HR Wallingford
Working with water

Updated projections of future water availability for the third UK Climate Change Risk Assessment

Technical Report

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Executive summary

The Committee on Climate Change commissioned HR Wallingford to produce a set of UK-wide water availability projections to inform the CCRA3 Evidence Report. These water availability projections for the UK are the first of their kind to use the UKCP18 Climate Projections.

Following extensive data review and preparation, this analysis comprises an assessment of the impacts to public water supplies (PWS) and an assessment of the impacts to all water using sectors ('all sectors').

Headline results and messages

All sectors

In terms of overall catchment water availability at average low flows, no factor has a greater influence on the water available for the environment than the environmental flow policy. Catchments in the west of the UK, particularly in Wales, are most likely to be unable to achieve existing environmental flow volume targets in a future 4°C world.

- Projected changes in river flows will act upon the water available for abstractors and water available for the environment alike:
  - Projected changes in river flows at Q95 across the UK are of the order of 0-20% reduction by the mid-century in a 2°C world everywhere except the western highlands in Scotland (where flows increase). In a 4°C world, this reduction increases (up to 30% flow reduction) in some areas, such as Wales, the Severn and Tweed river basins.
  - Projected changes in river flows at Q95 across the UK are of the order of 0-50% reduction by the late-century in a 4°C world.
- Projected changes in river flow will influence the naturally available resource at Q95 that is available for both large and small abstractors (i.e. those with and without abstraction licences). Where the policy is to keep the environmental flows fixed at the same absolute volume that they are today, many of the catchments across England, Wales, some in Scotland and one in Northern Ireland are unable to meet their environmental flow requirements without the addition of discharges to the river network.
- Catchments at risk of negative available resource i.e. not being able to meet the fixed volume environmental flow requirement tend to be along the west coast of Great Britain, where the reductions in low flows tend to be greatest, with a significant number of the catchments in Wales affected under this scenario.
  - In the mid-century (4°C world, central population projection and current and announced adaptation scenarios) 22 catchments across the UK (the majority in Wales), are projected to have negative resource availability i.e. the current absolute volume of environmental flow could not be met.
  - In the late-century (4°C world, central population projection and current and announced adaptation scenarios) 74 catchments across the UK many in Wales plus others in the south west of England, far north of England, western Scotland, are projected to have negative resource availability i.e. the current absolute volume of environmental flow could not be met.
- Catchments that are at risk of over-abstraction tend to be located in the south and east of the UK (although there are some exceptions in the north and west of the country).

- Adaptation in non-public water supply sectors may not equate to reduced water use. For example, new technologies in the energy sector or increases in fruit and vegetable production may require more water than is currently required. This impact will likely be greater the more the population grows.

Public Water Supplies

Current supply-demand balance

Although at a country level, each of the four countries that make up the UK operate a supply-demand balance surplus, some deficits already exist in some water company water resource zones. Without the actions already being taken by water companies, these zones would not be able to offer the level of resilience to drought specified by the current water resource plans.

- The UK currently operates a supply-demand balance surplus of around 950Ml/d.
- All four countries in the UK currently maintain a supply-demand balance surplus although at a water resource zone scale, some deficits already exist in water companies baseline plans.
- In the UK as a whole, current demand for public water from all users is over 17,000 Ml/d:
  - Household demand accounts for around 55% of all water demand.
  - Non-household demand and leakage account for around 20% of all water demand each.
- England accounts for around 80% of the UK’s demand for public water supplies; a reflection of the larger population.
- Household consumption in the UK accounts for more than half of the demand for public water supplies.
- Leakage and non-household demand in the UK are of a similar magnitude and account for a little over 20% of the total demand each.

Mid-century supply-demand balance

Changes in supply due to climate change and changes in demand due to population growth may lead to deficits across many water resource zones in the UK. The vast majority of zones impacted would be in England, with those in the south east the worst affected. Reducing household consumption and leakage from networks can significantly reduce the projected deficits; often, but not always, eradicating them.

- Across all of the scenarios the UK level supply-demand balance ranges from a deficit of around 2,740Ml/d to a surplus of around 4,620Ml/d:
  - This range is driven by the adaptation and population scenarios used.
  - Between around 200 – 470Ml/d of impact may be attributed to climate change, under the 2°C and 4°C worlds simulated.
- Under central population projection growth and no additional demand-side adaptation actions the deficit across the UK as a whole is projected to be between around 650 and 920 Ml/d (2°C to 4°C range):
  - The vast majority of this impact is realised in England. High population growth and no additional demand-side adaptation action may lead to deficits in Wales too.
  - In a 4°C world, Water Resources South East, Water Resources North and Water Resources East are all projected to have deficits if the central population projection is followed and no additional demand-side adaptation action is taken.

- Under the central population growth and current and announced demand-side adaptation scenario, the UK level supply-demand balance surplus ranges from 1,860Ml/d to 2,120 Ml/d, under the 2°C and 4°C worlds simulated. All countries in this scenario are in surplus. All regions, except for Water Resources South East in a 4°C world, are in surplus. At a Water Resource Zone scale, deficits may still exist.
  - The current and announced demand-side adaptation scenario is not sufficient to mitigate the projected impacts in Water Resources South East in a 4°C world but the additional demand-side adaptation scenario is.

Late-century supply-demand balance

Climate impacts on water supply are greater in the late-century compared to the mid-century. Population changes affecting demand, similarly, place additional pressure on water resources leading to increased deficits across water resource zones in the UK, which are greatest in England. Reducing household consumption and leakage from networks is unlikely to be sufficient to return all water resource zones to a surplus.

- Across all of the scenarios the UK level supply-demand balance ranges from a deficit of around 5,570Ml/d to a surplus of around 3,200Ml/d:
  - This range is driven by the adaptation and population scenarios used.
  - Between around 210 – 1,890Ml/d of impact may be attributed to climate change, under the 2°C and 4°C worlds simulated.
- Under central population projection growth and no additional demand-side adaptation actions the deficit across the UK as a whole is projected to be between around 1,220 and 2,900 Ml/d (2°C to 4°C range):
  - The deficit is driven by England. The Wales region, Northern Ireland and Scotland all maintain a surplus supply-demand balance under these scenarios. However, the combined surplus is not sufficient to counteract the deficits located primarily in England even if the infrastructure to transfer the water was available.
  - High population growth and no additional demand-side adaptation action may lead to deficits in Scotland, Wales and Northern Ireland too.
- Under the central population and current and announced demand-side adaptation scenario, the UK level supply-demand balance ranges from a deficit of around 70Ml/d to surplus of around 1,610Ml/d, under the 2°C and 4°C worlds simulated. In a 4°C world, it is the deficit in England (~910Ml/d), that causes the deficit at a national scale. All other countries remain in surplus through these particular scenarios, although at a smaller scale, deficits may still exist.
- England is affected by changes in climate more so than other countries due to the fact that so many more of the abstractions are already constrained by the yield of the water source (rather than other constraints such as infrastructure or licence).
- The climate modelling undertaken for the majority of the water resource zones in Wales and all those in Northern Ireland by water companies may not have identified thresholds in sensitivity to climatic changes that only appear in the second half of the century.
- Demand-side adaptation actions alone are unlikely to be sufficient to solve the deficits faced in all water resource zones. Even under the additional demand-side adaptation scenario which uses more ambitious leakage and per capita consumption targets, some water resource zones (mainly in England) are still projected to be in deficit.

Drought resilience

- Increasing the level of drought resilience in England to protect to a ~1 in 500 year drought event is projected to result in a reduction in England's deployable output of around 1,140 Ml/d, more than 2.5 times the present day surplus.

Water supply options and residual risks

Future surpluses may not be sufficient to 'solve' future deficits via transfers. Adaptation programmes are likely to require a combination of demand-side measures, supply-side measures and transfers.

- Inter-regional transfers may not be sufficient to ensure secure water supplies between regions.
- Where there are significant increases in demand projected in both the donor and recipient regions, a transfer of water may lead to greater deficits and reduced surpluses in the donor region without solving the deficits in the recipient region.
- In the assessment of the feasibility and sustainability of any transfer, the needs of both the donor and recipient zones / regions, at least to late-century, should be considered together.

Key datasets and approaches

Data review and preparation:

- **Climate change:** The UKCP18 global projections have been used to project future changes in climate. Results are usually presented in terms of a 2°C or 4°C (by 2100) where the values presented represent the 50th percentile value of all the simulations undertaken:
  - It is notable that some of the UKCP18 Global Projections fall outside the range of the UKCP18 Probabilistic Projections. In particular, some of the projections are hotter and drier, particularly in Autumn, often an important month in water resource systems. This, along with spatial coherence, contributed to the choice of the UKCP18 Global Projections for this assessment.
- **Population scenarios:** The central and high population scenarios developed by Cambridge Econometrics (2019) have been used to guide population change on a water resource zone, regional or country scale. A no population change projection has also been used:
  - It is notable that the central population projections provided by the Office for National Statistics and the those used by Water Companies for their water resource plans can differ (some significantly).
- **Flow scenarios:** Future Flows and UKCP18 global projections have been used to project future changes in river flows for Great Britain; surrogate flows from catchments in Scotland are used for flow changes in Northern Ireland. These are subsequently used for assessing 'impacts on all sectors' only.

Public Water Supplies

- **Impact on public water supply**: Impacts on water supplies are informed by the latest water company resource plans including the climate change scenario modelling completed by water companies to underpin their plans.
- **Impact on public water demand:** Impacts on water demand are informed by the latest water company resource plans and building upon a modelling framework developed for Water UK (Artesia).

Impact on all sectors, including the environment

The Environment Agency's WRGIS tool and similar tools developed for CCRA2 (HR Wallingford, 2015) are used to estimate the potential impacts at a catchment scale; informed by Wood (2020) for Defra and the earlier tasks in this assessment.

Comparison with CCRA2

The present day surplus reported in CCRA2 was around 2,000Ml/d. The primary reason for the reduction in present day surplus reported in this assessment is due to a change in the way that water companies, particularly in England and Wales, are accounting for climate change in their latest Water Resource Management Plans 2019. As a general rule, the methods and evidence base are improving, and the results presented here reflect an improvement in our understanding of the current level of risk.

The differences between the all sectors analysis presented in CCRA2 compared to similar results presented in this assessment are relatively small. These small differences reflect the changes in climate, population and adaptation scenarios. However, the most significant variable influencing the availability of water for all water users, and the environment, at a catchment scale, is still the policy on environmental flow that is applied.

Whilst the assessment methodology for CCRA2 and CCRA3 on water availability are similar, they differ in a number of key areas:

- Underpinning climate evidence.
- Underpinning public water supply evidence.
- Population projections.
- Adaptation scenarios for public water supplies and other sectors.
- Approach to deriving water resource zone sensitivity to climate change.
- Approach to deriving water resource zone demand projections.
- Combination of scenario tested.
- Presentation of climate change results in terms of 2°C and 4°C worlds.

Suggested citation

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Glossary

2°C and 4°C Worlds

A 2°C or 4°C world refers to the estimated level of impact in the UK when mean global warming by 2100, relative to pre-industrial temperatures, is at 2°C or 4°C.

Abstraction

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

Abstraction licence

The authorisation granted by regulating authorities to allow the removal of water from a source.

Adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

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.

Bias correction

Climate models contain systematic differences between results and observed data. Bias correction attempts to account for these differences by adjusting the modelled data in some way. Multiple methods have been developed, each with their own benefits, limitations and implicit assumptions. There is significant scientific debate around whether and how to apply bias-correction and there is currently not a single, accepted way of bias-correcting climate model outputs.

Bulk supply import/export

Volume of potable water imported or exported to/from another water company.

Confidence

A confidence score of low, medium or high is associated with each set of projections made in this assessment. The score is based upon the following definition:

- 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 (for example, agricultural irrigation).

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 abstracted 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.

Drought

Mishra and Singh (2010) define drought in a number of ways. Those that are relevant to this assessment include:

- Meteorological drought is defined as a lack of precipitation over a region for a period of time.
- Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system.
- Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water).

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.

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. There is a nationally consistent flow screening approach in the UK based on environmental standards set out by Sniffer project WFD48 (Sniffer, 2006) and by the UK Technical Advisory Group for the Water Framework Directive (UKTAG, 2008a,b, 2013). All regulatory bodies in the UK use indicators of environmental flows to support Good Ecological Status, or Good Ecological Potential for Heavily Modified Water Bodies (HMWBs).

Environmental Flow Indicators (EFI)

Following the 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.

Household demand (HH)

Total volume of water from public water supplies used by a household excluding supply pipe leakage but including leakage that occurs within the property boundary. Household consumption may be metered or un-metered.

Ml/d

Megalitres per day. A common unit of measurement in water resources. One megalitre is equivalent to 1,000,000 litres.

Naturally 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.

Non-household demand

Total volume of water from public water supplies used by non-household customers e.g. businesses, schools etc. Excludes supply pipe leakage but including leakage that occurs within the property boundary. Non-household consumption is usually metered.

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.

Public Water Supplies (PWS)

All water supplies provided by a water company.

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) and such flows would normally be expected in the summer (for around 18 days per year on average, although this can vary considerably from year to year). In this assessment, Q95 refers to the 30-year annual average Q95 unless specified otherwise.

Other Q statistics are also used in this work and follow similar principles to Q95. Qn refers to the natural flow, without artificial influence from abstractions or discharges.

Return period

A return period is an estimate of the average time between events, such as a specific type of drought or flood. A 1 in 200 year event has a 1/200 = 0.005 or 0.5% chance of being exceeded in any one year. In WRMP19 most water companies estimated the severity of a 1 in 200 year drought event and a 1 in 500 year event: 1 in 500 means there is a 5% chance of it happening over a 25 year period (1 in 200 is 12%).

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 and including the uncertainty buffer (Target Headroom) that water companies apply to their assessments.

Spatial coherent

A characteristic of some of the UKCP18 Climate Projections that enables the user to explore the impacts that may occur at two or more different locations at the same time. This is useful when considering the impacts on physical systems such as river catchments that may cross the geographical units provided by UKCP18. The UKCP18 probabilistic projections are not spatially coherent, the UKCP18 Global and Regional Projections are spatially coherent.

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- or 6-yearly cycle:

- Water Resource Management Plan (WRMP) (England and Wales.
- Water Resource and Supply Resilience Plan (WR&SR Plan) (Northern Ireland).
- Water Resource Plan (WRP) (Scotland).

All water companies aim to produce a baseline plan (no interventions to deal with any deficits) and final plan (to account for any projected supply-demand deficits).

Water Available For Use (WAFU)

Refers to Total WAFU: The Deployable Output plus bulk supply imports, less bulk supply exports and less reductions made for sustainability reductions, 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.

Contents

Figures

Tables

1. Introduction

The third UK Climate Change Risk Assessment (CCRA3) will be published by the Government in January 2022, and the Department for Environment, Food and Rural Affairs (Defra) and Devolved Administrations asked the Committee on Climate Change (CCC) to produce an accompanying Evidence Report by summer 2021. The CCC commissioned HR Wallingford to produce a set of UK-wide water availability projections to inform this Evidence Report. To meet the requirements set out by Defra and the Devolved Administrations this analysis must be:

- To 2100.
- Consistent with 2°C / 4°C degrees of mean global warming by 2100.
- Spatially coherent.
- Consistent with the latest water resource plans.
- Use the UKCP18 Climate Projections.
- Use the socio-economic dimensions developed by Cambridge Econometrics (2020).
- Assess adaptation using scenarios of possible futures.
- Evaluate the relative contribution of climate change and socio-economic factors.
- Consider sensitivity / levels of confidence / urgency.

This report records the main findings of this analysis, structured according to the chapters that will form the CCRA3 Evidence Report. For each chapter, relevant results from this assessment are presented to provide understanding of the level of risk, or, alternatively, to provide context and background to a risk. Where results may be of interest to more than one chapter, this is sign-posted in the text, rather than the discussion and results being repeated.

2. Approach

2.1. Method

The methods used to produce these water availability projections are summarised in Appendix C. For quick reference, Figure 2.1 and the content of this section, briefly describe the key datasets and approaches that were used in this analysis.

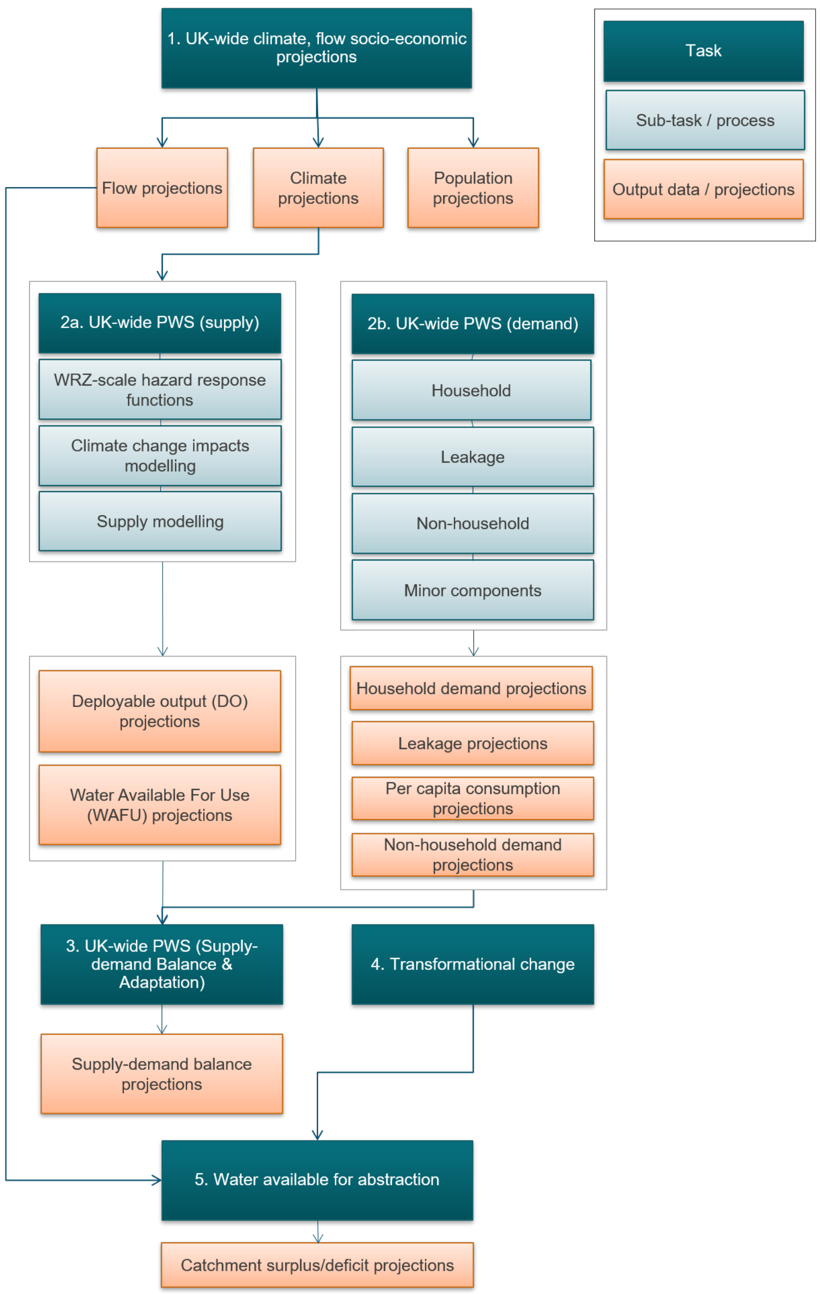

Figure 2.1: Simplified overview of CCRA3 water availability method

Notes: See Appendix C for more details.

2.1.1. Task 1: UK-wide climate, flow and socio-economic projections

This task involved data review and preparation. It comprises three main data sets:

- **Climate change**: This is the first assessment of its kind to use the new UKCP18 Climate Projections. The UKCP18 global projections have been used to project future changes in climate. Results are presented in terms of a 2°C or 4°C (by 2100) where the values presented represent the 50th percentile value of all the simulations undertaken (i.e. both CMIP5 and PPE members of the UKCP18 Global Projections). A few results are presented in terms of a “PPE” 4°C world where the 50th percentile value of only simulations using the UKCP18 Global projections PPE members (based on the latest Met Office Hadley Centre model) have been used to estimate the impacts.
- **Population scenarios**: the central and high population scenarios developed by Cambridge Econometrics (2019) for the CCRA3 project have been used to guide population change on a water resource zone scale. A no population change projection has also been used in order to evaluate the impact of climate change without a change in population.
- **Flow scenarios**: Future Flows and UKCP18 global projections have been used to project future changes in river flows for Great Britain; surrogate flows from catchments in Scotland are used for flow changes in Northern Ireland. These are subsequently used for assessing impacts on other sectors only; these estimated changes in river flows are not used in the public water supply part of the analysis.

2.1.2. Task 2a: UK-wide public water supply, supply-side assessment

The impacts on public water supplies are informed by the latest water company resource plans[1] and the climate change scenario modelling completed by water companies to underpin their plans[2]. For the majority of WRZs, the climate change scenario modelling completed by water companies is used to develop multiple linear regression models between the relevant climate variables and deployable output (the data are split to calibrate and validate the models). This relationship is then used to project the impacts on public water supplies using the UKCP18 Global Projections, see Figure 2.2. For a few WRZs with insufficient data to develop such relationships, impacts have been quantified either using simulation modelling or by scaling to appropriate donor WRZs.

The underpinning data and methods to evaluate the impact of climate change on deployable output used by water companies varies. For example, in the majority of England[3], Scotland and the SEWCUS WRZ in for Dwr Cymru, water companies reviewed the impacts on deployable output from climate change to the 2080s. The rest of Wales, Northern Ireland, Severn Trent Water’s sensitive zones reviewed their climate change impacts to earlier time periods (2030s for most, 2020s for Northern Ireland). The significance of this is that, this analysis is reliant on the relationship between deployable output and climate change identified by the water companies’ analysis. Where earlier time periods have been used, the climate signal may not be strong enough to identify thresholds or tipping points at which climate change becomes a significant issue. As a result, the water resource zone may not be sensitive to climate change in this assessment either.

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[1] Published WRMP19 draft plans for England and Wales and unpublished (at the time of writing) draft plans from Northern Ireland and Scotland.

[2] In a few instances, data were not available and alternative approaches, surrogate or older data have had to be used. More detail on the alternative approaches are provided in Appendix C.2 .

[3] Excluding Severn Trent Water’s zones. Where considered sensitive to climate change, the analysis was completed to the 2030s.

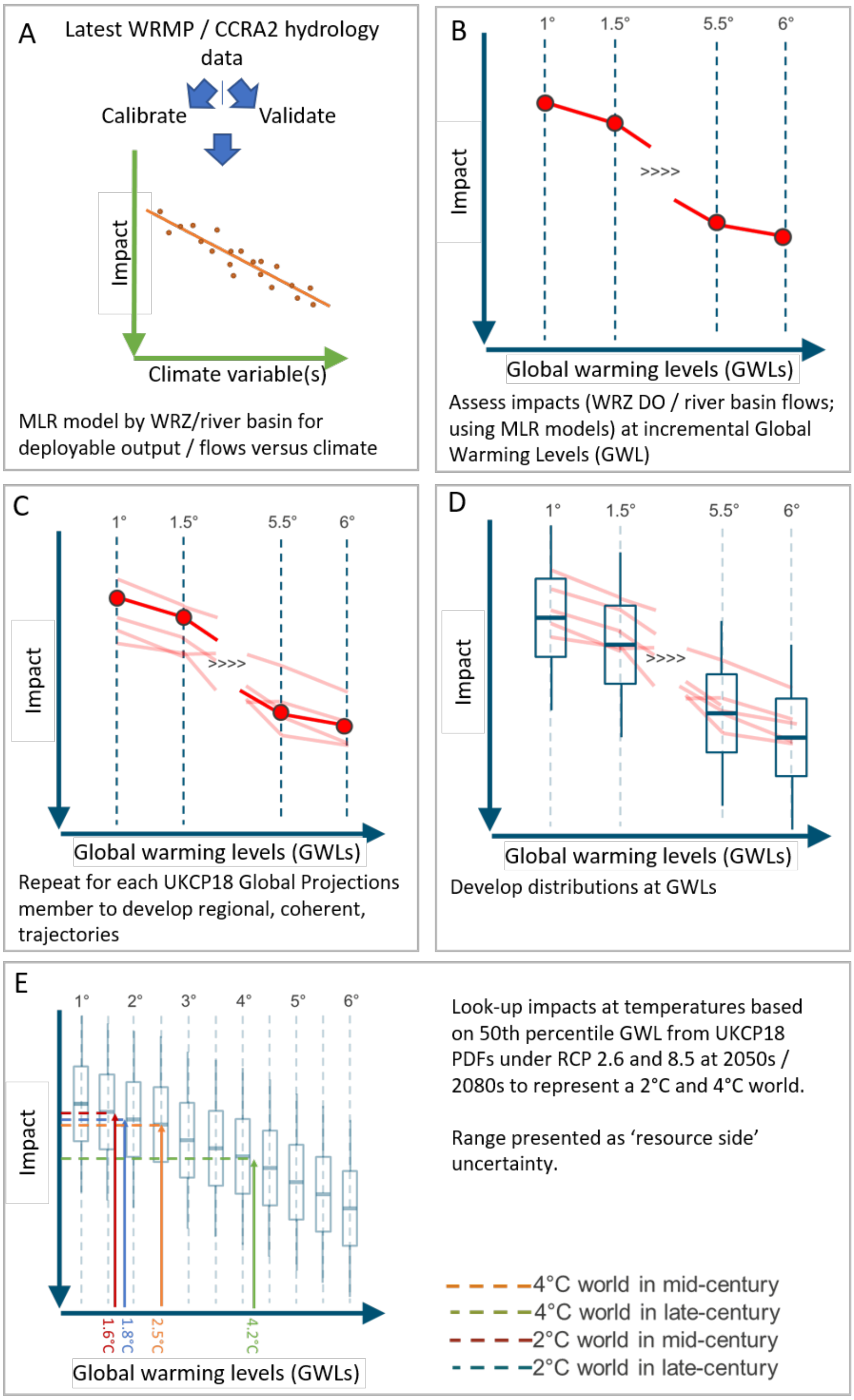

Figure 2.2: Method used to assess impact of climate change on river flows and deployable output using the UKCP18 climate projections

Source: n/a.

2.1.3. Task 2b: UK-wide public water supply, demand-side assessment

The impacts on water demand are informed by the latest water company resource plans[4] and build upon a modelling framework developed for Water UK and OFWAT (Artesia, 2018, 2019). Projected changes in demand according to three adaptation scenarios, see Table 2.3 are calculated for the mid- and late-century:

- **Household projections**: household level consumption analysis is undertaken, taking account of how occupancy and other household factors (such as measured or unmeasured meter status) affect the micro-components of water use (WC flushing, showering, clothes washing, drinking, etc.). Per capita consumption is calculated by dividing the household consumption by the occupancy (i.e. number of people).
- **Non-household projections**: non-household demand projections follow the latest water resource plans until the end of the 2044/45 (using the final plan figures from the water resource plans in England and Wales and baseline plans in Scotland and Northern Ireland) and are then kept fixed until the end of the century.
- **Leakage**: Leakage projections are based upon the latest water resource plans with different interventions applied depending upon the adaptation scenario in question and scaled accordingly to the population.
- **Minor components:** This represents the 'other demand' not covered by household, non-household or leakage. Projections follow the latest water resource plans until the end of the 2044/45 (using the final plan figures from the water resource plans in England and Wales and baseline plans in Scotland and Northern Ireland) and are then kept fixed until the end of the century.

2.1.4. Task 3: UK-wide public water supply, supply-demand balance projections and adaptation

The impacts on public water supplies and demand come together for the quantification of the supply-demand balance at the water resource zone, regional and Devolved Administration scales. In order to calculate the regional and Devolved Administration level supply-demand balance, the water resource zone supply-side results were summed (for each climate change scenario considered) and the 50th percentile impact was used in conjunction with the sum of the demand-side results to compute the supply-demand projection for a given scenario (see Table 2.1 and Table 2.2). The supply-demand balance results at a regional or Devolved Administration scale are therefore not simply the sum of the supply-demand balance results of the relevant water resource zones.

The effects of different combinations of population, climate change, adaptation (demand-side measures only) scenarios on the supply-demand balance are estimated. Values, such as Target Headroom and sustainability reductions[5] reported in the water resource plans at the appropriate time-horizons have been maintained. Deficits occur when demand for water outstrips the available supply (including Target Headroom).

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[4] Published WRMP19 draft plans for England and Wales and unpublished (at the time of writing) draft plans from Northern Ireland and Scotland.

[5] Sustainability reductions are the reductions in licenced volume that water companies are allowed to abstract, applied by environment regulators. This reduction is driven by the need to protect the environment. The vast majority of sustainability reductions to date have been applied in England.

Also, in this task, the potential reduction in supply-demand balance due to the provision of enhanced drought resilience is calculated.

Furthermore, until this step, only demand-side adaptation measures are considered in the analysis. This is consistent with the way in which measures tend to be considered in water company WRMPs. However, water companies also consider supply-side adaptation measures and transfers along with future enhancements to levels of drought resilience provided to customers. The feasible and preferred supply-side options from the latest water resource plans and the transfers between regions are separately and jointly applied to the supply-demand balance to estimate the potential residual deficits that may occur, should these options be implemented in the future.

2.1.5. Task 4: Transformational change and Task 5: Water Available for Abstraction

Referred to as the "all sectors" analysis, the WRGIS tool and WRGIS-lite tools developed/used for CCRA2 (HR Wallingford, 2015) are used to estimate the potential surplus or deficit in water at a catchment scale. The WRGIS was the primary tool for undertaking national assessments of abstraction pressures and water availability in England and Wales including surface flow analysis for the Water Framework Directive. The tool is still used in England but is no longer used in Wales and therefore the version of the tool used in CCRA2 is used for this assessment as well. A similar spreadsheet-based tool for Scotland and Northern Ireland was created for CCRA2, known as WRGIS-lite.

The WRGIS tools estimate the influence of the environmental flow indicator (EFI), abstractions (from all consumptive abstractions) and discharges on the flow left in a water body, aggregated to a catchment scale. Where the abstractions plus discharges are above the designated environmental flow volume, then the waterbody/catchment is in surplus. Where the abstractions plus discharges are below the designated environmental flow volume, then the waterbody/catchment is in deficit.

The manner in which abstractions change in the future is informed by Defra (2020) for non-public water supply sectors and earlier tasks in this assessment for the public water supply sector. Note that the aim for the additional adaptation scenario is to use an ambitious scenario of adaptation for a particular sector, then scaled to the population. However, for agriculture and energy in particular, an ambitious adaptation scenario (which may include mitigation measures) i.e. move towards a diet lower in meat and take other steps to achieve decarbonisation, does not equate to lower water use when scaled to the population (see Appendix C.5 and C.6 for more information).

The all sectors results include estimates of the water resource available naturally (i.e. without the influence of abstractions or discharges) and whether existing environmental flow requirements are achievable given the potential for change in the natural flows in the future. Where unachievable, this is referred to as negative available resource. In the majority of scenarios in this assessment, the environment flows are equal to the proportion of the natural flow that they are today. A second scenario is also tested, where the environmental flow is equal to the absolute volume of the environmental flows today i.e. is a greater proportion of natural flow if it decreases.

2.2. Future scenarios assessed

Results are presented for a selection of 21 scenarios, see Table 2.1 and Table 2.2. The scenarios are the baseline (public water supplies: 2019/20; all sectors September 2014) plus 20 combinations of alternative futures for climate change, population, demand-side adaptation and environment flow policy. Supply-side adaptation measures, including enhanced levels of drought resilience, are considered separately, at the end of the assessment, see Section 3.2.4 for the public water supplies analysis only. Results are presented over two future time periods: mid-century (previously known in CCRA2 as the 2050s, which assumes a mid-point of 2055 and a range of 2040 – 2069 for analytical purposes) and late-century (previously known in CCRA2 as the 2080s which assumes a mid-point of 2085; and a range of 2070 – 2099 for analytical purposes).

Short-hand notations are used for each scenario e.g. 'NAAMPBY' in Figure 3.10. These are usually found in maps and are translated as follows:

- Time: baseline = BY; mid-century = MC, and late-century = LC (or L for PPE climate scenarios).
- Degree of change: 2D, 4D or 4D and a PPE suffix.
- Population: no population change = LP, central population change = MP, and high population change = HP.
- Adaptation scenarios: no additional action = NAA, current and announced = CAA and additional action = AA.
- Environmental flow options: fixed = EFIfixed and proportional = EFIprop.

Results are most commonly presented in megalitres per day (Ml/d) which is equivalent to 1,000,000 litres. Other units used are litres per head per day (l/h/d) and percentages (%).

This assessment is similar in concept to HR Wallingford's Water Availability study for CCRA2 (HR Wallingford, 2015) insofar as the analysis is separated into two main streams, public water supply and 'all sectors' analyses. However, there are a number of key differences in the methods and underpinning data, of most significance are:

- this assessment uses the latest water resource plans for the demand and supply side public water supply analysis:
  - the method for projecting water demand into the future is different, now following Artesia, 2018, 2019.
  - the method for projecting water supply into the future is slightly different and was developed specifically for this assessment.
- this assessment uses the latest population projections provided by ONS.
- this assessment makes use of the UKCP18 climate projections.
- the all sectors analysis is consistent with the latest assessment on projected changes in non-public water supply for Defra (2020).

Table 2.1: Baseline and mid-century scenarios

#	Time	Degrees of change	Population	Adaptation (demand-side measures)	Environmental flow options
1	Baseline, 2019	n/a	WRMP 2019	No additional action	n/a
2	Mid-century ("2050s": 2055; 2040-2069)	2°C world (50th%ile of all GCMs)	No population change	No additional action	Proportional
3			UK central	No additional action	Proportional
4			UK high	No additional action	Proportional
5			UK central	Current and announced	Proportional
6		4°C world (50th%ile of all GCMs)	UK central	No additional action	Proportional
7			UK central	Current and announced	Fixed
8			UK central	Additional adaptation	Proportional
9			UK central	Current and announced	Proportional
10			UK high	No additional action	Proportional

Notes: Proportional: Environmental Flow Indicator evolves as a proportion of natural flow irrespective of climate change impacts. Better protects abstractors at lower flows.

Fixed: Environmental Flow Indicator is fixed at current volumes irrespective of climate change impacts. Offers greater environmental protection at lower flows.

Table 2.2: Late-century-scenarios

#	Time	Degrees of change	Population	Adaptation (demand-side measures)	Environmental flow options
11	Late-century ("2080s": 2085; 2070-2099)	2°C world (50th%ile of all GCMs)	No population change	No additional action	Proportional
12			UK central	No additional action	Proportional
13			UK high	No additional action	Proportional
14			UK central	Current and announced	Proportional
15		4°C world (50th%ile of all GCMs)	UK central	No additional action	Proportional
16		4°C world (50th%ile of PPEs)	UK central	No additional action	Proportional
17		4°C world (50th%ile of all GCMs)	UK central	Current and announced	Fixed
18			UK central	Additional adaptation	Proportional
19			UK central	Current and announced	Proportional
20		PPE 4°C world (50th%ile of all PPEs)	UK high	Additional adaptation	Proportional
21			UK high	No additional action	Proportional

Notes: *Proportional: Environmental Flow Indicator evolves as a proportion of natural flow irrespective of climate change impacts. Better protects abstractors at lower flows.*

Fixed: Environmental Flow Indicator is fixed at current volumes irrespective of climate change impacts. Offers greater environmental protection at lower flows.

Adaptation scenarios used in this assessment are summarised in Table 2.3.

Table 2.3: Summary of adaptation scenarios

Task	Water use factor	No additional action	Current and announced	Additional
2b, 3 and 5. Public water supply, demand-side actions only	Leakage	All countries: Baseline plan, 2019. Then hold absolute value to 2100.	For England, Wales and Northern Ireland, Final plan to end 2045. For Scotland, the baseline plan to end 2045 is used. Then reduce to 50% of 2019 leakage by 2050. Then hold absolute value to 2100.	All countries: As "current and announced" then reduce absolute leakage to 10% (of 2019 Distribution Input) by 2100.
	Household adaptation values	All countries: Baseline plan, 2019. Per capita consumption will reduce slightly throughout the century as meter penetration increases (all new properties are metered).	England and Wales: As per final plan to 2044/45. Then fixed per capita consumption to the end of the century. Scotland and Northern Ireland: As per baseline plan (no final plan available and meter penetration not to change significantly).	All countries: "Enhanced-03" scenario (Water UK, EA National Framework) to 2065. Then hold absolute value to 2100.
	Non-household demand	All countries: Non-household demand matches water resource plans (final plans where available) from the base year until 2045 and is then held fixed for the rest of the century.		
5. Water available for abstraction 'All sectors' analysis only	Industry and Commerce (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to regional population figures.	All countries: As per 'No additional action'.	All countries: Percentage change value estimated from the Sustainable Regional scenario from Defra (2020) based upon key sectors and using the growth factor devised for that project.
	Agriculture (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to the regional population figures.	All countries: As per 'No additional action'.	All countries: Percentage change value for spray irrigation estimated from the Sustainable Globalisation scenario from Defra (2020) scaled to regional population figures.
	Energy Generation (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to regional population figures.	All countries: As per 'No additional action'.	All countries: Percentage change value estimated from the Sustainable Regional scenario from Defra (2020) scaled to regional population figures.

Task	Water use factor	No additional action	Current and announced	Additional
3 Supply-demand balance Evaluation of residual deficits after supply-side measures are included.	Preferred supply options	Options applied to all scenarios to estimate any residual deficits.		
	Feasible supply options	Options applied to all scenarios to estimate any residual deficits.		
	Inter-regional transfers	Options applied to all scenarios to estimate any residual deficits.		

3. Results

3.1. Natural Environment

There are a number of climate-related risks in the natural environment that are associated with freshwater scarcity. The following risks in the natural environment chapter of the main CCRA3[6] report may be relevant:

- Risks to terrestrial and freshwater species and habitats from changing climatic conditions and extreme events, including, water scarcity and altered hydrology (including water scarcity, flooding and saline intrusion).
- Risk to soils from changing climatic conditions, including seasonal aridity and wetness.
- Risks to natural carbon stores and sequestration, agriculture and forestry (and opportunities) from changing climatic conditions, including temperature change and water scarcity.
- Risks to and opportunities for agricultural and forestry productivity from extreme events and changing climatic conditions (including temperature change, water scarcity, wildfire, flooding, coastal erosion, wind and saline intrusion).
- Risks to freshwater species and habitats from changing climatic conditions and extreme events, including higher water temperatures, flooding, water scarcity and phenological shifts.
- Risk to regulating services provided by species and habitats, including pollination, water quality, water regulation and urban cooling.

Whilst this assessment of water availability does not directly evaluate the ecological impact of water scarcity, a number of the interim and final outputs may be useful in informing the future exposure to such risks.

This section will present information on changes in natural available resource (i.e. the natural flow of the river minus the environmental flow requirement) followed by changes in catchment water availability (including available resource i.e. the naturally available resource plus discharges).

3.1.1. Changes in naturally available resource

Figure 3.1 shows the baseline naturally available resource at Q95 for each catchment in the UK as calculated using the WRGIS and WRGIS-lite tools developed for CCRA2 Water availability assessment (HR Wallingford, 2015) and updated for this assessment. The naturally available resource is the accumulation of natural flows minus the environmental flows[7] set according to the regulator's rules aggregated to a catchment scale. The Spey and Tay catchments in Scotland are notable in their high natural resource availability. The Severn and Thames corridors are the largest catchments in England and Wales. Although the catchments in Northern Ireland shown in Figure 3.1 are smaller, it is worth noting that 43%[8] of the land area of Northern Ireland drains into Lough Neagh, which can be seen on many of the maps in this document in the centre of the country.

[6] Risk definitions correct at end 2019.

[7] The short-hand notation applied to the maps to refer to environmental flows is EFI (Environmental Flow Indicator). See sections 2.1.5 and 2.2 for more information.

[8] https://www.infrastructure-ni.gov.uk/articles/lough-neagh-levels.

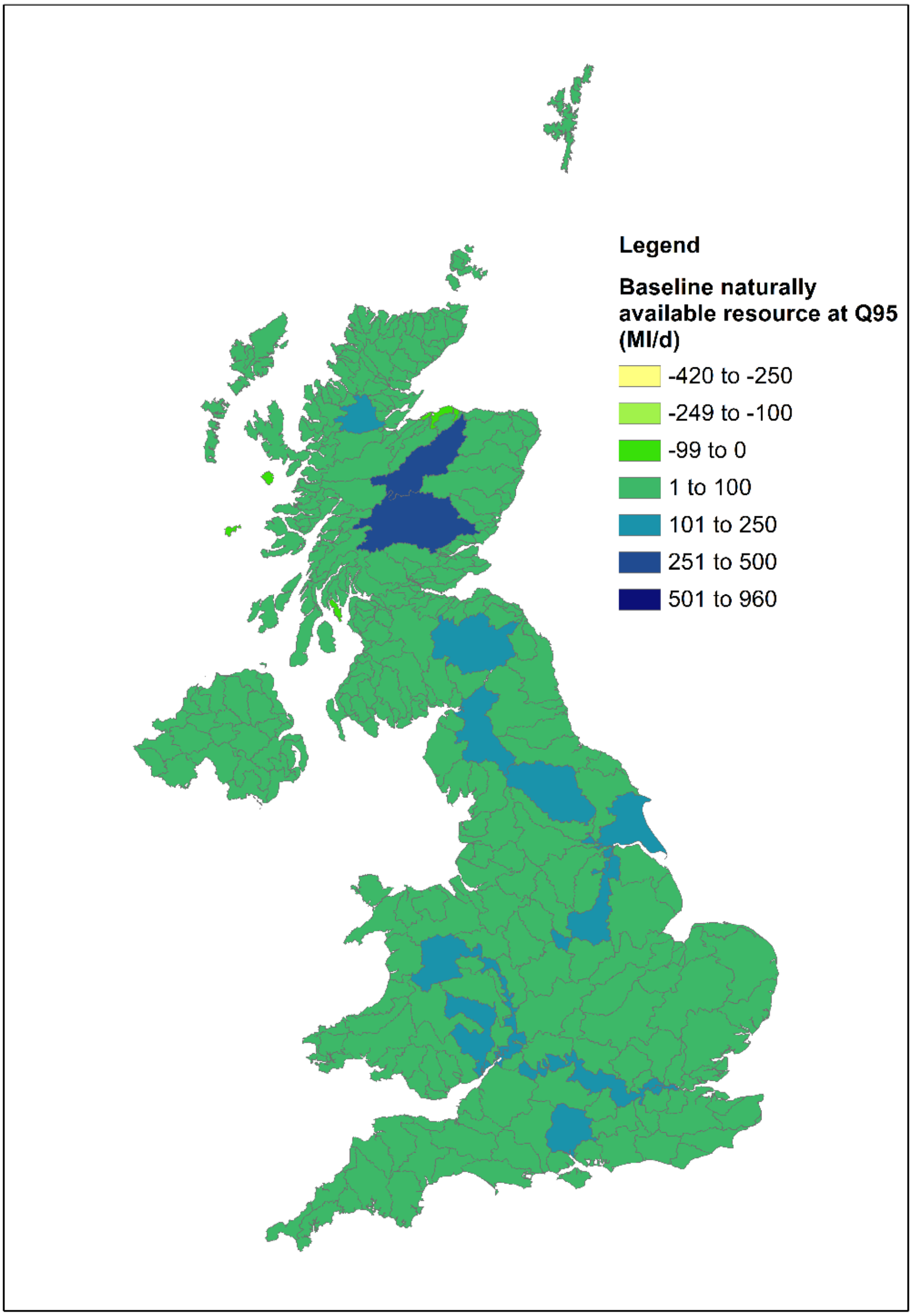

Figure 3.1: Baseline naturally available resource at Q95 by river catchment

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It is important to note that:

- ‘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 Water Framework Directive. Environmental flows are usually defined as a percentage of the natural flow that is available for abstraction. Critically, not all rivers currently meet their objectives for environmental flows and, where they do, it does not necessarily result in Good Ecological Status. This may be because there are other factors influencing the ecological status of the water body or, in some cases, that the specific habitat in question requires alternative volume or timing of flow support.

Figure 3.2 to Figure 3.4 show the percentage change values that were used to estimate changes in natural flow at Q95 in the mid- and late- century under a 2°C, 4°C and PPE-4°C worlds. Western Wales, the Severn, Solway and Tweed river basins are the most significantly impacted by the end of the century with reductions in naturally available flows at Q95 projected to be more the 40% of the baseline. Under a 2°C world in the mid- and late-century, in the Western Highlands in Scotland, the percentage change values used are positive i.e. a projected increase, rather than a reduction, in flows. Under a 4°C world, reduction in Q95 flows is projected in the Western Highlands.

Although the percentage change values at the basin scale generally reduce naturally available resource at a catchment scale, the impact of the percentage change doesn’t appear on the scale when the environment flow scenario is set as proportional, see Figure 3.5 and Figure 3.7. Figure 3.5 and Figure 3.7 show the naturally available resource in the mid- and late-century, respectively. In both cases, the central population projection is simulated, and they show a 4°C world with current and announced level of adaptation action on water demand. Figure 3.6 and Figure 3.8 show the same scenarios except for the environment flow scenario is fixed.

Under a fixed environmental flow scenario, reductions in flows at Q95 due to climate change result in reductions in naturally available resource; across Wales and the west of England to begin with in the mid-century and then reductions can be seen across much of England in the late century. In the late-century, larger reductions are also evident in Argyll and North East Scotland. Lower Lough Erne in Northern Ireland is projected a reduction in naturally available resource when environmental flow indicators remain fixed in the mid- and late-century. Where the values are below zero, there is no naturally available resource. Without the support provided by discharges, the environmental flow volumes required (at the catchment level) are not met.

The environmental flow scenario has the greatest relative impact on naturally available resource at Q95 (low flows) of all the aspects of the scenarios simulated in this analysis.

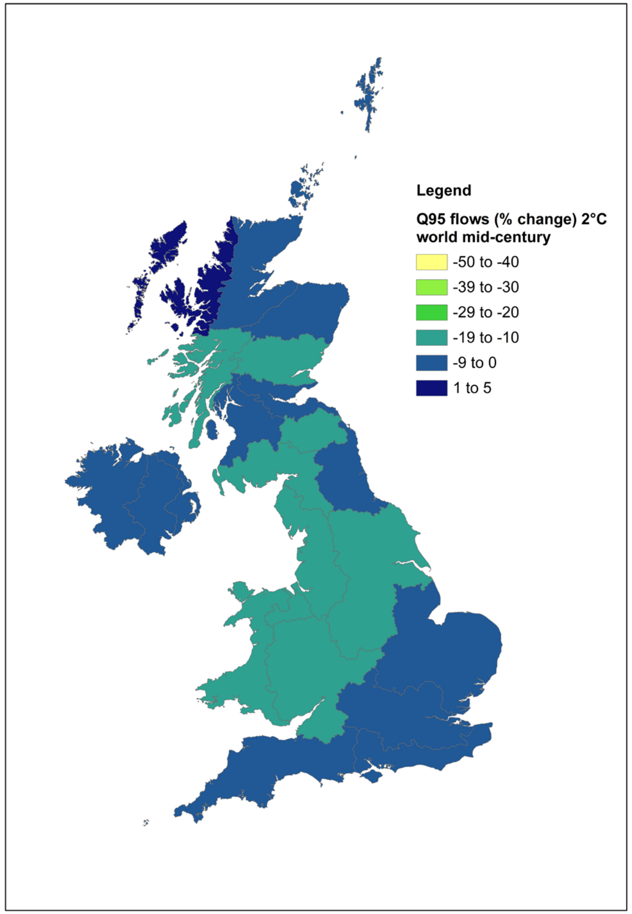

Figure 3.2: Percentage change in Q95 in a 2°C world in mid-century

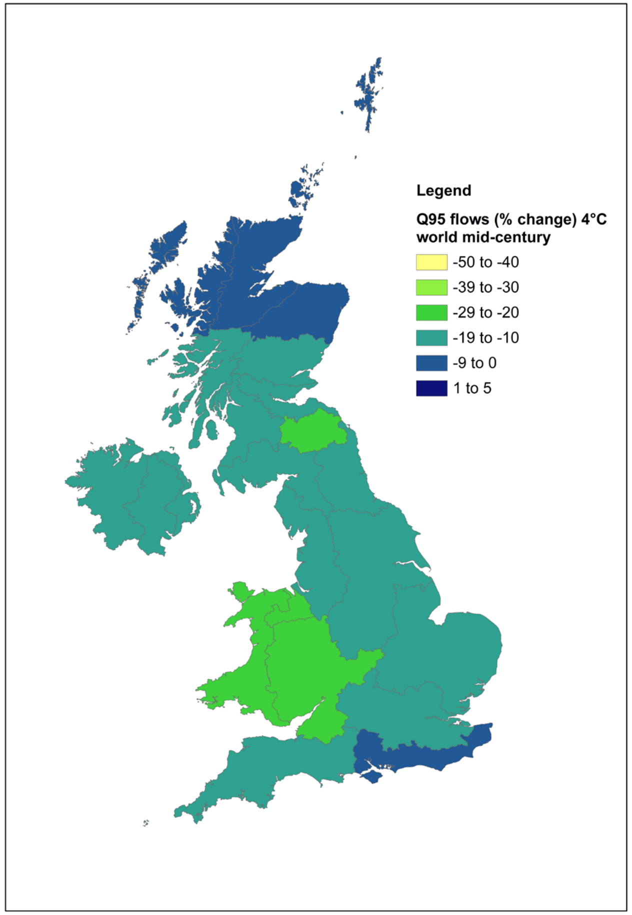

Figure 3.3: Percentage change in Q95 in a 4°C world in mid-century

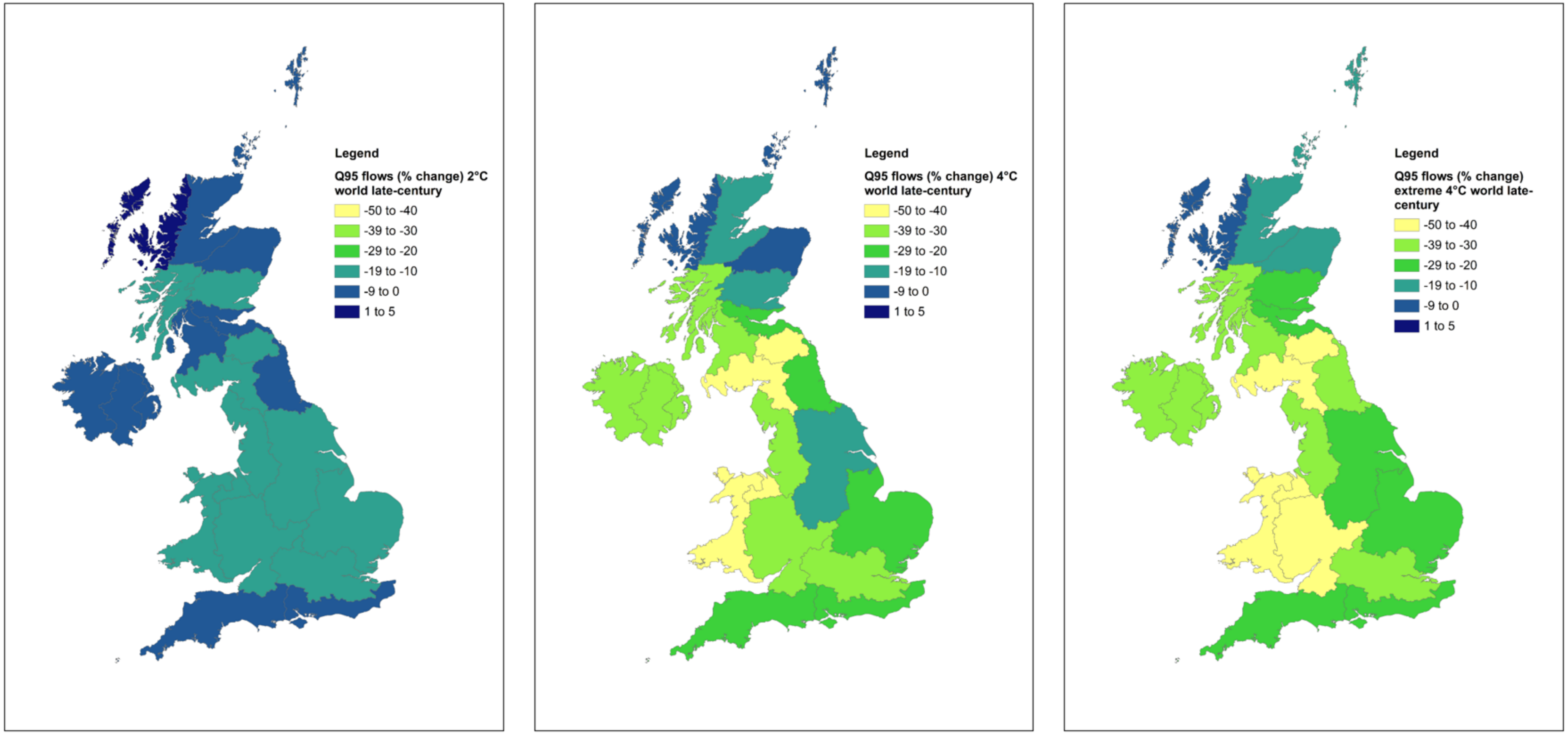

Figure 3.4: Percentage change in Q95 in a 2°C, 4°C and PPE-4°C worlds in late-century

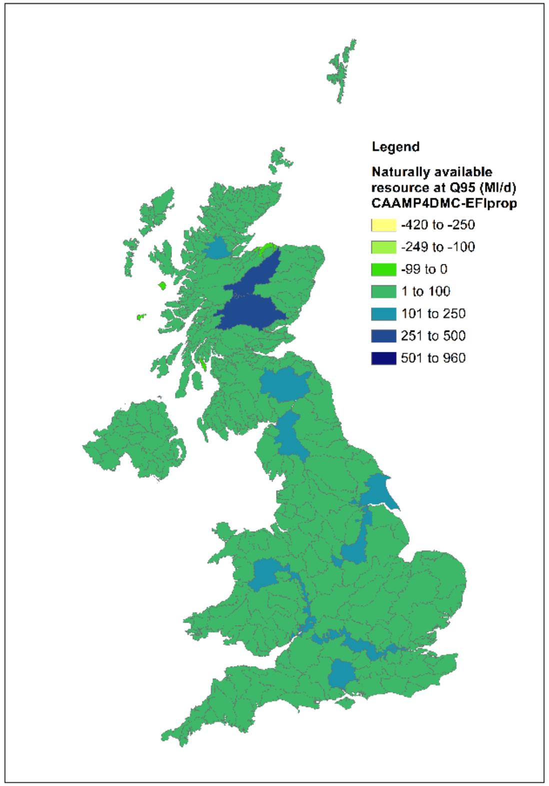

Figure 3.5: Change in flows (Ml/d) in the mid-century under a central population, 4°C world, current and announced adaptation and assuming proportional EFI scenario

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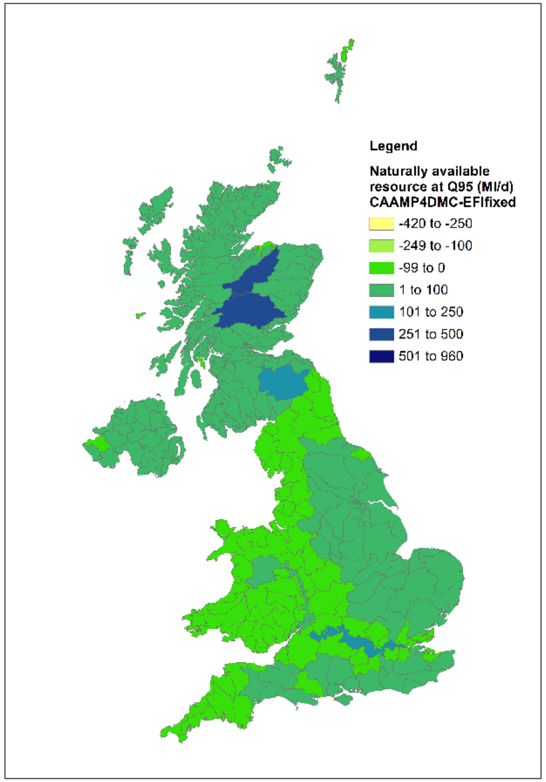

Figure 3.6: Change in flows (Ml/d) in the mid-century under a central population, 4°C world, current and announced adaptation and assuming fixed EFI scenario

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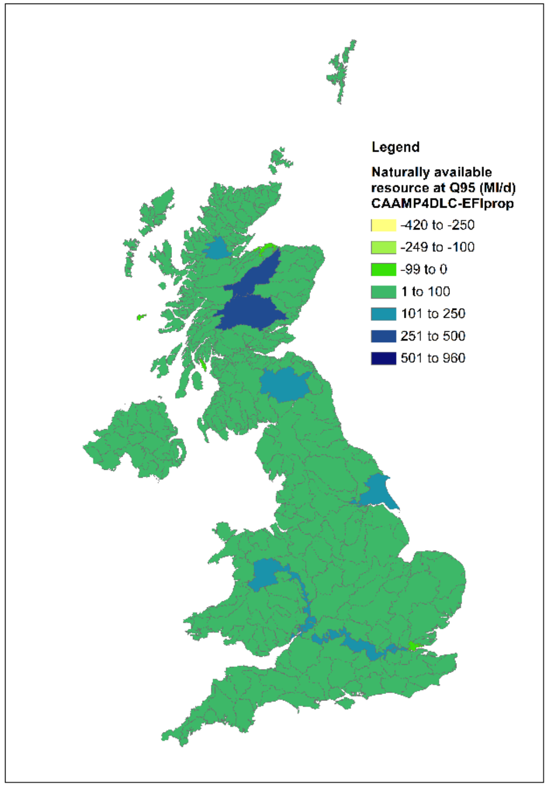

Figure 3.7: Change in flows (Ml/d) in the late-century under a central population, 4°C world, current and announced adaptation and assuming proportional EFI scenario

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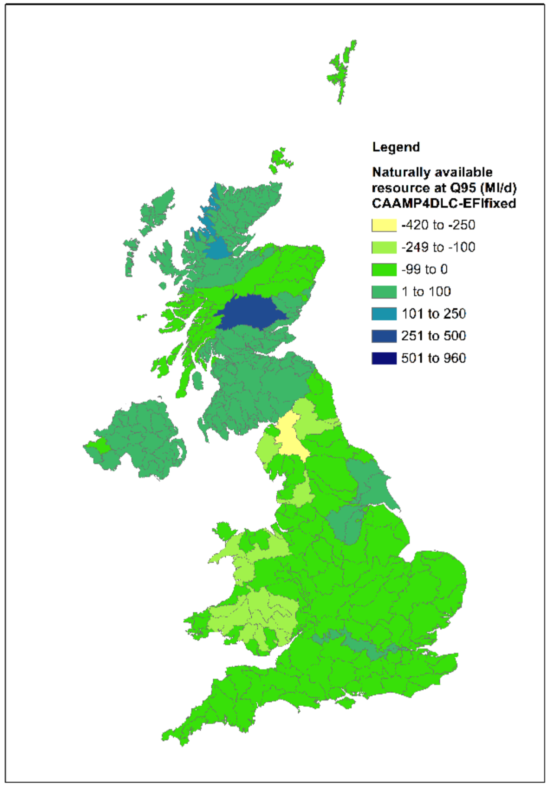

Figure 3.8: Change in flows (Ml/d) in the late-century under a central population, 4°C world, current and announced adaptation and assuming fixed EFI scenario

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3.1.2. Changes in catchment water availability

Available resource

The water available in a catchment for human use is not simply a product of the water available naturally in rivers, lakes and groundwater; discharges released back into the environment contribute to the available flows. Crucially, discharges may not be released in the same location in which they were abstracted. Figure 3.9 shows the available resource i.e. the natural resource plus discharges. There are many catchments with increased Q95 available resource compared to the naturally available resource, notable examples are the Thames Corridor, Lower Mersey & Alt, Tamar, Bristol Avon, Lough Neagh and Lower Bann and many of the catchments in the North East of England.

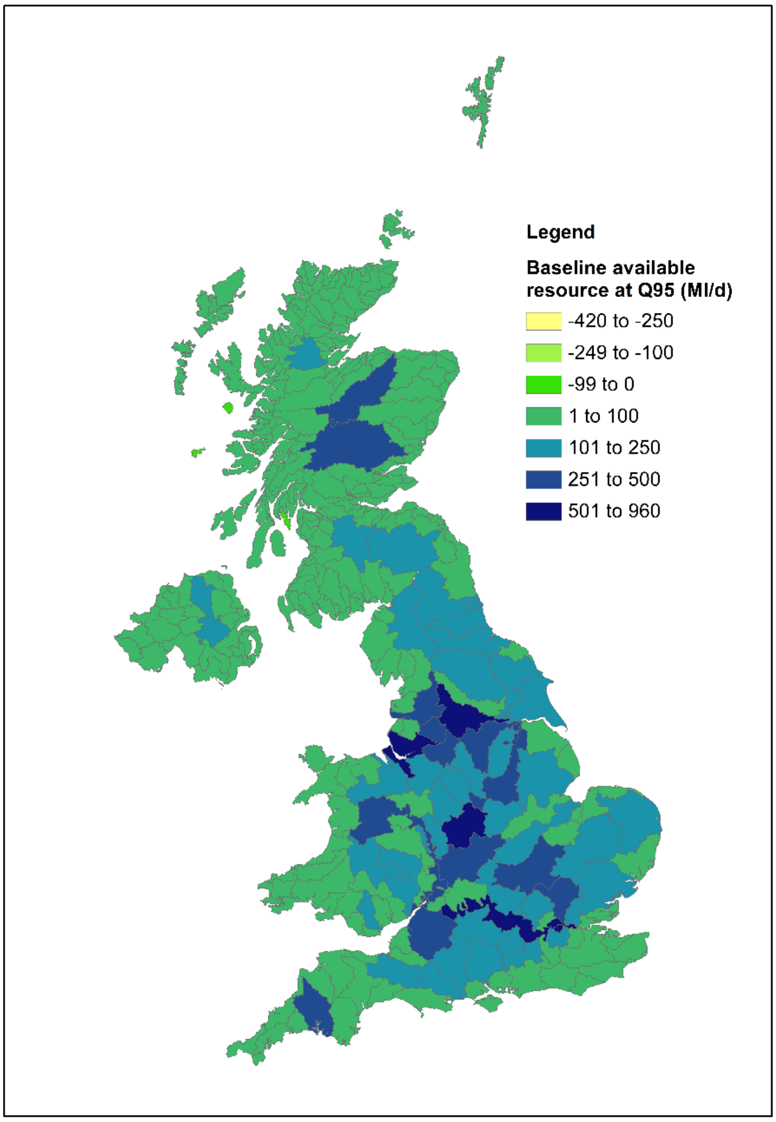

Figure 3.9: Baseline available resource (naturally available resource plus discharges) at Q95 by catchment

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In future scenarios, an increased population would require a larger amount of water to be abstracted and subsequently discharges would also increase. Under different adaptation scenarios, the water used per person or per organisation may reduce, thus bringing the discharges down again. Discharges are often made to support low flows and meet environmental flow requirements. Therefore, decreasing water use and correspondingly the required abstraction, may relieve pressure on a water source at one location but at the discharge location, it may increase pressure on the local environment because there is less discharge to support the lowest flows. Hypothetically, pressure on the freshwater environment may come from either abstraction and/or reduction in the discharges that support low flows. The precise impacts will be highly localised and specific.

Catchment water availability

Overall catchment water availability is calculated by taking the consumptive abstraction demand (i.e. all groundwater and surface water abstractions where the treated water is not discharged into the same water body) away from the available resource (Figure 3.9). All abstractors with an abstraction licence, for consumptive water use, are included in this analysis.

Changes in catchment water availability are shown in Figure 3.10 to Figure 3.17. Red to blue colouring indicates the proportion of available flow that remains in the catchment after the balance between natural flows, environmental flow requirements, abstractions and discharges has been calculated. In some cases, the flow is too low for the environmental flow conditions to be met i.e. there is no flow left over to abstract for any human use. This appears on the maps in a maroon colour and is referred to as negative available resource[9].

These final results are presented as average low flows (the average impacts at Q70 and Q95). Average low flow was a measure favoured in the Case for Change analysis (Environment Agency, 2011 and Environment Agency and Natural Resources Wales, 2013) 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 in the assessment due to the data availability in the WRGIS. Current regulation would not usually allow some of the abstraction that would be suggested at Q95 and therefore the Q95 results could be overestimating the potential impacts. Whilst presenting the average impacts at Q70 and Q95 provides a more measured view of the future projections, this analysis should still 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 a precise representation of the realised flow for the environment and actual abstractions at average low flows. Also, for this reason, results are presented as proportions, rather than absolute values.

Influence of climate change on catchment water availability

Figure 3.10 shows projections for the overall catchment water availability at average low flows for the mid-century. The left-hand map shows the baseline and the middle and right-hand maps show a 2°C and 4°C world. The scenarios are based upon the central population projection, no additional action in adaptation and a proportional approach to environmental flow requirements.

In Figure 3.10, the baseline map on the left shows that 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

[9] Naturally available resource minus environmental flow requirements plus discharges is a negative number.

available for human uses. The deficit or surplus situation for individual water bodies within each catchment may be different to the catchment as a whole.

There are 40 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.

The scenarios in a 2°C and 4°C world for the mid-century are almost indistinguishable from one another. A few catchments have less water available or greater deficit at a catchment scale, the differences are relatively small. The changes in flows have limited impact at a catchment scale on the overall water availability. It is important to note that the environmental flow policy in these scenarios is set as proportional i.e. the amount of water available to the environment has reduced by the same proportion as the overall reduction in flows. As a result, the impact on the water available for human use generally differs only a little. At a local scale impacts may be more significant.

Figure 3.11 shows projections for the overall catchment water availability at average low flows for the late-century. The left-hand map shows the 2°C world, the middle a 4°C world and the right-hand map an PPE 4° world. The scenarios are based upon the central population projection, no additional action in adaptation and a proportional approach to environmental flow requirements.

Figure 3.11 shows a similar pattern of impact to the future scenarios in Figure 3.10. Increasing flow impacts with climate change results in a slight reduction in water availability at a catchment scale. Most notable is the River Severn corridor and Hull & East Riding which move from a position of surplus to a position of deficit in the late-century under a 4°C world.

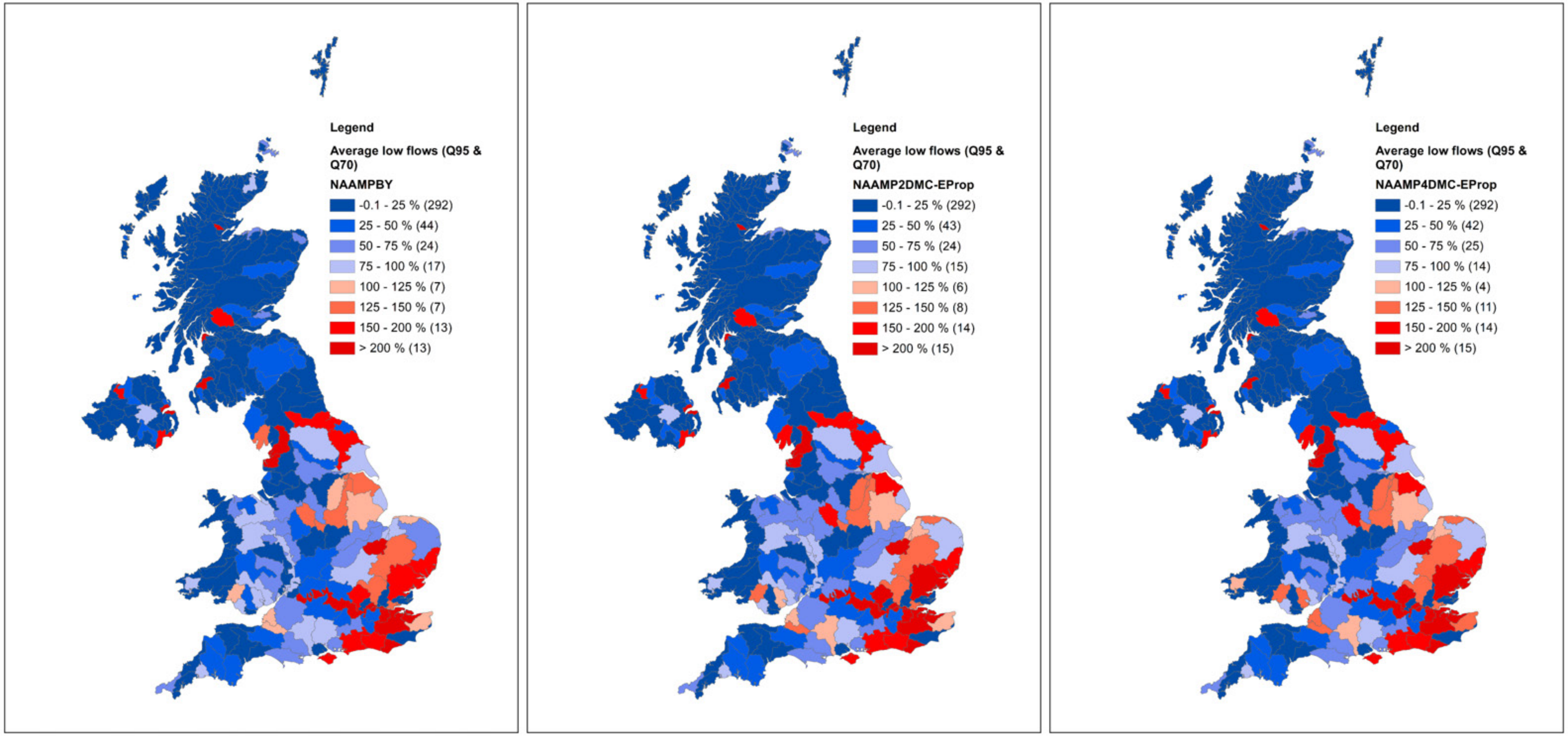

Figure 3.10: The present day baseline and influence of climate change in the mid-century on catchment water availability. From left to right, baseline, 2°C and 4°C worlds) in the mid-century, assuming a proportional EFI and central population projection and no additional adaptation action

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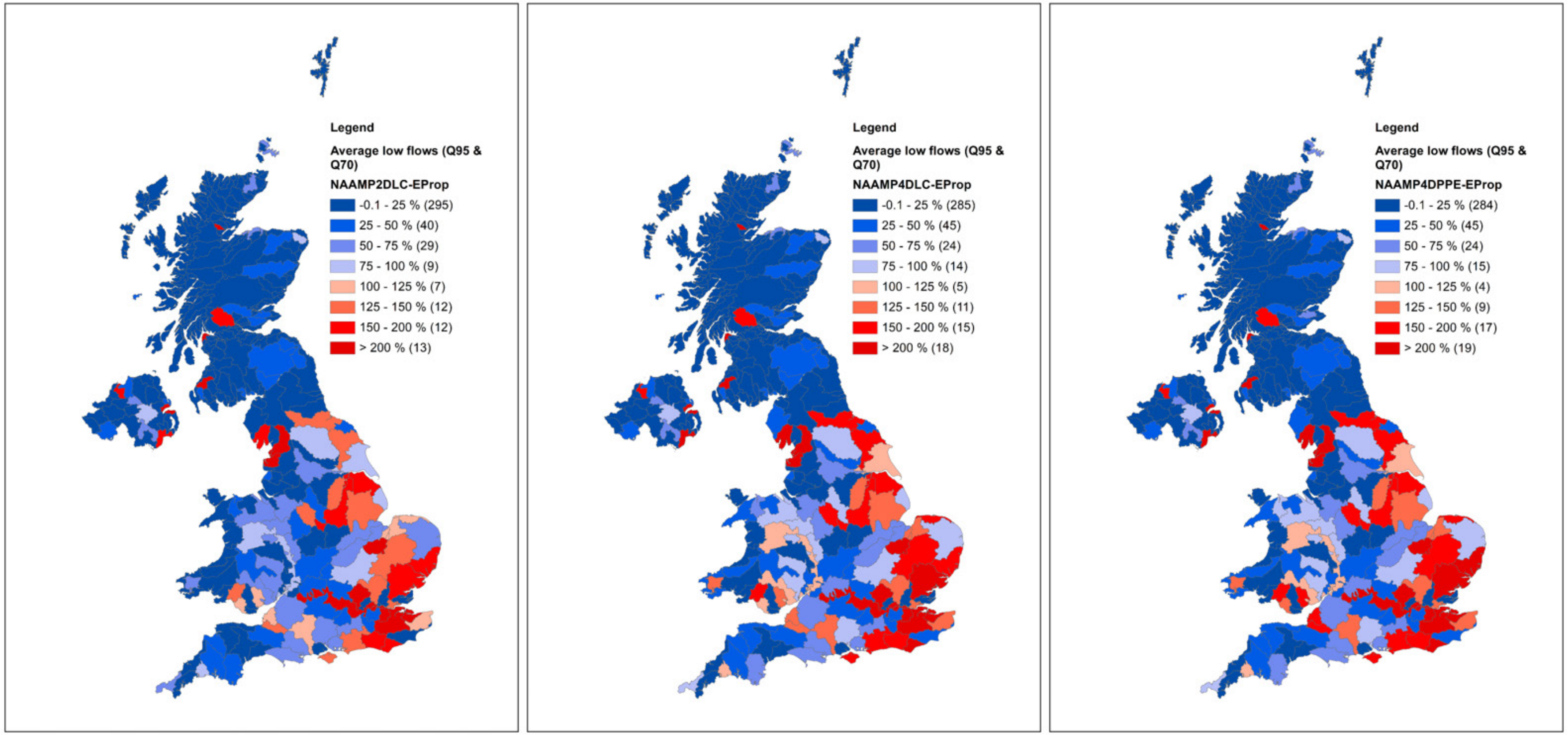

Figure 3.11: Influence of climate change in the late-century on catchment water availability. From left to right, 2°C, 4°C and PPE 4°C worlds assuming a proportional EFI, central population projection and no additional adaptation action scenario, on catchment water availability

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Influence of population on catchment water availability

Figure 3.12 shows projections for the overall catchment water availability at average low flows for the mid-century. The left-hand map shows the mid-century under a no population projection scenario. The middle map shows the central population scenario and the right-hand map shows the high population scenario. The scenarios are based upon the no additional action in adaptation in a 2°C world and with a proportional approach to environmental flow requirements. Figure 3.13 shows the same information for the late-century.

The influence of population on the overall catchment water availability at average low flows is minimal. A reduction in surplus or increased deficit is evident for some catchments. The Usk and River Severn corridor move to a deficit under the high population scenario. Interestingly, the Witham catchment has a lower projected deficit under a high population than it does under a central population projection which is likely to be due to discharges into the catchment increasing with the increased population.

In terms of catchment-scale water availability, the influence of population scenarios is of a similar magnitude to the influence of climate change scenarios between a 2°C and PPE-4°C worlds.

Influence of adaptation on catchment water availability

Figure 3.14 and Figure 3.15 show projections for the overall catchment water availability at average low flows for the mid- and late-century, respectively. The left-hand maps show the projections under a no additional action adaptation scenario. The middle maps show the current and announced adaptation scenario and the right-hand maps the additional adaptation scenario. The adaptation scenarios used are described in Section 2.2. All scenarios are based upon a 4°C world, central population projection and a proportional approach to environmental flow requirements.

In the main, increasingly ambitious adaptation actions (demand-side only for public water supplies) result in a reduction in deficits and increase in surplus at a catchment scale. In the mid-century, in Figure 3.14, the River Forth catchment deficit is projected to reduce considerably. The Tees is projected to move from a deficit to a surplus under the additional action adaptation scenario. In the late-century, The River Severn corridor and Usk are projected a similar improvement in the current and announced adaptation scenario. The Faughan catchment is also projected a reduced deficit under the additional adaptation scenario. The changes between the scenarios are still relatively small.

It is notable that whilst the public water supply demand-side measures under the additional adaptation scenario do result in a reduction in water demand, additional adaptation in agriculture and energy and some areas of industry (once scaled to the population) result in a water demand increase. This is one reason why the changes seen in these results are small.

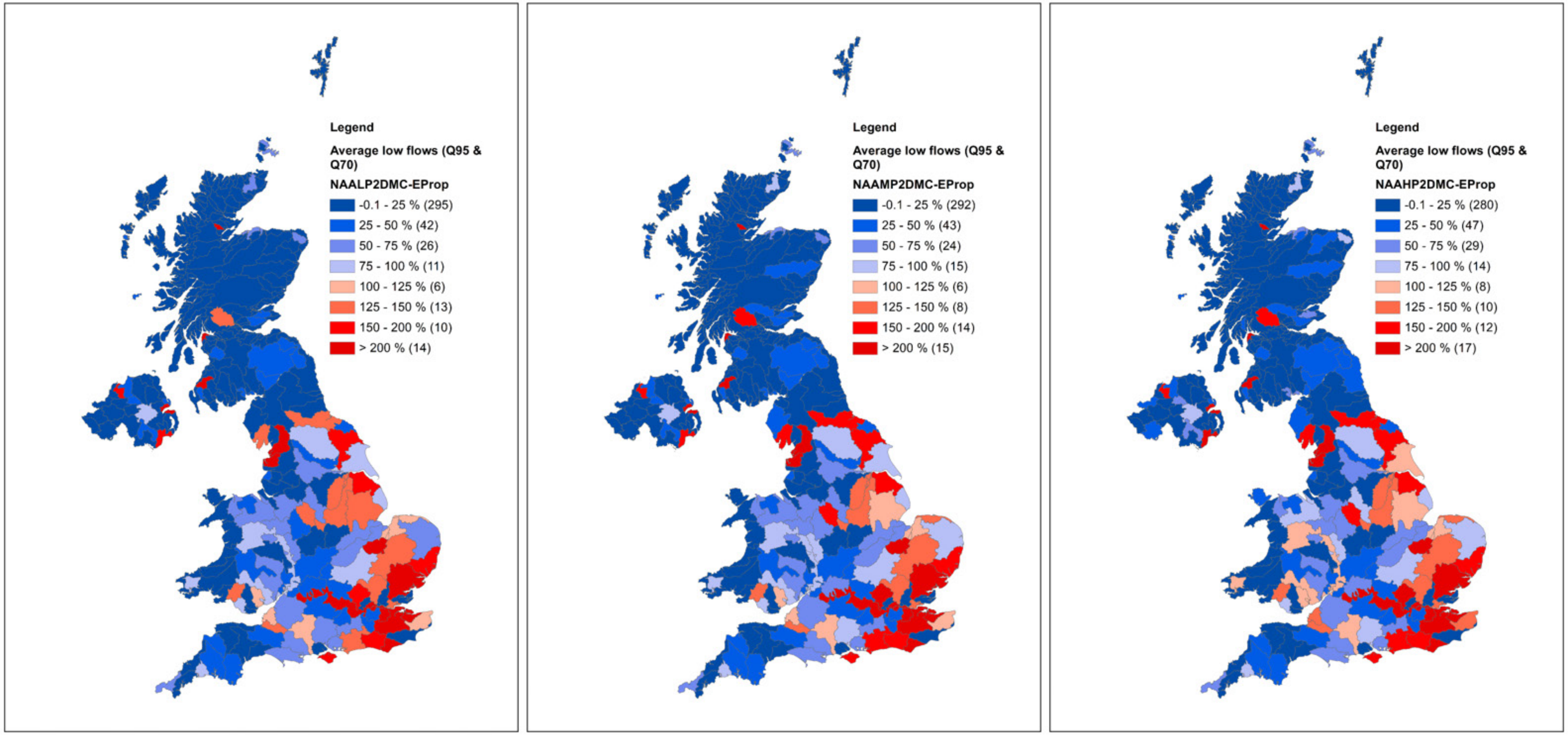

Figure 3.12: Influence of population (from left to right, no population, central population and high population) in the mid-century on catchment water availability (2°C world and assuming a proportional EFI scenario)

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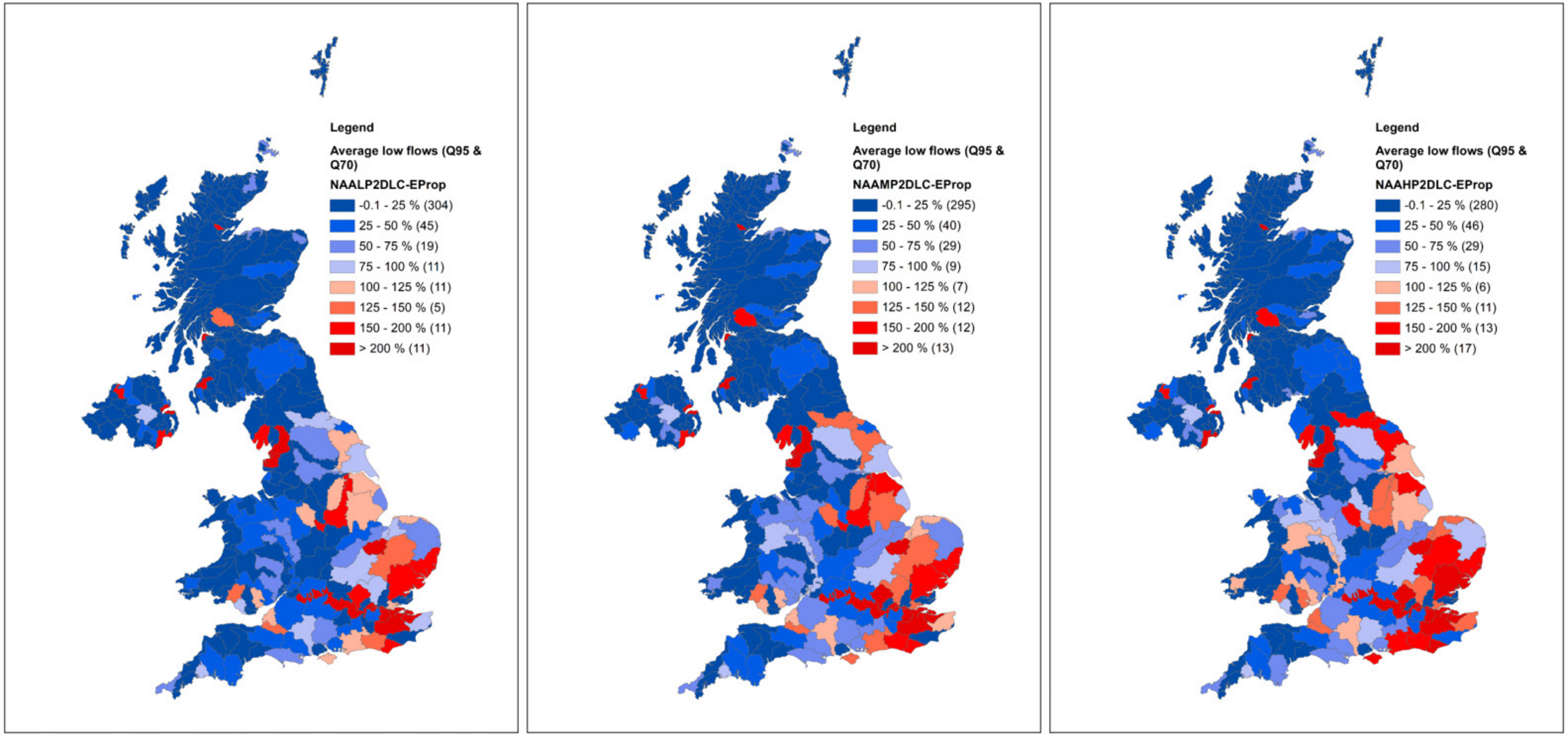

Figure 3.13: Influence of population (from left to right, no population, central population and high population) in the late-century on catchment water availability (2°C world and assuming a proportional EFI scenario)

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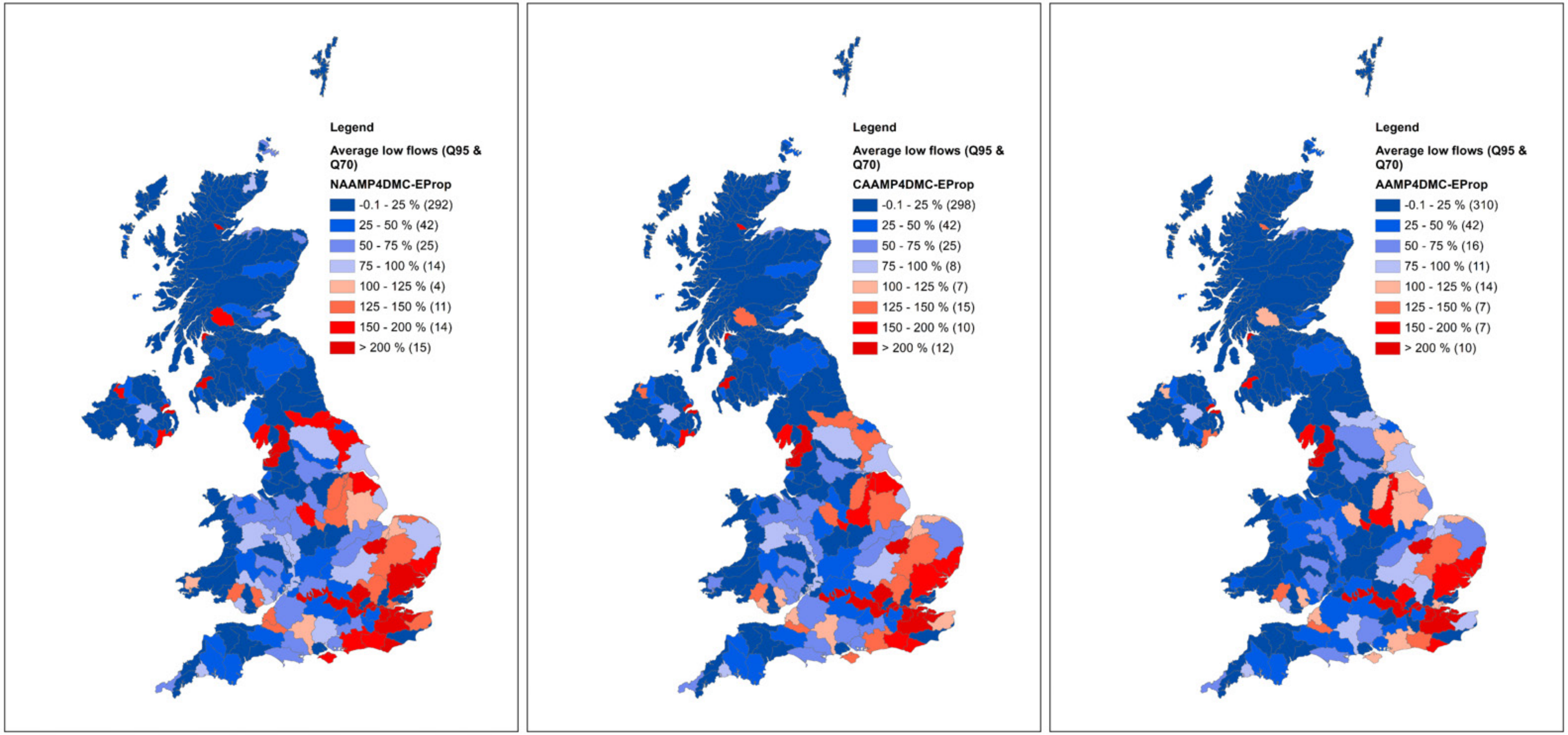

Figure 3.14: Influence of adaptation scenarios (from left to right, no additional adaptation, current and announced adaptation and additional adaptation) in the mid-century on catchment water availability (4°C world, central population and assuming a proportional EFI scenario)

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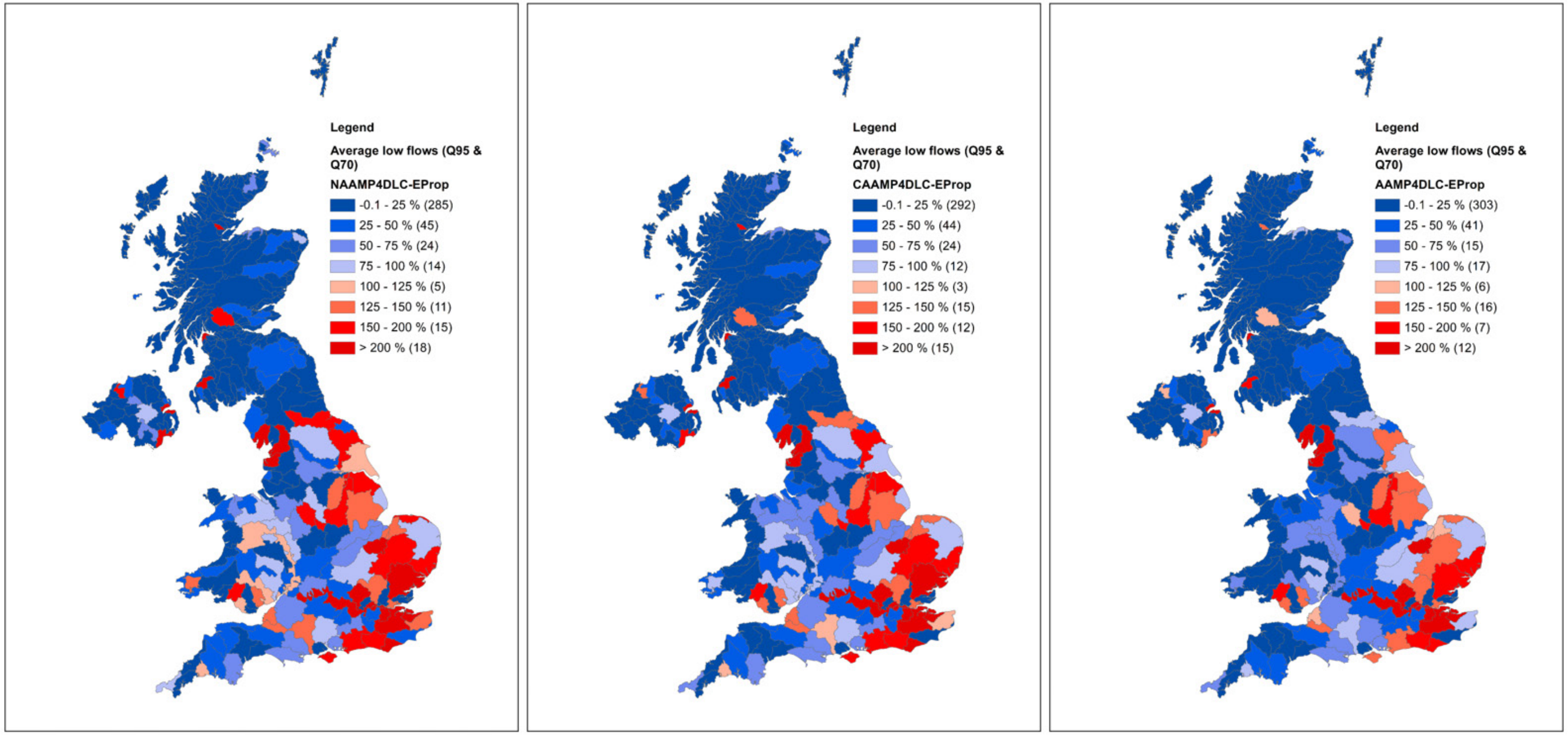

Figure 3.15: Influence of adaptation scenarios (from left to right, no additional adaptation, current and announced adaptation and additional adaptation) in the late-century on catchment water availability (4°C world, central population and assuming a proportional EFI scenario)

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Impact of EFI scenarios on catchment water availability

Figure 3.16 and Figure 3.17 show projections for the overall catchment water availability at average low flows for the mid- and late-century, respectively. The left-hand maps show the projections under a proportional approach to environmental flow requirements scenario. The right-hand maps show the projections under a fixed volume approach to environmental flow requirements scenario. All scenarios are based upon a 4°C world, central population projection and current and announced adaptation scenarios.

The choice of approach to environmental flows has a large influence on the availability of water at average low flows at a catchment scale in both the mid- and late-century. Catchments in west Wales, north west and south west England are projected to not be able to meet their current environmental flow requirements in terms of a fixed volume by the mid-century; they show negative available resource.

In the late-century, 74 catchments across the UK are projected to be unable to meet current environmental flow requirements (52 more than in the mid-century). The additional catchments are across Wales, northern and south west England and Argyll with a few catchments along the east coast of England, and west coast of Northern Ireland also indicating negative available resource.

In the late-century, under the fixed environmental flow scenario, 60 catchments are in deficit. This figure was 40 in the baseline. Affected catchments are located throughout the UK, although there are fewer in Scotland and Northern Ireland. In Northern Ireland, Lough Neagh is projected to be in deficit under a fixed environmental flow scenario in the late-century. The River Tweed and River Dee in Scotland also show deficits in this late-century scenario. In England and Wales, there is a general pattern of negative available resource to the west and available resource, but with associated deficits in the east.

Environmental flows were designed to support the ecology in our rivers. It follows that a reduction in the volume of flow held back for the ecology (by following a proportional approach to environmental flows as the climate changes) may result in a reduction in its current quality. The influence of the environmental flow requirement approaches on the environment, as opposed to on water resource availability for human use, is out of scope for this assessment. However, Figure 3.16 and Figure 3.17 illustrate that maintaining the current volume of environmental flows, in some catchments may not be possible under a 4°C world even if all human water use ceases.

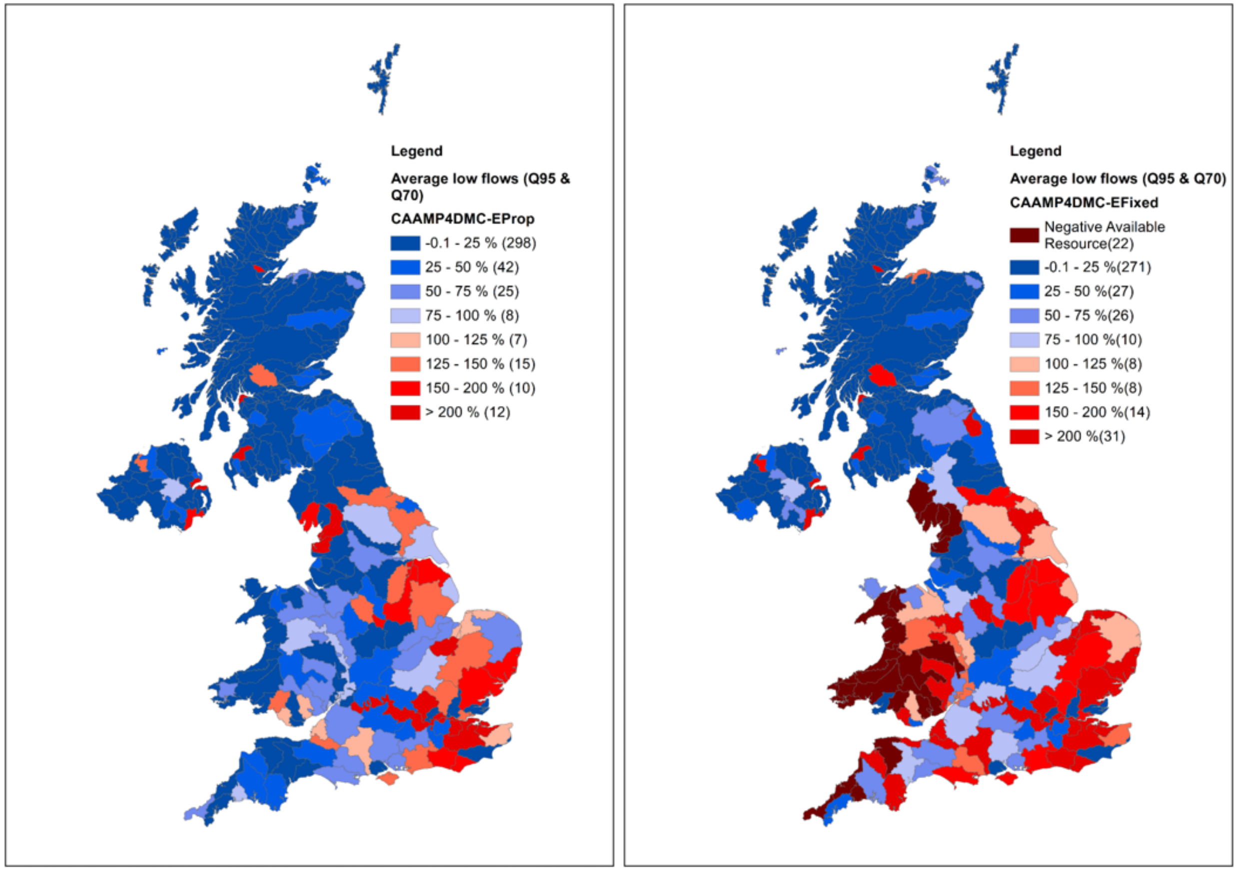

Figure 3.16: Influence of EFI policy (left-hand plot is proportional EFI scenario, right-hand plot is fixed EFI scenario) in the mid-century (4°C world, central population projection and current and announced adaptation scenarios)

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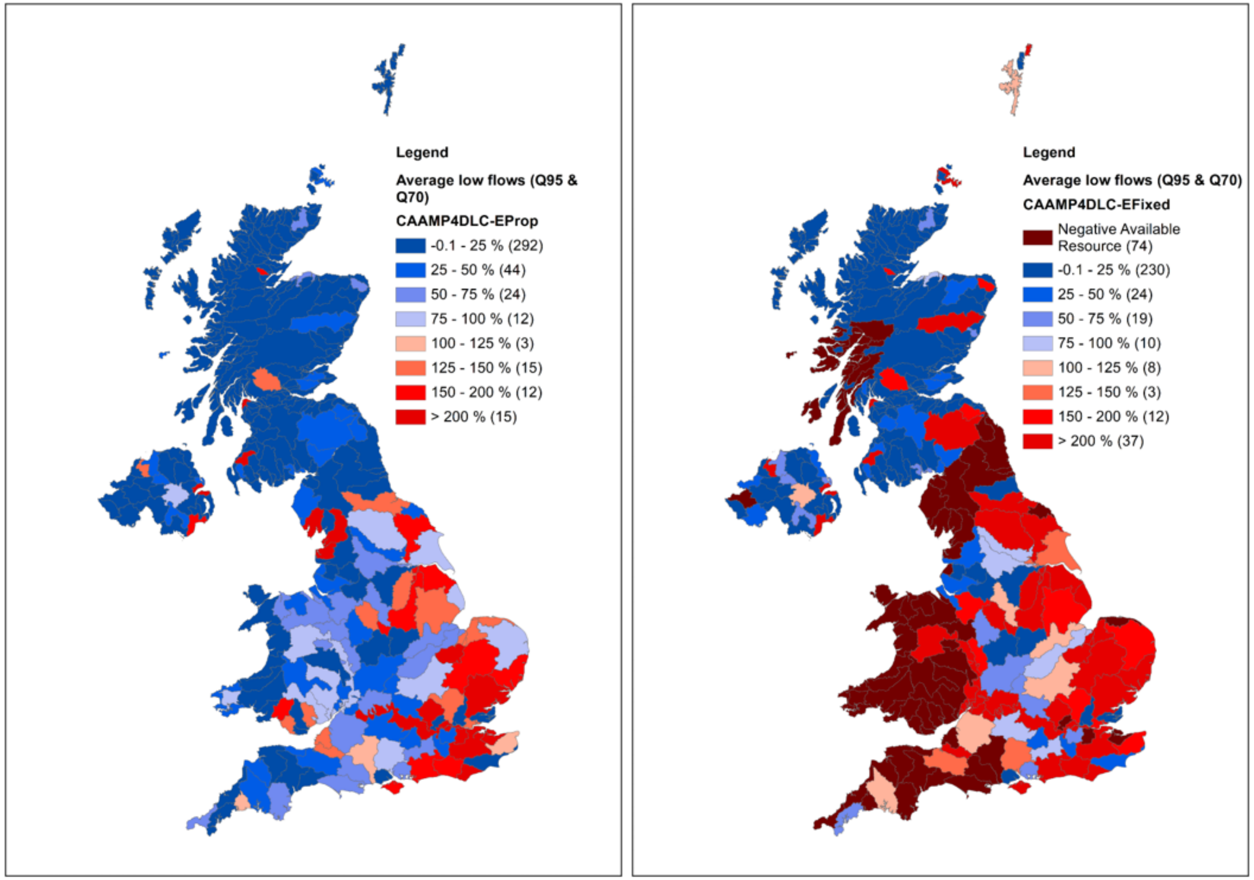

Figure 3.17: Influence of EFI policy (left-hand plot is proportional EFI scenario, right-hand plot is fixed EFI scenario) in the late-century (4°C world, central population projection and current and announced adaptation scenarios)

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Comparison with CCRA2

This "all sectors" analysis uses the same tools and underpinning baseline data as the analysis in CCRA2 (HR Wallingford, 2015) and as such, the results are the same for the baseline.

Subtle differences between CCRA2 and CCRA3 are introduced when reviewing the future scenarios, noting that the scenarios in the analysis in CCRA2 do differ from those in CCRA3. Key differences are:

- The UKCP09 probabilistic climate projections were used in CCRA2. CCRA3 has used the UKCP18 Global Projections. The approach to using climate change projections and characterising their uncertainty has also changed, with this assessment framing the analysis in terms of 2°C or 4°C worlds.
- An earlier set of population projections from ONS were used in CCRA2 compared to CCRA3, see Table 3.2 and Table 3.3.
- CCRA2 tested an additional environmental flow scenario: "no deterioration" where the future environmental flow rate is set at the absolute flow rate of either the current threshold or the level of recent actual observed flow, whichever is less. Also, more scenarios used the fixed environmental flow policy.
- Adaptation in agriculture, energy and industry was informed by the Case for Change Sustainable Behaviour scenario (Environment Agency, 2011 and Environment Agency and Natural Resources Wales, 2013) whereas CCRA3 is informed by the Defra (2020) Sustainable Regional scenario.
- Adaptation in public water supplies also differ slightly in the way in which per capita consumption and leakage reductions have been applied:
  - In CCRA2, leakage was reduced in the most ambitious adaptation scenario by approximately 70%; however, the current objectives scenario (similar to current and announced scenario in CCRA3) changed leakage little.
  - Per capita consumption was reduced to 125l/h/d and 92l/h/d in the two adaptation scenarios in CCRA2. CCRA3 has taken a different approach to per capita consumption entirely, as water company targets are also taken into account however, at a UK scale, the current and announced scenario has a per capita consumption of around 123 l/h/d and the additional adaptation value is around 84 l/h/d in the late century.

Figure 3.18 shows the catchment water availability results for scenarios in CCRA3 (left and centre) and the most similar scenario from CCRA2 (right). The CCRA3 scenarios are for the late-century and consider the central population projection and current and announced adaptation scenario. The left-hand map is for a 2°C world and the centre map is for a 4°C world. The CCRA2 scenario is for the 2080s (same as the late-century) and considers the UKCP09 medium emission p50 scenario, principal population projection, current objectives adaptation scenario and proportional environmental flow policy. Figure 3.18 illustrates the close similarity between the CCRA2 and CCRA3 results.

The pattern of the results across the UK between CCRA2 and CCRA3 is also very similar. The most striking aspect of the CCRA2 results was the impact of environmental flow policy and again, the CCRA3 results indicate this.

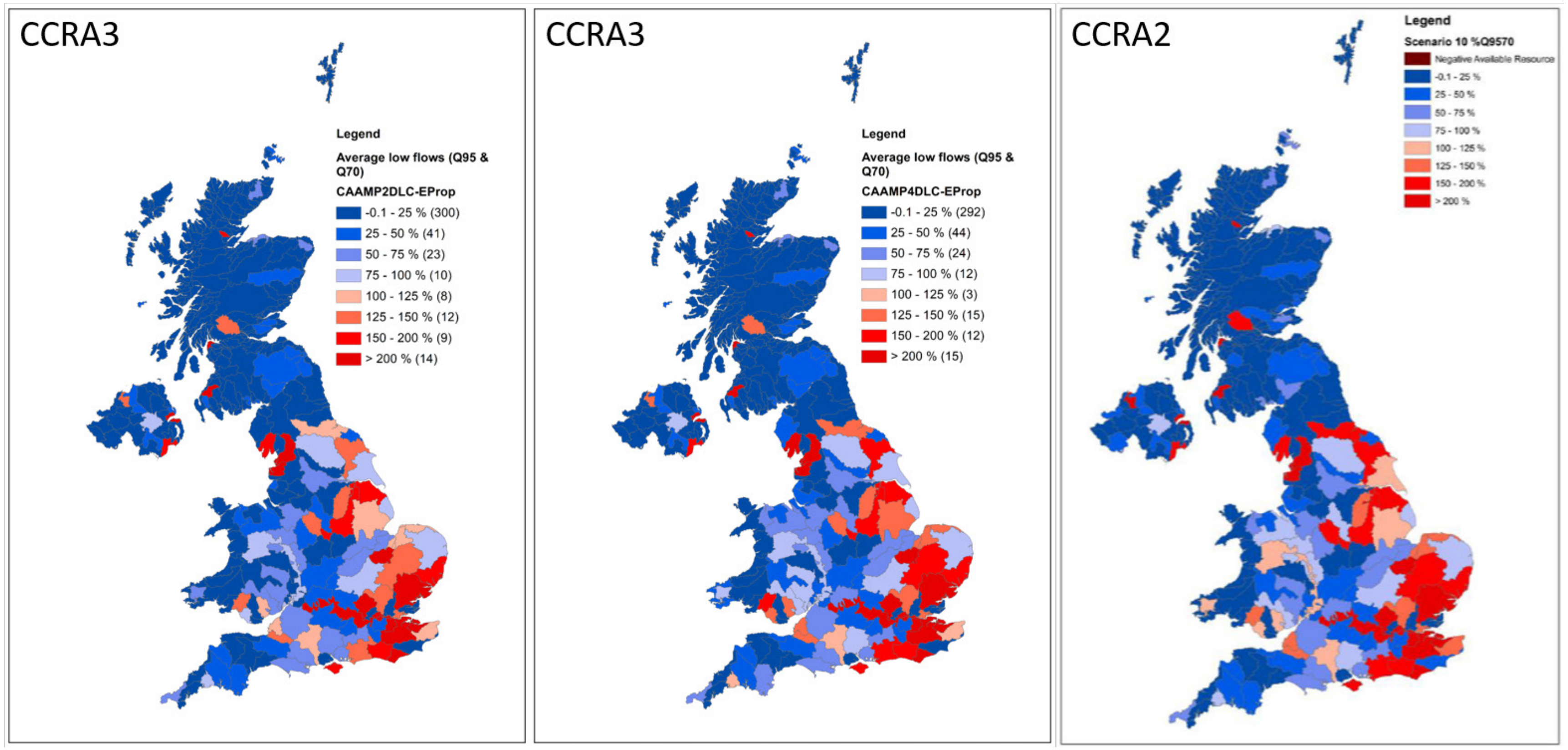

Figure 3.18: All sectors analysis results from CCRA2 and CCRA3; presenting the similarity between catchment water availability results. Left: CCRA3, 2°C world, central population scenario, current and announced adaptation scenario and proportional environmental flow policy. Centre: CCRA3, 4°C world, central population scenario, current and announced adaptation scenario and proportional environmental flow policy. Right: CCRA2, 2080s, UKCP09 medium emission p50 scenario, principal population projections, current and announced adaptation scenario and proportional environmental flow policy

Source: CCRA2 map from HR Wallingford, 2015

3.2. Infrastructure

There are a number of climate related risks in infrastructure that are associated with changes in water availability. The following risks in the infrastructure chapter of the main CCRA3[10] report may be relevant:

- Risks to public water supplies from reduced water availability.
- Risks to energy generation from reduced water availability.
- Risks to infrastructure networks (water, energy, transport, ICT) from cascading failures.
- Risks to hydroelectric generation from low or high river flows.

Whilst this assessment of water availability does not directly evaluate the impact of changing water availability on energy generation, the projected changes in river flows presented in Section 3.1.1 may be useful in informing the potential exposure to such risks. Authors of the infrastructure chapter may also be interested to note that some members of the UKCP18 Global Projections are drier than any of the UKCP18 Probabilistic Projections under the same emissions scenario, RCP 8.5 (particularly prominent in autumn in the south of England).

The risk to public water supplies from reduced water availability is central to this assessment. The results related to this risk are described in full throughout the rest of this section. Results are presented for the present day, mid-century and then late-century. Section 3.2.4 provides an assessment of the impact of drought resilience changes, public water supply supply-side adaptation options (and inter-regional transfers) and any residual supply-demand balance deficits. Section 3.2.5 discusses areas of interdependence with other sectors, risks or adaptation measures.

3.2.1. Current supply demand balance

There is a medium level of confidence[11] in this baseline assessment.

In the UK as a whole, current demand for public water from all users is over 17,000 Ml/d, see Table 3.1. Water companies plan to the average water use per person in the UK being approximately 140 litres every day, in the home (England ~137 l/h/d; Wales ~146 l/h/d; Scotland ~158 l/h/d and Northern Ireland ~152 l/h/d)[12].

The supply-demand balance, deployable output and water demand for the four countries of the UK is shown in Table 3.1. Note that these figures are rounded to the nearest 10 Ml/d. The UK as a whole is currently in surplus of around 950 Ml/d. The surplus reported in CCRA2 was around 2000 Ml/d. This is based on water companies meeting their baseline target levels of service (e.g. frequency of demand restrictions) as set-out in their latest resource plans. The primary reason for this reduction is due to a change in the way that water companies in England and Wales are accounting for climate change in their latest Water Resource Management Plans 2019. As a general rule, the methods and evidence base are improving, and the results presented here reflect an improvement in our understanding of the current level of risk.

[10] Risk definitions correct at end 2019.

[11] See glossary for definition.

[12] Average, weighted by population of the dry year per capita consumption values used for planning purposes, extracted from company water resource plans, year 2019/20.

Table 3.1: Main components of baseline (~2019/20) supply-demand balance, deployable output and demand in the four countries of the UK

Country	Supply-demand balance (Ml/d)	Deployable output (Ml/d)	Water Available for Use	Demand Ml/d (% of total demand)					Target headroom
				Household	Non-household	Leakage	Other	Total demand	
England	400	16,250	15,150	7,790 (56%)	2,830 (20%)	2,940 (21%)	320 (2%)	13,880	870
Wales	80	1,060	1,010	460 (55%)	180 (21%)	170 (20%)	20 (2%)	840	90
Scotland	300	2,260	2,340	830 (44%)	410 (22%)	590 (31%)	60 (3%)	1,890	150
Northern Ireland	170	840	770	290 (51%)	110 (19%)	160 (28%)	20 (4%)	570	30

Source: Figures rounded to the nearest 10 Ml/d. Informed by from the latest water company resource plans. Factors such as target headroom, sustainability and other DO reductions are not recorded in this table; hence why deployable output minus demand does not equal the supply-demand balance. 'Other' demand includes more ad-hoc water demand, such as that required for firefighting.

England accounts for around 80% of the UK's demand for public water supplies; a reflection of the larger population. Consequently, the deployable output in England is similarly high. Deployable output is the amount of water that can be abstracted from a water company's sources (e.g. rivers, reservoirs and groundwater), constrained by the licensed volume, hydrology or hydrogeological factors i.e. the yield of the source and, works capacity. The weather and climate influence the yield directly and yield is often the determining constraint on resource availability, particularly in England.

A water company will lose a small amount of deployable output simply through the process of moving and treating the abstracted raw water and from outages. Deployable output from sources may also be transferred to other water resource zones either within the same company or between companies. The water available for use is therefore the deployable output, minus any losses, exports and outages and plus any water imports.

Figure 3.19 shows how the water available for use is split between the different types of demand at a UK scale. At a national level, household consumption accounts for more than half of the demand for public water supplies. Leakage and non-household demand are of a similar magnitude and account for a little over 20% of the demand each. Leakage varies between the four countries of the UK considerably. Other demand, e.g. that used for fire-fighting, accounts for a very small amount of total demand.

Also included in the demand in Figure 3.19 is target headroom. 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. This does include climate change as well as other supply-side and demand-side uncertainties. However, due to the way in which water companies report this value it is not always possible to remove individual components consistently and therefore, this has not been done in this assessment. The values reported through the water resource planning horizons have been maintained in the analysis presented here.

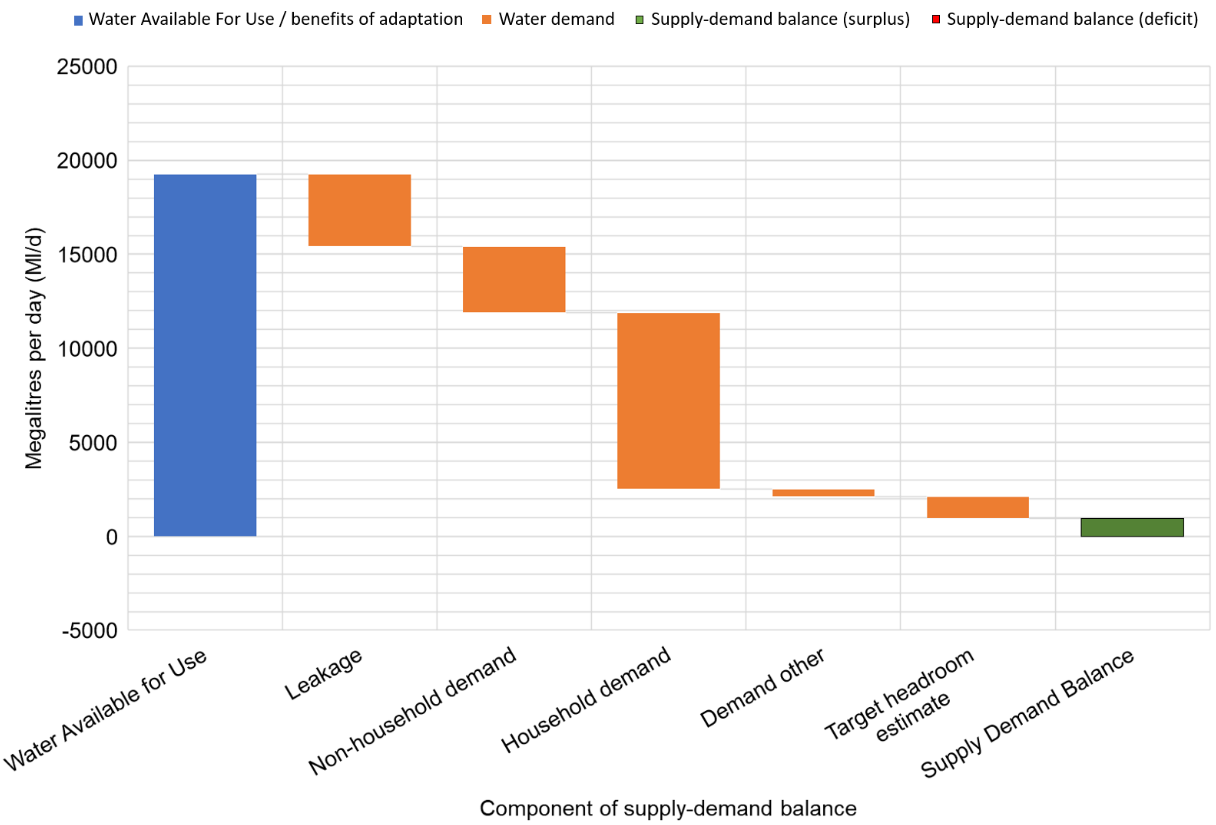

Figure 3.19: Components of baseline (2019/20) supply-demand balance (~950 Ml/d surplus) for the UK

Notes: Supply-demand balance shown as a green block, i.e. a surplus. Household demand is dry year values.

Figure 3.20 shows the supply-demand balance across the UK, by water resource zone, in the base year (usually 2019). A water resource zone is defined as the largest possible area in which customers are exposed to the same level of risk of a shortfall in water. This is the standard unit by which water companies in the UK evaluate their water supplies in their resource plans. The latest plans produced in England and Wales were in 2019. The programme for water resource management in Scotland and Northern Ireland is different to England and Wales. Scottish Water and Northern Ireland water are currently in the process of completing their latest plans. The figures presented in Figure 3.20 and used to inform this assessment are either taken from the latest water company water resource plans or, in the case of Scotland and Northern Ireland, personal communication with those water companies.

Whilst Figure 3.20 shows that the vast majority of water resource zones operate a surplus in the present day, there are a few notable exceptions. Around 16.7 million people live in water resource zones that are currently operating in a deficit (7.89 million of which are in London), often reflecting recent sustainability reductions or climate change impacts to which they have yet to adapt. In reality, this means that the water company does not currently meet its specified target levels of service and drought resilience (noting that specified levels of service vary between companies). As a result, customers may experience more frequent temporary use bans (e.g. hose pipe bans) and other restrictions than is the water company's target level of service. Furthermore, water companies may already be attempting to obtain other sources of water either through new supply schemes and transfers and/or taking advantage of reductions in demand in other areas of the system e.g. powerplant closures.

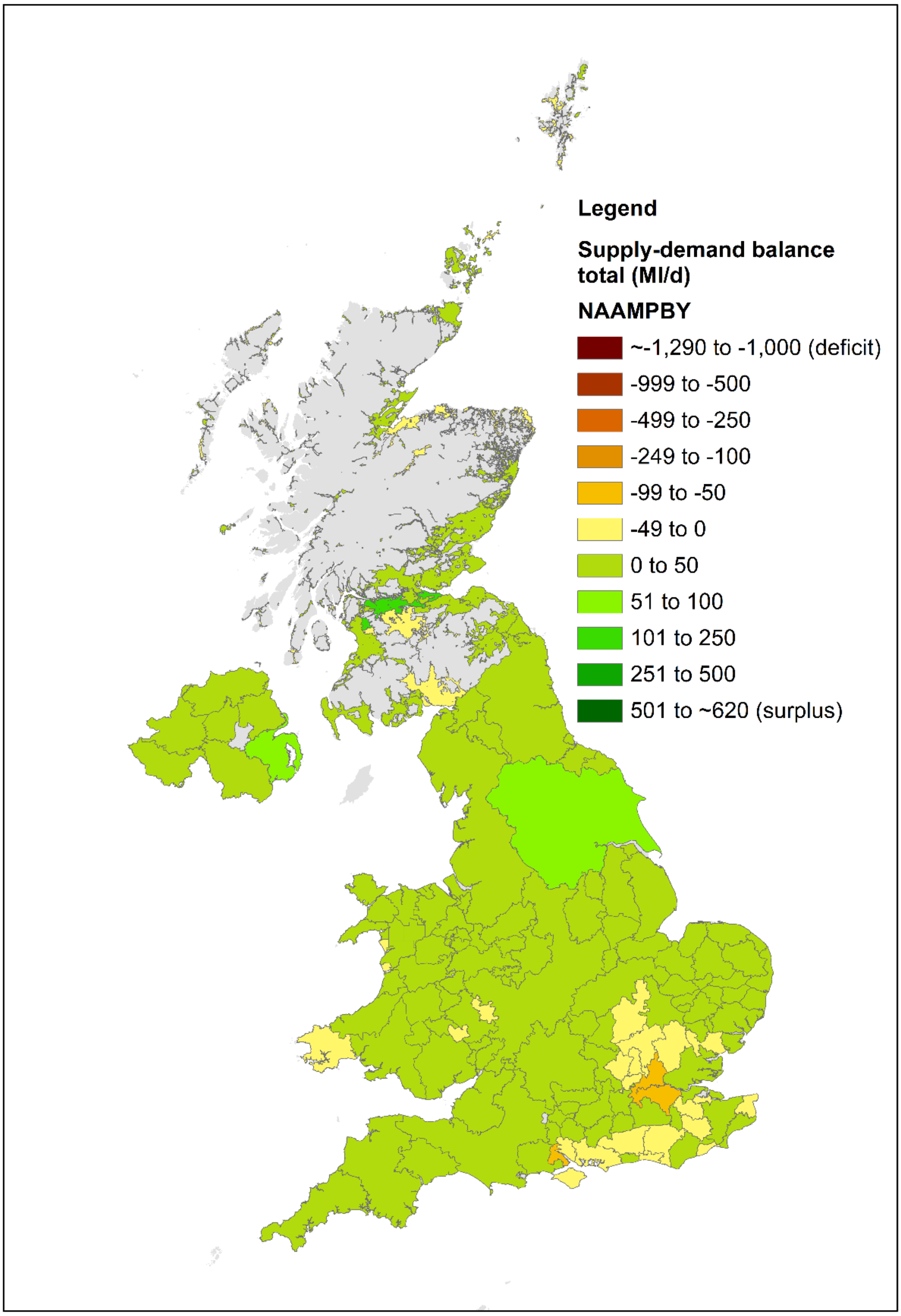

Figure 3.20: Current supply-demand balance by water resource zone

Source: Latest Water Company resource plans (2019 in England and Wales; unpublished data used for ongoing plans in Northern Ireland and Scotland).

In England, there is a move towards a regional, multi-sector, approach to water resource planning in order to increase drought resilience of water supplies into the future (Environment Agency, 2020). A key aspect of a regional approach is that water companies will not solely focus on their own supplies, but also that of their neighbouring water companies with a view to enabling more water sharing within a region. Therefore, although the underpinning data in this assessment is at the water resource zone scale, the public water supply results in this assessment are calculated and presented at the regional and devolved administration scales as well.

Figure 3.21 shows the same results as Figure 3.20 aggregated at the regional scale. The regions in the map are labelled:

- WRSE – Water Resources South East, contains 38 water resource zones.
- WRE – Water Resources East, contains 36 water resource zones.
- WCWR – West Country Water Resources, contains 6 water resource zones.
- WRW – Water Resources West, contains 24 water resource zones.
- WRN – Water Resources North, contains 6 water resource zones.
- Wales “region” – includes the rest of Wales that is not part of WRW, contains 21 water resource zones.
- Scotland – the whole of Scotland, no English water resource zones are included. Scotland has 191 water resource zones and large areas of the country have no public water supplies, only private ones, hence the grey areas in the maps throughout the report.
- NI – the whole of Northern Ireland. Northern Ireland has 7 water resource zones.

In contrast to Figure 3.20, only one area in Figure 3.21 has a present day supply-demand deficit, Water Resources South East. In all other regions, the deficits in one water resource zone are balanced by the surplus in another. For example, the small deficits apparent in a few water resource zones in Scotland in Figure 3.20 no longer exist because overall, the country has a surplus of water.

Crucially, the regionalisation of results assumes that water can be readily shared between water resource zones within each region. Whilst there are many existing transfers of water between zones throughout the UK, this is not true of all zones and in some areas, such as in Scotland, transfers across challenging terrain are likely to be prohibitively expensive or impossible. Therefore, presenting the results on a regional basis may obscure hotspots of risk both now and in the future. However, this scale of presentation is appropriate for this national level assessment as it is not the purpose of this work to evaluate the detail or manage risk to water resources at the water resource zone level.

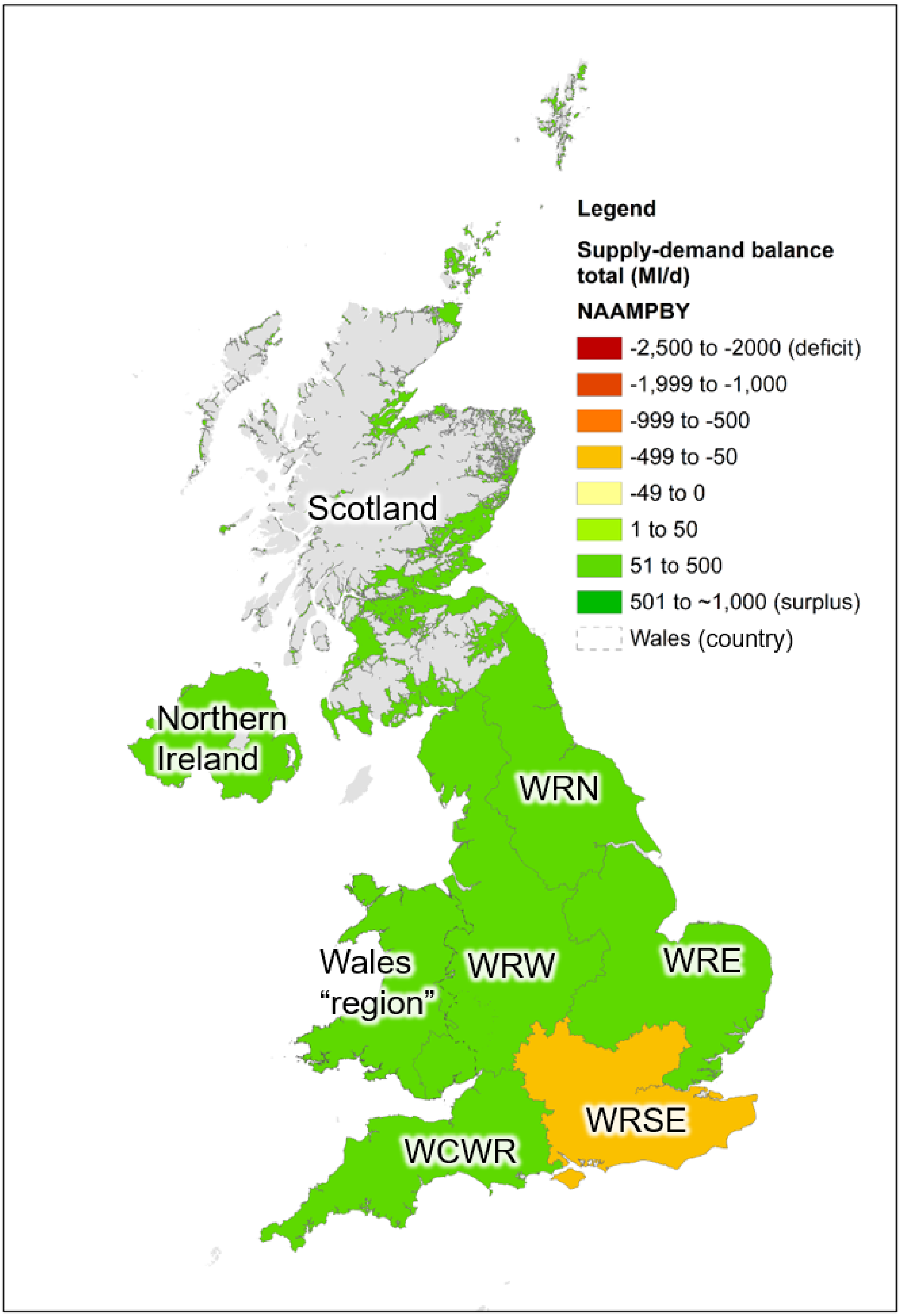

Figure 3.21: Current supply-demand balance by region

Source: *Latest Water Company resource plans (2019 in England and Wales; unpublished data used for ongoing plans in Northern Ireland and Scotland).*

3.2.2. Mid-century supply-demand balance

There is a medium level of confidence[13] in this assessment.

Figure 3.22 and Figure 3.23 show projections of supply-demand balance (Ml/d) by region, in the mid-century under a central population and a no additional adaptation action future, based on water companies maintaining the baseline target levels of service and drought resilience as specified in their latest water resource plans. Figure 3.22 shows a 2°C world and Figure 3.23 shows a 4°C world. In both cases the results reflect the 50th percentile value of the range (ensemble of 28 members) of the projections simulated. Overall, the UK faces a supply-demand balance deficit of between -650 and -920 Ml/d. This equates to the daily usage of around 4.7 – 6.6 million people (based on the present day average per capita consumption of 140 l/h/d). These values assume that water can be freely transferred between supply systems around the country as a whole to wherever it is required. Even if this could be realised, it is worth noting that this would likely be associated with additional operational losses.

Under a scenario of no additional adaptation action, three out of the eight regions in the UK are in deficit by the mid-century; the increases in demand from a rising population places additional pressure on water resources even when the impact of climate change is relatively low. By mid-century, the difference in climate change impact between 2°C and 4°C worlds, is around 270 Ml/d at a national scale. The difference in impact between the low and high population projections in the mid-century is around 3,220 Ml/d day at a national scale. Therefore, in the mid-century, the projected impact of climate change on the supply-demand balance at the UK scale is around 10% of the range of the potential projected impact of population growth. Whilst 270 Ml/d is small compared to the baseline nationwide demand (Table 3.1) it is nearly 30% of the current supply-demand balance surplus. The vast majority of this impact is realised in England (220 Ml/d).

The population scenarios used in this assessment are shown in Figure 3.26. Three scenarios were used: no population change i.e. the same values as the baseline year; a central population projection and a high population projections, both of which use projections by Office for National Statistics, provided by Cambridge Econometrics for CCRA3 and scaled to water resource zones for this assessment. The colours in the maps show the absolute population size and the text in the maps indicates the percentage change from the baseline. The population is projected to increase most quickly in England, particularly in the south. This is the same pattern of increase as CCRA2. It is worth noting that these population figures may differ from those used by water companies in the water resource plans. In England and Wales, local population projections from local authorities are used. They are often (but not always) greater than the population projections used here. It is unclear to the authors exactly why this is and has been presumed that housing targets at a local level may play a part.

The population figures for similar scenarios in this assessment and the water availability assessment for CCRA2 are shown in Table 3.2 and Table 3.3 respectively. With the exception of Northern Ireland, both the principal and high population projections used in the CCRA2 water availability assessment were higher absolute values than the central and high population projections used in this assessment. In the late-century, the CCRA2 principal population projection is around 6% higher than the CCRA3 central population projection at a national scale. In the late-century, the CCRA2 high population projection is around 7% higher than the CCRA3 high population projection at a national scale. As a general rule population projections become less accurate the further you look into the future as the drivers of fertility, mortality and immigration become more uncertain. Population projections also tend to be most accurate after a census. Although

[13] See glossary for definition.

there is a trend of improvement over time in the accuracy of population projections, there is some variation, and both over-prediction and under-prediction of population size at a particular date are both possible, based upon historic data (ONS, 2015).

Table 3.2: Total population values (000's) for the baseline, central and high population projections for this assessment, by devolved administration. Percentage variation from baseline shown in brackets

	Baseline (2019)	Mid-century (2055)		Late-century (2085)	
		Central projection	High projection	Central projection	High projection
England	56,650	64,670 (14%)	67,570 (19%)	69,150 (22%)	74,630 (32%)
Wales	3,140	3,220 (3%)	3,410 (9%)	3,210 (2%)	3,570 (14%)
Scotland	5,300	5,520 (4%)	5,940 (12%)	5560 (5%)	6,350 (20%)
Northern Ireland	1,890	2,030 (7%)	2,240 (19%)	2,020 (7%)	2430 (29%)
Total	66,980	75,440 (28%)	79,160 (59%)	79,940 (36%)	86,980 (95%)

Source: Cambridge Econometrics (2019)

Table 3.3: Total population values (000's) for the baseline, principal ("central") and high population projections for the CCRA2 water availability assessment, by devolved administration. Percentage variation from baseline shown in brackets

		Mid-century (2056)		Late-century (2085)	
	Baseline (2012)	Principal projection	High projection	Principal projection	High projection
England	53,490	67070 (25%)	70,950 (33%)	74,300 (39%)	83,680 (56%)
Wales	3,070	3,410 (11%)	3,610 (18%)	3560 (16%)	4,040 (32%)
Scotland	5,310	5,970 (12%)	6350 (20%)	5970 (12%)	7,170 (35%)
Northern Ireland	1,820	2040 (12%)	2160 (19%)	2,010 (10%)	2,300 (26%)
Total	63,690	78490 (60%)	83,070 (90%)	85,840 (77%)	97,190 (149%)

Source: ONS 2014 and ONS 2013 a-d

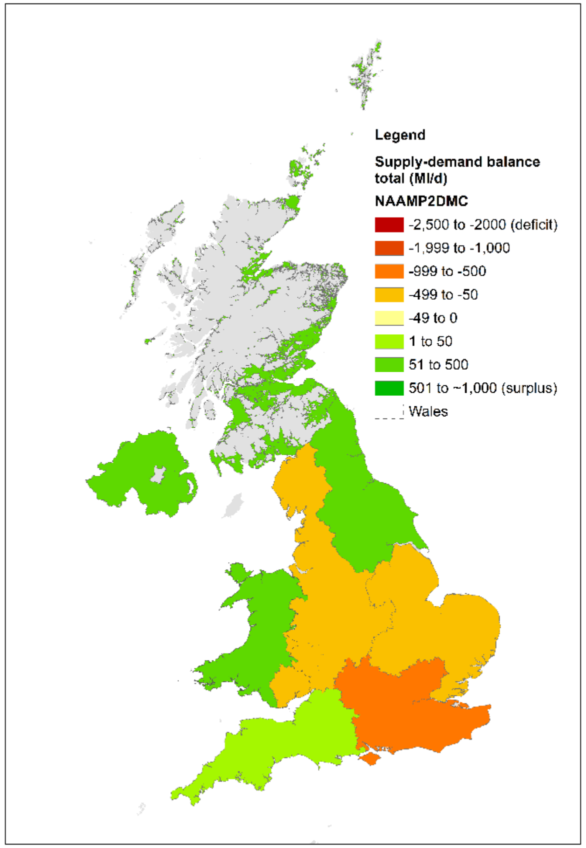

Figure 3.22: Supply-demand balance in the mid-century, in a 2°C world, central population projection and assuming no additional adaptation action

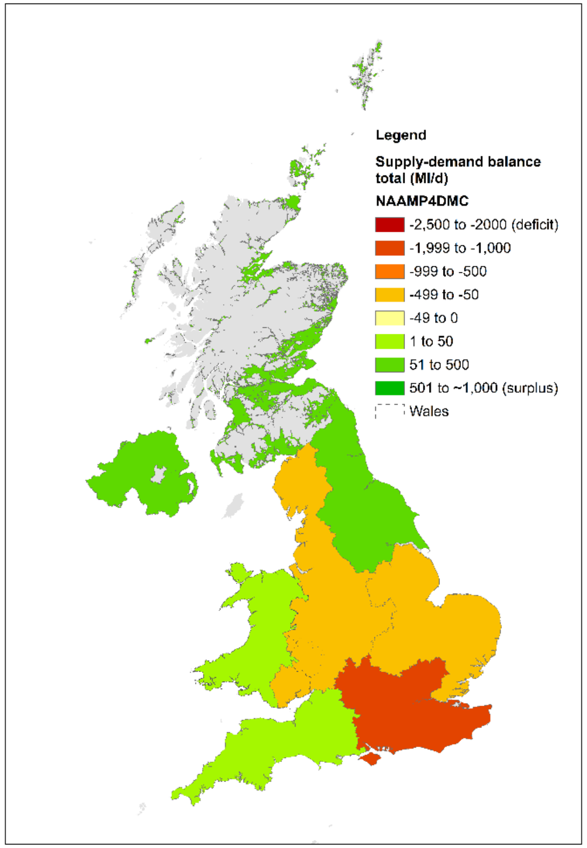

Figure 3.23: Supply-demand balance in the mid-century, in a 4°C world, central population projection and assuming no additional adaptation action

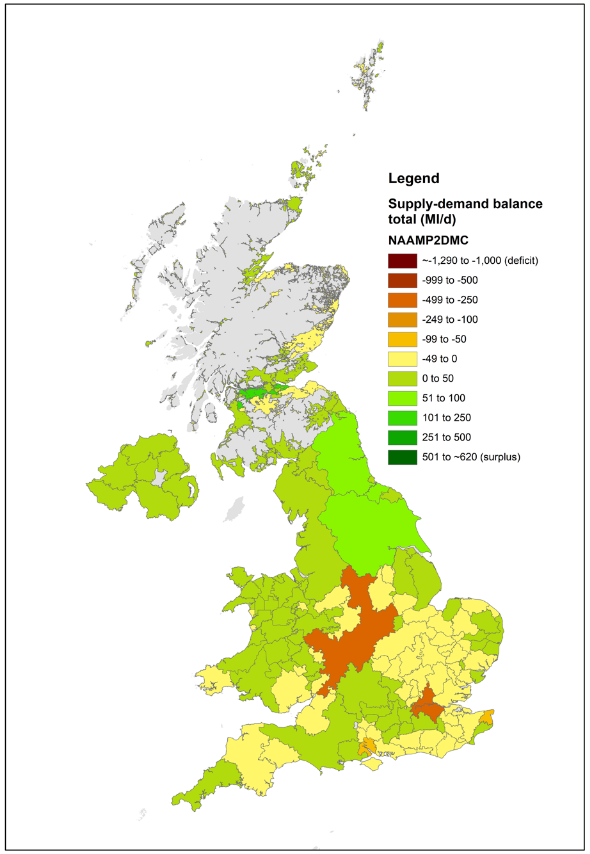

Figure 3.24: Supply-demand balance in the mid-century, in a 2°C world, central population projection and assuming no additional adaptation action, at the water resource zone scale

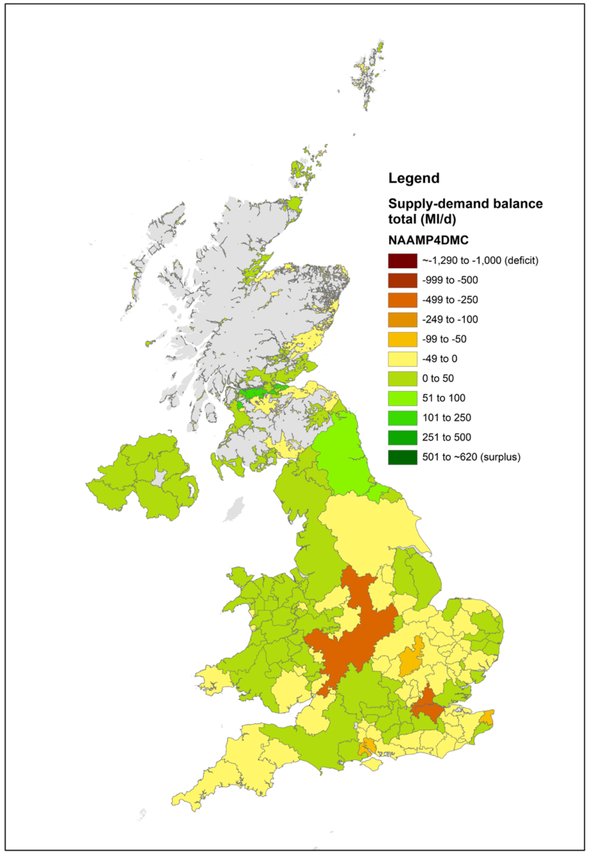

Figure 3.25: Supply-demand balance in the mid-century, in a 4°C world, central population projection and assuming no additional adaptation action, at the water resource zone scale

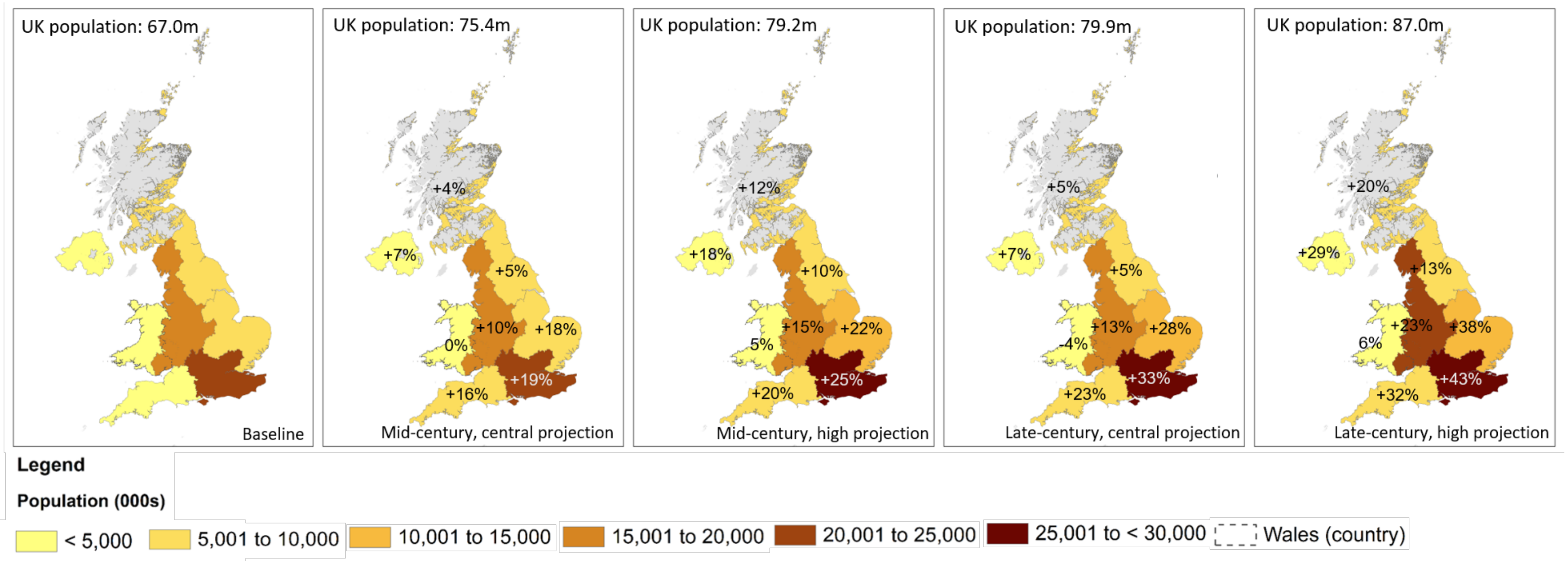

Figure 3.26: UK population projection scenarios for the base year (and no population change projection), central population projection and high population projection for the mid- and late-century for each of the regions. The proportional change for each region and total UK population is also provided

Source: Cambridge Econometrics (2019) and latest water company water resource plans.

Figure 3.27 shows a selection of the scenarios that were simulated for the mid-century time period at the UK scale. Figure 3.27 shows the deployable output and water available for use for the baseline, 2°C and 4°C worlds on the left-hand side in dark and light blue. The different components of demand for each scenario are on the right-hand side in red, orange and yellow tones. The water available for use in a 2°C and 4°C world are also represented by dotted blue horizontal lines across the graph. It is desirable for the demand on the right-hand-side of the graph to sit beneath these dotted blue lines as that means supply is in excess of demand, at a national scale. Each column on the demand side of the graph illustrates the proportion of household demand, non-household demand, leakage and other demand that make up the total demand figure. It is evident from this graph that the household demand is significantly larger, across all scenarios than the change in deployable output or water available for use between a 2°C and 4°C world.

The high population and no additional adaptation action scenarios put the UK-wide supply-demand balance at risk of deficit. In the late century, under a high population scenario, only the additional action scenario (i.e. a more ambitious level of demand-side adaptation than is currently planned, results in a UK-wide supply-demand balance surplus. The influence of adaptation actions, reducing leakage and per capita consumption are evident when comparing the three scenarios that use the central population projection.

It should be noted that:

- In all future scenarios simulated, sustainability reductions already committed to in water companies baseline plans are included in this assessment. There will be some reductions in water available for use in the future due to sustainability reductions that have already been agreed but not yet implemented. This will appear in this analysis as an increasing difference between deployable output and water available for use, as sustainability reductions have been subtracted from the latter. If, in the future, environmental regulators enforce additional sustainability reductions then this would reduce the supply-demand balance further unless additional demand-side or supply-side adaptation actions were taken to compensate for the loss of resource.
- Changes to outage, imports and exports through the baseline plan also impact upon the water available for use, relative to the deployable output, in the mid- and late-century.
- In all scenarios, target headroom is extracted from the baseline plan of the latest water company resource plans to 2045. It is assumed that this does not change throughout the rest of the century. The target headroom will include the water companies estimate of uncertainty with respect to climate change, population growth and other sources of uncertainty. The individual components have not been removed because it is not possible to do so in a consistent manner for all water resource zones based on the data made available to this study.
- In all future scenarios simulated, the baseline levels of service stated in the water company resource plans are maintained.

Similar graphs to Figure 3.27 are available in Appendix A, for each of the countries of the UK, separately.

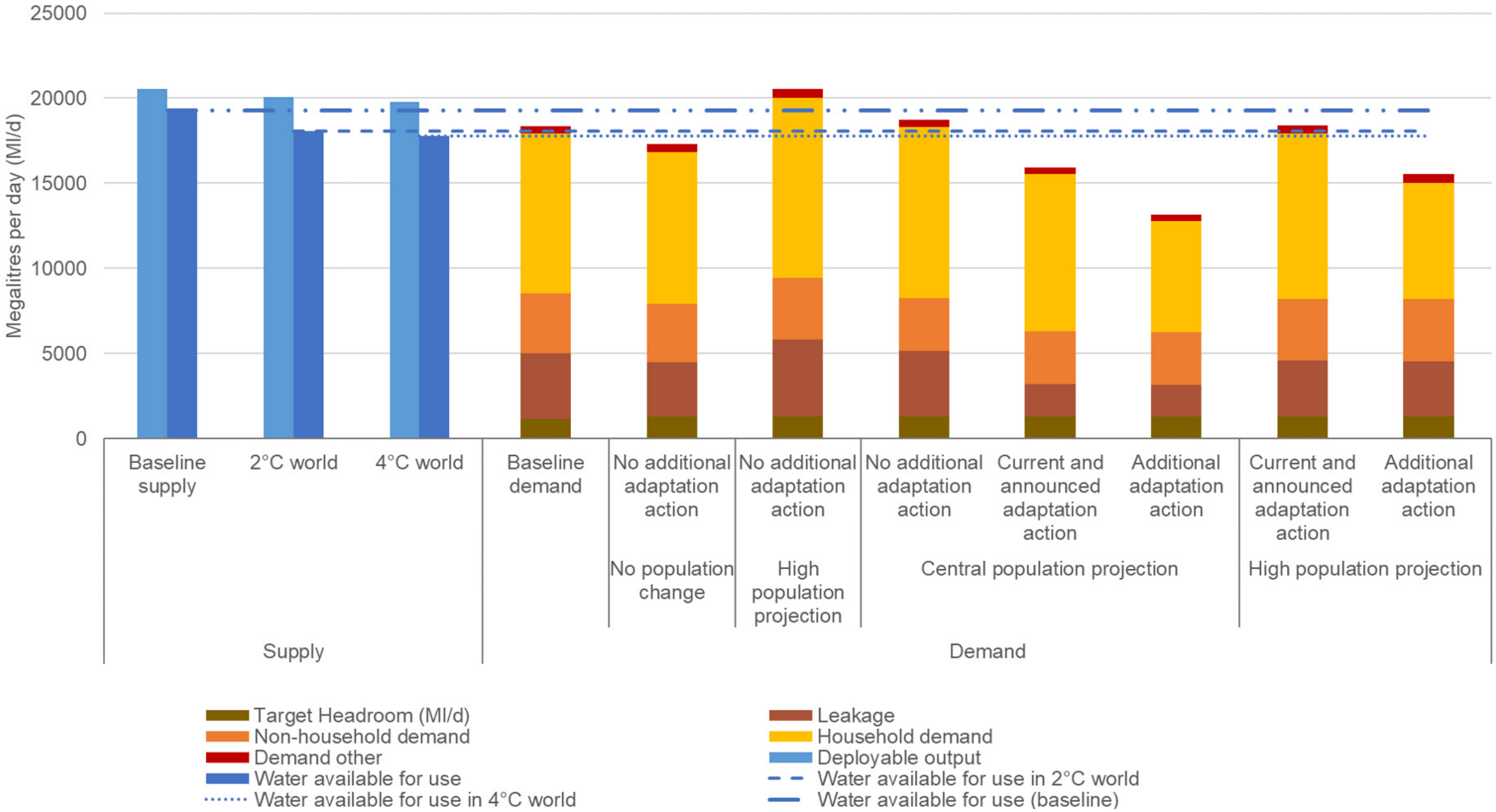

Figure 3.27: Scenarios of water supply and demand in the mid-century. Only demand-side adaptation actions are included in the scenarios above

Impact of adaptation

At a national scale, only the no additional action adaptation scenario combined with a high population scenario indicates a nationwide supply-demand balance deficit. At a finer scale, Water Resources South East, Water Resources North and Water Resources East are all projected to have deficits under a 2°C world, central population projection with no additional adaptation action, see Figure 3.22 and Figure 3.23. Figure 3.28 illustrates the potential impact that demand-side adaptation measures might have on these deficits in a 2°C and 4°C world.

The left-hand map in Figure 3.28 presents the regional supply-demand balance for a 2°C world, central population projection and current and announced adaptation scenario. In this scenario, the current and announced demand-side adaptation actions serve to solve the deficit in all regions. As with all regionalised results, this assumes that water can be freely transferred within a region and that no additional pressures, such as sustainability reductions are placed upon the water available for use.

The middle map in Figure 3.28 presents the regional supply-demand balance for 4°C world, central population projection and current and announced adaptation scenario. In this scenario, with a more extreme change in the climate, the current and announced demand-side adaptation actions serve to solve the deficit in all regions except for Water Resources South East.

The right-hand map in Figure 3.28 presents the regional supply-demand balance for a 4°C world, central population projection and additional action adaptation scenario. In this scenario, the additional demand-side adaptation actions project sizable surplus' in all regions, including Water Resources South East.

Figure 3.29 to Figure 3.32 show the reduction in demand across the three adaptation scenarios, by region, for the mid-century and central population projections. These reductions correspond to the adaptation scenarios described in Table 2.3. The greatest reductions are in per capita consumption / household demand (which are closely related) and leakage. As per Table 2.3, changes in non-household demand reflect the latest water resource plans (using the final plans where available) to the mid-century and so reflect water companies current understanding and expectations on how this factor will change; only minimal changes are anticipated at this scale.

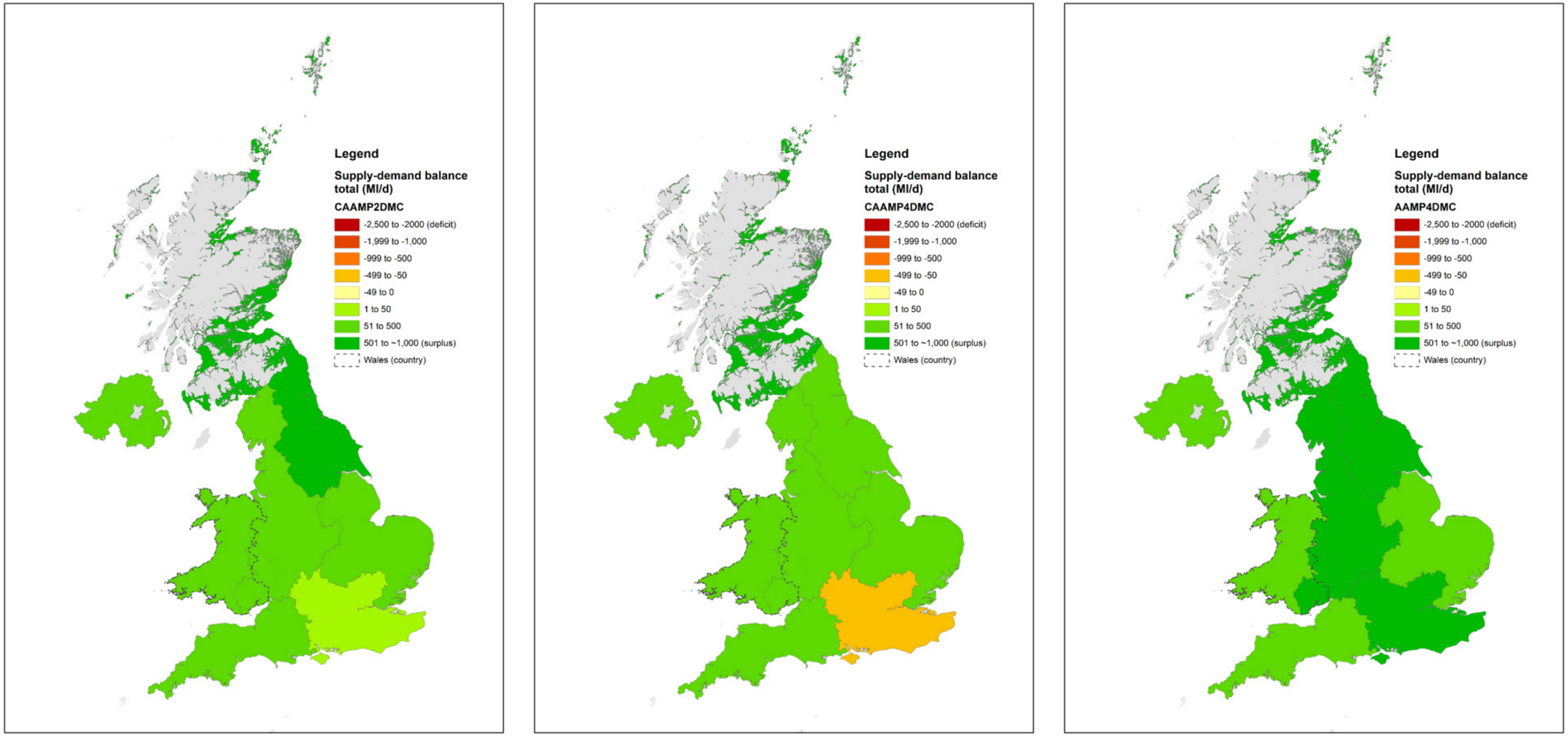

Figure 3.28: Impact of adaptation in the mid-century. Left to right: 2°C world, central population projection, current and announced adaptation scenario; 4°C world, central population projection, current and announced adaptation scenario; 4°C world, central population projection, additional action adaptation scenario

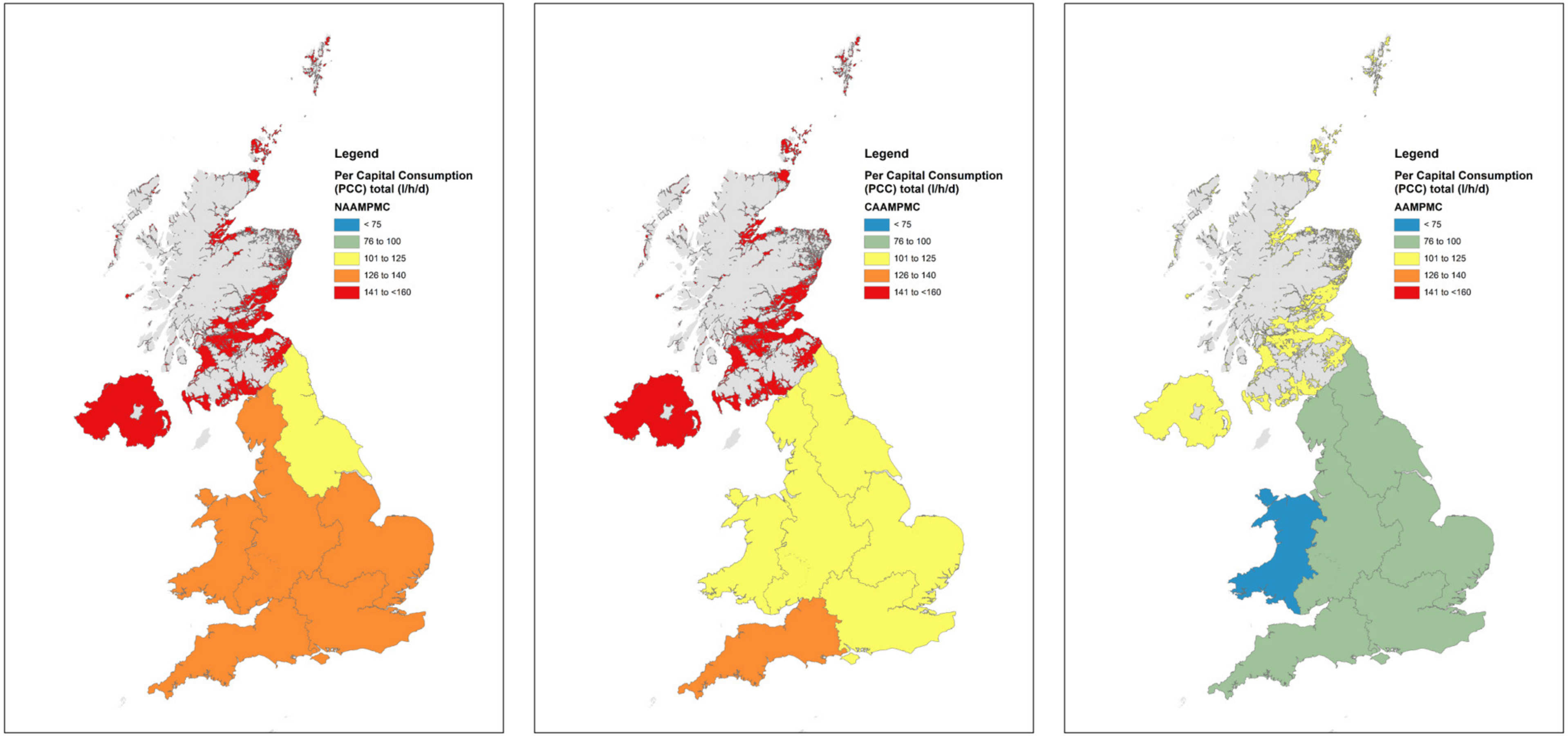

Figure 3.29: Per capita consumption across three adaptation scenarios in the mid-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

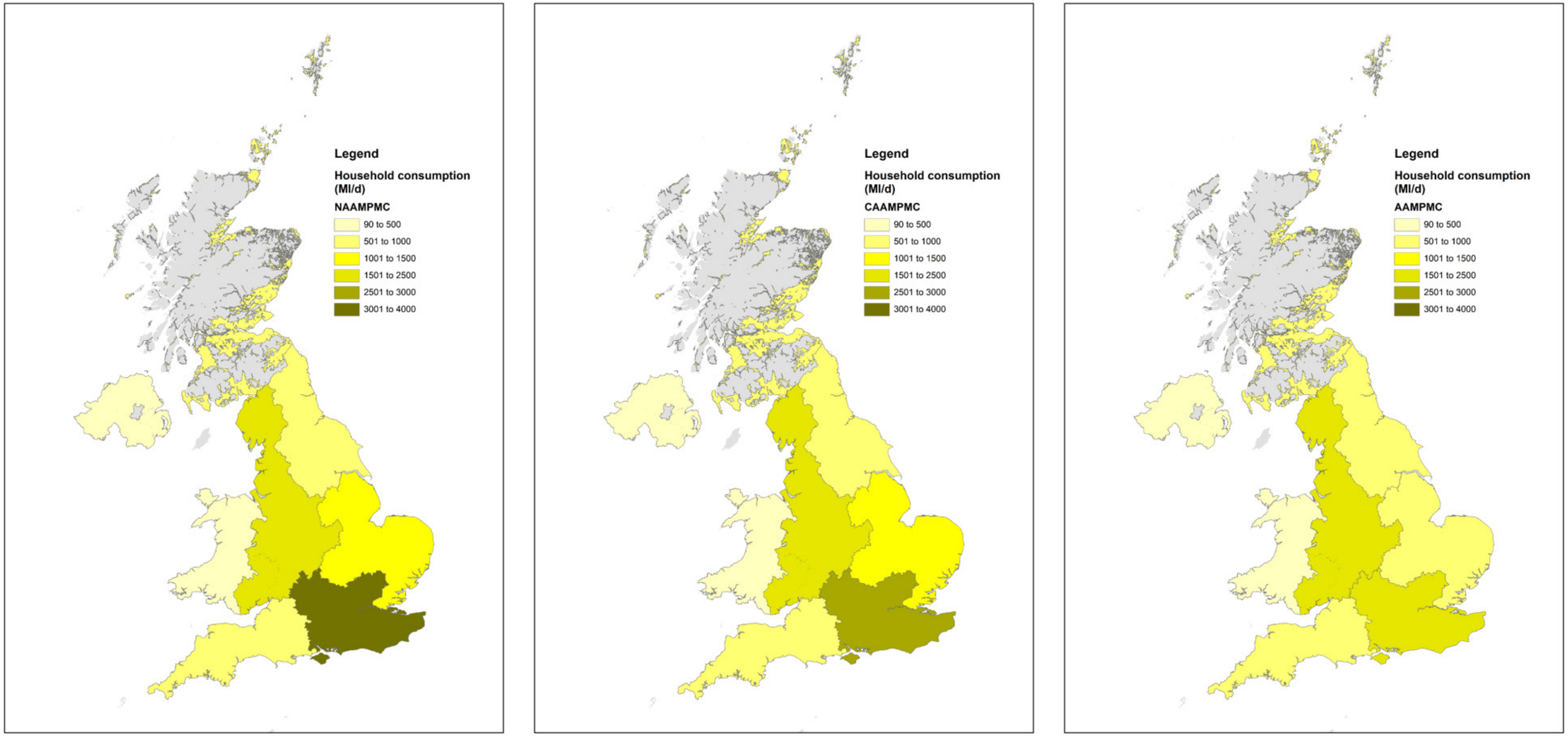

Figure 3.30: Household demand across three adaptation scenarios in the mid-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

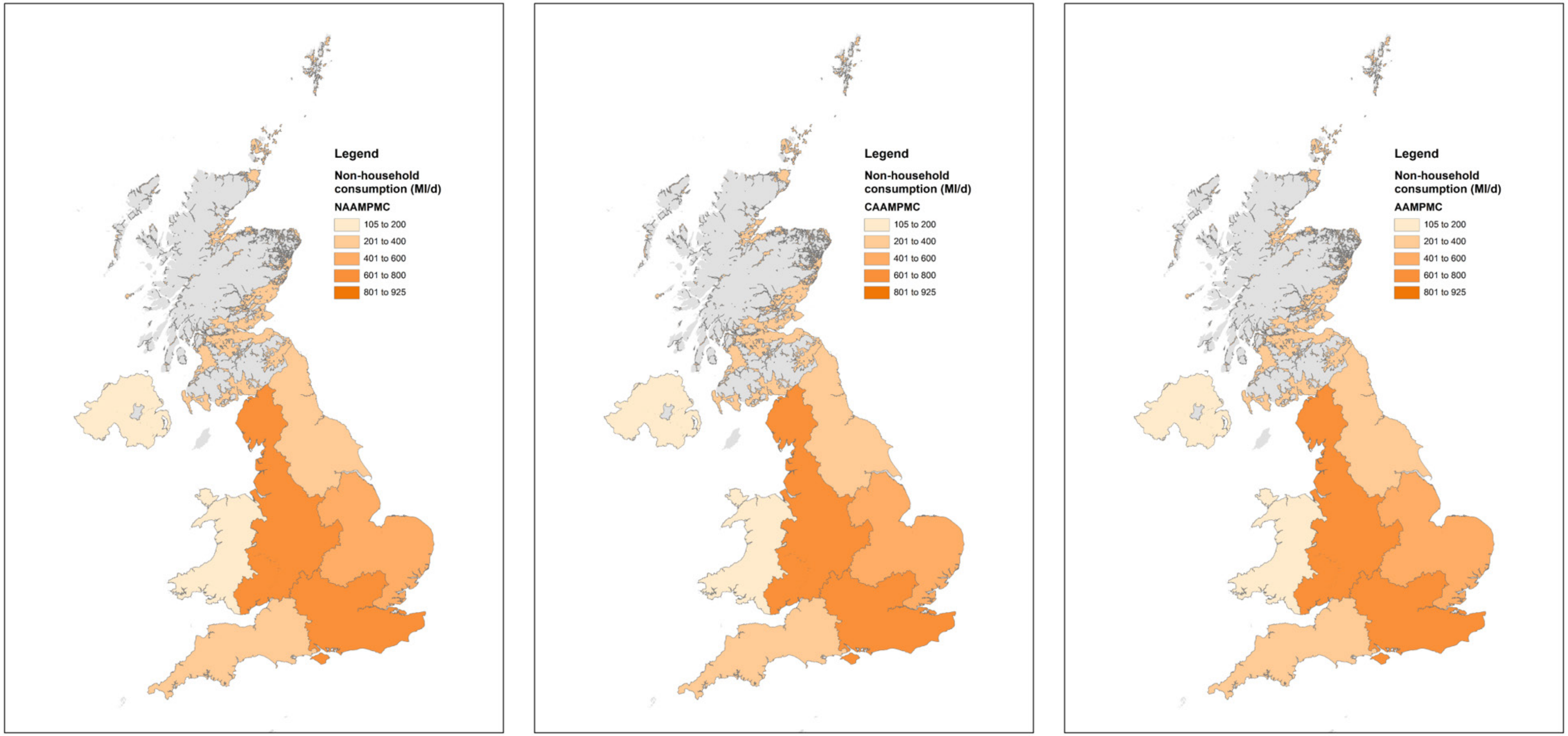

Figure 3.31: Non-household demand across three adaptation scenarios in the mid-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

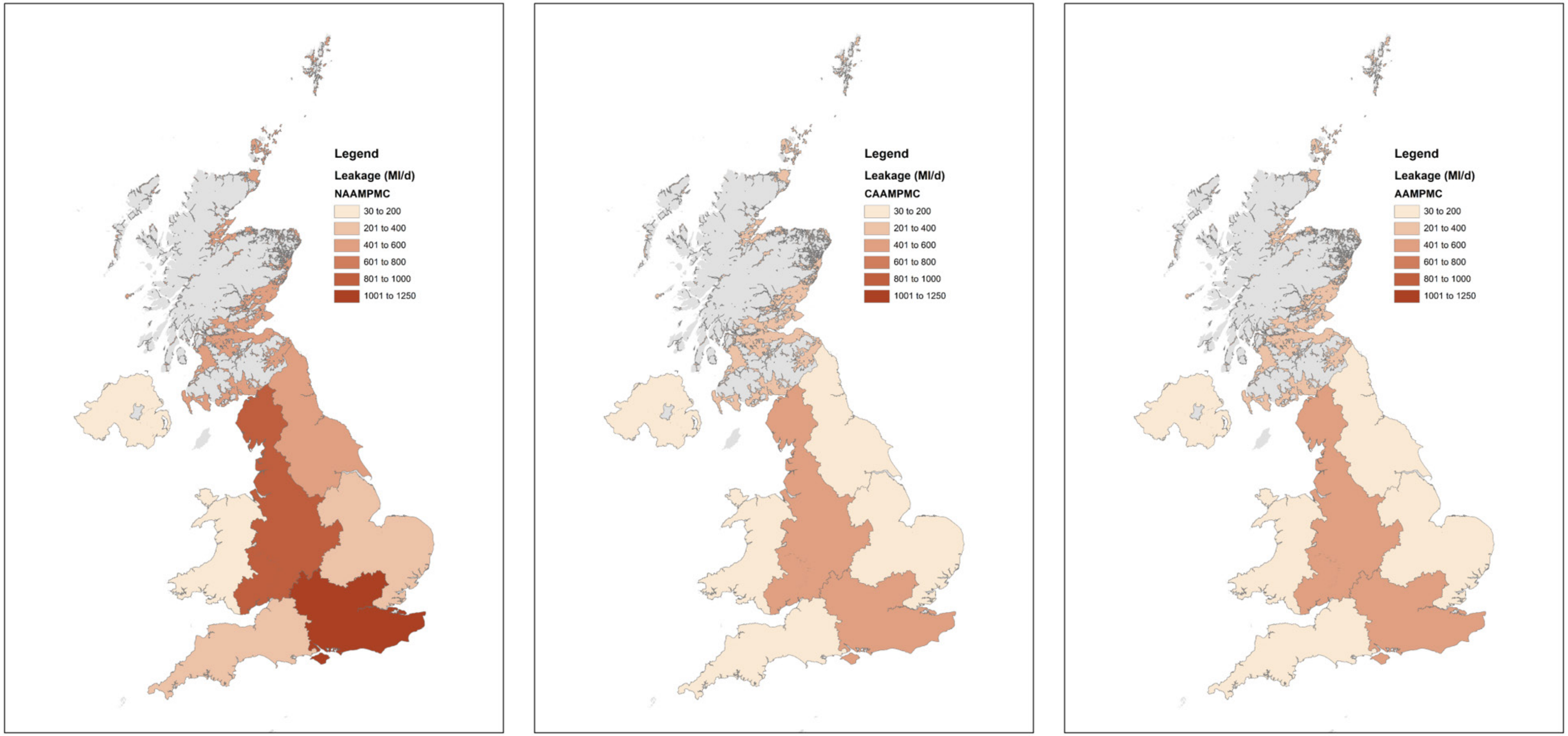

Figure 3.32: Leakage across three adaptation scenarios in the mid-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

3.2.3. Late-century supply-demand balance

There is a medium level of confidence[14] in this assessment

Figure 3.33 and Figure 3.34 show projections of supply-demand balance (Ml/d) by region, in the late-century under a central population and a no additional action adaptation future, based on water companies maintaining the baseline target levels of service and drought resilience as specified in their latest water resource plans. Figure 3.33 shows a 2°C world and Figure 3.34 shows a 4°C world (in both cases the 50th percentile value of the range of the projections simulated is presented).

Figure 3.35 and Figure 3.36 show the same information as Figure 3.33 and Figure 3.34 but at the water resource zones scale rather than the regional scale. The water resource zone level population projection for the central population projection in the late-century is shown in Figure 3.37. Hotspots of deficit tend to be co-located in areas of higher population increases in London, Severn Trent's and United Utilities strategic zones and Yorkshire Water Grid zone. The latter three are notable in their large area and hence larger populations.

Another area of note is in Bristol Water's zone, where the population projections indicate a greater than 40% increase in population by the late-century, similar to the increase anticipated for London.

The outlook in a late-century world with central population projection growth and no additional adaptation actions is one of deficit across the UK as a whole of between around 1,220 and 2,900 Ml/d (2°C to 4°C range; Figure 3.33 and Figure 3.34). This equates to the daily water usage of around 8.7 to 20.7 million people (based on the present day average per capita consumption of 140 l/h/d). These values also assume that water can be freely transferred around the country without additional operational losses. On closer inspection, the Wales region (i.e. those Welsh water resource zones that are not part of Water Resources West), Northern Ireland and Scotland all maintain a surplus supply-demand balance under these scenarios. However, the combined surplus is not sufficient to counteract the deficits located primarily in England.

[14] See glossary for definition.

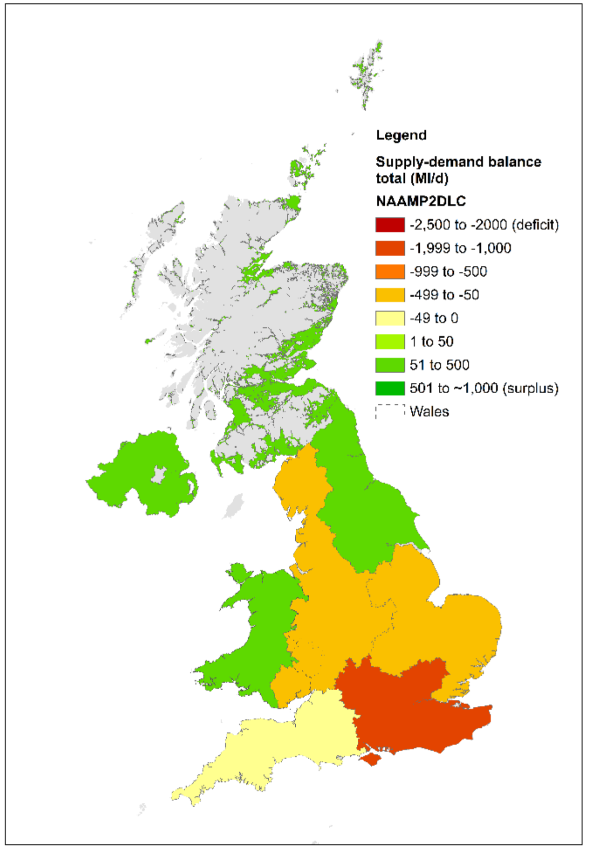

Figure 3.33: Supply-demand balance in the late-century, in a 2°C world, central population projection and assuming no additional adaptation action

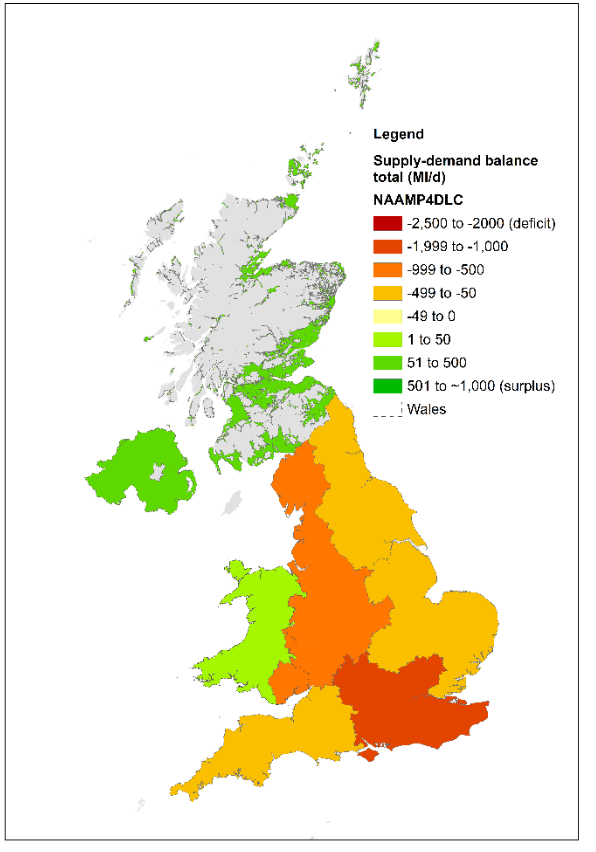

Figure 3.34: Supply-demand balance in the late-century, in a 4°C world, central population projection and assuming no additional adaptation action

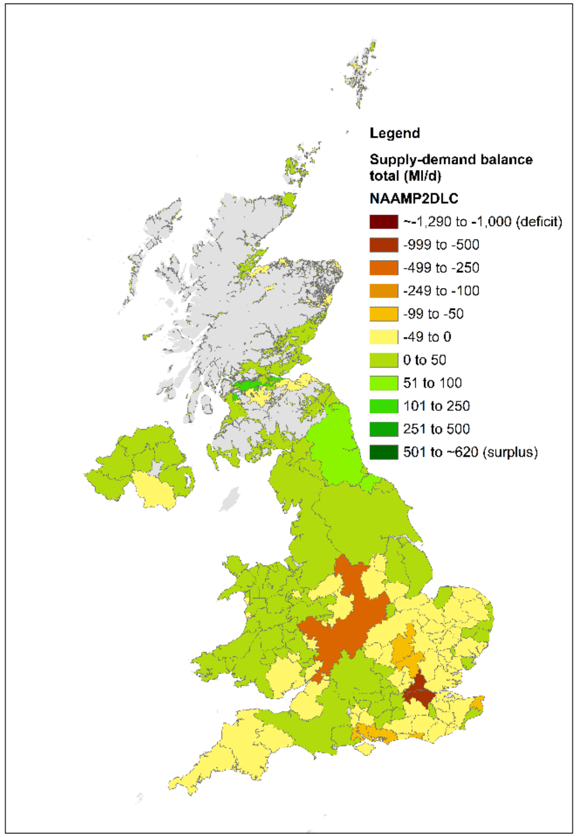

Figure 3.35: Supply-demand balance in the late-century, in a 2°C world, central population projection and assuming no additional adaptation action, by water resource zone

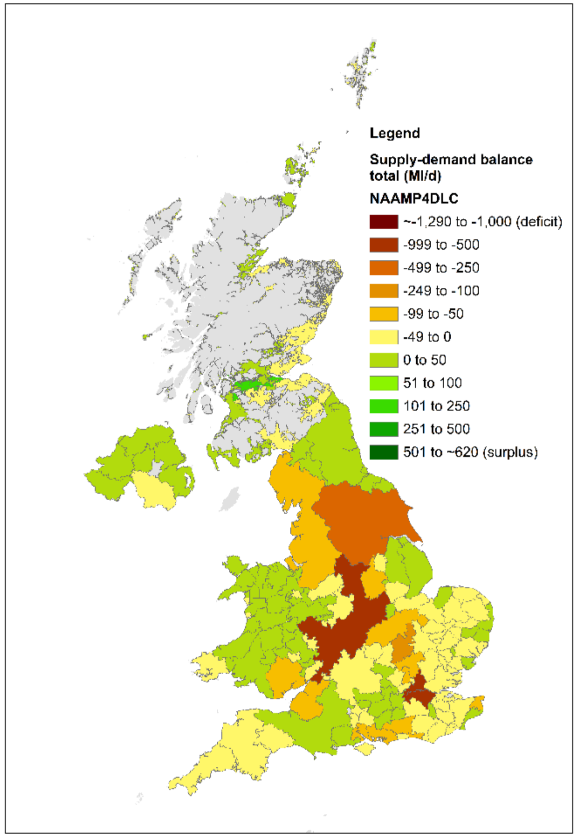

Figure 3.36: Supply-demand balance in the late-century, in a 4°C world, central population projection and assuming no additional adaptation action, by water resource zone

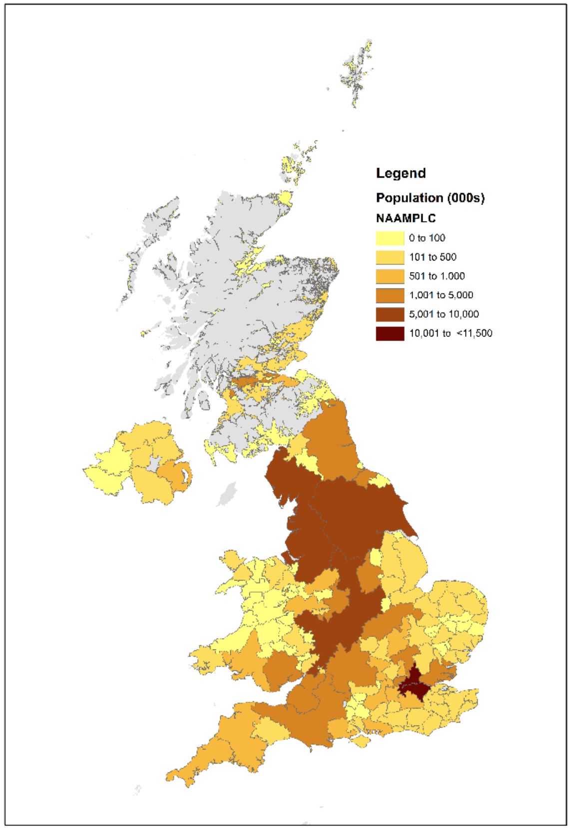

Figure 3.37: Central population projection in the late-century by water resource zone

Source: Cambridge Econometrics (2019) and latest water company resource plans.

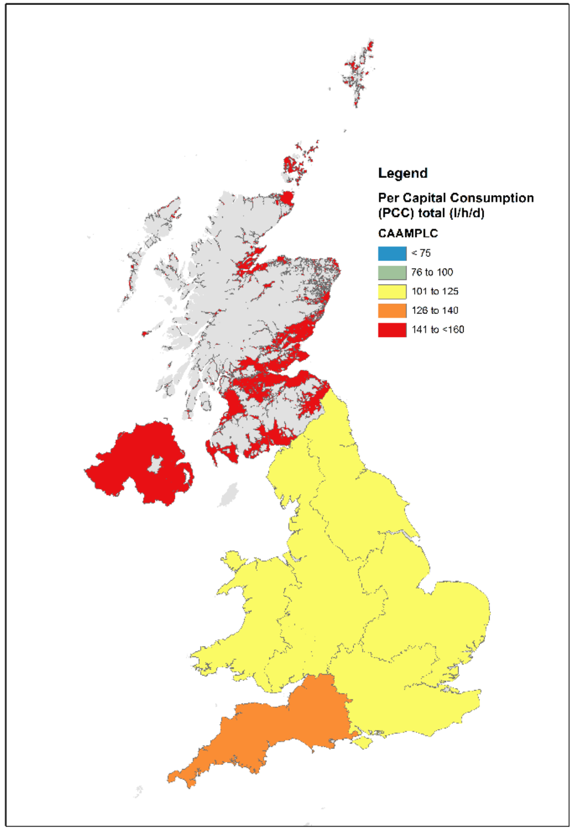

Figure 3.38: Per capita consumption (l/h/d) assuming current and announced adaptation actions continue into the future

Source: Red = >140 l/h/d; orange = 126 – 140 l/h/d; yellow = 101-125 l/h/d; light green = 75-100 l/h/d; and dark green = <75 l/h/d.

Range of impact due to climate change

In a 4°C world (Figure 3.41), the Water Resources South East region is not the only region of England projected to be in supply-demand balance deficit (nearly 750 Ml/d under this scenario). Water Resources West has a deficit of around 180 Ml/d and Water Resources East has a deficit of around 15 Ml/d. As can be seen in Figure 3.26, these regions are projected to experience the greatest increases in their already large, populations.

Figure 3.39 shows the variation in supply-demand balance for England, Wales, Scotland and Northern Ireland due only to the climate change impact on deployable output. The ranges presented are based on the full range of climate change impact across the 24 ensemble members that reach 4°C, the central black line represents the 50th percentile most commonly used in the presentation of results in this assessment. The red dots are the baseline supply-demand balance. The impact on supply-demand balance in a 4°C world in the late-century is presented as this is when climate change impacts are most significant. Figure 3.39 assumes the central population projection and current and announced adaptation action (demand side-measures only).

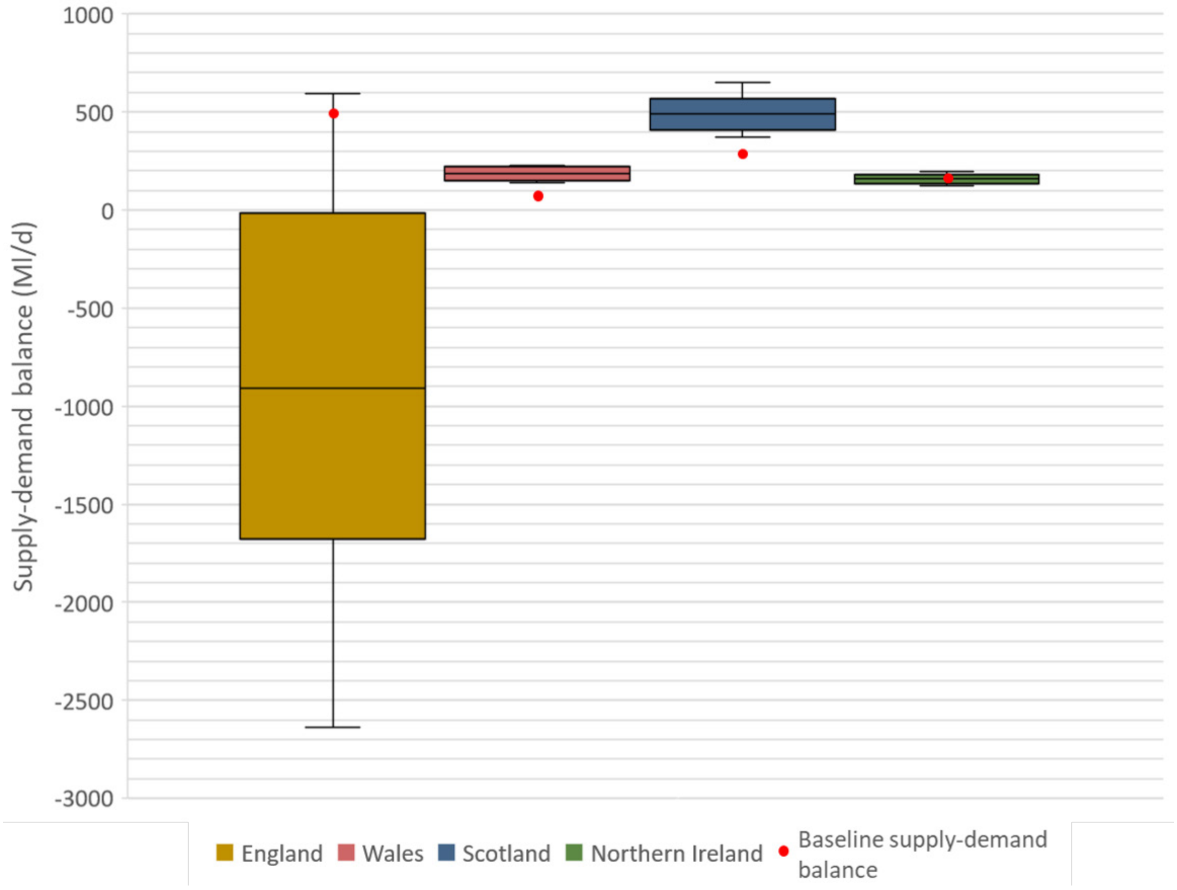

Figure 3.39: Variation in supply-demand balance due to climate change in the late-century under a 4°C world, assuming a central projection population and current and announced adaptation scenario

Notes: *Central black lines indicate the 50th percentile values that are most commonly presented in this report. The black 'whiskers' indicate the impact of the full range of the climate change projections at 4°C of mean global warming used in this assessment i.e. the UKCP18 Global Projections.*

At a country scale, only England has projected deficits due to climate change under this scenario (i.e. central population growth and current and announced adaptation action). For Wales and Scotland, all supply-demand balance projections in this range, under this scenario, exceed the baseline surplus, at the country wide scale. For Northern Ireland, the projected surplus at the 50th percentile is around 160Ml/d, 10 Ml/d less than the baseline surplus.

The large range shown in England (~20% of baseline deployable output), compared to the other countries (around 10% of baseline deployable output) is most likely due to the fact that more sources are yield constrained in England. Yield constrained means that the source of water cannot provide any more water than it already is without exceeding the measures applied to it for environmental protection, i.e. a larger pump or greater licensed quantity wouldn't help produce more water, the source is at its maximum capacity. Furthermore, sustainability reductions have been more widely applied in England, compared to the other countries, further increasing dependency on the remaining abstractions. As a result, any change in river flows as a result of a change in climate will impact upon the deployable output of such sources.

Additionally, Wales and Northern Ireland water resource plans modelled climate change impacts to the 2030s and 2020s respectively, which may not be far enough into the future to identify thresholds at which yield may become the dominant factor on resource availability. This assessment uses this climate modelling to develop a relationship between climate variables and deployable output. This relationship is then used, in conjunction with the UKCP18 climate projections to project the potential impact on deployable output under alternative climate futures. If the water company climate modelling suggests little or no climate sensitivity, then that message will permeate through into this assessment. The reason for little or no climate sensitivity may be genuine, or it may be due to factors in the water company climate modelling such as only projecting a few decades into the future such that tipping points in a systems' resilience may not be identified.

In the late-century, the projected impact of climate change on the supply-demand balance at the UK scale is around 40% of the potential projected impact of population growth. The range of impact between a 2°C and 4°C world has increased compared to mid-century, with the difference of around 1680 Ml/d at a national scale.

Potential impact of demand-side adaptation measures

With concerted effort on demand-side adaptation measures the supply-demand balance in the late-century may be improved. The current and announced adaptation scenario uses the per capita consumption values that are found within the latest water company resource plans up to 2044/45 and then fixed for the rest of the century. Average per capita consumption is projected to be around 122 l/h/d (England ~120 l/h/d; Wales ~105 l/h/d; Scotland ~156 l/h/d and Northern Ireland ~152 l/h/d).

In England and Wales, the final plan, including the water companies own ambitions for reducing per capita consumption is used. A similar final plan was not available for Scottish Water and Northern Ireland Water and those companies have reported no intention to significantly increase meter penetration across households to reduce household consumption[15]. As a result, the baseline plan values are used and the per capita consumption in Scotland and Northern Ireland are higher than in England and Wales (see Figure 3.38).

Leakage is also reduced to 50% of baseline values by the mid-century and then held fixed to the end of the century. This applies to all water companies in all regions.

[15] Northern Ireland Water has committed to reviewing means to reduce household consumption in their final plan.

Under the current and announced adaptation scenario and central projection population increases, only the Water Resources South East region is in supply-demand deficit by the late-century in a 2°C world (see Figure 3.40). This assumes that water is readily transferable within each region which, is not necessarily the case using existing infrastructure and may be prohibitively expensive to achieve in some cases (e.g. Scotland). At a national level, the UK supply-demand balance is in surplus at around 1,610 Ml/d.

The deficit shown in the Water Resources South East region in Figure 3.40 is of the order of 310 Ml/d (the supply for a little more than 2.1 million people every day based on present day levels of UK water consumption).

Figure 3.42 to Figure 3.45 show the reduction in demand across the three adaptation scenarios, by region, for the late-century and central population projections. These reductions correspond to the adaptation scenarios described in Table 2.3. As per the mid-century, the greatest reductions are in per capita consumption / household demand and leakage. With minimal changes to non-household demand.

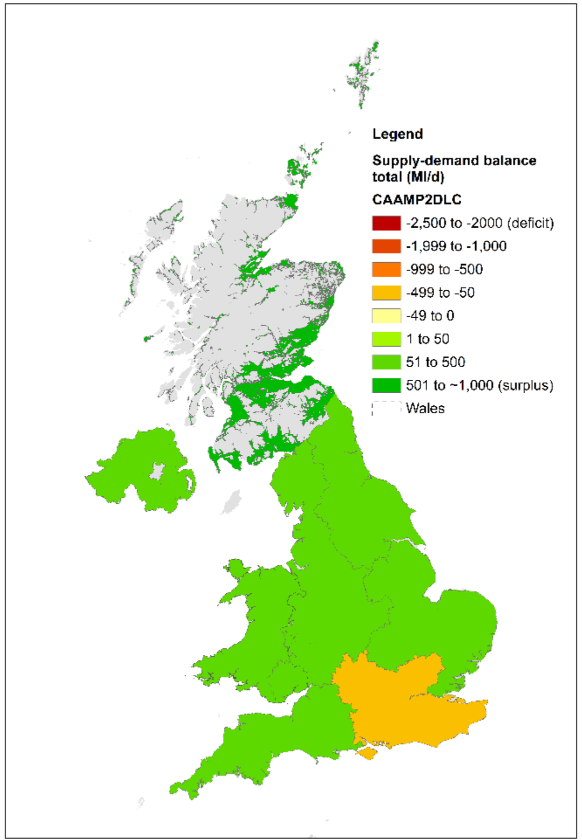

Figure 3.40: Supply-demand balance in the late-century, in a 2°C world, central population projection and current and announced adaptation action scenario

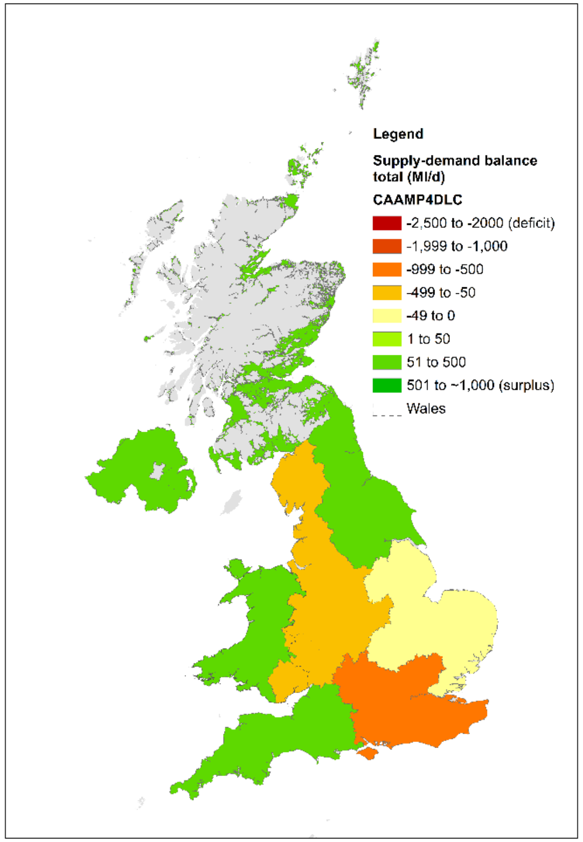

Figure 3.41: Supply-demand balance in the late-century, in a 4°C world, central population projection and current and announced adaptation action scenario

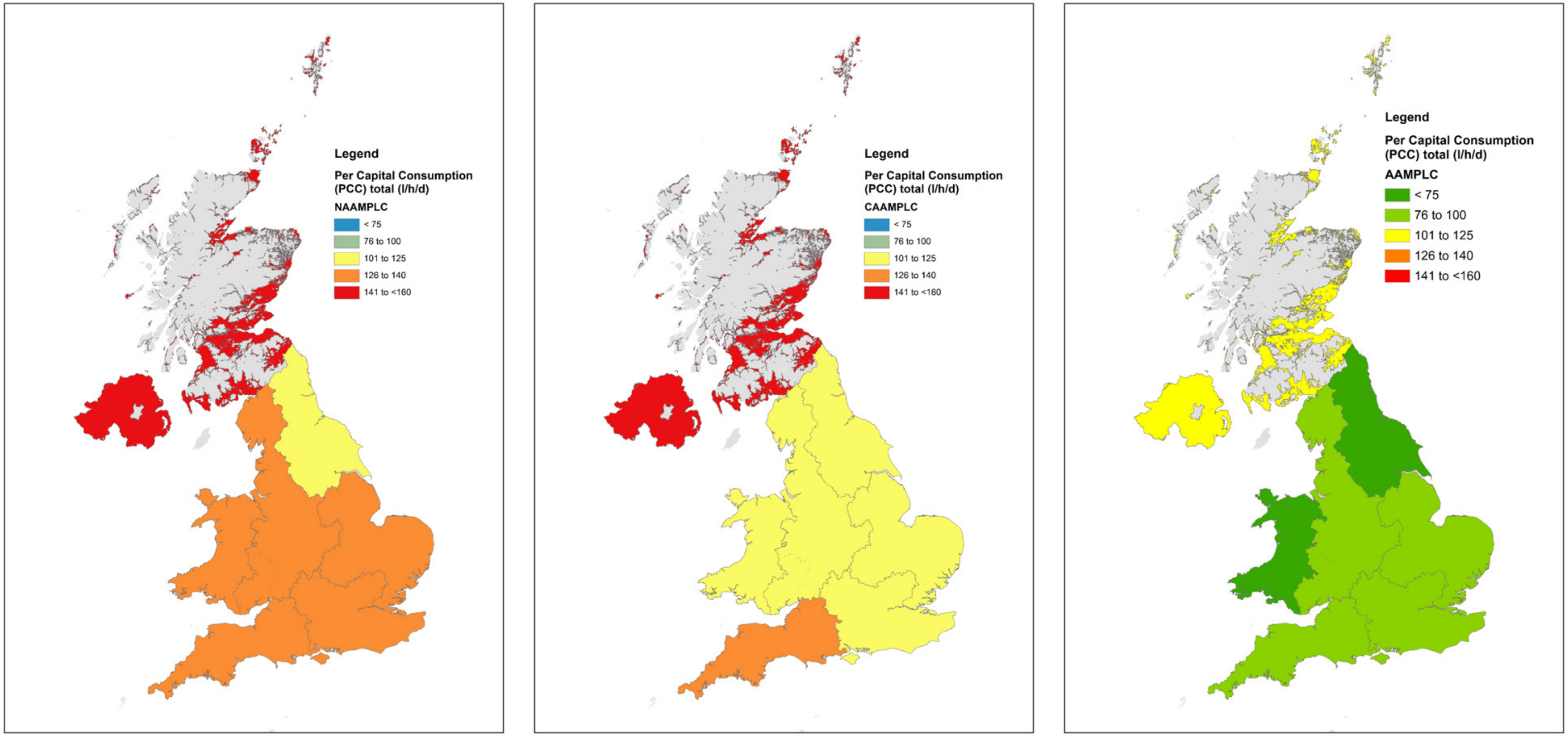

Figure 3.42: Per capita consumption across three adaptation scenarios in the late-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

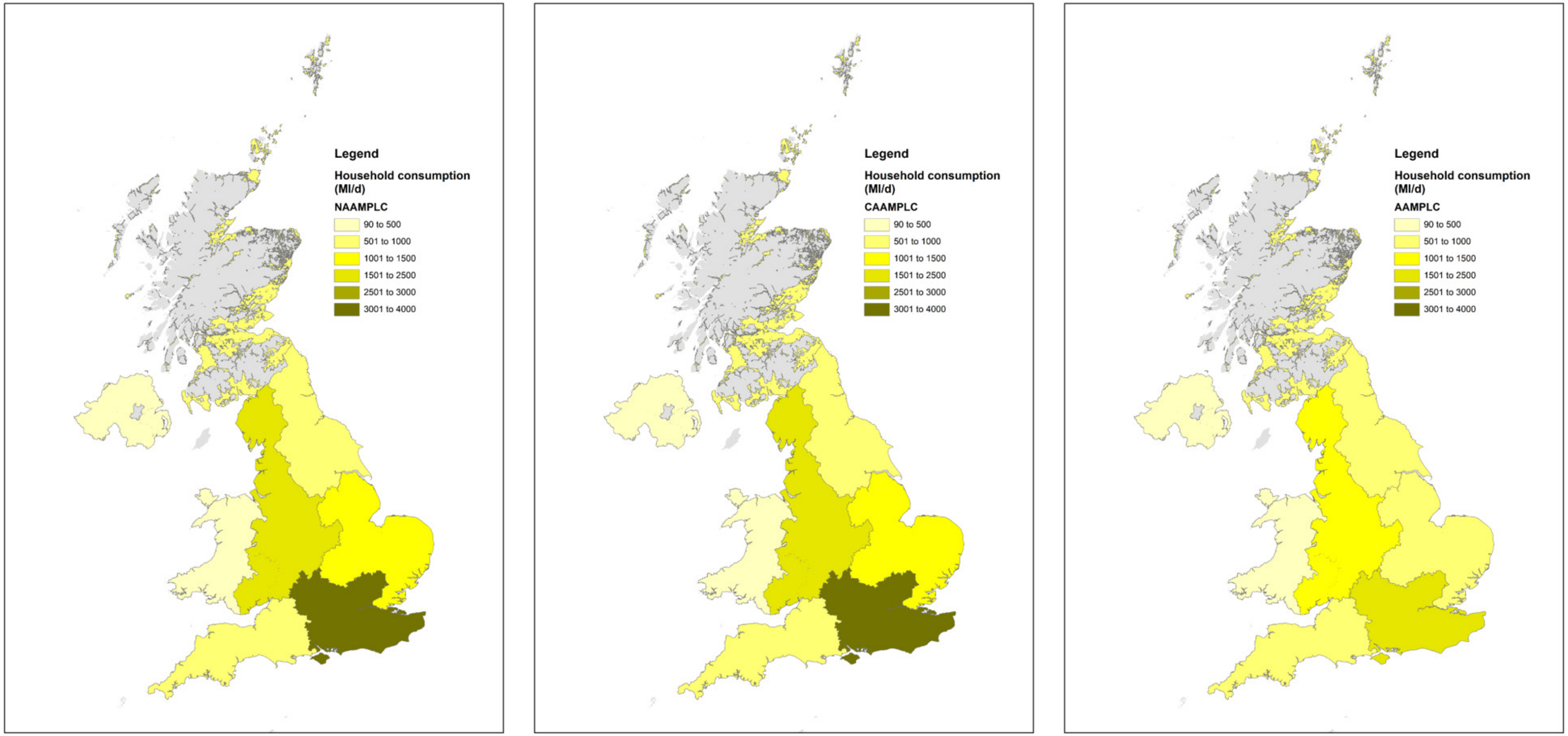

Figure 3.43: Household demand across three adaptation scenarios in the late-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

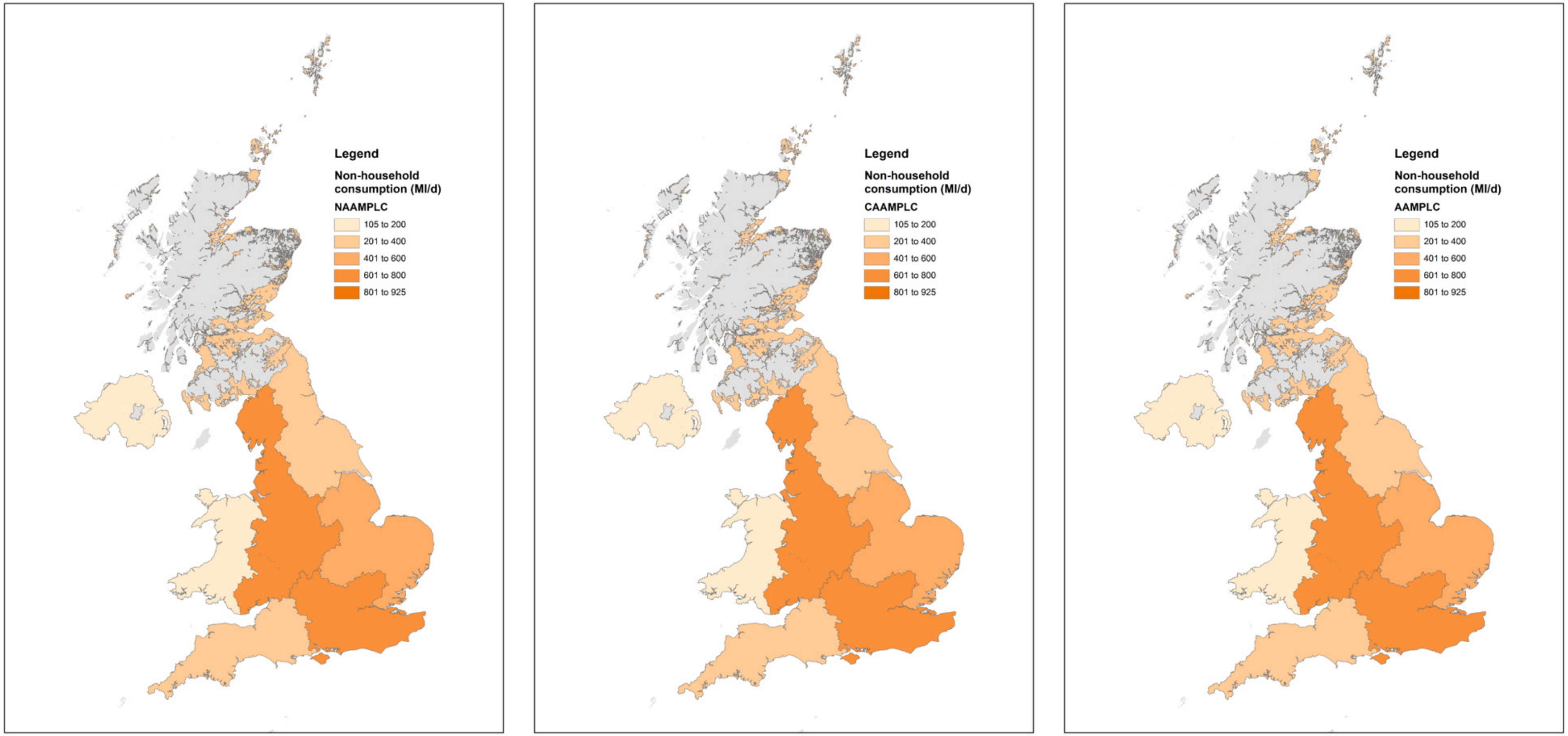

Figure 3.44: Non-household demand across three adaptation scenarios in the late-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

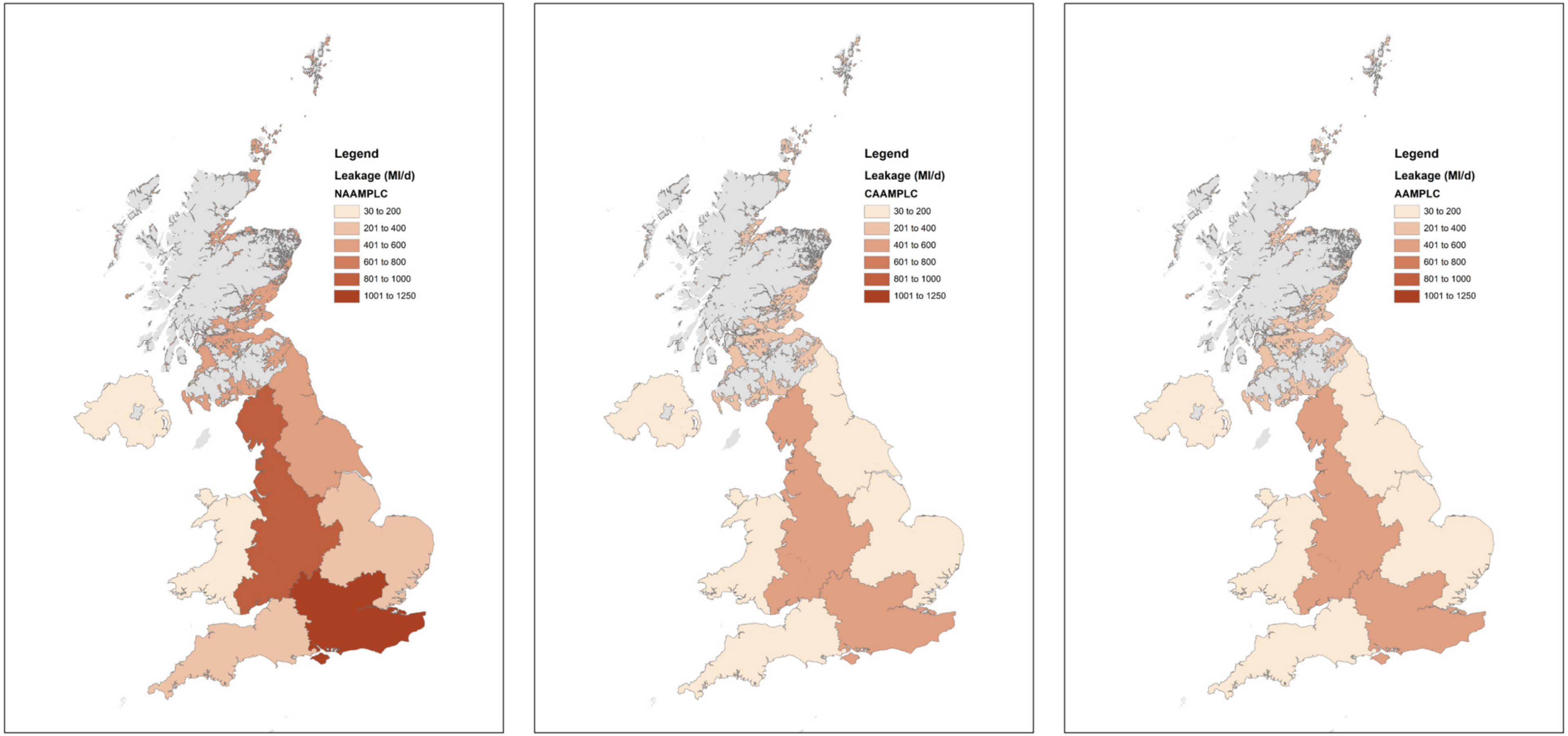

Figure 3.45: Leakage across three adaptation scenarios in the late-century by region. Left to right: no additional adaptation, current and announced adaptation, and additional adaptation

The components of the supply-demand balance at a UK scale are broken down in Figure 3.46. This figure shows a scenario in the late-century, 4°C world, central population projection and current and announced adaptation action. Under this scenario, reducing leakage to around 50% of its baseline value is substantially more ambitious than the reductions in per capita consumption that are seen in the household adaptation reductions. A deficit in supply-demand balance remains at the UK scale.

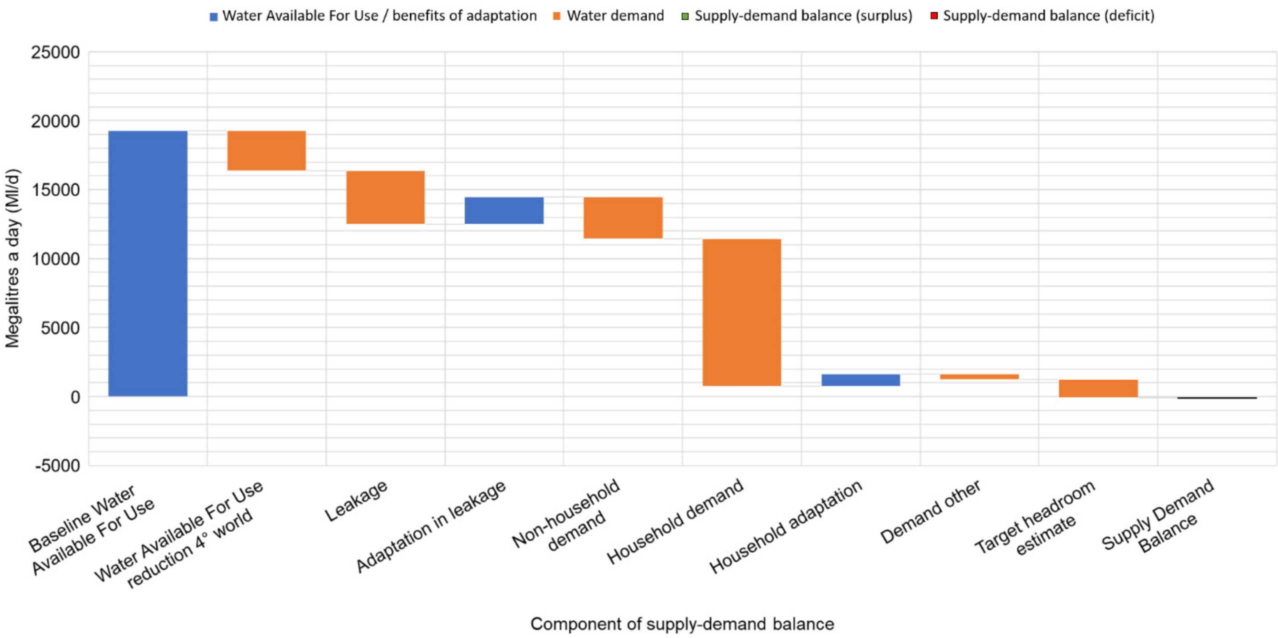

Figure 3.46: Components of UK supply-demand balance in a late-century, 4°C climate change future (~-400 Ml/d deficit). Assumes central population projections and current and announced demand-side adaptation action

Source: Supply-demand balance shown is a deficit.

The more ambitious demand-side adaptation actions under the ‘additional adaptation’ scenario results in surplus in all regions of the UK in a central population projection and 4°C world, see Figure 3.47. As with previous results, this assumes that no further sustainability reductions are made, and that water can be readily transferred within regions. This is crucial because, as shown in Figure 3.48, hotspots of risk remain, even under such ambitious demand-side adaptation measures. Compared to the no additional adaptation action scenario, Severn Trent Water’s strategic zone has improved significantly; the deficit having been reduced by more than 60% from demand management measures alone in these scenarios. However, it still has the largest deficit in the country (around 250 Ml/d in this scenario). London has the next greatest projected deficit (over 150 Ml/d) followed by Ruthamford South (~65 Ml/d).

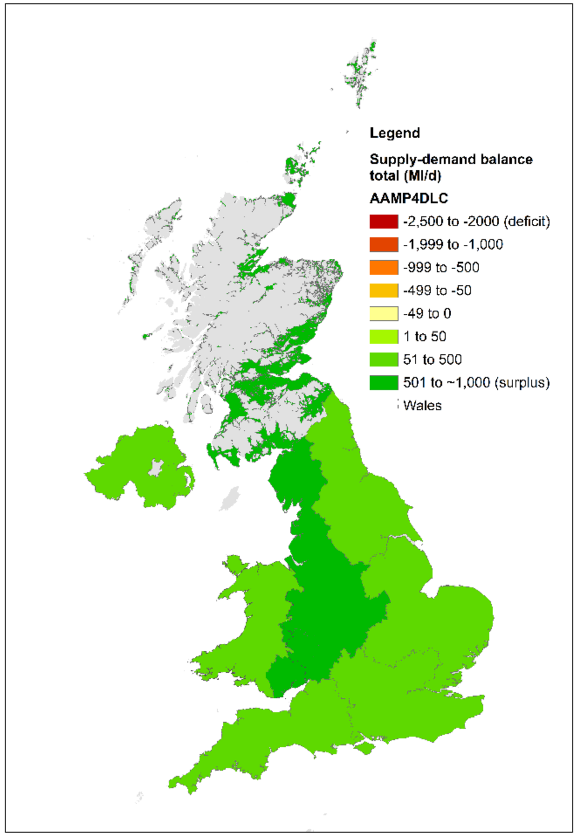

Figure 3.47: Supply-demand balance in the late-century, in a 4°C world, central population projection and additional adaptation action scenario, at a regional scale

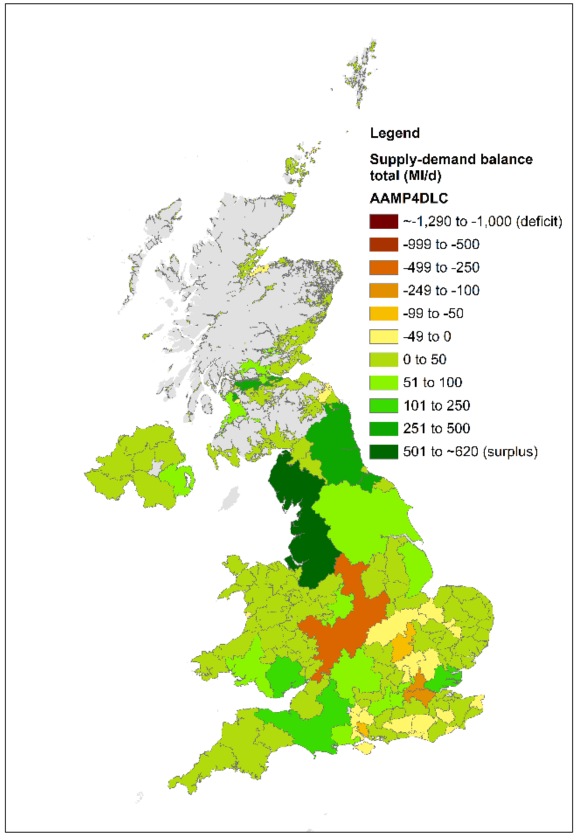

Figure 3.48: Supply-demand balance in the late-century, in a 4°C world, central population projection and additional adaptation action scenario, at a water resource zone scale

Figure 3.49 shows the components of demand, at a national scale for the same scenario shown in Figure 3.47 and Figure 3.48. When compared to Figure 3.46 the increasingly ambitious household adaptation measures are evident. It is the adaptation measures for households and leakage plus, the assumption that water is easily transferred around a region that creates the supply-demand balance surplus at the national scale in this scenario.

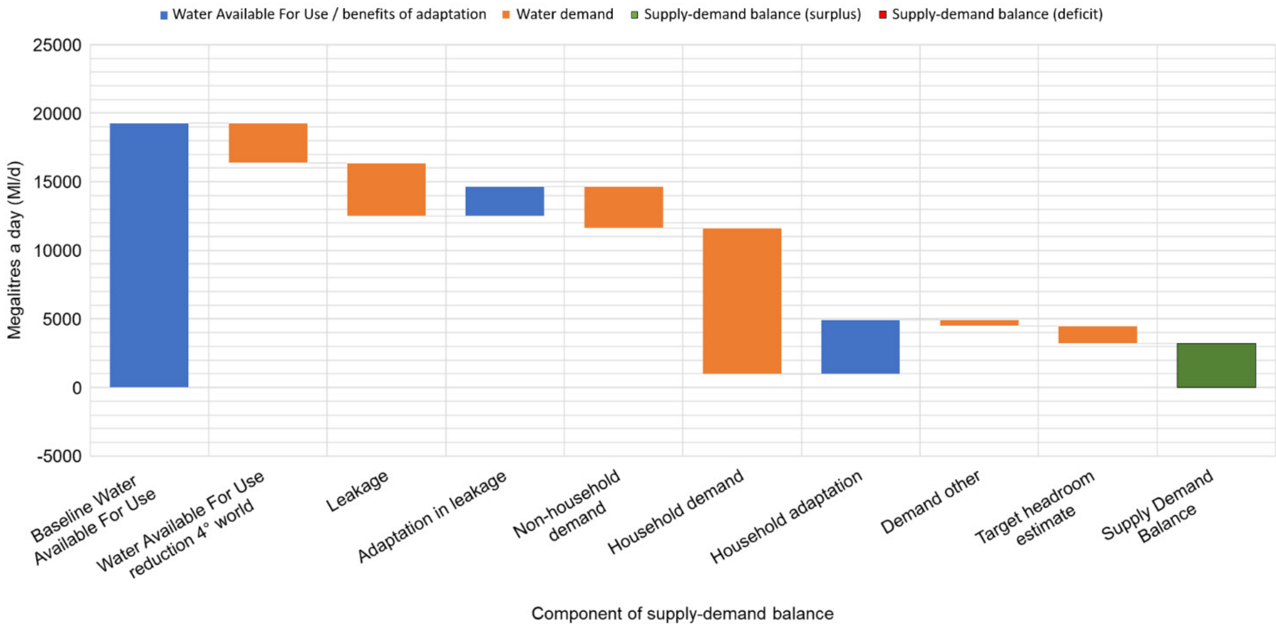

Figure 3.49: Components of UK supply-demand balance in a late-century, 4°C climate change future (~-400 Ml/d deficit). Assumes central population projections and additional demand-side adaptation action

Source: Supply-demand balance shown as a green block, i.e. a surplus.

The scenario presented in Figure 3.46 to Figure 3.48 is based upon the central population projection and on the 50th percentile value of the full range of UKCP18 Global Projections. However, more extreme scenarios were simulated:

- The Office for National Statistics, from which the population projections are derived by Cambridge Econometrics (2019) provides a higher population trajectory based primarily upon higher fertility figures. This becomes the high population projection in this assessment.
- The UKCP18 Global Projections are made up of two different groups of climate projections, one group[16], based upon the latest climate science at the time, tends to be more sensitive to emission levels and becomes hotter and drier more quickly than the other, which is based upon previous climate modelling[17]. This more sensitive group also tend to demonstrate relatively drier Autumns at different levels of global warming (see Appendix C.1.1 for more details), a critical time of year for many water resource systems. This becomes the PPE 4°C world scenario in this assessment.

[16] The PPE members of the UKCP18 Global Projections.

[17] The CMIP5 members of the UKCP18 Global Projections.

Figure 3.50 and Figure 3.51 show the projections of supply-demand balance, in the late-century considering the high population projection and the PPE 4°C world climate projection. Figure 3.50 presents the results under a no additional adaptation scenario and Figure 3.51 presents the results under an additional adaptation action scenario (demand-side only).

In an PPE 4°C world, with high population projection and no additional adaptation actions, all regions of the UK are projected to be in supply-demand balance deficit by the late-century. The highest deficits are in the Water Resources South East, Water Resources East and Water Resources West regions; following a similar pattern of impact to other scenarios (see Figure 3.50). As shown in Figure 3.51, additional adaptation actions (demand-side only), bringing leakage down to 10% of baseline distribution input and per capita consumption reduced to a national average of around 85 l/h/d does not correct the deficit in all regions: Scotland, Water Resources West and Water Resources South East are all projected to experience deficits under this scenario.

Figure 3.52 shows a selection of the scenarios that were simulated for the late-century time period at the UK scale. Figure 3.52 shows the deployable output and water available for use for the baseline, 2°C, 4°C and PPE 4°C worlds on the left-hand side. The different components of demand for each scenario are on the right-hand side. As per the mid-century projections, it is evident from this graph that the household demand is significantly larger, across all scenarios than the change in deployable output or water available for use between a 2°C and 4°C world.

The only scenarios that result in a significant UK-wide supply-demand balance surplus are the ones in which additional adaptation action is taken to reduce demand or where the current and announced adaptation scenario is applied to the central population. As can be seen in Figure A.1 to Figure A.8 in Appendix A, it is the demand in England relative to the available supply that drives the deficits at a national scale.

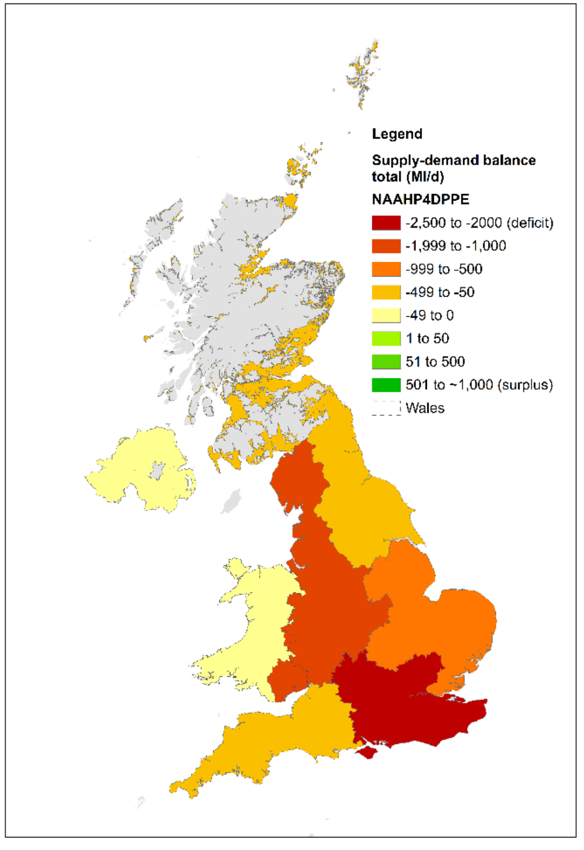

Figure 3.50: Supply-demand balance in the late-century, in an PPE 4°C world, high population projection and assuming no additional adaptation action scenario

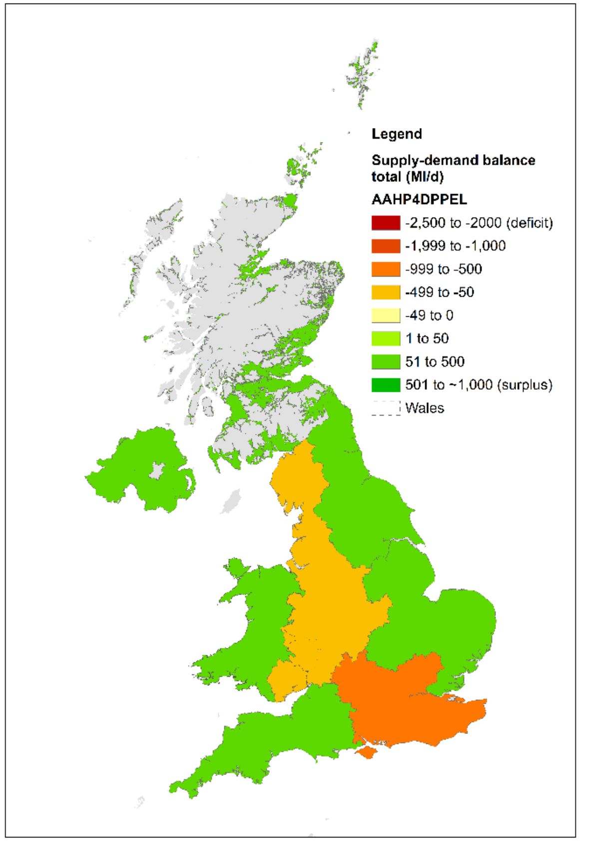

Figure 3.51: Supply-demand balance in the late-century, in an PPE 4°C world, high population projection and assuming additional adaptation action scenario

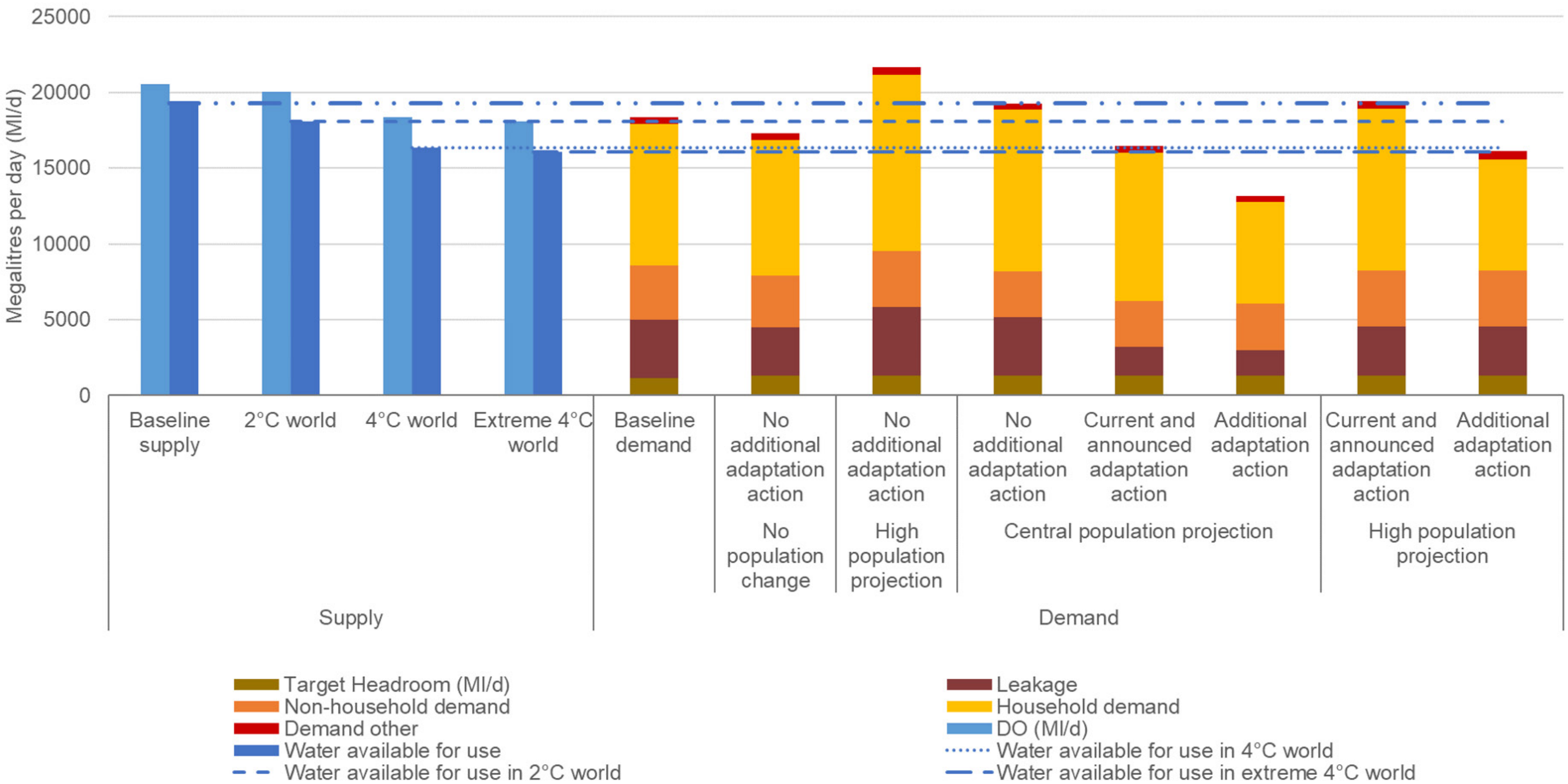

Figure 3.52: Scenarios of water supply and demand in the late-century at the UK scale. Only demand-side adaptation actions are included in the scenarios above

Comparison with CCRA2

Table 3.4 presents supply-demand balance results from this assessment and the percentage change, in brackets, from the previous assessment for CCRA2 (HR Wallingford, 2015) for a selection of similar scenarios for each of the four countries in the UK. At a UK level, the results are very similar in the mid-century for the high population and 4°C/high climate change projections. The absolute results of the CCRA2 low population and medium climate change scenario are most similar to the CCRA3 central population and 2°C climate change projection (they differ by around 130 Ml/d). In this assessment, a 'no population' scenario has been undertaken rather than a 'low' population scenario; a direct comparison is not available.

The results for Northern Ireland are significantly different between CCRA2 and CCRA3 at 2°C of warming in both the mid- and late-century. This is assumed to be due to changes between the current and previous Water Resource and Supply Resilience Plan that informed the respective assessments. For example, baseline per capita consumption in Northern Ireland was around 185 l/h/d in CCRA2 and is around 152 l/h/d in this assessment. These changes will also be due to the differences in the methods between the CCRA2 and CCRA3 water availability studies.

In the late-century, the results of the CCRA2 low population and medium climate change scenario are most similar to the CCRA3 central population and 2°C climate change projection (they differ by around 60 Ml/d). The greatest absolute difference is seen in the more severe projections. The results of the CCRA2 high population and high climate projection are most similar to the CCRA3 high population and the PPE 4°C climate change projections. This is not unsurprising since the high climate change scenario in CCRA2 was the 90th percentile of the 10,000 member UKCP09 probabilistic projections which will be more similar to the upper end of the UKCP18 Global Projections than to the 50th percentile value of the 28-member global projection ensemble used in this assessment. The value used in this assessment are considered to be a more appropriate estimate of a 4°C world than the upper values used in CCRA2.

Table 3.4: Comparison of national supply-demand balance between CCRA3 (Ml/d) and CCRA2 (Ml/d)

	Mid-century (2050s)		Late-century (2080s)		
	CCRA3: Central population, 2°C CCRA2: low population, medium climate	CCRA3 High population, 4°C CCRA2: high population, high climate	CCRA3 Central population, 2°C CCRA2: low population, medium climate	CCRA3 High population, 4°C CCRA2: high population high climate	CCRA3 High population, PPE 4°C CCRA2: high population high climate
England	-1,110 (-1,170)	-2,700 (-3,010)	-1,660 (-1,860)	-3,450 (-5,660)	-5,230 (-5,660)
Wales	50 (30)	-50 (-70)	50 (40)	-70 (-140)	-130 (-140)
Scotland	290 (320)	0 (100)	280 (330)	-50 (-90)	-160 (-90)
Northern Ireland	120 (-20)	10 (-90)	110 (10)	-10 (-150)	-50 (-150)

Source: *All scenarios assume no additional adaptation action. Information in brackets relates to CCRA2 water availability results rounded to the nearest 10Ml/d (HR Wallingford, 2015). Information outside the brackets relates to results from this assessment which, are rounded to the nearest 10Ml/d.*

It should be noted that the adaptation scenarios used in CCRA2 and CCRA3 whilst similar in concept, differ in their details. The adaptation scenarios used in this assessment are summarised in Table 2.3 and discussed in more detail in the respective sections of Appendix A. Demand-side adaptation measures are considered first, and these are the main results presented. Supply-side adaptation measures and inter-regional transfers are considered separately and are presented in Section 3.2.4.

3.2.4. Drought resilience, water supply adaptation options and residual deficits

In sections 3.2.2 and 3.2.3 the adaptation scenarios described cover changes in demand for water and the implicit assumption that water can be freely transferred within a region. This section considers new supply-side options, considered separately and alongside inter-regional transfers. The level of drought resilience offered in England is also anticipated to change over the next planning cycle. Both of these factors will influence the supply-demand balance over the coming years. This, and any residual deficits after these factors have been taken into account are discussed in this section.

Impact of enhancing the level of drought resilience in England

As per the Environment Agency's National Framework (Environment Agency, 2020), it has been agreed that water companies in England should move towards an increased level of drought resilience; offering resilience to a 1 in 500 year drought (0.2% annual probability). Moving to this increased level of resilience will be associated with a reduction in deployable output. The reductions in deployable output of meeting 1 in 200 year and 1 in 500 year levels of resilience respectively for each region are shown in Table 3.5. The reduction in deployable output calculated are for the present day. The reduction in deployable output in Water Resources South East is by far the greatest, followed by Water Resources East and Water Resources West. The total reduction in deployable output of moving to a 1 in 500 year level of resilience in the Water Resources South East region alone is estimated to be greater than the current level of supply-demand surplus across the whole of the UK.

Resilience to a 1 in 500 year drought in the present day should also afford some resilience to future changes in climate. However, describing the characteristics and estimating the impacts of a present day 1 in 500 year drought is very challenging and it is not known how such extreme droughts will change in the future due to climate change. It is worth noting that the impact of a 2°C world on supply-demand balance in England, assuming no change in population and a no additional adaptation action scenario is around 40Ml/d. Assuming a 2°C and 4°C world with the central population projection and no additional adaptation action, the supply-demand balance in England is around -1,110 to 1,330 Ml/d. Therefore, the potential reduction in deployable output due to changing the level of resilience is in excess of current projection of the impact climate change but possibly less than the impact of population change (for the central projection). The total impact of changing the level of resilience is more than 2.5 times the current level of surplus in England as a whole.

Table 3.5: Deployable output cost of moving to a 1 in 500 year level of drought resilience

Regional Group	DO reduction moving to 1:200 drought resilience	Further DO reduction moving to 1:500 drought resilience	Total DO reduction moving to 1:500 drought resilience
Water Resources North	<5 Ml/d	~ 40 Ml/d	~ 50 Ml/d
West Country Water Resources	<5 Ml/d	~ 30 Ml/d	~ 30 Ml/d
Water Resources West	~ 100 Ml/d	~ 90 Ml/d	~ 190 Ml/d
Water Resources East	~ 160 Ml/d	~ 60 Ml/d	~ 220 Ml/d
Water Resources South East	~ 430 Ml/d	~ 220 Ml/d	~ 650 Ml/d

Source: Water Resource Management Plans (2019). All figures are rounded to the nearest 10 Ml/d.

At the time of writing, there is no similar direction regarding drought resilience by regulatory authorities in Wales, Scotland or Northern Ireland.

Impact of water supply-side adaptation options and inter-regional transfers

During the planning process water companies identify feasible supply options that may be able to help mitigate any deficits they predict they might experience over the planning period. From this list of feasible options, they select a preferred list of options to promote for implementation over the planning horizon.

At the time of writing, options are only available for those water companies in England and Wales.

At a regional scale, there are around 940 Ml/d of preferred supply options, not including transfers between regions, being planned for by water companies in England and Wales. These are broken down by region in Table 3.6.

Table 3.6 also shows that 430 Ml/d of water in transfers between regions i.e. inter-regional transfers (it is implicit in this assessment at a regional scale that all necessary intra-regional transfers take place). There is a discrepancy of 10 Ml/d in these inter-regional transfers due to Bristol Water having a feasible, not preferred, transfer option where the donor water company is not specified.

Table 3.6: Changes to water available for use by supply and transfer options (Ml/d)

Region	Preferred supply options (Ml/d)	Feasible supply options (Ml/d	Net transfers (Ml/d)	Total supply options (Ml/d
WRSE	750	2,850	510	4,110
WRE	60	570	-50	580
WRN	0	210	0	210
WCWR	0	120	0*	120
WRW	120	830	-450	500
Rest of Wales	10	50	0	60
Total	***940***	***4,630***	***10****	***5,580***

*Notes: Preferred and feasible supply options exclude transfers. *10Ml/d of water import specified by Bristol Water where the donor water company is not specified.*

The additional water available for use, specified in Table 3.6 was applied to all supply-demand balance scenarios evaluated at a regional scale for England and Wales. Under a no additional adaptation action future (in terms of demand reduction), the preferred supply-side measures or transfers, when used in isolation, are not sufficient in reducing the supply-demand balance deficit in Water Resources South East, Water Resources East or Water Resources West. This is the case across the majority of the scenarios in the mid- or late-century. In Water Resources West, deficits are projected in some other scenarios too, for example: in late-century, under a central population projection, 4°C world and the current and announced adaptation in demand scenario the deficit is around 580 Ml/d when only transfers are considered and around 60 Ml/d when only other supply options are considered. This is because the inter-regional transfers associated with Water Resources West are transfers out of the region. In the scenarios tested in this assessment, there is not sufficient supply to make such a transfer. When both preferred options and transfers are considered, the deficit in Water Resources West under that same scenario[18] is 459 Ml/d of deficit. In this scenario, Water Resources West would either need more supply options or to reduce the export of water from the region.

Results for scenario that do not include demand-side adaptation measures

Figure 3.53 and Figure 3.54 show the supply-demand balance by region for a selection of scenarios in the mid- and late-century that do not include demand-side adaptation measures. Figure 3.53 shows the supply-demand balance after considering all feasible and preferred supply options and inter-regional transfers. Scenarios were selected for presentation if, in at least one region of England and Wales, a deficit was projected i.e. in all other scenarios assessed, all regions were projected to be in surplus after all supply options were taken into account.

Figure 3.54 shows the same scenarios as presented in Figure 3.53 however, in this case, the supply-demand balance includes all of the feasible and preferred supply options but not the inter-regional transfers.

All of the scenarios presented in Figure 3.53 and Figure 3.54 include the no additional adaptation action scenario (in terms of demand reduction). Otherwise, they include combinations of both a 2°C and 4°C world, a high and central population projection and are projected into the mid- or late-century.

When no action is taken to further reduce public water supply demand, deficits in the supply-demand balance are projected under more scenarios when inter-regional transfers are included in the supply-side adaptation options than when they are excluded.

The magnitude of the deficits projected in Figure 3.53 are also greater than in Figure 3.54 where inter-regional transfers are excluded. This is most evident between the Water Resources West and Water Resources South East regions. With the inclusion of all the supply-side options, Water Resources South East is projected to be in significant surplus across all the scenarios in which Water Resources West, in Figure 3.53, is projected to be in deficit. When transfers are removed from the supply-side options, the projected surplus in Water Resources South East reduces and so too does the number and magnitude of deficits projected for Water Resources West.

Results for scenario that include demand-side adaptation measures

Figure 3.55 shows the impact of preferred supply options on the supply-demand deficits and Figure 3.56 shows the impact of preferred supply options plus inter-regional transfers on the supply-demand deficits across the range of scenarios in this assessment that consider current and announced and additional adaptation actions with respect to demand-side measures. The vast majority of the regions in England and

[18] i.e. late-century, central population projection, 4°C world and the current and announced adaptation in demand scenario.

Wales are in surplus across the majority of scenarios. However, when transfers are considered in addition to the preferred supply options, more of the scenarios project a deficit in Water Resources West and the deficits are also higher.

Water Resources West and Water Resources South East are linked by a large potential transfer option, from the River Severn to the River Thames. Water Resources West and Water Resources South East regions also have the highest population (see Figure 3.26). Under future scenarios where this population increases but household water use and leakage are not driven down beyond what they are today, additional pressure is placed upon the water resources in both these regions. In scenarios where other supply-options are undertaken within each region to mitigate such pressure, the transfer places additional pressure on Water Resources West and deficits remain in two scenarios.

Where demand-side measures are included in the scenarios tested, Water Resources West is able to meet the inter-regional transfer export in all scenarios tested except where climate change is most severe i.e. under the PPE-4°C scenarios in the late-century.

Currently all of the feasible other supply options and transfer options used in this assessment are ideas; plausible ways that water companies have considered may support their water supply to customers. It is unlikely that it will be cost-effective for Water Resources South East region to implement enough supply options to give them a surplus in excess of 2000Ml/d. Conceptually, moving water from an area of surplus to an area of deficit is a good way of increasing resilience and securing supplies; this assessment assumes that this is done extensively within regions. However, where there are significant increases in demand projected in both the donor and recipient regions, a transfer of water alone may not be sufficient to ensure secure water supplies in all areas. This suggests that significant transfer options such as this need to be considered alongside other demand and supply options, looking at least until the late-century, across all affected regions in order to find the most equitable and sustainable solution.

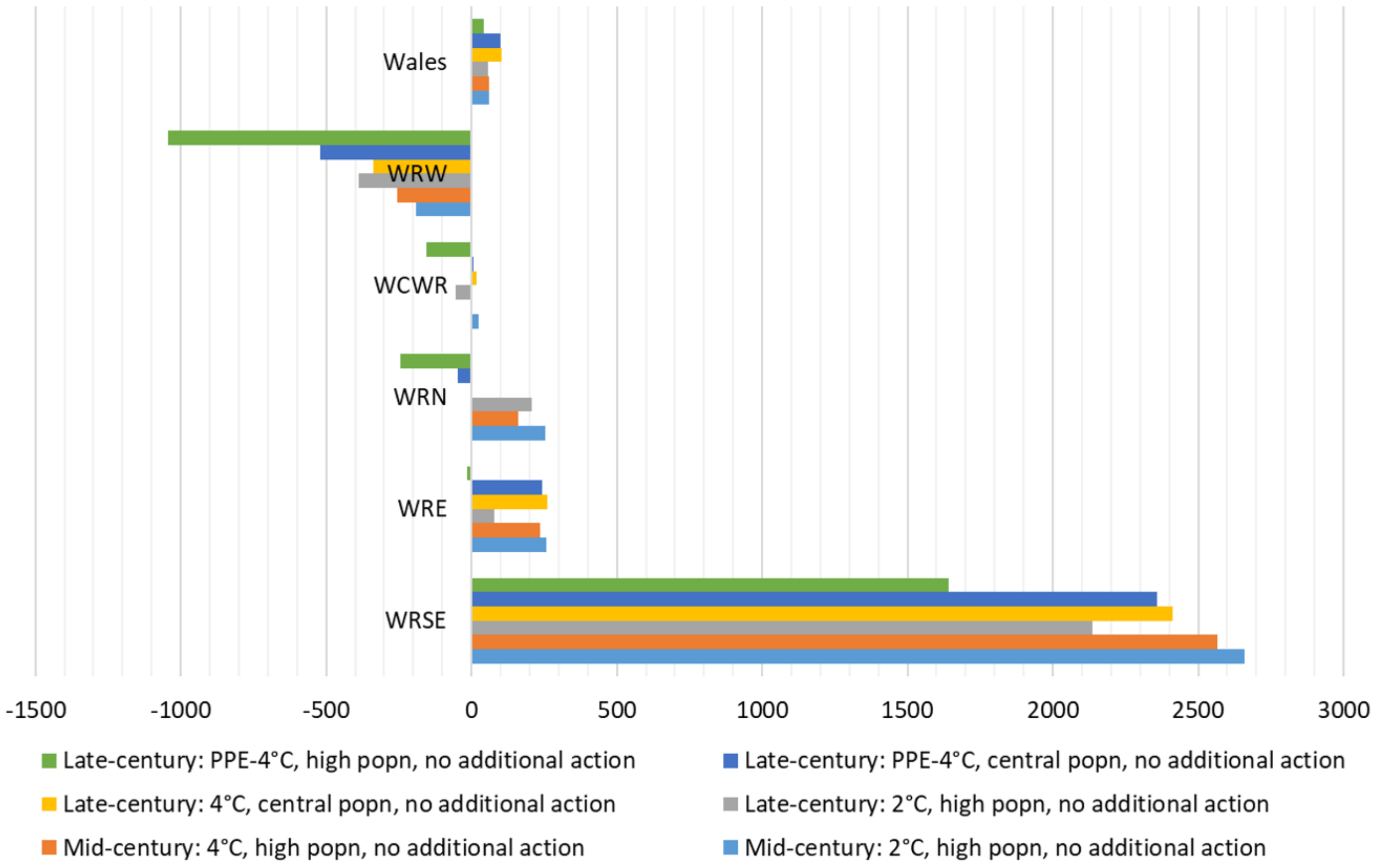

Figure 3.53: Supply-demand balance (Ml/d) after considering all feasible and preferred supply options and inter-regional transfers in England and Wales for all scenarios that show any deficit in any region

Source: n/a.

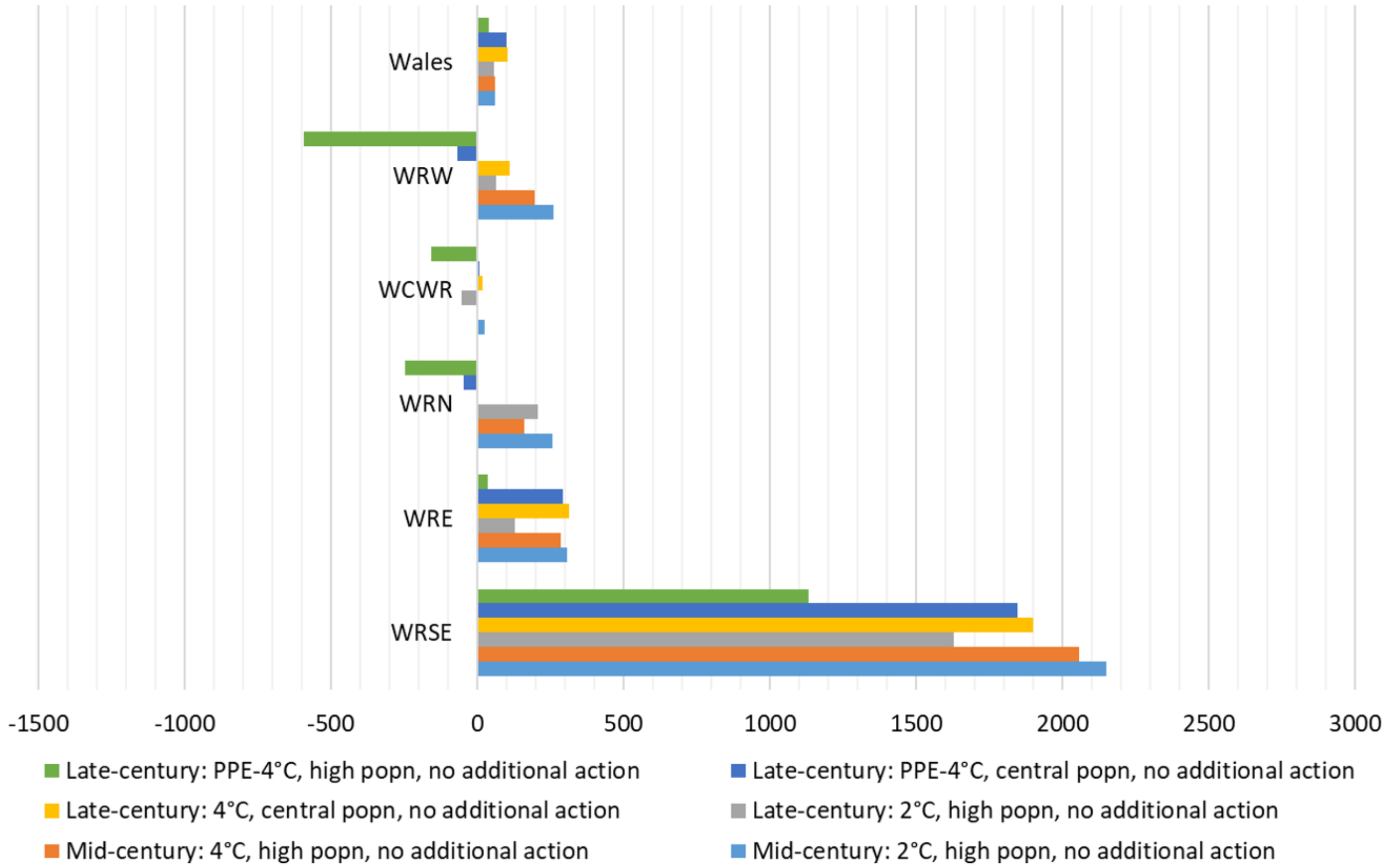

Figure 3.54: Supply-demand balance (Ml/d) after considering all feasible and preferred supply options but not inter-regional transfers in England and Wales for the same scenarios displayed in Figure 3.53

Source: n/a.

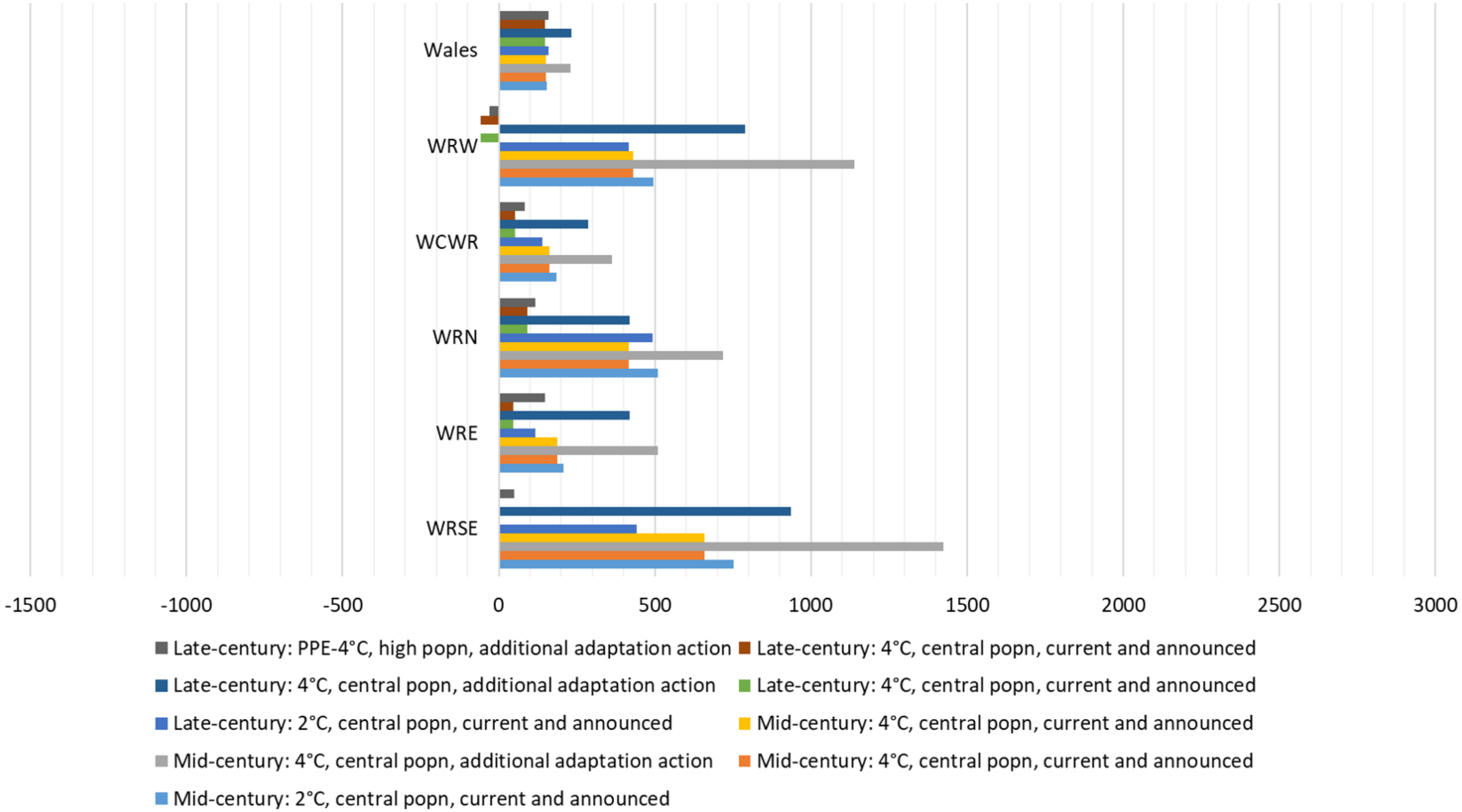

Figure 3.55: Supply-demand balance (Ml/d) after considering preferred supply options only in England and Wales for all current and announced and additional adaptation scenarios

Source: n/a

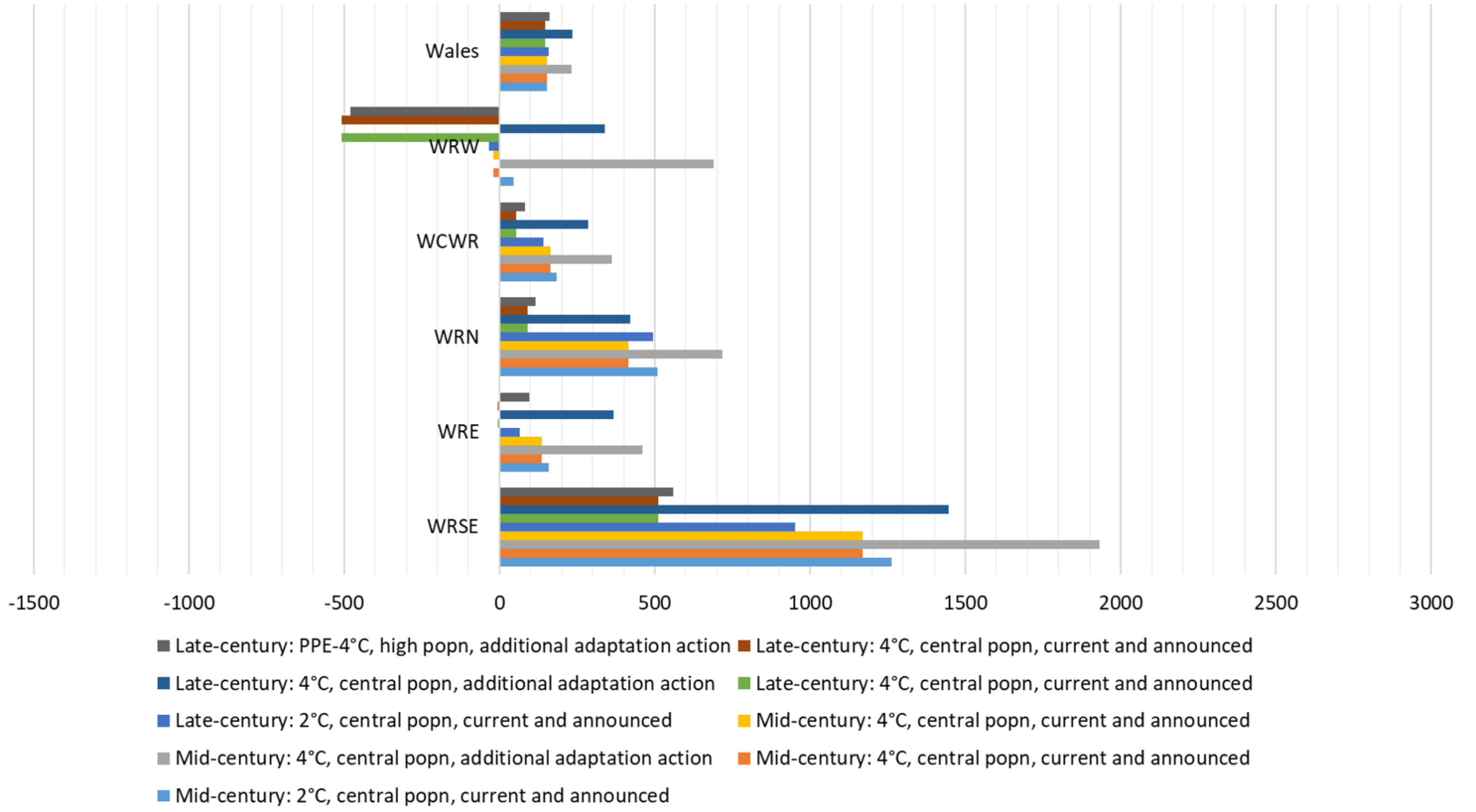

Figure 3.56: Supply-demand balance (Ml/d) after considering all preferred supply options and inter-regional transfers in England and Wales for all current and announced and additional adaptation scenarios

Source: n/a

Combined impact of increased drought resilience and existing preferred supply options

Figure 3.57 and Figure 3.58 show the projected supply-demand balance in mid- and late-century across a selection of scenarios. All preferred supply-side adaptation options (but not inter-regional transfers) have been taken into account at regional level. For all those water resource zones that belong to the regional groups that are largely in England all zones also assume a 1 in 500 year level of resilience to drought and the associated deployable output cost. For the baseline scenario, the additional level of resilience has been added to the supply-demand balance, but the supply-side options have not.

In comparison with Figure 3.21, the current supply-demand balance, the additional level of resilience causes the deficit in Water Resources South East to increase and Water Resources West and Water Resources East are projected to move into deficit. Naturally, there is a pattern of increased deficit or reduced surplus when the drought resilience level is increased across all regions and all scenarios. The only scenario where all regions are projected to be in surplus under this selection of scenarios in the mid-century (Figure 3.57) is where additional adaptation action with respect to demand-side options is implemented.

The pattern continues into the late-century, see Figure 3.58 with the exception that Water Resources South East, under this combination of scenarios is never projected to be in surplus. As shown in Table 3.6 the feasible supply-side options would be sufficient to mitigate the deficits in Water Resources South East in all the late-century scenarios shown in Figure 3.58.

The maps in Figure 3.59 and Figure 3.60 present a plausible range of future impact on the regional supply-demand balance. These results assume:

- the current and announced demand-side measures are implemented;
- the preferred supply-side measures are implemented;
- intra-regional transfers happen freely, as needed;
- inter-regional transfers and other feasible supply-side options do not occur;
- the population increases in line with the central population projection;
- regions in England offer a 1 in 500 year level of drought resilience and the rest of the UK offers the same level of resilience as it does today; and,
- there are no other changes that affect the water available for use such as additional sustainability reductions, changes to target headroom, etc.

Figure 3.59 shows a 2°C world and Figure 3.60 shows a 4°C world in the late-century. In both figures, deficits in Water Resources East and Water Resources South East are projected. Under a 4°C world, Water Resources West is also projected to be in deficit. Additional adaptation actions to control demand can bring all regions into surplus according to the scenario’s simulated in this assessment. However, it is worth noting that when a drought occurs, water companies currently restrict demand (e.g. through Temporary Use Bans etc.) in order to ensure that supplies can be maintained. When demand is at a minimum the opportunity to reduce demand to protect water resources during a drought, for which the system was not designed for, is significantly reduced.

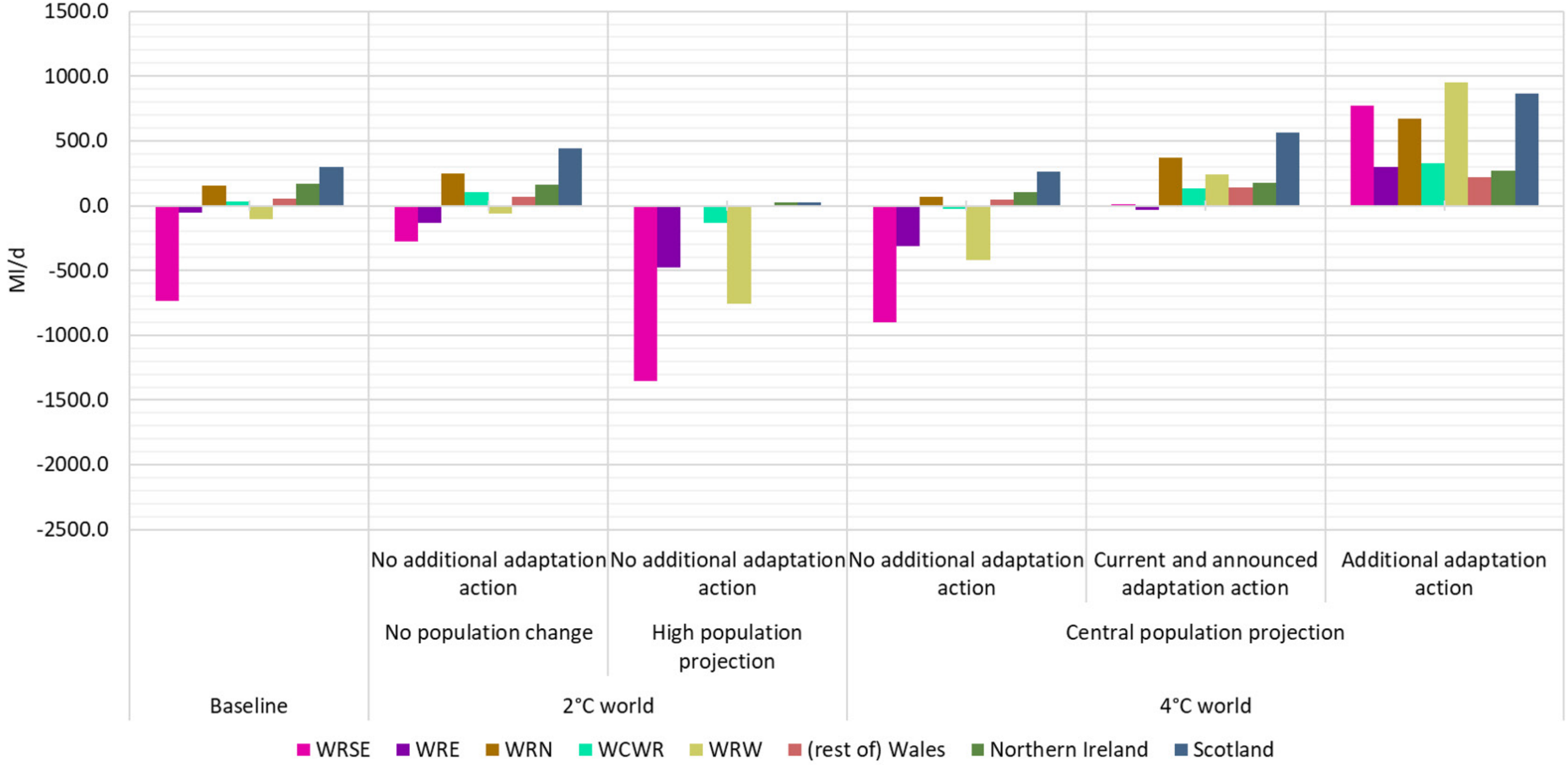

Figure 3.57: Projected supply-demand balance in mid-century across selected scenarios, including all preferred supply-side adaptation options (but not inter-regional transfers) and assuming a 1 in 500 years level of resilience to drought except in Scotland, Northern Ireland and Wales region i.e. where not part of Water Resources West region)

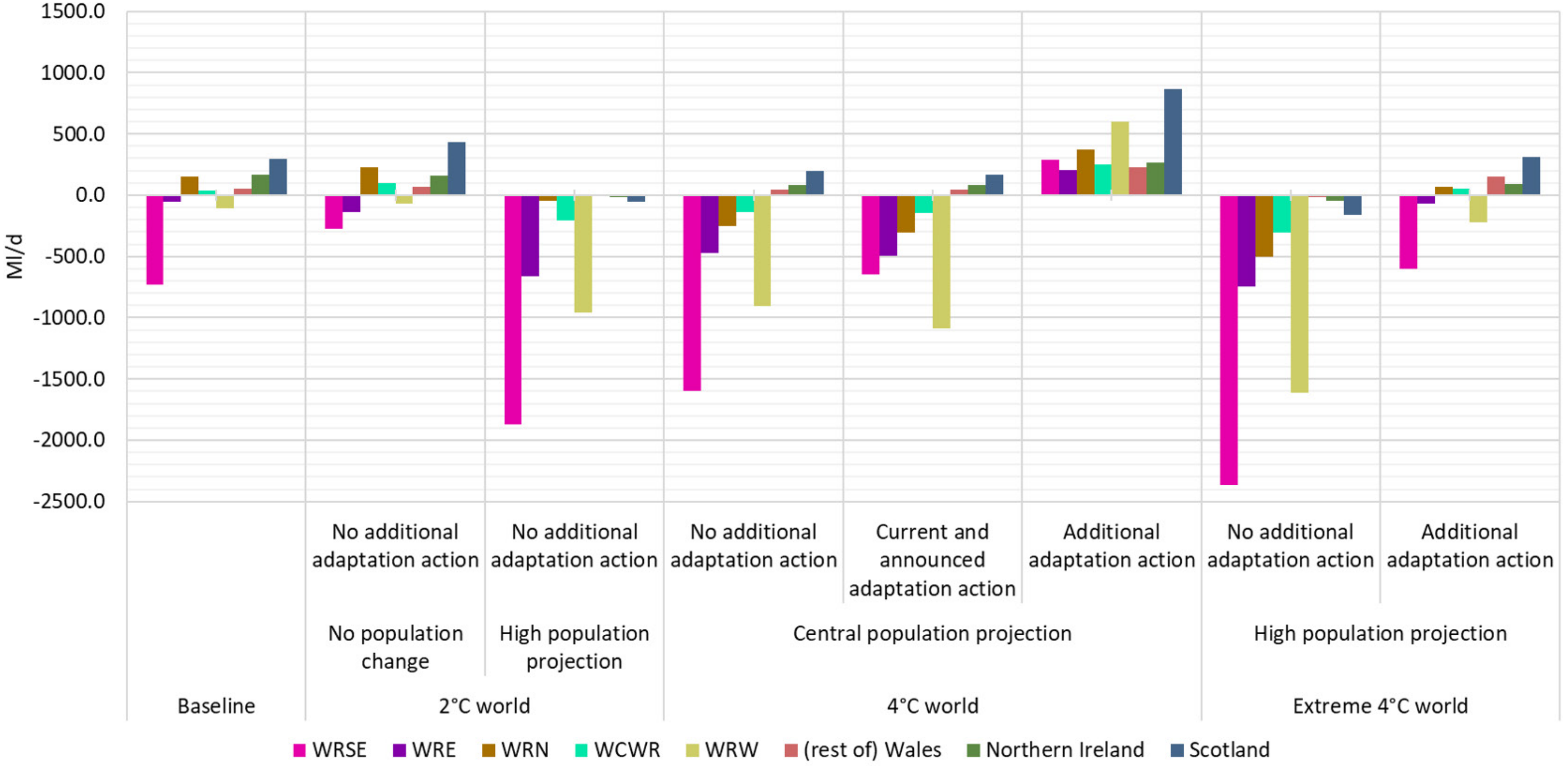

Figure 3.58: Projected supply-demand balance in late-century across selected scenarios, including all preferred supply-side adaptation options (but not inter-regional transfers) and assuming a 1 in 500 years level of resilience to drought except in Scotland, Northern Ireland and Wales region i.e. where not part of Water Resources West region)

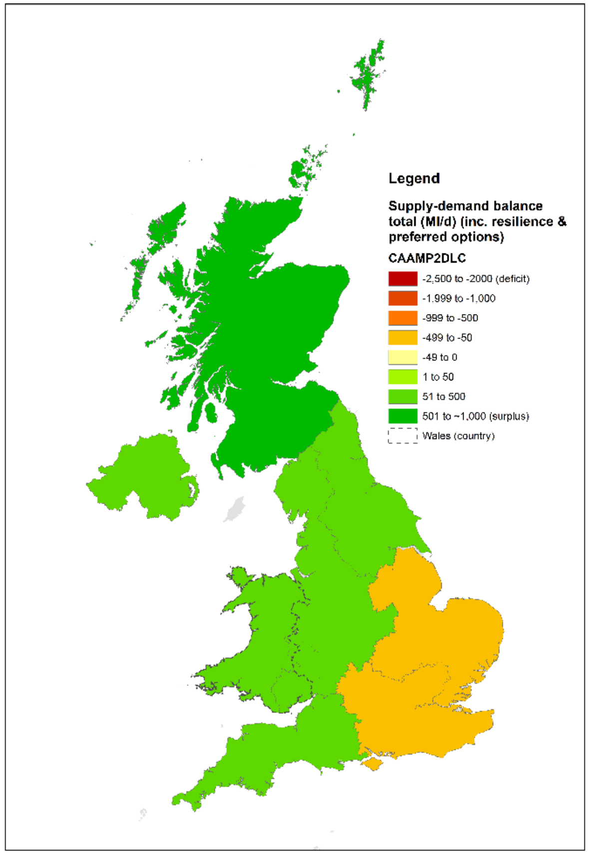

Figure 3.59: Supply-demand balance in the late-century, in a 2°C world, central population projection under a current and announced adaptation scenario for water demand and assuming all preferred supply-side options (excluding inter-regional transfers) are implemented. Drought resilience in England is moved to a 1 in 500 year level

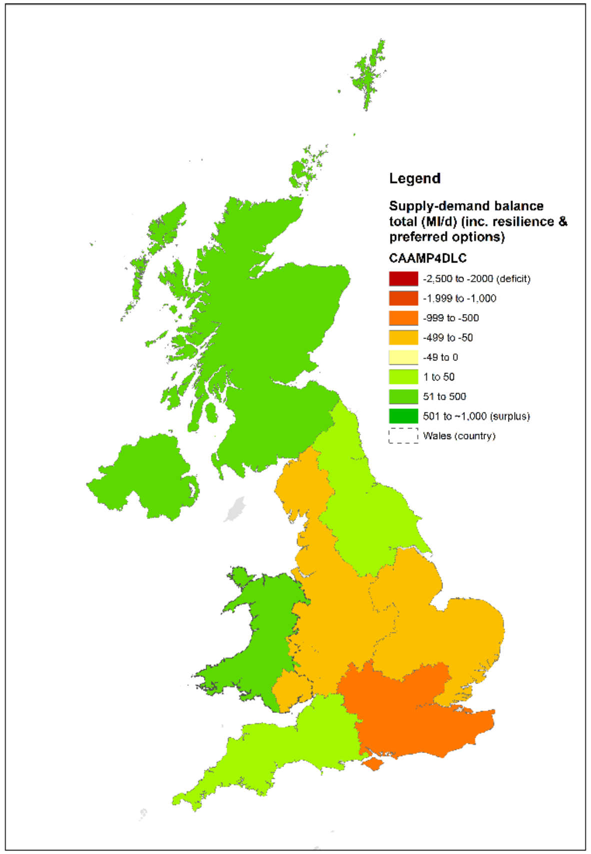

Figure 3.60: Supply-demand balance in the late-century, in a 4°C world, central population projection under a current and announced adaptation scenario for water demand and assuming all preferred supply-side options (excluding inter-regional transfers) are implemented. Drought resilience in England is moved to a 1 in 500 year level

3.2.5. Interdependencies

Formal evaluation of interdependencies between this water availability assessment and other risks was not in the scope of this assessment. However, in the course of carrying out this assessment, a number of possible interdependencies arose, and these are captured below for information:

- Significant interdependencies exist across the non-public water supply sectors reviewed as part of Defra (2020), see section C.5:
  - Unexpected water demand consequences of meeting the most ambitious decarbonisation strategies noting that the locational decisions of the energy companies may have a major influence on how each catchment is affected.
- An adaptation or a more “sustainable” approach in one sector can drive demand in an upward trajectory in another, and in the absence of stronger mitigation, this may lead to increase water demand or a shift in the location of demand. Some examples might be:
  - A shift from plastic packaging to paper-based packaging may see a decrease in water demand from the chemicals manufacturing sector to the paper manufacturing sector.
  - A shift from a meat-dominated diet to a more vegetable-based diet may lead to increased cropping and in turn, irrigation. In addition, this might see a shift in water demand from the west of the UK (where livestock production is typically concentrated) to the east.
- A future in which self-sufficiency, sustainability and increased demand for “home-grown” products is valued could, in the absence of other adaptations lead to an increased water demand across a variety of industries.

3.3. People and the built environment

There are two climate related risks in the built environment chapter of the main CCRA3 report that are associated with changes in water availability or quality:

- Risk of household water supply interruptions.
- Risks to health from poor water quality.

For information on the risk to household water supply interruptions, the People and Built Environment chapter authors should look to the results presented in Section 3.2.

Whilst this assessment of water availability does not directly evaluate the impact of changing water quality on human health, the projected changes in river flows presented in Section 3.1.1 may be useful context to inform the potential exposure to such a risk.

3.4. Business

Businesses may be impacted by water scarcity (highlighted by one risk in the business chapter of the main CCRA3 report). To consider the impact on businesses that rely on the public water supply, please see the results presented in Section 3.2.

Projected changes in in catchment water availability that may impact business that rely on their own abstraction licenses rather than the public water supply, are shown in Section 3.1.

4. Headline messages

All sectors

In terms of overall catchment water availability at average low flows, no factor has a greater influence on the water available for the environment than the environmental flow policy. Catchments in the west of the UK, particularly in Wales, are most likely to be unable to achieve existing environmental flow volume targets in a future 4°C world.

- Projected changes in river flows will act upon the water available for abstractors and water available for the environment alike:
  - Projected changes in river flows at Q95 across the UK are of the order of 0-20% reduction by the mid-century in a 2°C world everywhere except the western highlands in Scotland (where flows increase). In a 4°C world, this reduction increases (up to 30% flow reduction) in some areas, such as Wales, the Severn and Tweed river basins.
  - Projected changes in river flows at Q95 across the UK are of the order of 0-50% reduction by the late-century in a 4°C world.
- Projected changes in river flow will influence the naturally available resource at Q95 that is available for both large and small abstractors (i.e. those with and without abstraction licences). Where the policy is to keep the environmental flows fixed at the same absolute volume that they are today, many of the catchments across England, Wales, some in Scotland and one in Northern Ireland are unable to meet their environmental flow requirements without the addition of discharges to the river network.
- Catchments at risk of negative available resource i.e. not being able to meet the fixed volume environmental flow requirement tend to be along the west coast of Great Britain, where the reductions in low flows tend to be greatest, with a significant number of the catchments in Wales affected under this scenario.
  - In the mid-century (4°C world, central population projection and current and announced adaptation scenarios) 22 catchments across the UK (the majority in Wales), are projected to have negative resource availability i.e. the current absolute volume of environmental flow could not be met.
  - In the late-century (4°C world, central population projection and current and announced adaptation scenarios) 74 catchments across the UK many in Wales plus others in the south west of England, far north of England, western Scotland, are projected to have negative resource availability i.e. the current absolute volume of environmental flow could not be met.
- Catchments that are at risk of over-abstraction tend to be located in the south and east of the UK (although there are some exceptions in the north and west of the country).
- Adaptation in non-public water supply sectors may not equate to reduced water use. For example, new technologies in the energy sector or increases in fruit and vegetable production may require more water than is currently required. This impact will likely be greater the more the population grows.

Public Water Supplies

Current supply-demand balance

Although at a country level, each of the four countries that make up the UK operate a supply-demand balance surplus, some deficits already exist in some water company water resource zones. Without the actions already being taken by water companies, these zones would not be able to offer the level of resilience to drought specified by the current water resource plans.

- The UK currently operates a supply-demand balance surplus of around 950Ml/d.
- All four countries in the UK current maintain a supply-demand balance surplus although at a water resource zone scale, some deficits already exist in water companies baseline plans.
- In the UK as a whole, current demand for public water from all users is over 17,000 Ml/d:
  - Household demand accounts for around 55% of all water demand.
  - Non-household demand and leakage account for around 20% of all water demand each.
- England accounts for around 80% of the UK's demand for public water supplies; a reflection of the larger population.
- Household consumption in the UK accounts for more than half of the demand for public water supplies.
- Leakage and non-household demand in the UK are of a similar magnitude and account for a little over 20% of the total demand each.

Mid-century supply-demand balance

Changes in supply due to climate change and changes in demand due to population growth may lead to deficits across many water resource zones in the UK. The vast majority of zones impacted would be in England, with those in the south east the worst affected. Reducing household consumption and leakage from networks can significantly reduce the projected deficits; often, but not always, eradicating them.

- Across all of the scenarios the UK level supply-demand balance ranges from a deficit of around 2,740Ml/d to a surplus of around 4,620Ml/d:
  - This range is driven by the adaptation and population scenarios used.
  - Between around 200 – 470Ml/d of impact may be attributed to climate change, under the 2°C and 4°C worlds simulated.
- Under central population projection growth and no additional demand-side adaptation actions the deficit across the UK as a whole is projected to be between around 650 and 920 Ml/d (2°C to 4°C range):
  - The vast majority of this impact is realised in England. High population growth and no additional demand-side adaptation action may lead to deficits in Wales too.
  - In a 4°C world, Water Resources South East, Water Resources North and Water Resources East are all projected to have deficits if the central population projection is followed and no additional demand-side adaptation action is taken.
- Under the central population growth and current and announced demand-side adaptation scenario, the UK level supply-demand balance surplus ranges from 1,860Ml/d to 2,120 Ml/d, under the 2°C and 4°C

worlds simulated. All countries in this scenario are in surplus. All regions, except for Water Resources South East in a 4°C world, are in surplus. At a Water Resource Zone scale, deficits may still exist.

- The current and announced demand-side adaptation scenario is not sufficient to mitigate the projected impacts in Water Resources South East in a 4°C world but the additional demand-side adaptation scenario is.

Late-century supply-demand balance

Climate impacts on water supply are greater in the late-century compared to the mid-century. Population changes affecting demand, similarly, place additional pressure on water resources leading to increased deficits across water resource zones in the UK, which are greatest in England. Reducing household consumption and leakage from networks is unlikely to be sufficient to return all water resource zones to a surplus.

- Across all of the scenarios the UK level supply-demand balance ranges from a deficit of around 5,570Ml/d to a surplus of around 3,200Ml/d:
  - This range is driven by the adaptation and population scenarios used.
  - Between around 210 – 1,890Ml/d of impact may be attributed to climate change, under the 2°C and 4°C worlds simulated.
- Under central population projection growth and no additional demand-side adaptation actions the deficit across the UK as a whole is projected to be between around 1,220 and 2,900 Ml/d (2°C to 4°C range):
  - The deficit is driven by England. The Wales region, Northern Ireland and Scotland all maintain a surplus supply-demand balance under these scenarios. However, the combined surplus is not sufficient to counteract the deficits located primarily in England even if the infrastructure to transfer the water was available.
  - High population growth and no additional demand-side adaptation action may lead to deficits in Scotland, Wales and Northern Ireland too.
- Under the central population and current and announced demand-side adaptation scenario, the UK level supply-demand balance ranges from a deficit of around 70Ml/d to surplus of around 1,610Ml/d, under the 2°C and 4°C worlds simulated. In a 4°C world, it is the deficit in England (~910Ml/d), that causes the deficit at a national scale. All other countries remain in surplus through these particular scenarios, although at a smaller scale, deficits may still exist.
- England is affected by changes in climate more so than other countries due to the fact that so many more of the abstractions are already constrained by the yield of the water source.
- The climate modelling undertaken for the majority of the water resource zones in Wales and all those in Northern Ireland by water companies may not have identified thresholds in sensitivity to climatic changes that only appear in the second half of the century.
- Demand-side adaptation actions alone are unlikely to be sufficient to solve the deficits faced in all water resource zones. Even under the additional demand-side adaptation scenario which uses more ambitious leakage and per capita consumption targets, some water resource zones (mainly in England) are still projected to be in deficit.

Drought resilience

- Increasing the level of drought resilience in England to protect to a ~1 in 500 year drought event is projected to result in a reduction in England's deployable output of around 1,140 Ml/d, more than 2.5 times the present day surplus.

Water supply options and residual risks

Future surpluses may not be sufficient to 'solve' future deficits via transfers. Adaptation programmes are likely to require a combination of demand-side measures, supply-side measures and transfers.

- Inter-regional transfers may not be sufficient to ensure secure water supplies between regions.
- Where there are significant increases in demand projected in both the donor and recipient regions, a transfer of water may lead to greater deficits and reduced surpluses in the donor region without solving the deficits in the recipient region.
- In the assessment of the feasibility and sustainability of any transfer, the needs of both the donor and recipient zones / regions, at least to late-century, should be considered together.

5. References

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Appendices

A. Summary public water supply-demand balance, by country

Figure A.1 to Figure A.8 overleaf show the level of public water supplies and public water demand for a selection of the scenarios tested, for England, Wales, Scotland and Northern Ireland separately.

The graphs show the deployable output and water available for use for the baseline, 2°C and 4°C worlds (plus an PPE 4°C world in the late century) on the left-hand side in dark and light blue. The different components of demand for each scenario are on the right-hand side in red, orange and yellow tones. The water available for use in a 2°C, 4°C and PPE 4°C worlds are also represented by dotted blue horizontal lines across the graph. It is desirable for the demand on the right-hand-side of the graph to sit beneath these dotted blue lines as that means supply is in excess of demand, at a national scale (note that at a water resource zone scale, deficits may still exist). Each column on the demand side of the graph illustrates the proportion of household demand, non-household demand, leakage and other demand that make up the total demand figure.

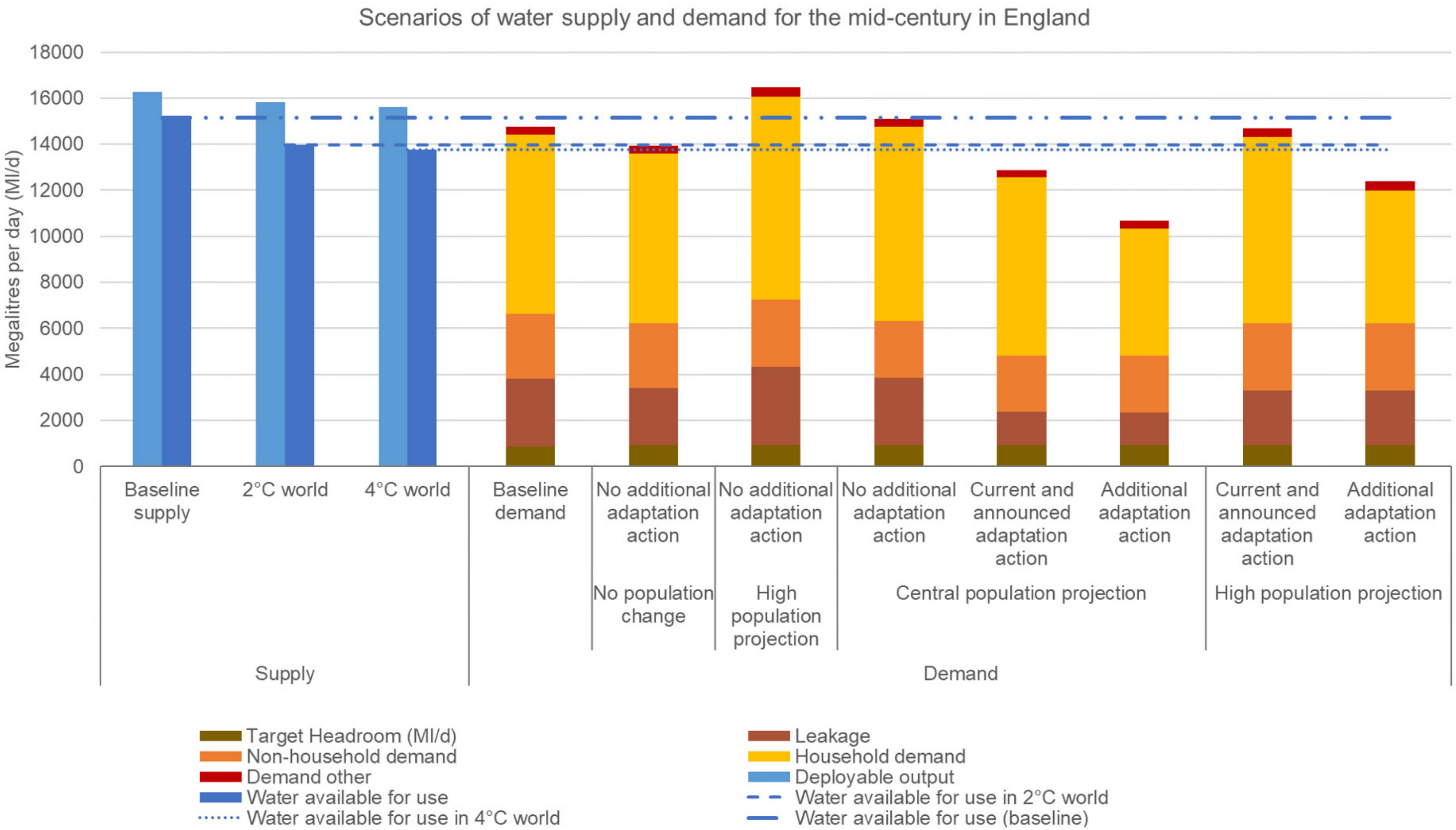


Figure A.1: Scenarios of water supply and demand in the mid-century in England. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

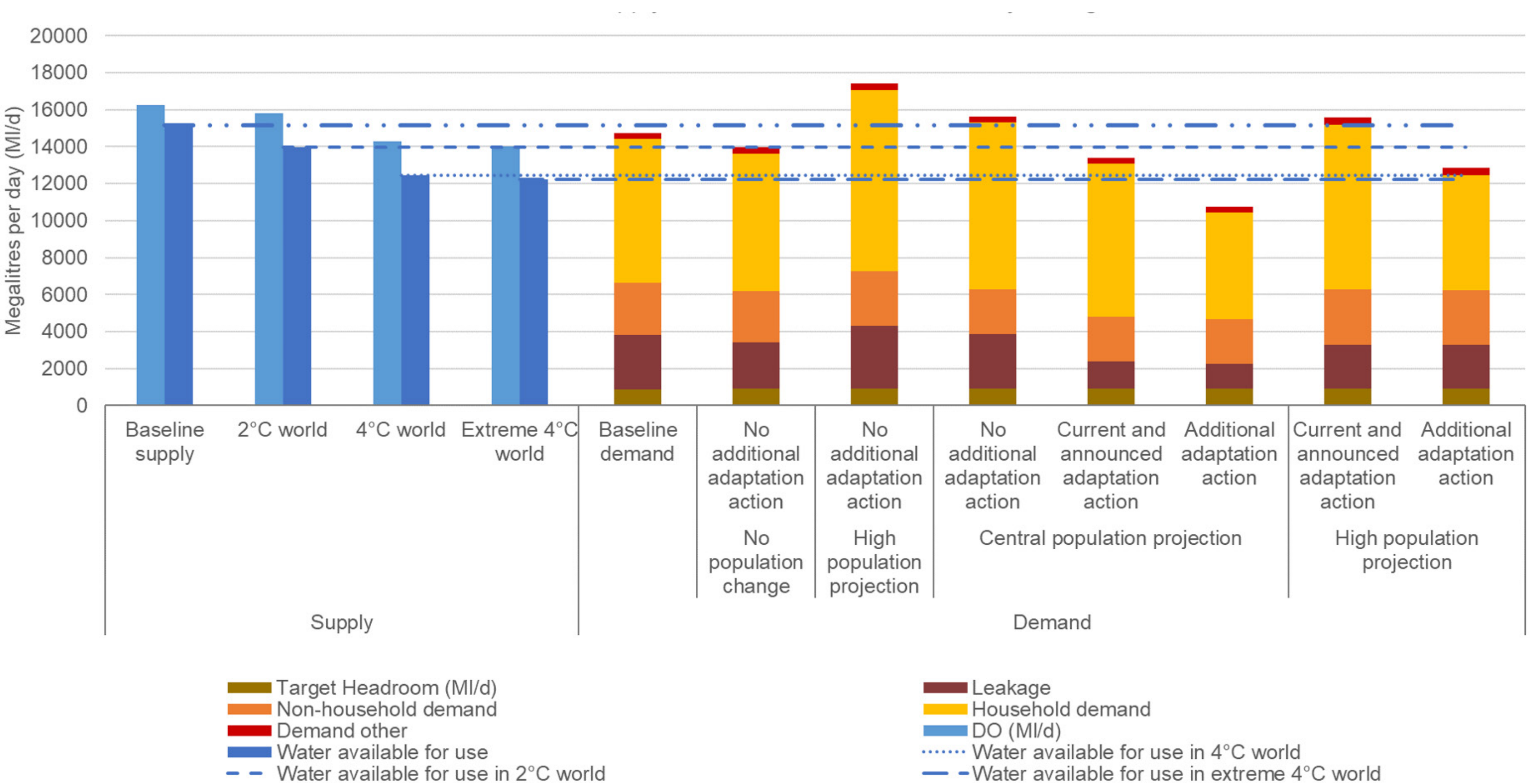


Figure A.2: Scenarios of water supply and demand in the late-century in England. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

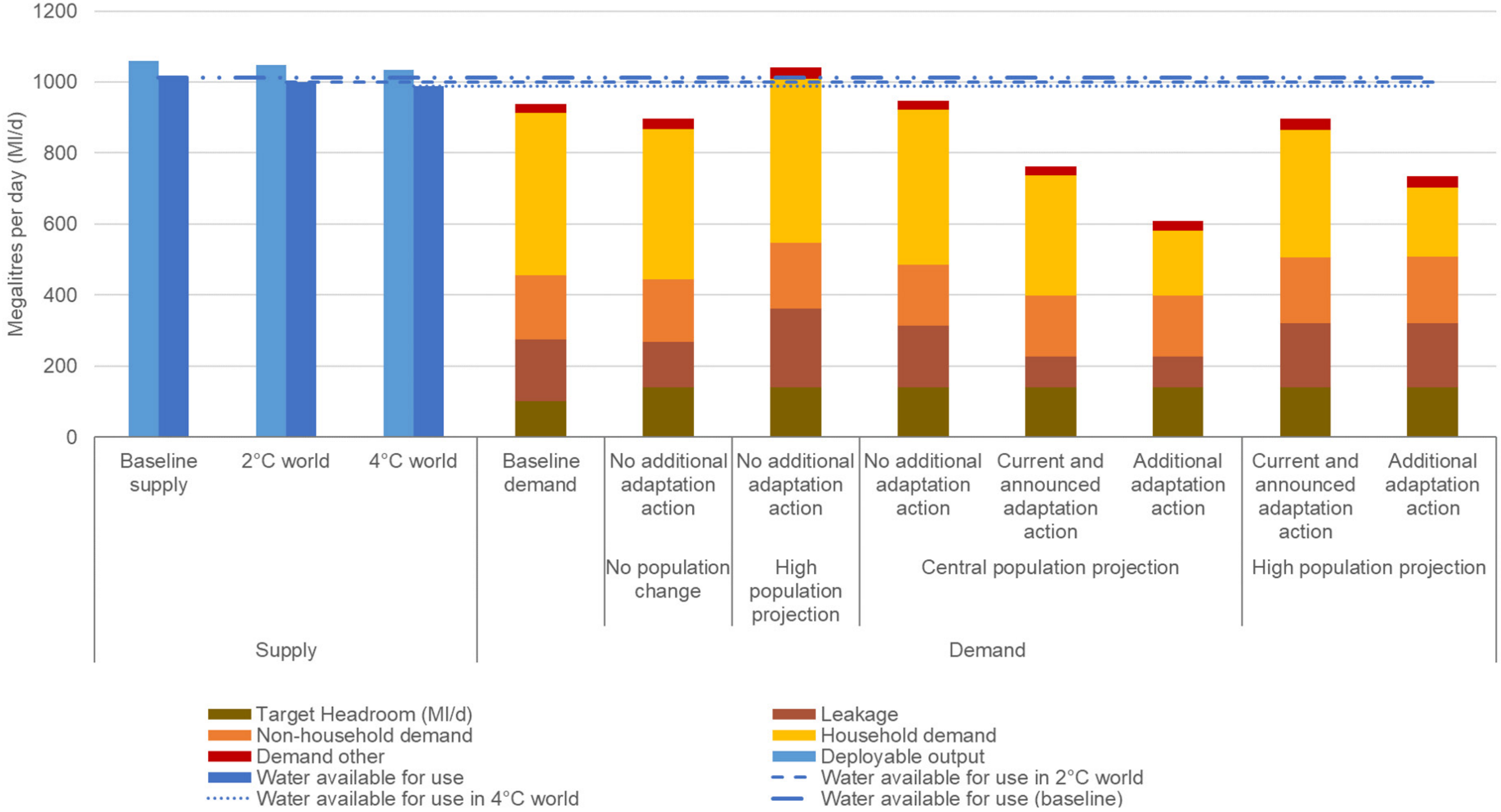


Figure A.3: Scenarios of water supply and demand in the mid-century in Wales. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

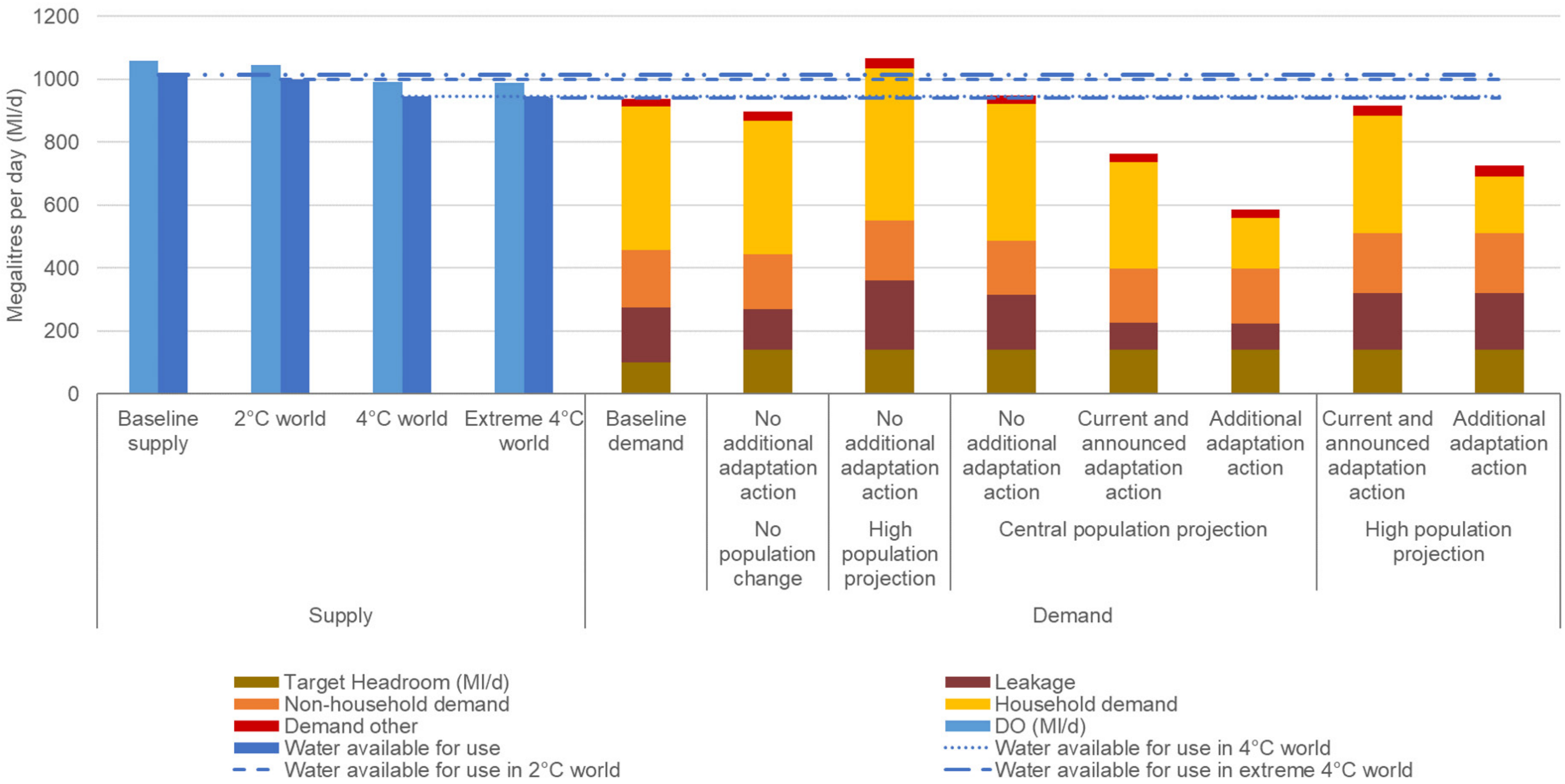


Figure A.4: Scenarios of water supply and demand in the late-century in Wales. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

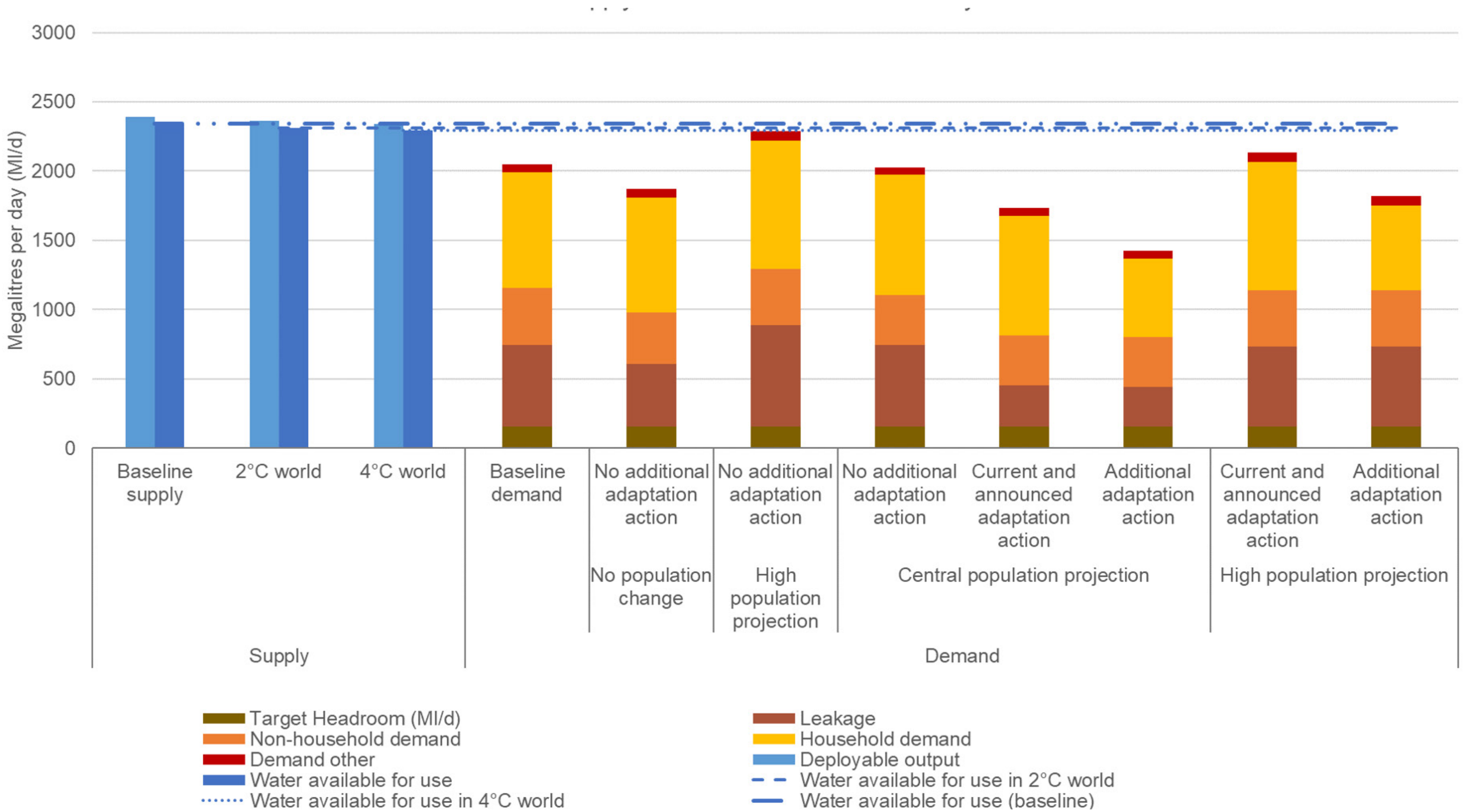


Figure A.5: Scenarios of water supply and demand in the mid-century in Scotland. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

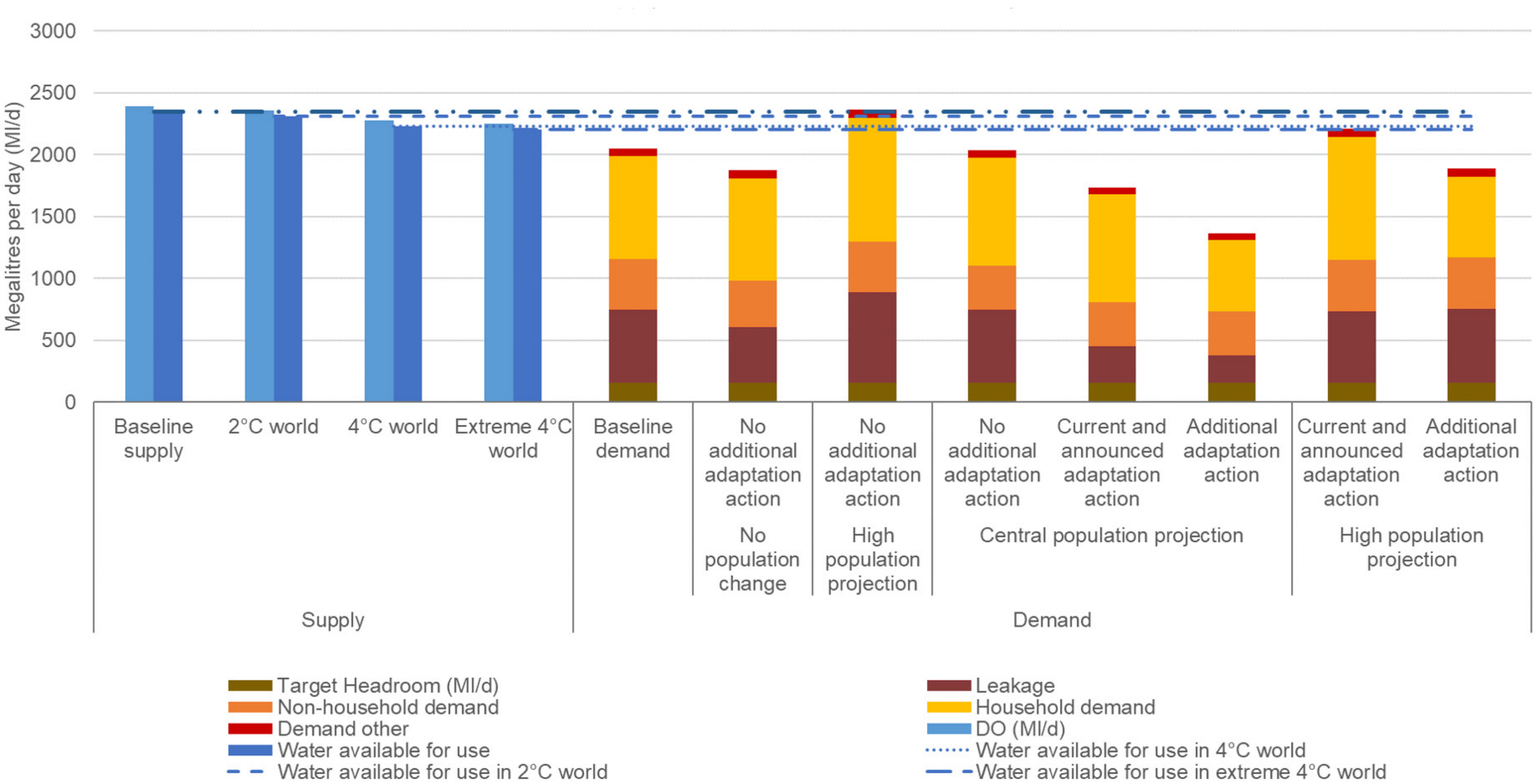


Figure A.6: Scenarios of water supply and demand in the late-century in Scotland. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

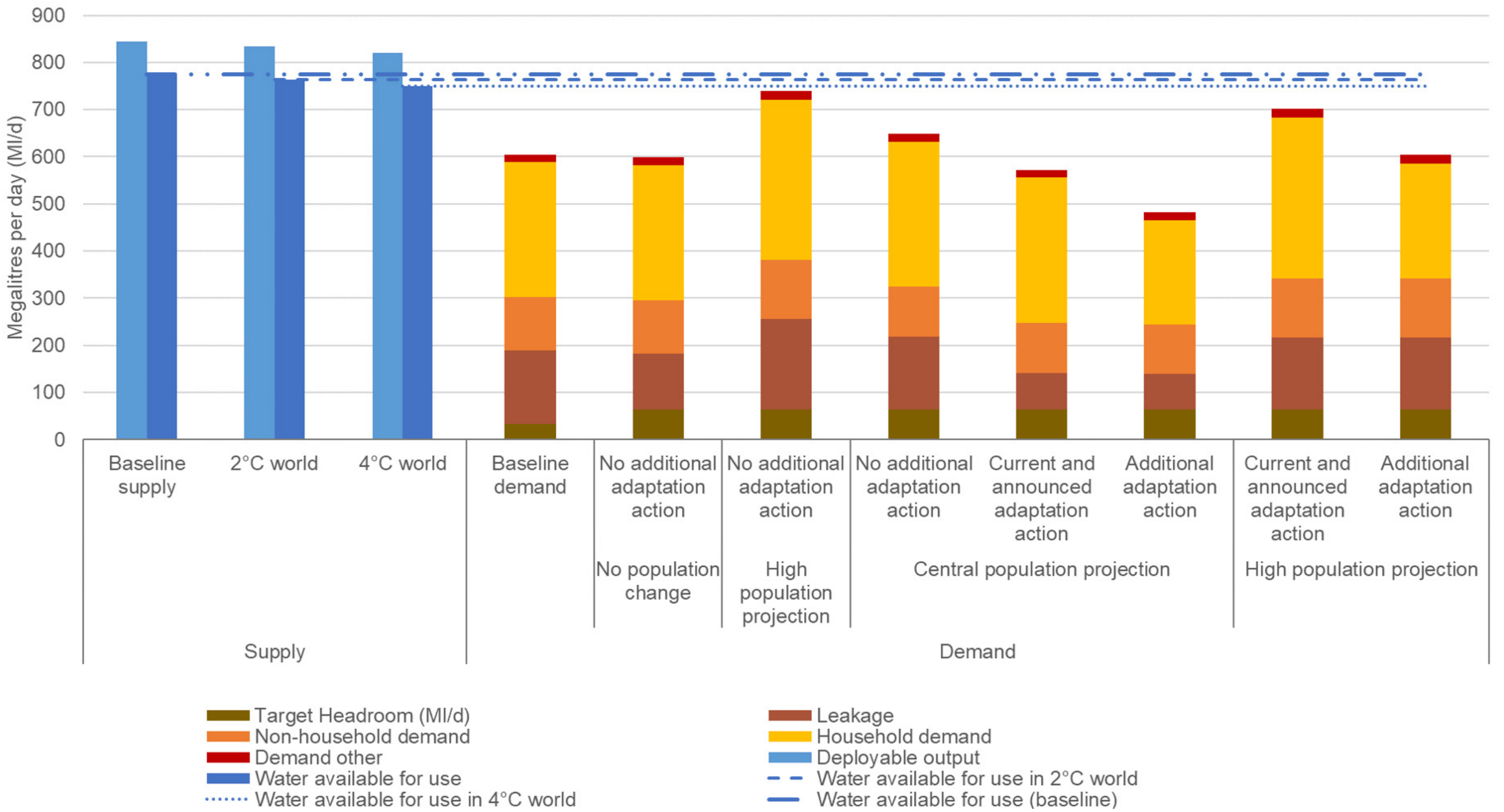


Figure A.7: Scenarios of water supply and demand in the mid-century in Northern Ireland. Only demand-side adaptation actions are included in the scenarios above

Source: n/a

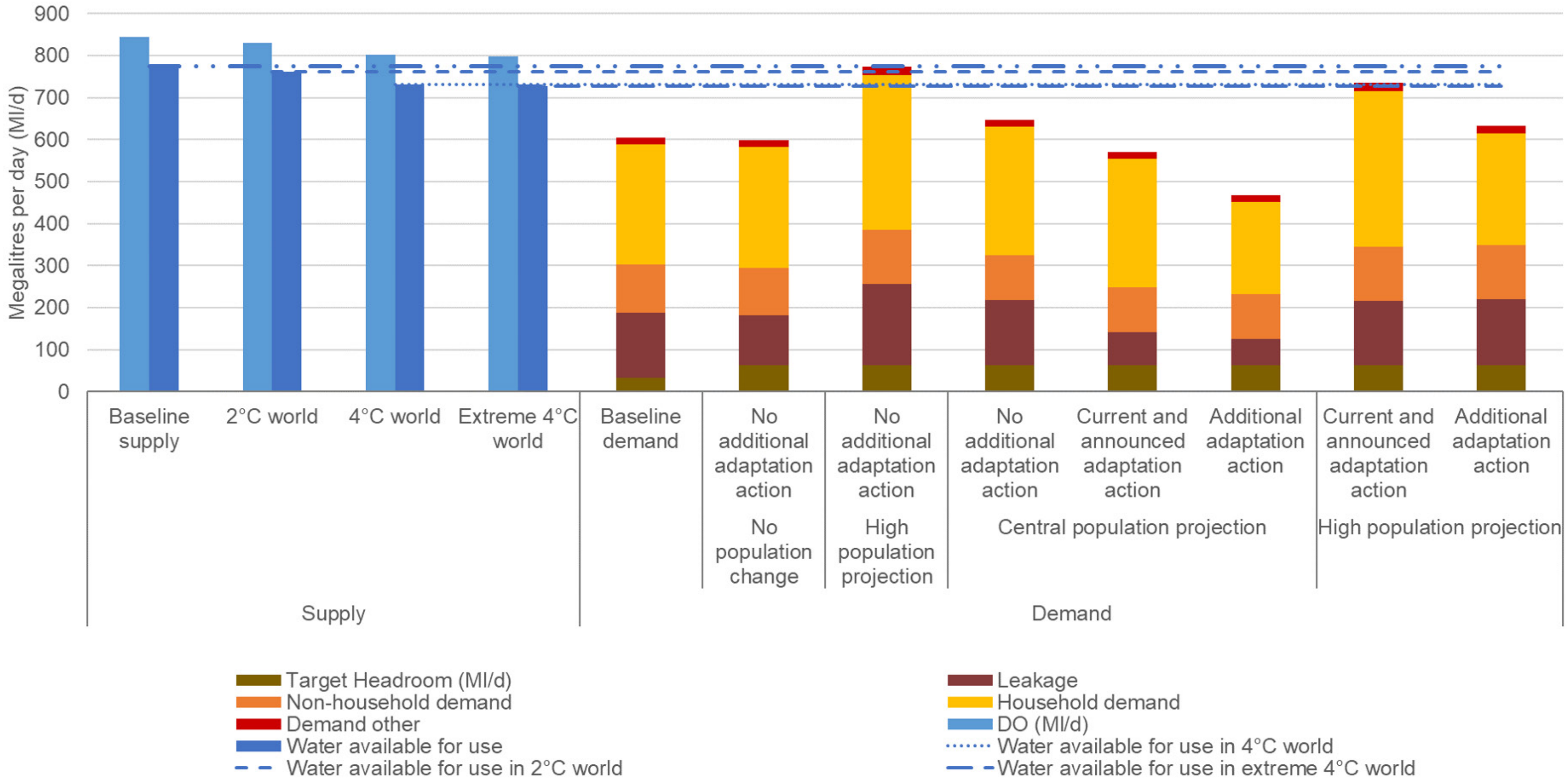


Figure A.8: Scenarios of water supply and demand in the late-century in Northern Ireland. Only demand-side adaptation actions are included in the scenarios above

B. Raw supply-demand balance results

The raw supply-demand balance results, by country and by region are shown in Table B.1 to Table B.4. Note that references to the results in the main body of the report are rounded to the nearest 5 Ml/d, partly to reflect the inherent but unquantifiable uncertainties in the results. These results provided are rounded to 1 Ml/d.

Short-hand notations are used for each scenario e.g. 'NAAMPBY'. These are translated as follows:

- Time: baseline = BY; mid-century = MC, and late-century = LC (or L for PPE climate scenarios).
- Degree of change: 2D, 4D or 4D and a PPE suffix.
- Population: no population change = LP, central population change = MP, and high population change = HP.
- Adaptation scenarios: no additional action = NAA, current and announced = CAA and additional action = AA.

Results are presented in megalitres per day (Ml/d) which is equivalent to 1,000,000 litres.

Table B.1: Supply-demand balance results (Ml/d) for the baseline and each mid-century scenario run, by country

Mid-century	NAAMPBY	NAALP2DMC	NAAMP2DMC	NAAHP2DMC	CAAMP2DMC	NAAMP4DMC	CAAMP4DMC	AAMP4DMC	CAAMP4DMC	NAAHP4DMC
England	401	36	-1106	-2477	1109	-1326	889	3105	889	-2697
Wales (country)	76	103	52	-41	238	41	226	380	226	-53
Northern Ireland	170	164	115	23	191	103	179	269	179	11
Scotland	298	441	286	23	583	265	562	869	562	2

Source: n/a

Table B.2: Supply-demand balance results (Ml/d) for each late-century scenario run, by country

Late-century	NAALP2DLC	NAAMP2DLC	NAAHP2DLC	CAAMP2DLC	NAAMP4DLC	NAAMP4DPPELC	CAAMP4DLC	AAMP4DLC	CAAMP4DLC	AAHP4DPPELC	NAAHP4DPPELC
England	36	-1660	-3449	611	-3180	-3441	-910	1711	-910	-644	-5230
Wales (country)	102	52	-67	237	-2	-7	183	359	183	217	-125
Northern Ireland	162	114	-13	189	85	80	160	263	160	94	-47
Scotland	437	276	-54	573	196	168	493	866	493	312	-162

Source: n/a

Table B.3: Supply-demand balance results (Ml/d) for the baseline and each mid-century scenario run, by region

Mid-century	NAAMPBY	NAALP2DMC	NAAMP2DMC	NAAHP2DMC	CAAMP2DMC	NAAMP4DMC	CAAMP4DMC	AAMP4DMC	CAAMP4DMC	NAAHP4DMC
WRSE	-83	-373	-909	-1451	2	-1001	-90	673	-90	-1543
WRE	158	22	-136	-322	148	-158	126	450	126	-344
WRN	199	291	206	46	509	113	415	717	415	-48
WCWR	67	134	30	-97	184	10	163	363	163	-117
(rest of) Wales	52	69	50	2	144	48	141	221	141	-1
WRW	83	8	-285	-689	375	-350	310	1019	310	-754
Northern Ireland	170	164	115	23	191	103	179	269	179	11
Scotland	298	438	284	24	576	263	555	856	555	4

Source: *n/a*

Table B.4: Supply-demand balance results (Ml/d) for late-century scenario run, by region

Late-century	NAALP2DLC	NAAMP2DLC	NAAHP2DLC	CAAMP2DLC	NAAMP4DLC	NAAMP4DPPELC	CAAMP4DLC	AAMP4DLC	CAAMP4DLC	AAHP4DPPELC	NAAHP4DPPELC
WRSE	-377	-1259	-1972	-308	-1699	-1753	-749	186	-749	-701	-2467
WRE	19	-247	-503	56	-317	-337	-14	359	-14	88	-593
WRN	272	193	-4	494	-209	-257	91	420	91	117	-455
WCWR	132	-14	-175	141	-102	-114	53	285	53	83	-275
(rest of) Wales	68	57	-3	149	45	42	137	224	137	150	-19
WRW	2	-362	-887	298	-838	-1019	-179	670	-179	-150	-1544
Northern Ireland	162	114	-13	189	85	80	160	263	160	94	-47
Scotland	433	275	-51	567	195	167	487	853	487	304	-159

Source: *n/a*

C. Method

Figure C.1 provides a summary of the method used to evaluate potential future water availability for CCRA3. The principles of each step are described in the sections below.

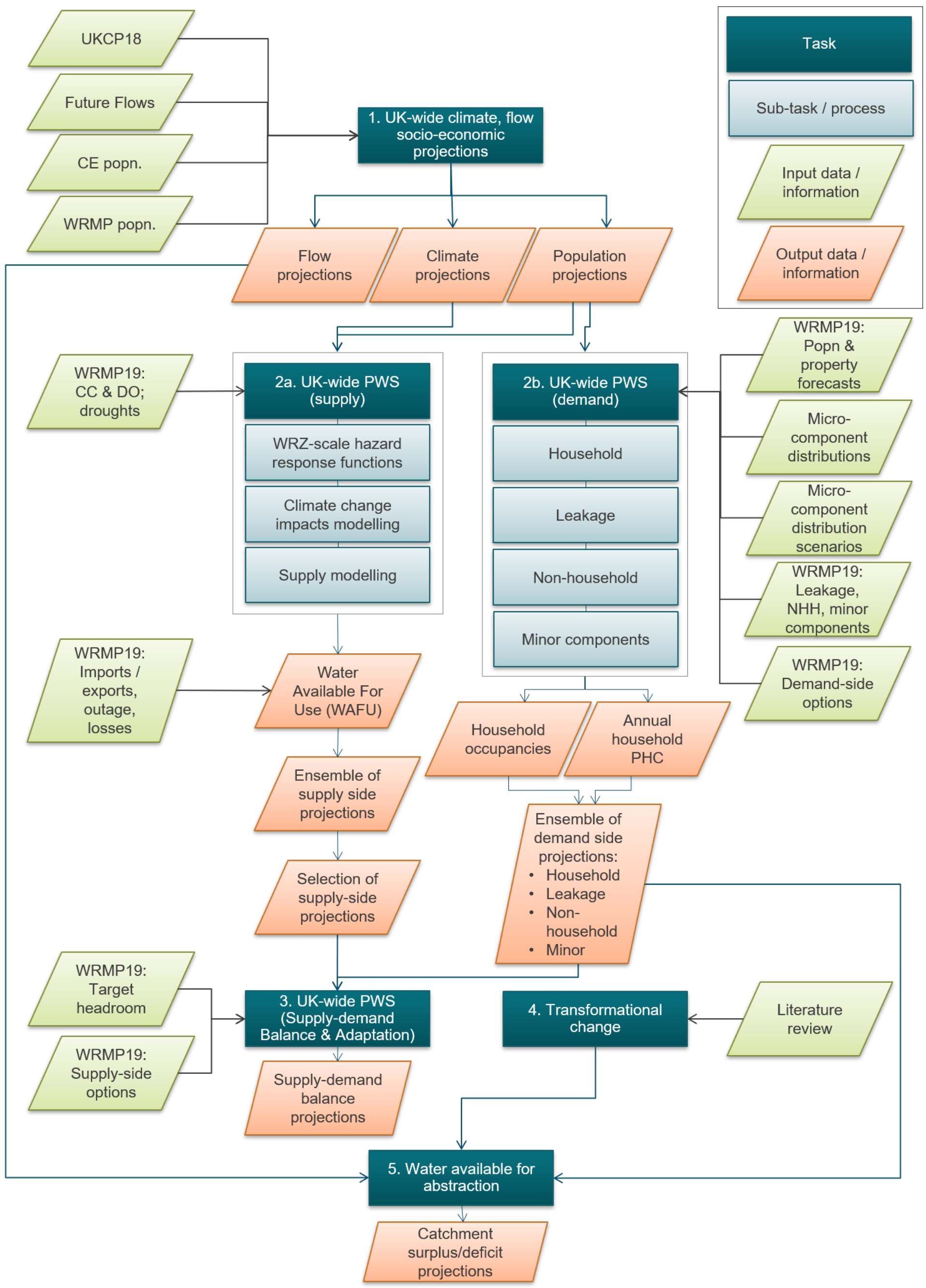


Figure C.1: Water availability projections project process and methodology

Source: n/a.

C.1. Task 1. UK-wide climate, flow and socio-economic projections

The aim of this step is to understand and develop a set of projections of climate change, flows and socio-economic scenarios that can be used throughout the entire project. It was desirable for there to be consistency with the rest of the CCRA3 analysis with respect to the climate change and socio-economic scenarios used and the way in which uncertainty in those projections was quantified. However, this was not always possible; and, this is highlighted where relevant in the sections below.

C.1.1. Climate projections

Projections of temperature and precipitation are calculated for every water resource zone and river basin. The projections provided are spatially coherent, extend to 2100 and represent the latest climate modelling publicly available for the UK. The projections are presented in the context of 2°C and 4° C worlds (mean global warming by 2100 relative to pre-industrial) in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099).

Reviewing UKCP18

This is the first time that the UKCP18 climate projections are being used for a national assessment of climate impacts on water availability. There is also little published literature on UKCP18 beyond the scientific reporting available from the Met Office that accompanies the UKCP18 projections. The project team undertook a review of the available UKCP18 products to ascertain their suitability for this assessment. The products available at the time under UKCP18 are illustrated in Figure C.2.

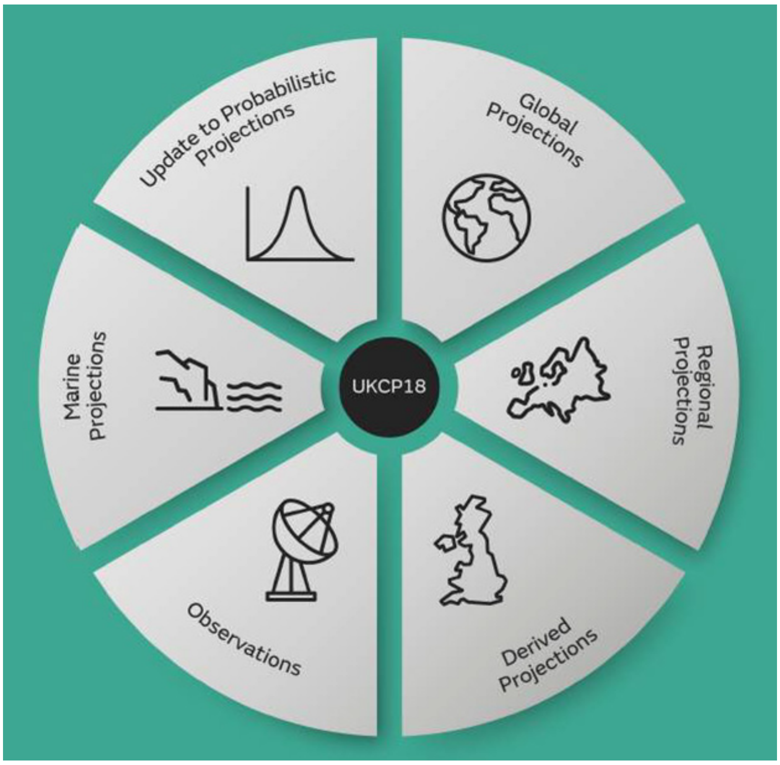


Figure C.2: UKCP18 products

Source: Murphy et al (2018).

Using six case study locations, the review considered:

- How the global and regional projections relate to the wider representation of uncertainty present in the UKCP18 probabilistic projections during different seasons.
- The ability of the global and regional projections to represent droughts, using drought severity indices.
- The prevalence of dry winters in the global projections.
- The potential value of using the derived projections.

Following the UKCP18 review, it was concluded that the UKCP18 Global Projections were the most suitable product to be used in this analysis because they are spatially and temporally coherent (key for water resources planning), extend to 2100 and are not based on a single underlying global climate model. The global projections are comprised of 15 simulations underpinned by the Met Offices' latest global climate model (known as 'PPEs') and 13 from the CMIP5 model inventory used to inform the IPCC 5th Assessment (known as 'CMIP5-MME'). Whilst the regional projections have a finer spatial scale, they comprise a smaller ensemble of 12 members all based on a single underlying climate model (Met Offices' latest global climate model). The use of the UKCP18 Global Projections was a deviation from the main CCRA method at the time in which the UKCP18 Probabilistic Projections were generally preferred. However, as described above, for the water availability analysis, these were not deemed to be the most suitable UKCP18 product.

There are several challenges with using the global projections for this type of analysis. The main challenges are:

- **A coarse spatial resolution of 60km**. This is likely to be of greatest significance in areas of the country that rely on rainfall in upland areas.
- **A potentially smaller range of uncertainty.** The 28 simulations provided by the global projections may not provide sufficiently comprehensive coverage of the known uncertainties that are presented within the UKCP18 probabilistic projections. However, the review noted that many of the projections of autumn precipitation provided by the 15 PPEs, unlike the CMIP5-MME members, from the global projections lie outside the uncertainty range of the UKCP18 probabilistic projections. As autumn rainfall is particularly important for many water resource systems, it is the range of results provided by the global projections that will be used in this analysis.
- **Not presented in terms of 2°C and 4°C of mean global warming.** The global and regional projections are provided for the highest emissions scenario available under UKCP18 (RCP8.5) only. At 2100, the upper end of RCP8.5, some PPE members suggest a level of mean global warming closer to around 6°C, with the 90th percentile from the UKCP18 Probabilistic projections around 5.4°C based on data provided by the Met Office.
- **No Potential Evapotranspiration projections are provided.** Similar to previous projections, Potential Evapotranspiration has to be calculated using a temperature-based method (Oudin) and the temperature projections available with these climate change scenarios.

Using the projections

To prepare the climate projections for use in the subsequent analysis, the monthly time series, in the global projections for temperature and precipitation were extracted for all water resource zones and river basins across the UK. Percentage change values were calculated, relative to a 1961-1990 baseline.

Understanding the impacts in the context of 2°C and 4°C worlds

In order to feed into the wider CCRA, the impacts presented must be consistent with 2°C and 4°C of global warming by 2100. Since this information is not available directly for the global projections, this must be estimated. This assessment uses a method similar to that used by the HELIX project (Bärring & Strandberg, 2018) and is described in Appendix C.2.

Table C.1: Assumptions and uncertainties when using UKCP18 to assess impacts to water availability

UKCP18 product	Assumption / uncertainty
Global and probabilistic projections	UKCP18 global projections are underpinned by two types of climate models, 15 'PPEs' (the latest HADGEM3 model) and 13 CMIP5 models. The global PPE projections are generally hotter and drier than the CMIP5 models. In autumn specifically, some of the projected changes in precipitation in the global PPE projections lie outside the range of precipitation changes projected using the probabilistic projections. As autumn is of importance to water availability in the public water supply sector, using the uncertainty range in the UKCP18 probabilistic projections alone would therefore not be sufficient for this type of assessment (i.e. because the global projections can provide a plausible future with a drier autumn than any of the members in the probabilistic projections).
Global projections	Assumed to be plausible "storylines" of the future. They are not an ensemble to which likelihoods can be ascribed.
Global projections	Only available in RCP8.5. RCP8.5 is considered to be a plausible worst-case outcome; it should not be interpreted as the most likely "business-as-usual" high emissions scenario. RCP8.5 represents the 90th percentile of the no-policy baseline scenarios available at the time (van Vuuren et al., 2011).
Global and regional projections	Whilst it is known that the latest HADGEM3 model is relatively hot and dry, sensitive to higher emissions scenarios, it is assumed that these reflect the best and latest climate science for the UK. The 13 CMIP5 model variants within the global projections also ensure that the analysis is not related to a single underlying global climate model.
Probabilistic projections	Assumed that the rate of global warming under a 2°C and 4°C world through the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) are an appropriate trajectory of how the climate may warm towards these mean global warming levels by 2100.

Source: n/a.

C.1.2. Flow scenarios

Flow metrics, changes in Qn30, Qn50, Qn70 and Qn95 relative to a 1961-1990 baseline, are calculated for each UKCP18 river basin at mean global warming levels between 1°C and 6°C degrees. Estimates are made for the changes that may occur in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) in a 2°C and 4°C world. See Figure 2.2 for visual description of this approach.

Using the large ensembles of naturalised flow changes under UKCP09 climate change scenarios, developed as part of the CCRA2 water availability study (HR Wallingford, 2015), multiple linear regression models have been developed between the climate change scenarios (in the form of monthly change factors) and the change in QnX. The sampled UKCP18 global projections at incrementing global warming levels (between 1°C and 6°C) described in Section C.2 below were run through the multiple linear regression models. This provides a range of projected impacts for each flow metric for each global warming level between 1°C and

6°C, incrementing every 0.5°C. Impacts at global warming levels in between the 0.5°C increments can then be linearly interpolated.

The global warming levels of each of the RCPs underpinning the UKCP18 probabilistic projections over the century are used to estimate the global warming level for a 2°, 4°C and PPE 4°C world in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099), see Table C.3 and associated description. The range of flow metric impacts described in the paragraph above are used as a look-up table to estimate the range of impacts at a particular global warming level.

These projected changes in flow are used in Task 5, Water available for abstraction (see Figure C.1) to project the change in catchment flows.

C.1.3. Socio-economic scenarios

Three population projections will be considered in this assessment. These are shown in Figure C.3 in blue text (central and high population scenarios and a no population change scenario).

For this assessment, the wider CCRA3 method requires that the socio-economic scenarios driving the analyses should, ideally, be taken from another project commissioned by the CCC entitled "*A consistent set of socio-economic dimensions for the CCRA3 Evidence Report research projects*" (Cambridge Econometrics "CE", 2019). The project produced a consistent set of population scenarios plus other scenarios that were potentially applicable to multiple CCRA3 research projects.

Unfortunately, key information of interest for the water availability project on how household occupancy and numbers may vary with population change, dimensions around technological change and factors that would influence behavioural change around water use were either out of the scope of the Cambridge Econometrics project and/or the required underpinning data and information was not available.

Water companies also use population projections in the water resource planning process. This information is usually provided by local authorities. The data underpinning those population projections provided by CE (2019) are from the Office for National Statistics. Figure C.3 compares the projected change in population using these two datasets for Wales.

The CE (2019) local authority level population projections have been mapped onto water resource zones. Consideration has been given to the extent to which areas are urbanised in order to try and account for the variation in population density. The population projections are a little higher than the central projection from CE. The extent to which this differs varies between WRZs and tends to be greatest in WRZs in the north of England.

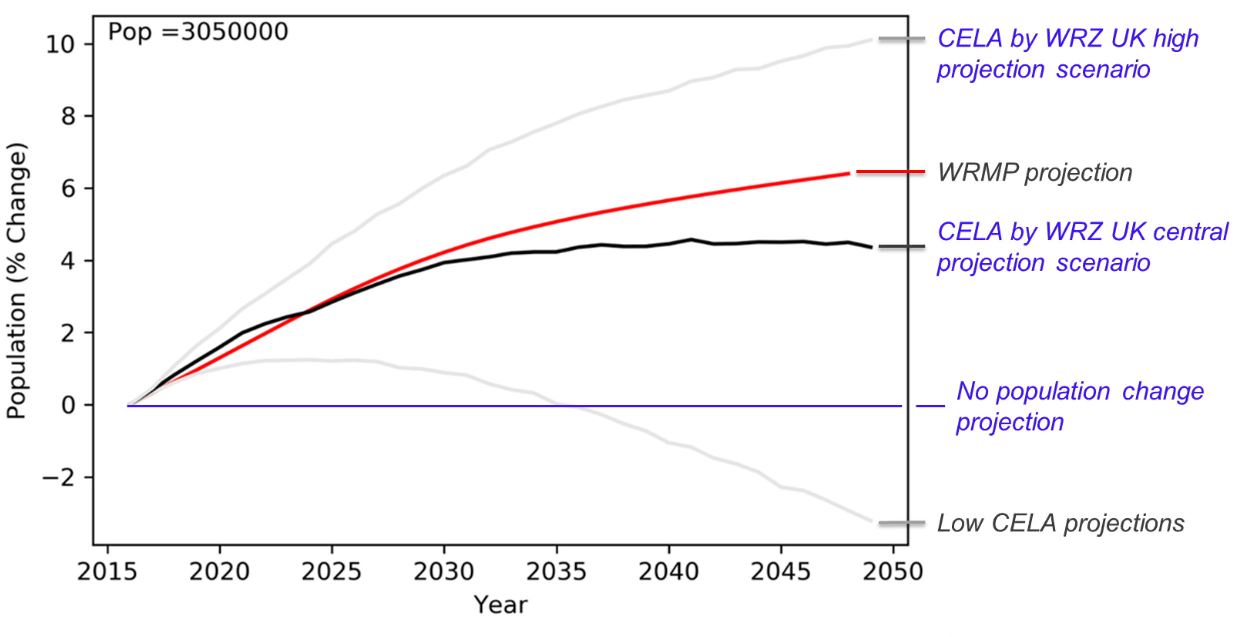


Figure C.3: Comparison of population figures provided by Cambridge Econometrics (2019) and population figures extracted from the latest Water Resource Management Plans; for Wales

Source: Cambridge Econometrics (2019); water company management plans, various.

C.2. Task 2a: UK-wide Public Water Supply (PWS); Supply

Task 2a provides projections of deployable output, the amount of water that can be deployed from a water company's sources[19], for every water resource zone, region and devolved administration. The absolute values and percentage change values are calculated for a 2°C and 4°C world in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099).

This assessment is underpinned by the latest Water Resource Management Plans (WRMPs) for England and Wales; Scottish Water's Water Resource Plan (2015) and the ongoing climate change impact assessment; and, Northern Ireland Water Resource and Supply Resilience Plan (publication date yet to be confirmed). Without the support from and information provided by all water companies in the UK, this assessment would not have been possible.

This part of the analysis assumes that water companies will maintain the Levels of Service stated in their latest water resource plans including the frequency of imposition of restrictions such as standpipes and rota-cuts.

Water resource zone-scale hazard response functions

The climate change modelling that informs the latest water company water resource plans has been used to create statistical emulators (multiple linear regression models) that describe the relationship between climate indicators and deployable output for every water resource zone in the UK. See Figure 2.2 for visual

[19] Including surface and groundwater sources that may be constrained in a number of ways, including the licence, hydrology or hydrogeological factors and works capacity.

description of this approach.. Typically, a selection of seasonal metrics for temperature and rainfall were used in the MLR analysis. The input data were split to enable calibration and validation of these statistical models. For the majority, a good relationship was found between the relevant climate variable(s) and deployable output. However, for a few water resource zones, this primary method could not be used and either donor sites were used to scale impacts or simulation models were employed. The alternative methods used are summarised in Table C.2.

Table C.2: Alternative methods for evaluating climate change sensitivity

Water Company	Reason for not using primary method	Alternative method
Anglian Water	Anglian Water only used 5 UKCP09 projections all the way through their modelling processes to calculate DO impacts in their water resource management. Five scenarios were not considered sufficient to develop a robust statistical emulator.	A simplified water resources model for the water resource zone, Ruthamford South, has been used to inform the impacts in those zones that Anglian water consider to be vulnerable to climate change in their latest water resource management plan.
SES Water / Cambridge Water / Southern Water / South Staffordshire Water / Wessex Water / Hafren Dyfrdwy	The underlying climate modelling either did not produce a robust multiple linear regression model or the full data associated with the WRMP19 modelling were not readily available with which to develop such a model. These issues were typically for small WRZs that have relatively limited climate sensitivity.	The climate change impacts reported in the WRMPs were used to scale the results from the most appropriate donor sites.

Source: n/a.

Water companies have used a range of climate change evidence to evaluate climate change impacts and inform their latest resource management plans. Climate change has typically been considered using the UKCP09 climate projections, or products derived from these projections such as the Future Flows scenarios. For the majority of water resource plans, the 2080 time-horizon under a medium emissions scenario has been considered, although some companies have adopted different time-horizons (2030s in much of Wales[20] and Severn Trent Water and 2020s[21] in Northern Ireland). This means that the outputs from different water companies are underpinned by different levels of evidence and the associated level of confidence in the assessments may vary. However, all assessments have assimilated the best evidence available to date for each water company.

It should be noted that to date, many groundwater dominated water resource systems have been considered insensitive to climate change. Where any system is considered to be insensitive to climate change, that will permeate through this assessment, as it is the climate change impacts analysis undertaken by water companies that underpin this analysis.

[20] All zones except SEWCUS

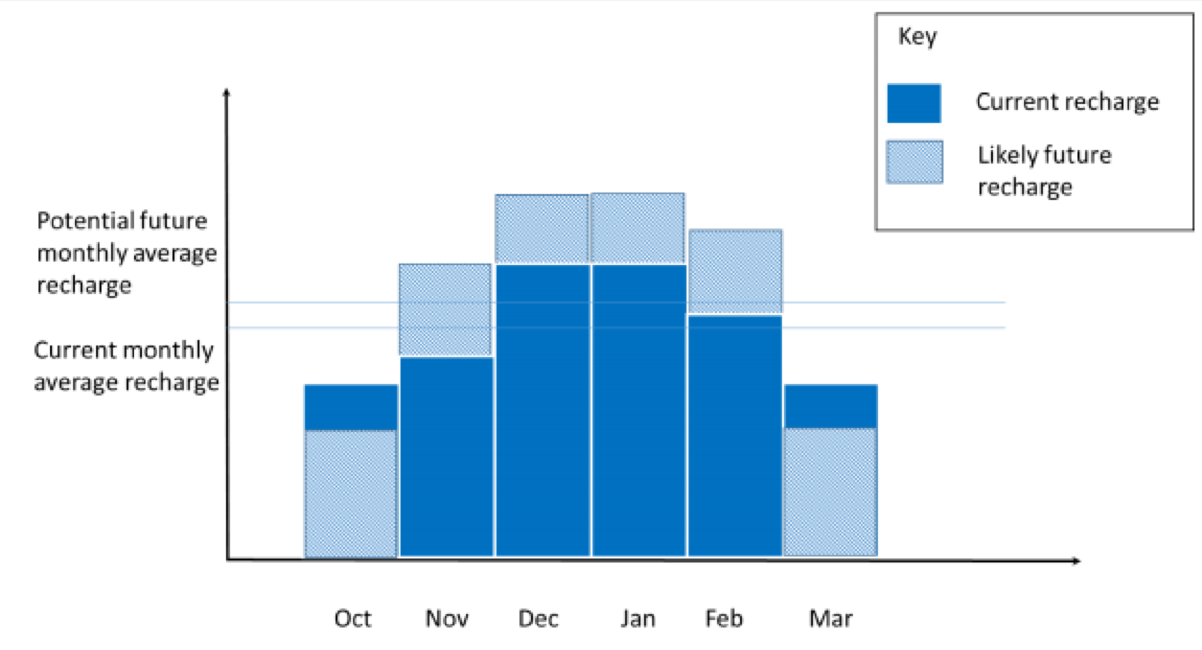
[21] 2011-2040 and extrapolated to 2042

Climate change in groundwater dominated systems

The main messaging from the probabilistic projections in UKCP09 and UKCP18 is that there are likely to be warmer, wetter winters, and hotter, drier summers in the future. When considering only this messaging, it could be concluded that groundwater recharge will increase during winter, and that this will result in an increase in the resilience of groundwater sources. However, Mansour and Hughes (2017) demonstrated that, when using a change factor approach, the recharge season becomes generally shorter in the future, reducing by approximately 40%.

Whilst recharge volumes tend to increase in the future (although there are a range of outcomes, of which some indicate a reduction in recharge volumes), the reduced recharge window could mean that if a dry winter occurs, groundwater sources could potentially have increased drought vulnerability when compared with present day.

The indicative changes in recharge from Mansour and Hughes (2017) are shown in the figure below.



Source: Mansour and Hughes (2017).

The approach used by Mansour and Hughes (2017) involved using bias-corrected Potential Evapotranspiration (PET) datasets from Future Flows (which are not available as part of UKCP18). In the context of UKCP18, the PPE members within the Global Projections and the Regional Projections show changes in autumn that are distinctly different to evidence used within WRMP19 and the other evidence available in UKCP18. This increased temperature and changes in precipitation patterns in autumn may have significant consequences for PET and aquifer recharge. This means that groundwater system should be assumed to be resilient to climate change.

As recommended in the new supplementary guidance for the next WRMP in 2024 (in press), when using a mean change factor approach for assessing impacts, changes to the risk of consecutive dry winters cannot be fully explored. Currently, where water companies believe there is a risk to groundwater sources, second or third dry winter scenarios can be run as part of system stress and drought resilience testing.

Without moving to an approach that makes direct use of UKCP18 time-series (which would require bias correction of climate outputs) the consequences of consecutive dry winters cannot be fully explored but remains an important aspiration in the water sector for the future.

Detailed evidence as to whether the latest models within UKCP18 provide robust, meaningful evidence of changes in the risk and severity of consecutive dry winter scenarios is not currently available and therefore it is not considered appropriate to move beyond a mean change factor approach for WRMP24. Consequently, appropriate stress testing of consecutive dry winters, or a "third dry winter" scenario, as part of the WRMP process in 2024 should still be undertaken.

Climate change impacts modelling

The water resource zone-scale hazard response functions and samples of UKCP18 global projections at incrementing global warming levels are used to determine the impacts of climate change on deployable output at incrementing global warming levels between 1°C and 6°C. Once this trajectory has been created, the UKCP18 probabilistic projections, as described in Table C.3, are used to estimate the impacts in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) in a 2°C, 4°C and PPE 4°C worlds.

The modelling results in an impact on deployable output, for every water resource zone, region and devolved administration for the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) in a 2°C, 4°C and PPE 4°C worlds.

1. **Sample UKCP18 global projections at incrementing Global Warming Levels (between 1°C and 6°C)**
   For each of the UKCP18 global projections (PPEs and CMIP5 members) identify when each member hits a specific level of mean global warming (every 0.5°C between 1-6°C) and then sample the temperature and precipitation change for a 30[22] years window around that date, relative to 1961 to 1990 (the reference period adopted by water companies in their latest WRMPs). 30 years windows have been used to be consistent with the climate change impact methodology adopted by water companies in their latest Water Resource Plans.

   This step provides a range of climate impacts for each mean global warming level assessed. It should be noted that at higher global warming levels, there are fewer projections in the sample because not every projection will reach the highest global warming levels by the end of the century.
2. **Use sampled UKCP18 global projections to evaluate impacts at incrementing Global Warming Levels (between 1°C and 6°C)**

   For each of the samples in Step 1, use the water resource zone-scale hazard response functions to estimate the impact on deployable output at incrementing Global Warming Levels between 1°C and 6°C (every 0.5°C). This creates an ensemble of spatially coherent, trajectories of impact on deployable output at each Global Warming Level, for each water resource zone (which is also aggregated to a regional and Devolved Administration scale). This method is based upon the 'time-sampling' approach described by James *et al* 2017.

22 Using the approach adopted by the Met Office (Gohar et al., 2018), the date at which a specific mean global warming level is reached is taken as the central date in a 25 year window. Given the global projections terminate in 2100, the latest date that could be considered is 2087. Where this date is 2087, the change factors are based on a 28 year future time slice (and a 29 year time slice if the central date is 2086).

3. **Identify mean global warming levels through the 21st century.**

   The global mean surface temperature anomalies that underpin the UKCP18 probabilistic projections are used to estimate the global warming level for a 2°C and 4°C world in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099). For each member of the ensemble, the warming between the baseline period (1850-1900) and future time periods (mid- and late-century) is computed and the 50th percentile (or 10th or 90th percentiles) of these anomalies is extracted. These are described in Table C.3. RCP2.6 (50th percentile) is broadly representative of a 2°C world (green line in Table C.3) and RCP8.5 (50th percentile) is broadly representative of a 4°C world (red line in Table C.3). Where an PPE 4°C world is described, this used the values at 4.2°C as per Table C.3 but, only extracts the impacts projected by the PPE members of the UKCP18 Global Projections.

Table C.3: Mean global warming levels (°C) for the UKCP18 probabilistic projections for the mid- and late-century. The 10th, 50th and 90th percentiles are presented. Values are relative to pre-industrial temperatures (1850-1900)

	Mid-century 2040-2069			Late-century 2070-2099		
Emissions scenario	**10th percentile**	**50th percentile**	**90th percentile**	**10th percentile**	**50th percentile**	**90th percentile**
SRES-A1B	1.2	1.8	2.5	2.1	2.9	3.9
RCP8.5	1.8	2.5	3.3	3.2	4.2	5.4
RCP6.0	1.3	1.9	2.5	2.3	3.1	4.0
RCP4.5	1.4	2.0	2.6	2.0	2.8	3.6
RCP2.6	1.1	1.6	2.2	1.2	1.8	2.5

Source: Met Office Hadley Centre (2018).

4. **Look-up impacts in a 2°C, 4°C and PPE 4° world**

   Using the trajectories of impact from Step 2 and the global warming levels in the mid- and late-century from Step 3, extract the 50th percentile from the range of impacts (linearly interpolating between the sampled global warming levels where necessary) for use in subsequent supply-demand balance calculations. For the 2°C and 4°C worlds, the 50th percentile is based upon the results from all of the UKCP18 Global Projections scenarios. For the PPE 4°C world, the 50th percentile is based upon only those PPE members used in the analysis.

The same steps 1-4 above are used to evaluate the impact on flows as summarised in Section C.1.2 above and a conceptual diagram is provided in Figure 2.2.

Supply modelling

The final stage of Task 2a is to calculate the water available for use, to feed into the supply-demand balance calculation in Task 3. Water available for use is the deployable output plus bulk supply imports, less bulk supply exports and less reductions made for outage allowance and operational losses. We have also maintained the sustainability reductions and other impacts on DO committed to in the latest resource management plans (using the resource plan values for the Base Year and 2044/45 for mid-century and late-century) have been maintained in the calculation of WAFU.

The water available for use will be calculated for each water resource zone and for mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) in a 2°C, 4°C and PPE 4°C worlds.

C.3. Task 2b: UK-wide Public Water Supply (PWS); Demand

Task 2b provides projections of different aspects of public water supply and demand. Household consumption, non-household consumption, leakage and minor components are all modelled at a water company level to 2100. Results are presented for the base year, 2019, the near term (2035), mid-century (2055) and late-century (2085). This aspect of the CCRA3 Water Availability study was undertaken by Artesia for HR Wallingford.

Household consumption and leakage have been modelled with three different scenarios:

- No Additional Action (NAA): no intervention is considered in the future; levels of consumption and leakage are the same as 2019 for the whole century.
- Current and Announced (C+A): interventions already planned by water companies are considered.
- Additional Adaptation (AA): further adaptation, beyond measures already planned, is considered.

Non-household consumption and minor components are modelled with only one scenario. Uncertainty is estimated for all four components separately in the form of upper, central and lower scenarios similar to the socio-economic scenarios described above.

Different modelling approaches have been taken for the four aspects of demand and are summarised below.

Household projections

The final outputs are distributions of household consumption for each of the years of interest, 2019, 2035, 2055 and 2085.

The approach is based on consumption analysis at household level, taking account of how occupancy and other household factors (such as measured or unmeasured meter status) affect the micro-components of water use (WC flushing, showering, clothes washing, drinking, etc.). An overview of the approach is summarised in Figure C.4.

As per Figure C.4, in the first step, unmeasured and measured occupancy, meter penetration, measured and unmeasured per capita consumption are calculated for each company, each year and for each adaptation scenario. For consistency, data taken from water company plans are considered between 2019/20 and 2044/45 and held fixed thereafter.

In the second step, a stochastic, rather than deterministic approach is taken. This will lead to an array of results from which uncertainty values can be derived. Modelling per capita consumption in this assessment is based upon an understanding of how the micro-component usage in the home changes with occupancy and meter status. Empirical data on the micro-components of household water use are combined with water company information on the properties monitored, including household occupancy, meter penetration and un- / metered household consumption in order to understand how ownership, frequency of use and volume per use of different micro-components changes with occupancy and meter status. This understanding allows assumptions to be made about how each adaptation scenario will impact each element of water use in the home.

The consumption model resulting from this micro-component analysis allows household level consumption to be predicted depending on occupancy and meter status. So, as average occupancy changes through time and meter penetration increases, so the average household consumption will also change. Furthermore, by varying the ownership, volume and frequency distributions of the micro-components (based on the considered interventions for the three-adaptation scenarios), it is possible to output per capita consumption distributions for each scenario revealing the effect on average household consumption, with an accompanying confidence level.

The outputs from the analysis are household level consumption which are aggregated to form a distribution of household consumption at the company level. A total of 100,000 properties is simulated for each of the years of interest, the number of households per water company is split proportionally.

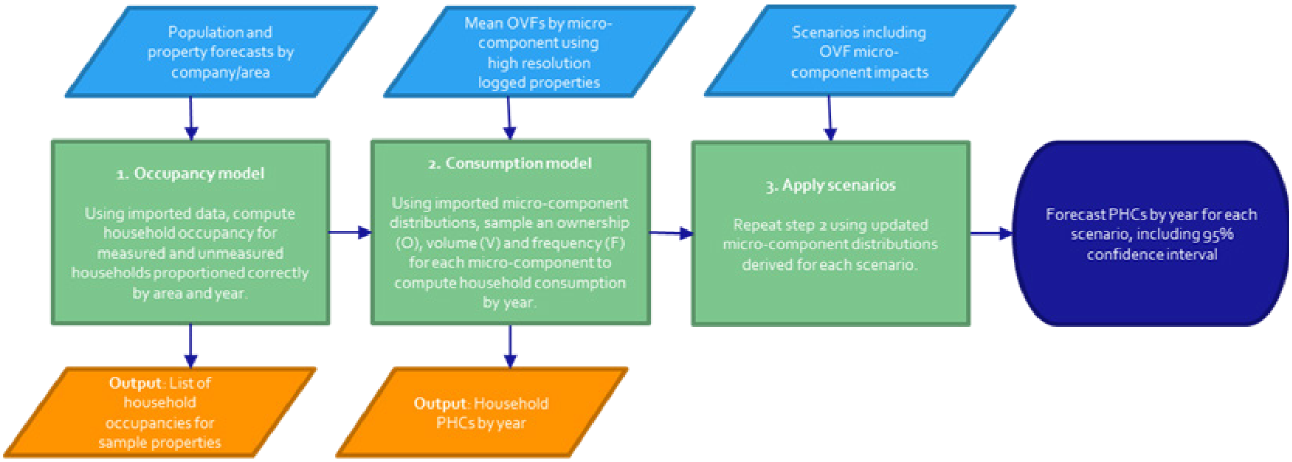


Figure C.4: Overview of stochastic household consumption modelling methodology

As described above, three adaptation scenarios are considered in this assessment:

- **No Additional Action:** No intervention is considered in the future; levels of consumption are the same as today for the whole century. In terms of household consumption, this corresponds to keeping the baseline 2019 per capita consumption figures fixed throughout the century. However, the balance between measured and unmeasured households will change over time due to all new properties being metered, and the various metering policies of different water companies. As a result, overall meter penetration is expected to increase. As the per capita consumption of measured households is lower than that of unmeasured households, the overall per capita consumption is expected to reduce throughout the century, although just marginally. Therefore, even if this scenario is considered 'fixed' throughout the century, results will show a slight decrease in average per capita consumption over time, due to an increase in metered new properties.
- **Current and Announced:** Interventions already planned by water companies are considered in this scenario. In terms of household consumption, this corresponds to the water resource management plan, final plan. The final plan represents all planned interventions to reduce per capita consumption and generally do not go beyond 2044/45. For consistency, WRMPs that go beyond 2044/45 are considered only up to 2044/45. The per capita consumption figures are then kept fixed until the end of century. For Scottish Water and Northern Ireland Water a final plan equivalent is not available. However, considering that both companies do not have significant plans to change their meter penetration, the baseline plan is used.
- **Additional Adaptation:** Further adaptation is considered based on recent work on long-term pathways for per capita consumption reduction carried out by Artesia for Water UK and used by the Environment Agency in their work on the National Framework. In particular we have used forecast per capita consumption values per company from one of the most ambitious per capita consumption reduction scenarios developed for Water UK.

This assumes firstly that water companies outside areas of serious water stress are able to encourage their customers to switch to meters on a voluntary basis. This would be delivered using the 'progressive metering' model that Southern Water developed, which provides customers with the option to switch over a two-year period. Secondly this scenario includes a government-led mandatory water labelling scheme, linked to building regulations. The water labelling programme would have tightening minimum standards so that all households would have increasingly efficient water using devices installed over time.

For each of the adaptation scenarios, three population scenarios (see Section C.1.3 above) are also considered, resulting in nine scenarios in total.

These scenarios are then translated to the water resource zone scale by reference to the latest resource management plans at the appropriate time-horizons to preserve the relative values across a water company's different water resource zones. In the case of **Current and Announced** and **Additional Adaptation** scenarios for England and Wales, a 'collar' is applied to ensure that all WRZs are within +/- 10 l /h/d of the target mean company value to reflect that reductions would be more focussed towards those WRZs currently subject to higher PCC values and that WRZs that are already relatively very low are not driven to disproportionately low levels.

Leakage projections

The final outputs are leakage forecasts for each of the years of interest, 2019, 2035, 2055 and 2085, based upon leakage levels from the latest water resource plans and the three adaptation scenarios:

- **No Additional Action:** no intervention is considered in the future; levels of leakage are the same as today for the whole century. Baseline 2019 leakage figures are kept fixed throughout the century.
- **Current and Announced:** interventions already planned by water companies in their final water resource plan are considered. For consistency, any water resource plan that goes beyond 2044/45 is considered only up to 2044/45. Leakage is then reduced to 50% of baseline 2019 figures by 2050, and this value is then kept fixed until the end of century. For Scottish Water and Northern Ireland Water a final plan equivalent is not available, therefore the baseline plan is used.
- **Additional Adaptation:** this scenario is the same as the current and announced scenario up to 2050. After 2050, leakage is reduced to 10% of DI (baseline 2019 value) by 2065 and then fixed for the rest of the century. If the leakage value in 2050 is already less than 10% of DI, then the 2050 value is fixed for the rest of the century.

Uncertainty is estimated using historical leakage figures (Artesia, 2019 unpublished). The uncertainty applied to the different adaptation scenarios differs between scenario and over time. The more that leakage is reduced compared to the baseline value, the more the upper boundary increase and the more the lower boundary approaches the projection value. This is to reflect the uncertainty in whether the targets will be met. These scenarios are then translated to the water resource zone scale by reference to the latest resource management plans at the appropriate time-horizons to preserve the relative values across a water company's different water resource zones.

Non-household projections

The projection of non-household demand follows water companies' projections until the end of the 2044/45 (using the final plan figures from the water resource plan; or baseline figures for Scotland and Northern Ireland) and are then kept fixed until the end of the century.

The uncertainty estimated is comprised of:

- Uncertainty on water companies' intervention implementation based upon the difference between the baseline and final plans.
- Uncertainty on population projections, based upon the historic relationship between population and non-household demand and the CE population projections described in Section C.1.3 above.

Similar to the approach for leakage, these scenarios are then translated to the water resource zone scale.

Minor component projections

Minor components are the residual element of the water balance not covered by household consumption, non-household consumption or leakage. Although minor in volume, they are important to consider to correctly close the water balance. Minor components include demand from the distribution system for operational use by the water company (i.e. mains flushing) and water taken unbilled (e.g. sewer flushing, fire training and fire-fighting); it also includes water taken illegally.

These components are not very volatile in time and are not strongly driven by socio-economic factors. For this reason, they are modelled as fixed values throughout the century. This is the same approach that water companies use in their water resource plans. Additionally, they do not represent significant volumes, therefore water companies have no plan to reduce consumption which means that the reported values in the baseline and final plans are equal for all companies.

Uncertainty is estimated using historic minor component figures, at a national scale, for England and Wales (OFWAT, 2018). Similar to the approach for leakage, these scenarios are then translated to the water resource zone scale.

C.4. Task 3: UK-wide Public Water Supply (PWS); Supply-demand balance and adaptation

This task delivers future water supply-demand balance estimates for public water supply across the UK, by WRZ, regional group and Devolved Administration. Water companies calculate the supply-demand balance to satisfy the following:

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

This task comprises four parts: supply projections; demand projections; quantification of the supply-demand balance; and, quantification of the effects of different adaptation scenarios, including provision of enhanced levels of drought resilience, on the supply-demand balance.

Supply projections

For each of the climate change scenarios the supply–demand balance is calculated at the WRZ, Regional Group and DA scale. At each scale for each global warming trajectory (2°C and 4°C, and for some scenarios also PPE 4°C) and at each future time-horizon (mid-century, late-century) we have 28 estimates of water availability (WAFU). At each scale we have taken the 50th percentile estimate into the calculation of supply-demand balances.

It should be noted that, the values for the regional groups and DAs are not simply the sum of the 50th percentile values for the WRZs within each because, at the WRZ scale, different scenarios may correspond to the 50th percentile. It should also be noted that values stated for regional groups and DAs implicitly assume that water can be readily shared within each unit without penalty (i.e. loss of resource). This may not be practicable for some areas (e.g. some parts of Scotland) and therefore local hot-spots may be masked when looking at the regional group and DA scales.

Demand projections

The estimates of water demand (in the form of Distribution Input) are the sum of water demand from people (i.e. household and non-household use), plus losses from leakage and minor components (process losses and water taken unbilled). For this project, the high population scenarios have been combined with the upper estimates of leakage, non-household demand and minor components to reflect an upper-bound demand scenario. Likewise, medium population scenarios have been combined with the central estimates of leakage, non-household demand and minor components and low population with the lower estimates of leakage, non-household demand and minor components. This results in three demand scenarios being considered.

Supply-demand balance

Supply-demand balance is the difference between supply (WAFU) and demand (Distribution Input) at any given point in time, including an allowance for uncertainty (called target headroom). This may result in a surplus or a deficit of water. For this study, the Target Headroom values reported in the resource management plans at the appropriate time-horizons have been maintained. Deficits occur when demand for water outstrips the available supply (including the target headroom allowance).

As noted above, these calculations have been undertaken at the WRZ, regional group and DA scales.

Adaptation

For adaptation three elements have been considered:

- Demand side options (primarily reduction in household consumption and leakage);
- Provision of enhanced drought resilience;
- Supply-side options (e.g. new sources).

The approach to demand side options is described in Section C.3.

For supply-side options, this has made reference to the latest water company resource management plans and the analysis has been undertaken at the regional group scale. As part of the WRMP process, water companies with a projected supply-demand deficit at some point during the 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 is only available for WRZs in England and Wales.

The demand-side options for household consumption and leakage listed in the resource plans have been discounted from this list as they are, in effect, considered within the analysis presented in Section C.3. Intra-region transfers have also been discounted as these are implicitly reflected in the above calculations of regional supply-demand balances.

This part of the analysis then establishes the extent to which the remaining options may be able to mitigate projected supply-demand deficits, distinguishing when the options required extend beyond those identified by water companies within their preferred lists. For the purposes of this evaluation, all feasible options are considered to be available at mid-century and late-century. The maximum potential Water Available For Use listed for each option in the WRMP tables is also assumed to be fully available at those times. Where companies have listed several similar options with different levels of potential water available for use, then the largest figure has been used in this analysis.

Whilst every effort has been made to avoid double-counting options, a detailed review of every feasible option across England and Wales was out of scope of this assessment and so some duplicates may have been overlooked. The project made use of the collation of options undertaken by the Environment Agency for the National Framework in which transfers we separated from other supply options.

C.5. Task 4: Transformational change

The baseline of non-public water supply direct freshwater abstractions across the United Kingdom captures a great diversity of industries, users and approaches to water management. Water demand within each sub-sector and for individual users depends on a multitude of factors including water availability, product and market forces, economics, policy and regulation. Generating water demand forecasts for these users is not straight forward.

Typically, work to develop future projections of water demand frames the assessments against a range of plausible future scenarios setting out how environmental or socio-political drivers might change. These socio-economic scenarios allow the impacts of changing pressures to be explored across different sectors in a structured way, and the differences between each scenario to be assessed – presenting a range of distinct but plausible outcomes.

Drawing on latest available evidence (Defra, 2020), changes in water demand expressed as growth factors (positive or negative proportional change against the baseline) were defined for high-level sector categories and applied in Task 5, Water Available for Abstraction. These categories were:

- Agriculture - spray irrigation.
- Industrial/Commercial – informed by the average growth factors derived for the Chemicals, Paper and Food and Drinks manufacturing sub-sectors by Defra (2020).
- Electricity Production – taking growth factors developed by Defra (2020).

Growth factors derived by Defra (2020) were based on an assessment of plausible changes in water demand under four socio-economic scenarios developed originally for Water Resources East (Atkins, 2017). These scenarios considered possible consumption patterns (ranging from “sustainable” to “uncontrolled demand”) and governance systems (ranging from “global” to “regional”). Exploring these on two axes of uncertainty the four scenarios are shown below.

Figure C.5: Socio-economic scenarios used to evaluate changes in non-public water supply demand in Task 5, section C.6

Source: Defra, 2020 (fig. 12.3).

While some industries and trade bodies recommend targets and have ambitions in water efficiency, few sectors produce statutory plans clearly setting out future water management approaches, as the regulated water industry does. As such, for both the “no additional action” and “current and announced” scenarios within the CCRA3, change from baseline water demand as applied in Task 5, is scaled only by projected population change.

For the “additional adaptation” scenario, growth factors for the Industrial/Commercial sector are informed by the Sustainable Regionalisation scenario described above. While a variety of interacting factors are likely to drive water demand in an upward or downward trajectory in this future scenario (for example, changing consumer trends, a shift in imports versus exports etc.), typically this scenario reflects the greatest level of ambition and potential for water use efficiencies and would reflect a reduced water demand in the absence of population growth.

For the agricultural sector (principally irrigated cropping), the “additional adaptation” scenario is informed by the Sustainable Globalisation scenario described in Defra, 2020. In this case, there is a high level of ambition in irrigation efficiency and also (in a global market) the retention of a significant proportion of imports to the UK of products that would otherwise be grown and irrigated here. Overall, despite improvements in irrigation efficiency and crop yields, a range of factors in this scenario (for example a shift from meat to plant-based diets, and an increased area of cropped and irrigated land) combine to suggest a net increase in water demand for the irrigated cropping sub-sector in the "additional adaptation" scenario.

Uncertainty is particularly evident in the electricity generation sector. This is a water-using sector characterised by a relatively small number of larger water users, in which individual business decisions or changes in site operation can have a significant effect on the balance of water resources within a catchment. There is significant uncertainty at both a national and site-specific level in the future water demands of the electricity production sector.

The latest Future Energy Scenarios (FES 2019) provide an indication of the pathways that could be taken by the industry to support UK decarbonisation targets, but there is little direct evidence available to translate these scenarios and the details within them into changes in water demand. Work is due to be carried out by sector in 2020 to address this information gap.

However, all scenarios within FES 2019 indicate an increase in overall electricity demand, with the most ambitious "Net Zero" scenario requiring the greatest increase in generation (an increase of 172% over current demand by 2050) as a result of wider reaching electrification of industry, transport and households. In the absence of any other changes to the energy supply mix, cooling technologies or site locations, this would result in a significant increase in freshwater demand. However, a complex range of interacting factors will influence the actual trajectory and magnitude of change.

The energy mix is critical. Gas-fired power stations with Carbon Capture and Storage for example (which are likely to play a role in ensuring resilience in a future network) may actually use more water than traditional installations per unit of output energy.

How and where electricity is generated will have a major bearing on national and local freshwater demand from this sector. Perhaps more so than any other water-using sector, water needs for the electricity production sector will vary considerably based on investment decisions at a very small number of sites. During network stress periods, or during periods in which typically "dormant" installations are required to generate electricity, freshwater demand may increase.

The growth factor used here for the electricity generation sector and applied within Task 5 under the "additional adaptation" scenario, is informed by Defra (2020), drawing from previous work carried out by the Environment Agency and Byers et al. (2014), most closely reflecting the potential for increased water demand in certain locations arising from more ambitious decarbonisation strategies and the technologies that may be required.

Note that for all industrial and commercial sectors, the effects of UK population change on water demand will vary considerably depending on the dependencies of those sectors on UK or global markets. However, resolving these subtleties in the context of the CCRA3 project is not possible, but worthy of further review. Here, where water demand is scaled according to population projections, only the UK population projection is accounted for.

It is also important to note that there is likely to be variation between regions, catchments and individual users. The evidence gathered for this project, and the broad sectoral scope did not allow for the derivation of regional or local industry growth factors. However, a consistent approach across the UK is appropriate for this high-level risk assessment since the priority sectors reviewed and their markets often respond to drivers at a national level.

Drawing upon the information discussed above changes in demand in different non-public water supply sectors are fed into the analysis in Task 5, Water Available for Abstraction; the scenarios are summarised in Table C.4.

Table C.4: Adaptation scenarios for non-public water supplies

Water use factor	No additional action	Current and announced	Additional
Industry and Commerce (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to the population figures (at a national scale).	All countries: As per 'No additional action'.	All countries: Change factor estimated from the **Sustainable Regional** scenario from Defra (2020) based upon key sectors and using the growth factor devised for that project.
Agriculture (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to regional population figures.	All countries: As per 'No additional action'.	All countries: Change factor for spray irrigation estimated from the **Sustainable Globalisation** scenario from Defra (2020) scaled to regional population figures.
Energy Generation (% change from baseline)*	All countries: Baseline figures from WRGIS (Sept 2014; CCRA2) scaled to regional population figures.	All countries: As per 'No additional action'.	All countries: Change factor estimated from the **Sustainable Regional** scenario from Defra (2020) scaled to regional population figures.

Source: n/a.

C.6. Task 5: Water available for abstraction

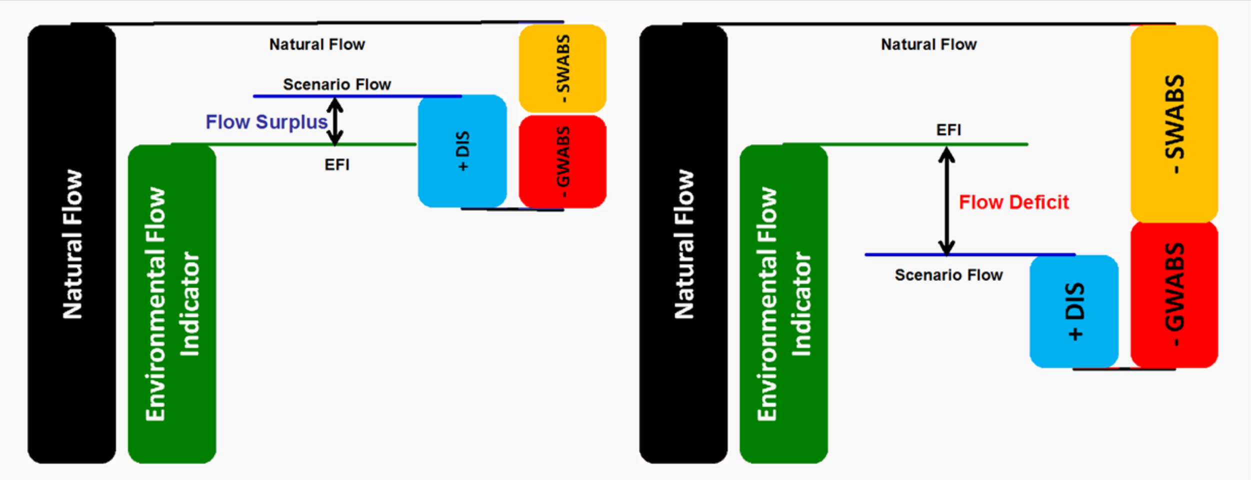
Using outputs from Tasks 1 to 4 and the WRGIS (New Building Blocks September 2014) and WRGIS-lite tools that were used in CCRA2 (HR Wallingford, 2015), projections of catchment water availability in the context of 2° and 4° worlds in the mid- (2050s; 2040 – 2069) and late-century (2080s; 2070 – 2099) were provided.

The WRGIS was the primary tool for undertaking national assessments of abstraction pressures and water availability in England and Wales including surface flow analysis for the Water Framework Directive. The tool is still used in England but is no longer used in Wales. Both the Environmental Flow Indicator and scenario flows influenced by abstractions and discharges are calculated from the natural flow estimated for every WFD water body and then compared to indicate whether there is a surplus or deficit.

The WRGIS is based on national (England and Wales) 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. Surpluses or deficits are calculated at four flow percentile snapshots (Q95, Q70, Q50, and Q30) to show how water availability varies across the flow range. For CCRA2 spreadsheets were developed for Scotland and Northern Ireland that assigned abstractions and discharges to Water Framework Directive surface water bodies and carried out ‘WRGIS-lite’ calculations to derive water surpluses or deficits by comparing scenario and environmental flows under the same percentile conditions. More information on the WRGIS is in the box overleaf.

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 below. 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, 3 and 4, are also applicable as outputs from these tasks feed into this analysis.

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), as per CCRA2.
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, but many CAMSLedgers currently have different periods of data.
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 calculates 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. Alternatively, 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.
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.

Discussion with Steering Group members indicates that the 2014 baseline of water body scale long term flow duration statistics and patterns of recent actual abstractions and discharges established by the CCRA2 work remain largely unchanged. Therefore, the same WRGIS and "recent actual" abstraction, discharge, and natural flow baseline assumptions as were used in CCRA2 will be used. The new natural flow change, abstraction and discharge data developed as part of tasks 1 – 4 in this assessment will then be used to update the projections in the tool.

Growth factors (positive or negative percentage change against the baseline) derived from the evidence review in Task 4, Section C.5 will be applied and change according to the adaptation scenario being tested, see Table C.4. The growth factors used are summarised in Table C.5. The acronyms in the column headings refer to scenarios tested. These are described in Section 2.2.

Table C.5: Factors applied to different additional adaptation scenarios for industry, agriculture and energy sectors and scale by regional population

		AALPMC	AAMPMC	AAHPMC	AALPLC	AAMPLC	AAHPLC
Industry	**NI**	0.860	0.933	1.044	0.860	0.928	1.146
	Scotland	0.860	0.902	0.981	0.860	0.908	1.057
	Rest of Wales	0.857	0.858	0.914	0.857	0.825	0.925
	WCWR	0.860	1.019	1.063	0.860	1.093	1.179
	WRE	0.860	1.036	1.085	0.860	1.141	1.237
	WRN	0.860	0.912	0.959	0.860	0.906	0.989
	WRSE	0.860	1.050	1.106	0.860	1.187	1.293
	WRW	0.860	0.958	1.010	0.860	0.994	1.092
Agriculture	**NI**	1.130	1.203	1.314	1.130	1.198	1.416
	Scotland	1.130	1.172	1.251	1.130	1.178	1.327
	Rest of Wales	1.127	1.128	1.184	1.127	1.095	1.195
	WCWR	1.130	1.289	1.333	1.130	1.363	1.449
	WRE	1.130	1.306	1.355	1.130	1.411	1.507
	WRN	1.130	1.182	1.229	1.130	1.176	1.259
	WRSE	1.130	1.320	1.376	1.130	1.457	1.563
	WRW	1.130	1.228	1.280	1.130	1.264	1.362
Energy	**NI**	1.360	1.433	1.544	1.360	1.428	1.646
	Scotland	1.360	1.402	1.481	1.360	1.408	1.557
	Rest of Wales	1.357	1.358	1.414	1.357	1.325	1.425
	WCWR	1.360	1.519	1.563	1.360	1.593	1.679
	WRE	1.360	1.536	1.585	1.360	1.641	1.737
	WRN	1.360	1.412	1.459	1.360	1.406	1.489
	WRSE	1.360	1.550	1.606	1.360	1.687	1.793
	WRW	1.360	1.458	1.510	1.360	1.494	1.592

Source: Factors derived from Defra (2020) sustainable regionalisation scenario, scaled to the regionalised population projections used in the rest of this CCRA3 assessment. Additional adaptation in this sense refers to wider adaptation actions, not just adaptation with respect to water use. As a result, some factors are an increase in water use.

In total, 21 scenarios will be tested using the WRGIS and WRGIS-lite tools. These are listed in Table C.6 and Table C.7 and reflect the scenarios used throughout the assessment.

Table C.6: Baseline and mid-century scenarios

#	Time	Degrees of change	Population	Adaptation	Environmental flow options
1	Baseline, 2019	n/a	WRMP 2019	No additional action	Proportional
2	Mid-century ("2050s": 2055; 2040-2069)	2° (50th%ile of all GCMs)	No population change	No additional action	Proportional
3			UK central	No additional action	Proportional
4			UK high	No additional action	Proportional
5			UK central	Current and announced	Proportional
6		4° (50th%ile of all GCMs)	UK central	No additional action	Proportional
7			UK central	Current and announced	Fixed
8			UK central	Additional adaptation	Proportional
9			UK central	Current and announced	Proportional
10			UK high	No additional action	Proportional

Source: n/a.

Table C.7: Late-century scenarios

#	Time	Degrees of change	Population	Adaptation	Environmental flow options
11	Late-century ("2080s": 2085; 2070-2099)	2° (50th%ile of all GCMs)	No population change	No additional action	Proportional
12			UK central	No additional action	Proportional
13			UK high	No additional action	Proportional
14			UK central	Current and announced	Proportional
15		4° (50th%ile of all GCMs)	UK central	No additional action	Proportional
16		4° (50th%ile of PPEs)	UK central	No additional action	Proportional
17		4° (50th%ile of all GCMs)	UK central	Current and announced	Fixed
18			UK central	Additional adaptation	Proportional
19			UK central	Current and announced	Proportional
20		4° (50th%ile of all PPEs)	UK high	Additional adaptation	Proportional
21			UK high	No additional action	Proportional

Notes: ***Proportional:*** *Policy/regulatory approach remains the same, we continue to protect % of Qn for the environment.*

Fixed (current environment): *We have the same environmental protection as now despite climate change. Fix Environmental Flow Indicator at current volumes.*

C.7. References

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