Dunbar, M. J., Hannaford, J., Bragg, O. M., Black, A. R., Rowan, J. S., King, J. (2006) Development of environmental standards (water resources). Stage 3: environmental standards. SNIFFER project WFD48. Scotland and Northern Ireland Forum for Environmental Research, Edinburgh.

Allen, D.J., Brewerton, L.J., Coleby, L.M., Gibb, B.R., Lewis, M.A., MacDonald, A.M., Wagstaff, S.J., and Williams, A.T. 1997. The physical properties of major aquifers in England and Wales. British Geological Survey Technical Report, WD/97/34. British Geological Survey, Keyworth, Nottingham.

AMEC (2011) Water Resource Assessment and Management (RAM) Framework. Environment Agency. Online: http://amec-ukenvironment.com/downloads/pp_500.pdf [Accessed: 07/04/215].

Bloomfield and Marchant (2013) Analysis of groundwater drought using a variant of the Standardised Precipitation Index. Hydrology and Earth Systems Science 17, 4769-4787.

Charlton, M.B. and Arnell. N.W. (2011) Adapting to climate change impacts on water resources in England - an assessment of draft Water Resources Management Plans.

Environment Agency (2005). Underground, under threat. The state of groundwater in England and Wales. Environment Agency, Bristol.

Environment Agency (2011) The case for change – current and future water availability. Environment Agency Report No: GEHO1111BVEP-E-E.

Environment Agency (2015) *Drought response: our framework for England*. Online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/440728/National_Drought_Framework.pdf [Accessed: 05/08/215].

Environment Agency, OFWAT, Defra and Welsh Government (2012) *Water resources planning guideline. The technical methods and instructions.* Online: http://webarchive.nationalarchives.gov.uk/20130206062158/http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/lit_6932_56bc01.pdf [Accessed: 10/04/2015].

Environment Agency and Natural Resources Wales (2013) Current and future water availability – addendum. A refresh of the Case for Change analysis. Report LIT8951.

Murphy, J.M., Sexton, D.M.H., Jenkins, G. J., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Humphrey, K.A., McCarthy, M.P., McDonald, R.E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R.A., (2009) UK Climate Projections Science Report: Climate Change Projections. Exeter, UK: Met Office Hadley Centre.

McKee, T.B., Doesken, N.J. and Kleist, J. (1993) The relationship of drought frequency and duration to time scales. *Eight Conference on Applied Climatology*. 17-22 January 1993, Anaheim, California.

NERA. (2012) A Non-Essential Use Drought Order for London: Economic Impact Assessment.

Prudhomme, C., Crooks, S., Jackson, C., Kelvin, J., Mackay, J. and Young, A. (2012a) Future Flows and groundwater levels. Final report - Science Report/Project Note – SC090016/PN9 p. 90, CEH, Wallingford.

Rance, J., Wade, S.D., Hurford, A.P., Bottius, E. and Reynard, N.S. (2012) CCRA Risk Assessment for the Water Sector. UK 2012 Climate Change Risk Assessment, Defra, London.

National Records of Scotland (NRS) (2014) 2012-based Population Projections Scotland, Tables, 2012-2037, [www.gro-scotland.gov.uk].

Northern Ireland Statistics and Research Agency (2013) Population projections for areas within Northern Ireland, 2012-2037, [www.nisra.gov.uk].

Office for National Statistics (2014) 2012-based National Population Projections, 1951-2087, [www.ons.gov.uk].

Office for National Statistics (2013a) 2012-based National Population Projections High Fertility variant projection, **England**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013b) 2012-based National Population Projections High Fertility variant projection, **Wales**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013c) 2012-based National Population Projections High Fertility variant projection, **Scotland**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013d) 2012-based National Population Projections High Fertility variant projection, **Northern Ireland**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013e) 2012-based National Population Projections Low Fertility variant projection, **England**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013f) 2012-based National Population Projections Low Fertility variant projection, **Wales**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013g) 2012-based National Population Projections Low Fertility variant projection, **Scotland**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013h) 2012-based National Population Projections Low Fertility variant projection, **Northern Ireland**, 2012-2112, [www.ons.gov.uk].

Office for National Statistics (2013i) 2012-based Subnational Population Projections for Local Authorities in England, 2012-2037, [www.ons.gov.uk].

Welsh Government (2013) 2011-based local authority population projections for Wales, 2011-2036, [www.statswales.wales.gov.uk].

Appendices

A. Method used

B. Method for deriving population projections

C. Data inventory

D. Additional results

E. Case studies

F. List of supporting documents

HR Wallingford is an independent engineering and environmental hydraulics organisation. We deliver practical solutions to the complex water-related challenges faced by our international clients. A dynamic research programme underpins all that we do and keeps us at the leading edge. Our unique mix of know-how, assets and facilities includes state of the art physical modelling laboratories, a full range of numerical modelling tools and, above all, enthusiastic people with world-renowned skills and expertise.

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