Water Stress and Resilience

Summary

Key Policy messages
The 25 year environment plan (25 YEP) includes a goal to reduce the risk of drought, with a target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. However, there is very little specific information on the target or actions that will be taken to achieve it. At the same time, the National Infrastructure Commission (NIC) has made recommendations to Government on increasing the resilience to droughts (although this has not yet been accepted by Government). This case study is primarily based on literature review, and has looked at previous work and the potential impact on extremes, i.e. supply/demand availability under more extreme drought events. It is stressed that the current water regulatory framework does include climate resilience, but there is a general anticipation that water companies will need to do more to address challenges by mid-century. Failure to address these issues is reported to lead to very high economic costs. These have been compared to the costs of enhancing resilience, and these show the cost of responding to a drought emergency are consistently higher than those of building long-term resilience to the same event, with upfront investment costs alone. The study has then reviewed the potential adaptation options to address these potential risks and achieve the outcome. Several studies report that an increase in the level of investment for enhanced climate resilience is needed to address the potential challenges of future climate change and that a broader portfolio of adaptation actions might be needed, for example to include more ambitious demand-level measures to reduce per-capita consumption, and inter-regional transfers between companies. For these measures to become effective, it is necessary to address existing barriers to their adoption (behavioural, regulatory, informational). Such an approach would involve potentially large economic costs, but would have a high benefit to cost ratio. There is therefore a strong economic argument for enhancing the strategy to provide resilience to 'extreme' drought and thus help to achieve the 25YEP outcome.

What is the outcome?
The 25 Year Environment Plan (25 YEP) (HMG, 2018) sets out the goal of boosting the long-term resilience of homes, businesses and infrastructure to climate change. This includes a goal to reduce the risk of drought and it sets a target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. It is also noted that the 25YEP has a goal of making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century, which would apply to water investment decisions.

However, there is very little specific information in the 25YEP on exactly what these targets involve (what is the metric of resilience, and what level to minimise to?) and what actions will be taken to achieve them. These could include ensuring that water companies have measures in place to offset projected deficits under more severe climate scenarios, such that the level of current resilience is maintained; or that there is a level of resilience to a drought with a particular return period. There is, however, an objective recommended by the National Infrastructure Commission (NIC, 2018b), which is for increasing the current levels of resilience (for droughts) from 1 in 100 to 1 in 500 by 2050 (where resilience means avoiding level 4 restrictions, where supplies can be limited or cut off). The Commission estimated that this would require additional capacity of 4,000Ml/day, considering a medium emissions scenario. Greater levels of adaptation might be required under a more severe climate scenario.

In England, the main organisations responsible for managing drought risks are the water companies, Environment Agency and Defra. The water companies have a requirement to produce Water Resources Management Plans (WRMP), which cover a 25 year planning period, and drought plans, that set out how to manage security of supply during drought events. It is stressed that these plans already include projections of climate change (as a minimum, using the medium emissions scenario).

How does climate change affect the outcome, in a 2 vs 4°C pathway?
This study conducted a literature review to investigate the potential impact of climate change on the 25 YEP outcome. Previous modelling work to support CCRA2 (by HRW, 2015) has already estimated the impact of climate change (medium and high emission UKCP09 scenarios) on the supply-demand balance (with no additional adaptation action).

The UK currently has a supply-demand surplus of around 2,000 Ml/d in an average dry year. However, supply-demand deficits are reported by water companies from the 2030s: with projections that 27 water resource zones will have a supply-demand deficit of greater than 5 Ml/d. The water companies are already working to resolve these issues. Looking beyond 2030s, deficits are projected to be widespread by the 2050s under a high population growth and a high climate change scenario, in the absence of any additional adaptation interventions over those currently implemented, increasing further beyond this time.

In England, changes in the supply-demand balances are projected to reach -22% and -41% by the 2050s and 2080s respectively, under high population growth and high climate change projections. The HRW study also projected that supply-demand deficits would continue to be an issue in 2050s and 2080s, even under more ambitious adaptation pathways.

In terms of extremes, current water company plans have typically focused on a 1 in 100 year event, taking account of climate change (although some companies have started applying a 1 in 200 chance of occurrence, as required by the latest water resources planning guidelines). Other recent analysis (Water UK, 2016) has looked at high climate futures, which include scenarios of drier summers, wetter winters and higher variability (which are indicated by the recent UKCP18 projections). In these cases, the current WRMPs have greater risk of reductions in deployable output.

What are the economic costs of climate change, i.e. the effect on the outcome?
The next step in the analysis has been to assess the potential economic costs of not meeting the outcome (due to climate change). These costs would include:

- The need to implement emergency measures and related costs;
- The impacts on the economy (i.e. foregone revenues of businesses which rely on water supply);
- The direct and indirect impacts on people.

In relation to the first of these, the National Infrastructure Commission Assessment (NIC 2018: 2018b) assessed that the costs of providing proactive long-term resilience are less than those for relying on emergency response. The NIC compared the short-term emergency costs of providing water during a drought, weighted by their probability of occurrence in the 2020 to 2050 period, with the whole-life costs of building long-term resilience to an equivalent event.

With respect to the impacts on the economy, previous work on the 2012 drought in England (Defra, 2013) have identified large economic costs, reported at about £165 million in revenue and £96 million in profit. These assessments have also considered the costs that would have occurred under an extended drought (2 years), and estimated that turnover losses could have amounted to under £2.9 billion, equivalent to 6% of the total turnover under business as usual; and cumulative first round profit losses amount to just under £1.46 billion (over the two year period).

What are the potential additional adaptation options to address climate impacts on the outcome?
The study has then considered the potential adaptation options to address these potential risks and achieve the outcome. Measures to reduce current risks are already included in the draft WRMPs produced by water companies. These are expected to deliver a higher level of resilience than would otherwise be the case. However, several studies have showed that an increase in the level of investment for enhanced climate resilience is needed to address the potential challenges of future climate change. Furthermore, a broader portfolio of adaptation actions might be needed, for example to include more ambitious demand-level measures to reduce per-capita consumption, and inter-regional transfers between companies. For these measures to become effective, it is necessary to understand the existing barriers to their adoption (behavioural, regulatory, informational) and address them.

What are the benefits and potential costs of adaptation?
Water UK (2016) has estimated that a 'twin track' approach of demand management coupled with appropriate development of new resources and potential transfers is the most suitable strategy for providing drought resilience in the future. They estimated that total costs per annum for all potential future scenarios to maintain resilience at existing levels in England and Wales are between £50 million and £500 million per annum in demand management and new water resource options. If resilience to 'severe drought' is adopted, this increases to between £60 million and £600 million and for resilience to extreme drought ((beyond the 1 in 100 year event) at between £80 million and £800 million per annum. Further, they estimated that the costs of maintaining resilience to 'severe' events are less than £4/customer/annum (and only increases to £5/customer/annum under drier climates, as the relative cost increases). The 'central estimate' of the benefit:cost ratio is greater than 10:1 in all cases and remains greater than 4:1, even if lower bound estimates of the benefits are assumed. There is therefore a strong economic argument for considering a strategy that provides resilience to 'extreme' drought (central estimate benefit:cost ratio of greater than 5:1); this would typically cost less than £8/customer/annum (£10 under drier climates), compared with the 'baseline' worst historic drought resilience.

The benefits of a well-adapted water sector will be higher if all the health and environmental benefits resulting from increasing resilience are included (as highlighted also by NIC 2018b). For example, the figures above do not capture the additional economic gains from addressing social and environmental issues by protecting the ecology of water bodies through adaptation.

Step 1: What is the outcome?

The 25 Year Environment Plan (25 YEP) sets out the goal of boosting the long-term resilience of homes, businesses and infrastructure. This includes a goal to reduce the risk of drought. In Chapter 4, it sets a target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. The 25 YEP also has a goal of making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century.

These combined goals/targets are considered in this case study in the context of the water sector. This focuses on the target of ensuring interruptions to water supplies are minimised during prolonged dry weather and drought, and the goal of ensuring water sector investment decisions take climate change into account.

25YEP Goal: Boosting the long-term resilience of our homes, businesses and infrastructure (interpret with a focus on water supplies). Ensuring interruptions to water supplies are minimised during prolonged dry weather and drought. Combined with 25YEP: (by 2043) making sure that all policies, programmes and investment decisions take into account the possible extent of climate change this century (water resources planning)

However, while these goals and targets are set out, there is very little specific information on exactly what they involve, and how they will be measured. Indeed, the 25 YEP does not specify how it defines resilience, the time period for achieving the target (though this can be assumed to be the end of the 25 year period, i.e. 2043) and what level of risk reduction/minimalization is considered appropriate.

It is worth noting that it is quite challenging to define resilience, and there are different views of resilience either in terms of the current availability of resources or the future reliability of water resource options against which levels of service to customers can be assessed and compared (Water UK, 2016). However, the WRMPs have stated levels of services and these are reported by the NIC (2018b). In this case, resilient is set against a 'worst historic drought', a 1% annual probability, beyond which level the water companies' plans assume that in the event of more serious and prolonged drought, normal water supplies would be cut off and limited supplies provided.

A number of actions might be required to achieve the objective. These could include ensuring that water companies have measures in place to offset projected deficits under more severe climate scenarios, and maintain the current level of resilience in the future; or that resilience to a drought with a particular return period e.g. 1 in 100, is considered.

There is, however, an objective recommended by the National Infrastructure Commission (NIC, 2018b), which is for increasing the current levels of resilience (for droughts) from 1 in 100 to 1 in 500 by 2050 (where resilience avoids level 4 restrictions, where supplies can be limited or cut off). The Commission estimated that this would require additional capacity of 4,000Ml/day, based on a medium emissions scenario. Greater levels of adaptation might be required under a more severe climate scenario.

A theory of change has therefore been developed as follows:

- Activities: The long-term vulnerability of the water sector to climate change is understood (using the latest climate projections). Dialogue between the Government and water companies is carried out to understand the existing barriers to increasing resilience.
- Outputs. A coherent water resource management plan accounting for future climate change and environmental risks is developed. This lays out roles and responsibilities of different actors in achieving the goal of enhancing reliance in the future. The Plan includes a strategy to remove the existing barriers to adaptation.

- Outcomes: The risk of incurring water deficits in the future is minimised even under more pessimistic climate scenarios.
- Impact: England is prepared to future climate change impacts affecting its water sector.

Roles and responsibilities in the outcome delivery

The Cabinet Office identifies drought as a civil emergency within the National Risk Register of Civil Emergencies (2017 edition). In England, the main organisations responsible for managing water resources during drought are (Environment Agency, 2017):

- Water companies, responsible for managing water supply for their customers and taking a range of measures to maintain supplies whilst minimising environmental impact. This includes a requirement to produce a Water Resources Management Plan (WRMP), which cover a 25 year planning period. These include investment plans over the period. When these plans project a supply-demand deficit, they set out the options to reduce these. Water companies also produce drought plans, that set out how to manage security of supply during drought events. Water companies need to specify the frequency with which such interventions would be permitted - "Levels of Service" (LoS) agreements. A first review of the WRMP19 revealed that there some companies are improving their resilience to droughts reflected through their levels of service, including many adopting a 1-in-200 year frequency or better for severe restrictions. This reflects a Defra reference level of service and England's drought resilience performance commitment. In addition to water company specific WRMPs and Drought Plans, companies in some of the more water- stressed areas of the country have established regional water resources groups to try to consider how to optimise the sharing of water resources.
- The Environment Agency provides strategic oversight and is responsible for monitoring, reporting, advising and acting to reduce the impact of a drought on the environment and water users. The Environment Agency has overall responsibility for safeguarding the environment during drought and overseeing the actions water companies take to secure public water supplies. The EA also produces Drought Plans for each of its 14 operational areas, which describe the different operational responsibilities, and actions to recognise, monitor and reduce the effects of a drought at a local level.
- Government, responsible for policies relating to water resources. Defra is responsible for the policies relating to water resources in England and ensures the legislative framework for water resource management is fit for purpose. It directs water companies on the development and content of their water resources management and drought plans. During droughts, Defra works closely with the Environment Agency and water companies to ensure that public water supplies are maintained and damage to the environment is limited (EA, 2017). Local councils also have the duty to take a lead role in local resilience forums and prepare for severe drought impacts within their emergency plans.

A number of other organisations and groups also play an important part in managing drought, including Natural England, Canal and Rivers Trust, local councils and representative bodies such as National Farmers' Union (NFU), UK Irrigation Association and environmental charities (Environment Agency 2017).

A summary of the institutional setting and planning process is provided in figure 1.

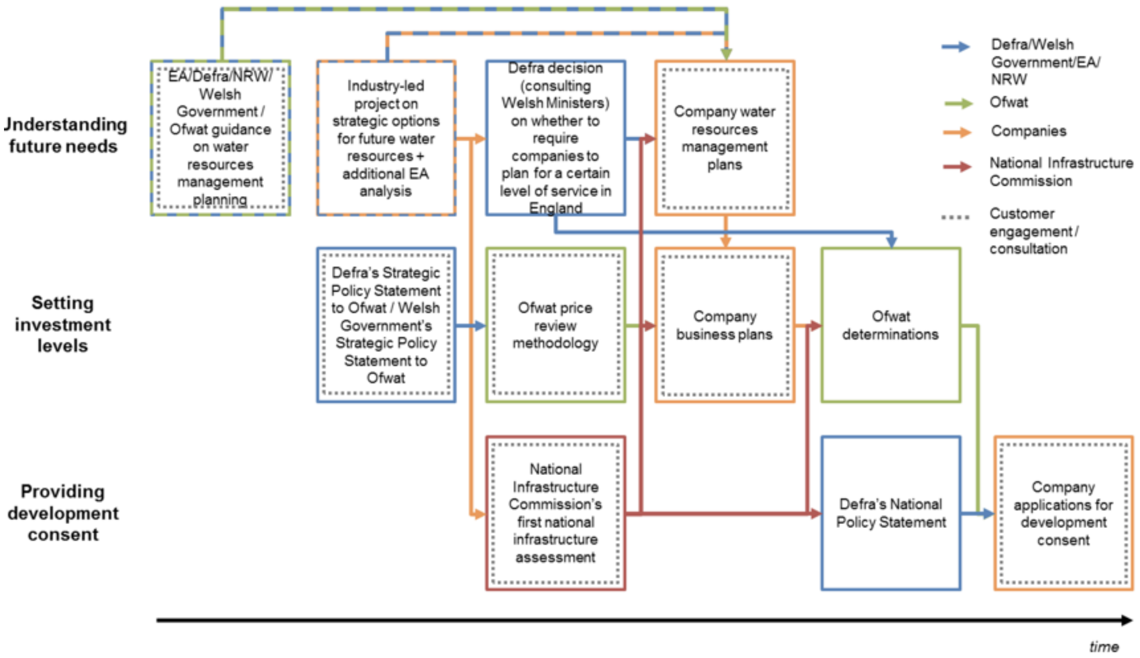
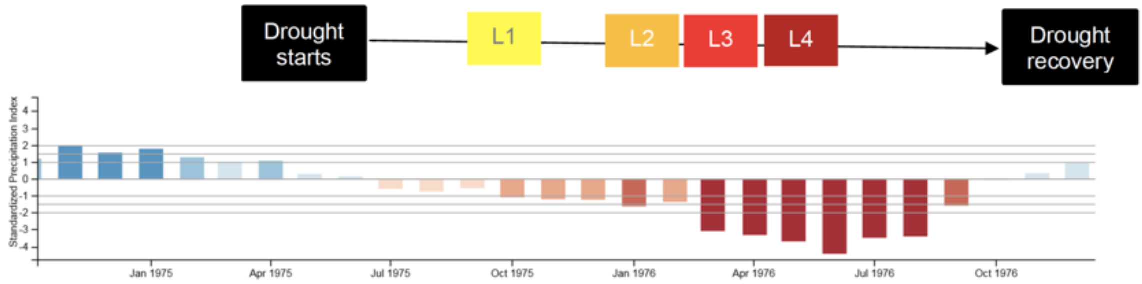


Figure 1 Summary of water resources planning processes and activities. *Source: Water UK (2016).*



Source: Standardised Precipitation Index for 6 months from Centre for Ecology and Hydrology https://eip.ceh.ac.uk/apps/droughts/

Figure 2 Drought development (6 month precipitation deficits) and levels of response

Figure 2 shows that water companies operate a system of 'drought triggers', which are designed to inform the water company of the ongoing severity of a drought and help them to plan interventions that can act to preserve resources in the event of a continuation or worsening of the drought. The timing of drought development in England is illustrated in below - rainfall deficits are used as surrogates for reservoir or groundwater storage. The drought response escalates from Level 1 with a media campaign, through to rapid succession of usage restrictions (Level 2) to Drought Orders and permits (Level 3) and then emergency measures (Level 4).

Step 2: How does climate change affect the outcome, in a 2 vs 4°C pathway?

The next step is to understand the potential impact of climate change on the outcome in a 2 and 4 degree world.

The long-term planning and measures of the WRMPs (and the Drought Plans in them) largely determine the impact that current and future drought events will have on households, businesses, and infrastructure. These plans are intended to ensure that a certain level of service (water supply) will be maintained throughout a drought event. Their effectiveness determines the current or 'baseline' level of resilience in England. Failing to plan today for future climate change would most likely result in an increase in the frequency of water supplies' restrictions and other emergency measures, which in turn would affect households' well-being and businesses' productivity in the future.

It is stressed that climate change medium emissions p50 and principal population projections are already factored into the companies' projections.

HR Wallingford (2015) undertook a study for the CCRA2 that assessed the potential impact of climate change on the supply-demand balance at the end of the 25 year water company resource planning horizon. This was based on the water resource system for the baseline period (i.e. this does not include planned interventions set-out in the latest water company resource plans). A total of 27 water resource zones (WRZs), 24 of which are in England, were found to be reporting a supply-demand deficit of greater than 5 Ml/d in their water company resource plans in the 2030s. For England and Wales this reflects the position in 2040s. The water companies that reported a deficit during the water company resource planning horizon set-out a programme of preferred measures to mitigate this deficit in their final plans.

Table 1 Summary of overall supply-demand balance for the 2030s (in Ml/d and as a % of baseline total Distribution Input) by country, with positive numbers indicating a surplus. Source HRW.

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

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

The supply-demand balance is determined by the effects of both population changes on demand for public water supplies (PWS) (Distribution input), and the impact of climate change on deployable output (DO). For the latter, the HRW study finds that the majority of climate change impacts reported in the water company resource plans are in England, with DO considered to be reduced by over 500 Ml/d across England as a whole by the end of the planning horizon without the introduction of any new measures (table below).

Table 2 Summary of climate change impacts on Deployable Output Ml/d (Ml/d and % of baseline Deployable Output) by country, as reported at the end of the water company resource planning horizons (2030s). Climate scenario(s) as per water company resource plan, planning tables, 'no additional action' adaptation. Source HRW.

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

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

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

According to a recent Water UK study prepared by Atkins et al. (Water UK, 2016), in terms of the short term 'drought response' at a national scale, there are up to 1500 Ml/d of drought plan options available to water companies, of which 400 Ml/d are straightforward to implement. The additional 1100 Ml/d of drought permit options are considered "possible" and "unlikely" and considered alongside other special emergency measures for dealing with severe and extreme droughts. The current round of draft plans in preparation for 2019 indicates that most companies in England are planning to maintain supplies for severe drought events with an annual probability of around 0.5%, which is consistent with recent industry research (UKWIR, 2016, Atkins, 2017), planning guidelines (Environment Agency, 2017) and business planning guidance from Ofwat, the economic regulator (Ofwat, 2017).

However, even though around one third of companies can maintain supplies during severe droughts by implementing their Drought Plans, others would find it difficult to maintain supplies; and a small number of zones, including London, could have significant deficits and supply problems without investment in supply and demand-side measures (Atkins, 2018)[1]. It was estimated (Water UK, 2016) that short-term water supply shortfalls of the order of 320 and 1100 Ml/d for 'severe' and 'extreme' drought scenarios across all companies in England could occur[2].

Atkins (2018 for the NIC) estimated potential regional supply shortfalls for a range of scenarios, with and without climate change. These assume that water companies invest to deal with the "worst historic drought" (with an annual probability of ca. 1%) and have planned for a central medium emissions climate change scenario. Therefore, the climate change impact shown is an incremental impact based on a more extreme "dry" climate change scenario (Atkins, 2018).

[1] Based on Water UK scenarios of severe drought and base year of 2016.

[2] Rounded figures based on the Water UK scenarios and assuming that companies invest to deal with the 'worst historic drought'; including demand restrictions and the "most likely" drought permits and orders, but excluding any new water transfers between regional water supply areas and any further investment.

Table 3 Summary of potential regional supply shortfalls based on the Water UK LTWRPF study

	Severe drought (Annual probability 0.5%)		Extreme drought (Annual probability 0.2%)	
Region	**No climate change**	**Including climate change (2065)**	**No climate change**	**Including climate change (2065)**
Southern England	29	55	132	159
Essex	40	45	113	118
Thames Basin	122	206	348	432
East of England	5	112	86	193
Yorkshire	69	171	236	339
Central	41	353	102	413
Bristol	15	28	40	53
North West	0	40	68	107
Sum	*320*	*1010*	*1125*	*1814*

Notes: Assuming investment to maintain supplies in moderate droughts and a central Medium Emissions climate change scenario. Figures based on Water UK (2017) with adjustments for the NIC study.

The graph presents the Thames region as an example to show that (Atkins, 2018):

1. This region has the highest potential shortfalls but also a wide range of drought permit options (Atkins, 2018 for NIC). The final WRMP19 will propose new supplies and demand reductions, which can maintain supplies up to certain level of risk (point A).
2. The relevant water company drought plans include emergency drought permits and orders, which could provide an additional 100 to 200 Ml/d in severe (0.5% probability or 1:200) and extreme (0.2% probability or 1:500 return period) droughts (point B).
3. However, the yields of these drought permits are highly uncertain so emergency measures may still be needed to deal with the most extreme droughts, particularly under future "dry" climate change scenarios.

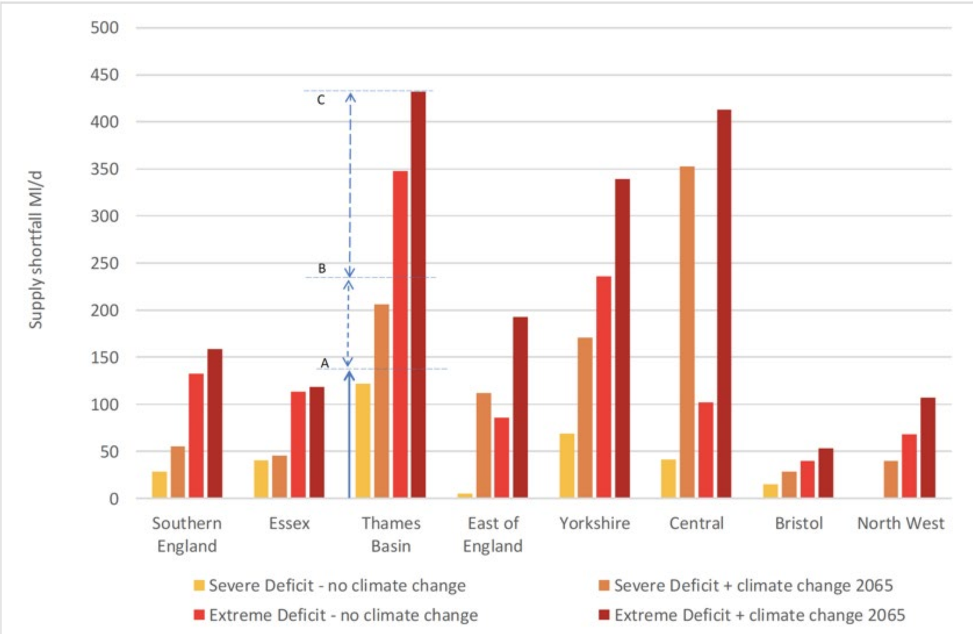


Figure 3 Summary of potential regional supply shortfalls and illustration of potential response measures (A – long term investment in new supplies and demand reduction; B – use of Drought Permits and C in extremis emergency measures)

Looking beyond the companies' planning horizons, HRW (2015) also estimated future climate change impacts under different scenarios and assuming no further adaptation action would be taken. England presents the highest supply-demand deficit, ranging from -1173 Ml/d to -5,657 Ml/d under the more optimistic and more pessimistic scenarios respectively.

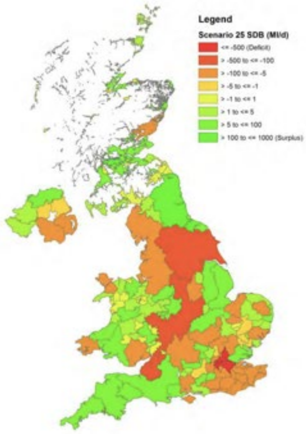


Figure 4.9: Plot of supply-demand balance for current water resource systems for 2050s under low population, medium climate change projections and a 'no additional action' adaptation scenario.

Source: n/a

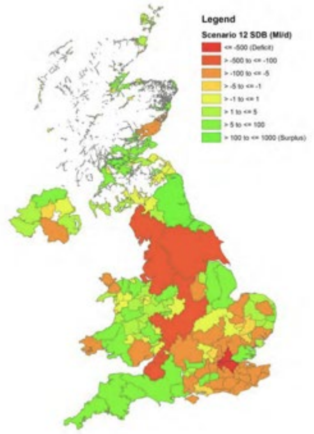


Figure 4.10: Plot of supply-demand balance for current water resource systems for 2080s under low population, medium climate change projections and a 'no additional action' adaptation scenario.

Source: n/a

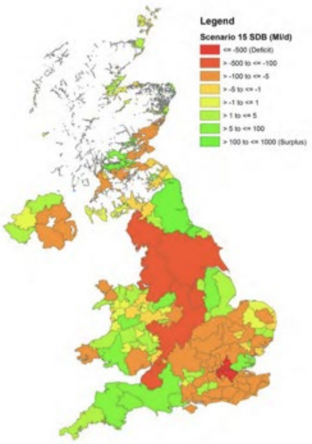


Figure 4.11: Plot of supply-demand balance for current water resource systems for 2050s under high population, high climate change projections and a 'no additional action' adaptation scenario.

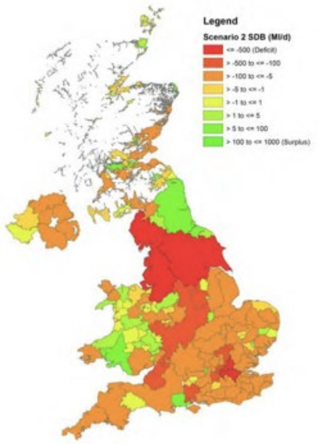


Figure 4.12: Plot of supply-demand balance for current water resource systems for 2080s under high population, high climate change projections and a 'no additional action' adaptation scenario.

HRW (2015) estimated that the impact of climate change alone on the supply-demand balance would be significant, particularly in England: the reduction in DO in England is 2,724 Ml/d under a high climate change projection for the 2080s, equivalent to a reduction of 16% from baseline Deployable Output.

Table 4 Summary of climate change reductions (shown as negative values) to Deployable Output (in Ml/d and as a % of baseline Deployable Output) by country for different climate projections for the 2050s and 2080s.

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

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

The 2016 study carried out by Atkins et al for Water UK has examined supply/demand vulnerability to more extreme drought events than have been considered under the current water resource planning framework, which has typically focused on the worst historic drought experienced and which is limited by the period of observed records (up to 100 years, and therefore broadly equivalent to droughts of return period of around 1 in 100 years). The baseline used in the study includes a range of drought measures, such as media campaigns, temporary use bans (formerly hosepipe bans), non-essential use bans and the most straightforward drought permits, classified as "likely" in the reports. The baseline excludes any planned water resources schemes that maintain supplies for more extreme droughts with an annual probability of less than 1% (return period 1 in 100 years).

Water UK (2016) considered the risks from drought severity on supply-demand balance. It used information on drought orders and permits (contained in WRMP14) and expected yield effects to assess the impact that different drought severities would have on the capabilities of water supply systems under different climate change futures. The study used three climate change scenarios: one 'median' future climate; and two 'dry' future climates[3] (one with worse summer conditions, but wetter winters, which is more significant to northern and western resources; and one with less winter rainfall, but also lower potential evapotranspiration (PET) and higher rainfall (in relative terms) over the summer, which is more significant to eastern and southern resources). It is noted that the latest UKCP18 projections indicate drier summers and wetter winters, with higher variability (Lowe et al, 2018). These assumptions were used to compare resource capability from the WRMP14 baseline (as described by DO) under three drought scenarios: worst historic (as the most severe in the historic record), severe, and extreme in five drought regions. It shows that under more severe/extreme drought scenarios, DO would be reduced significantly compared to the worst historic scenarios; and that the benefits that might be expected from permits and order are limited, leaving some residual deficits[4].

The impacts are highly variable between regions, depending primarily on resource type. Resources in the South East are typically more resilient to climate change because of a drier starting climate, with more significant existing storage already in place, and greater reliance on groundwater, which also has a higher effective level of storage. The Central/West is particularly sensitive to climate change, but with considerable uncertainty. Bar charts showing climate impacts by region – base and extended, for 2040 and 2065 are shown below. Noting the 'baseline' climate change scenario is equivalent to a

[3] For the scenario analysis, an average of the two impacts was taken and translated into a single 'dry' climate impact.
[4] See Water UK (2016), table 6.3, page 65.

'median' climate future; whilst the extended climate change future, represents a 'dry' realization of the future climate.

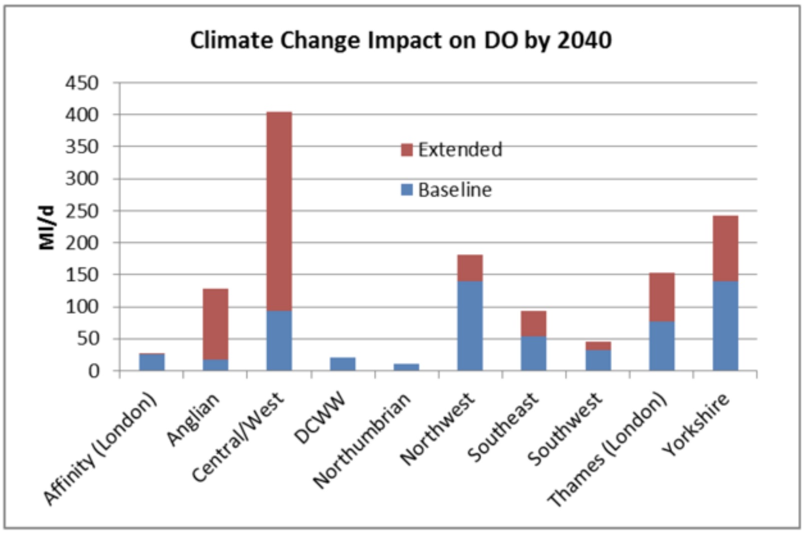


Figure 4 Baseline and extended climate change impacts on DO by 2040

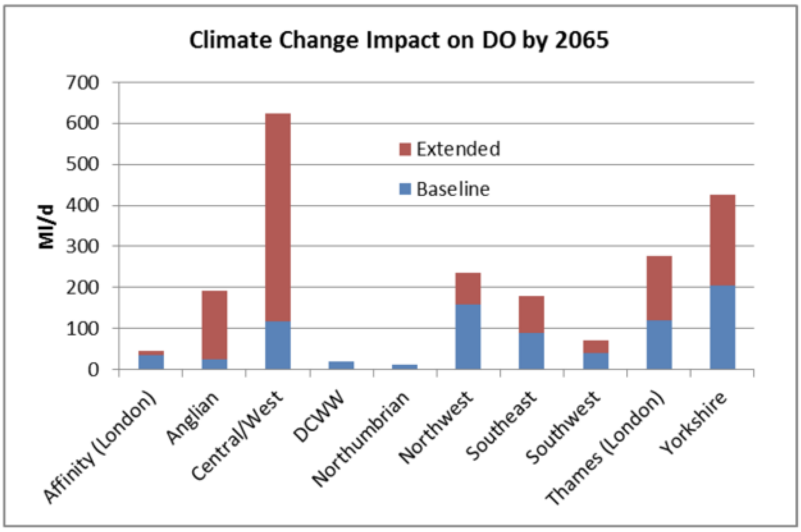


Figure 5 Baseline and extended climate change impacts on DO by 2065

The graphs show that although they are drought vulnerable in the baseline, the resources in the South and East have a strong groundwater component, which is predicted to be less vulnerable than surface water. Spatial impacts of climate change therefore tend to be dominated by the vulnerability of the associated surface water systems. The anticipated spatial variability is shown below.

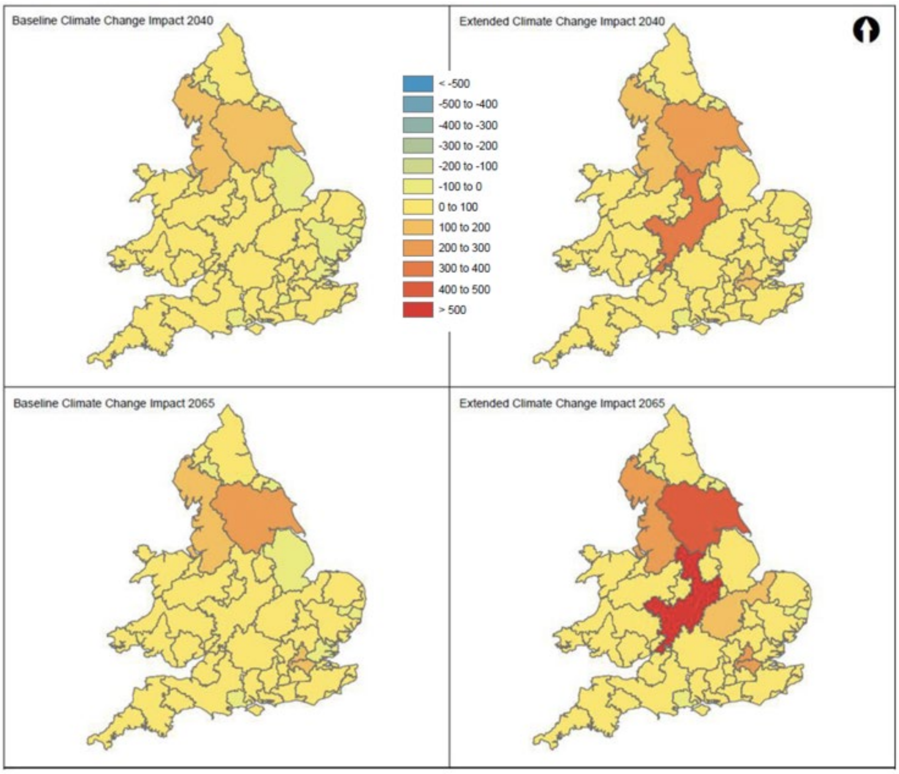


Figure 6 Baseline climate change impact on DO by supply area – 2040 (top) and 2065 (bottom) under base (left) and extended (right) scenarios

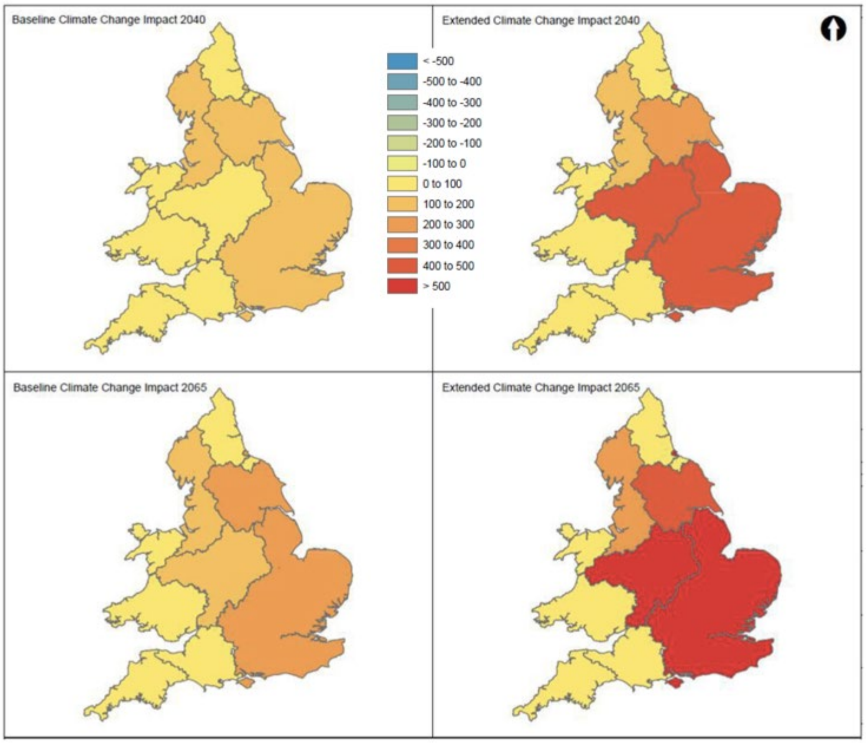


Figure 7 Baseline climate change impact on DO by Drought Region – 2040 (top) and 2065 (bottom) under base (left) and extended (right) scenarios

The figure below shows the additional supply-side resources that Water UK (2016) anticipated to be required by sub-Region in 2040, expressed as a percentage of existing demand. Each bar represents a different scenario (36 in total), all under BAU base demand management[5]. This shows that there is a wide variability in deficit risk across all regions, with the biggest percentage deficits expected across London and the South East, which require an increase in supply side resources of between 5% and 40% by 2040. The Central West and Yorkshire Regions were found to be the next most vulnerable, requiring between 2% and 35% increase, with Anglian between 1% and 20%, and the Southwest up to 5%. Welsh Water is vulnerable under upper demand growth only, with a 3% resource gap, and the Northwest only under upper demand growth alongside extreme drought – by up to 8%. Northumbrian is drought resilient under all scenarios in 2040.

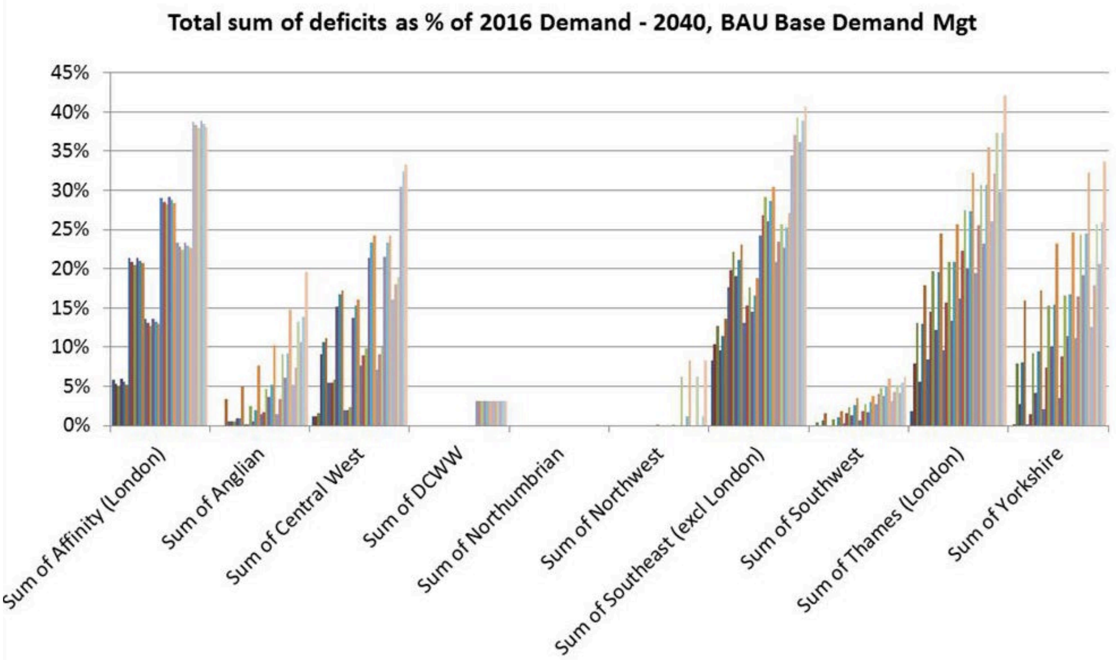


Figure 8 Sum of 2040 Supply Area deficits as % of 2016 demand, BAU Base demand management strategy (for 36 future scenarios)

Step 3. What are the economic costs of climate change, i.e. the effect on the outcome?

The next step in the analysis has been to assess the potential economic costs of not meeting the outcome (due to climate change), i.e. of not being able to reduce resilience above current levels.

This would translate to a substantial risk of incurring water deficits in the future. In practice, costs resulting from implementing emergency measures would most likely occur. Therefore inaction would result in three sets of impacts and related costs:

- The need to implement emergency measures and related costs;
- The impacts on the economy (i.e. foregone revenues of businesses which rely on water supply);
- The direct and indirect impacts on people.

[5] This reflects a strategy where ongoing, significant investment continues to ensure that the trend in per-capita consumption (PCC) planned at WRMP14 through water efficiency schemes and more sustainable new homes is continued into the future (although it should be noted that this relates to the 'underlying' trend – initial high meter penetration achieves a higher rate in the early years of the period).

Costs of emergency measures in response to drought

The emergency drought options that can be used to maintain supplies in severe to extreme droughts, when drought severity is beyond the capacity planned for through long-term water resources planning, include (Atkins 2018 for NIC):

1. "Medium" and "high" risk drought permits, which can provide supplies but with some risks related to their successful implementation or environmental impacts; these options are described in water company drought plans, were collated in Atkins (2017) and have been updated for this study (Appendix B). The reliable yield of drought permits declines in longer drought situations.
2. Rehabilitation of old groundwater sources, which have been mothballed or are out of use due to water quality issues or environmental impacts;
3. Some small additional river transfers, where infrastructure already exists or schemes that can be implemented very quickly;
4. Emergency desalinisation, where there are possibilities of "plugging in" additional capacity into the water supply network;
5. Enhanced leakage detection and repair, moving beyond what is planned and mobilising teams for greater levels of activity;
6. Radical network management measures to reduce water pressure and consequently demand and leakage.
7. Road tankers to transport water from an area with supplies to zones threatened by shortages.
8. Ship tankers to transport water from elsewhere in Europe to England in the event of extreme drought.
9. Non-potable water reuse or effluent recycling to make greater use of wastewater, including the use of indirect potable re-use where treated waste-water is pumped upstream or into raw water storage reservoirs.
10. Further abstraction from the environment following the introduction of Government emergency powers, which would allow additional water abstraction but would have very high environmental costs.

All these measures are costly, and in practice most capital costs would need to be borne upfront due to short time periods available for drought response. For example, emergency desalinization measures would need 'enabling works' to ensure that they could be implemented within the short timescales of a drought. The company would need to maintain the space for a 'treatment element' as well making sure there was sufficient capacity in the 'network element' to take this water. For sea tankers there would need to be docking facilities, offloading facilities, storage, connections to the supply network and sufficient capacity (Atkins, 2018).

The costs of some of these emergency measures have been reported by Atkins (2018), extracted from the first drafts of the WRMP19 (below). *Note: the high figures reported for transfers and drought permit costs were still being checked by the Environment Agency at the time of publication. Opex costs were calculated as the median annual cost over the planning period (Atkins, 2017).*

Table 5 Summary of feasible options extracted from first round of dWRMP19 tables (Dec 15th data) to explore specific emergency drought measures.

	Number of options	Median Capex (£ '000 per Ml/d)	Median Opex (£ '000 per Ml/d)	Median Environmental and Social Costs £ '000s
Drought Permit	54	27119	1386	1 *
Transfer options	191	3178	162	45
Leakage (all sub-types)	474	4488	461	0.8*
Groundwater Options	128	2803	104	36
Surface Water Options	201	4222	13	13
Effluent Reuse	53	5480	354	68
Desalination	76	6138	1268	229

(*) Surface water environmental costs were used instead of those presented against DPs, Leakage management environmental costs were assumed to be zero.

Most emergency measures present some limitations or caveats which affect their effectiveness. For example, regarding drought permits, which are essentially changes in surface water and groundwater abstraction licenses to allow greater abstraction at existing sites or additional sites. In the latest draft WRMPs companies report very small or no benefits of, indicating that they do not provide a reliable yield (Atkins, 2018). Other measures' limitations are summarized in the table below.

Table 6 List of emergency options, descriptions and limitations (source: elaboration from Atkins 2017)

	Description	**Caveats/Limitations**
Drought Permits	Changes in surface water and groundwater abstraction licenses to allow greater abstraction at existing sites or additional sites	Potential high environmental cost Unreliable yields Difficult to implement in time
Borehole rehabilitation	Existing boreholes that have already been drilled within a company area but have been abandoned or are no longer used. In many cases the licence is still held by the water company	Existing boreholes do not have operational pumps or treatment and many are no longer connected to the distribution mains network To investigate, drill and licence new boreholes is deemed as impossible within the lead times that are available for the drought events
Emergency Leakage control	Active Leakage Control (ALC) activities to reduce leakage (currently implemented as droughts approaches Band 2)	Likely to be practically limited to around 10% of leakage
Severe pressure management	Reducing the mains pressure across a distribution zone to lower than the reference 15m during the critical part of the drought.	Issues surrounding critical users (hospitals, schools, prisons etc), tower blocks and zones with large variations in elevation mean that it is deployable in 25% of zones without incurring excessive water quality and interruptions problems. Potential to impact on performance commitments and even incur penalties or fines. High economic cost given related health risk[6]

[6] For every 2000 customers affected by a boil water notice there is anecdotal evidence (based on interviews) that one customer would fall ill and require hospital admission (Atkins, 2017). Using willingness to accept costs (which is all that are

Emergency desalinisation	Conventional desalination schemes where only the enabling infrastructure is constructed and the remaining (largely M&E) costs are deferred until a 'band 3' drought event occurs.	ESIA is likely to be required for such enabling works, so they would *have* to be delivered in advance. Time estimated by water companies for procuring, installing and commissioning the M&E equipment is at least 6 months, even with enabling works in place Likely to be unable to address water shortages in time.
Road tankers	Tankering either raw or potable water using road tankers.	The ability to maintain very large numbers of road tankers working 24/7 during longer drought events is uncertain Logistical, health, and safety concerns
Ship tankers	Adapted bulk liquid tankers that take water from either Norway or the Netherlands and deliver to a suitable port location.	Legal requirement of comprehensive water quality testing by the water company Capacity constrained by need and infrastructure capacity near to relevant ports

The Atkins (2018) study used cost benefit analysis to build marginal abatement cost curves of emergency measures for each region in England. An example is provided below (box). The results indicate the many emergency measures would be challenging to implement, provide uncertain yields and incur significant costs (Atkins, 2018):

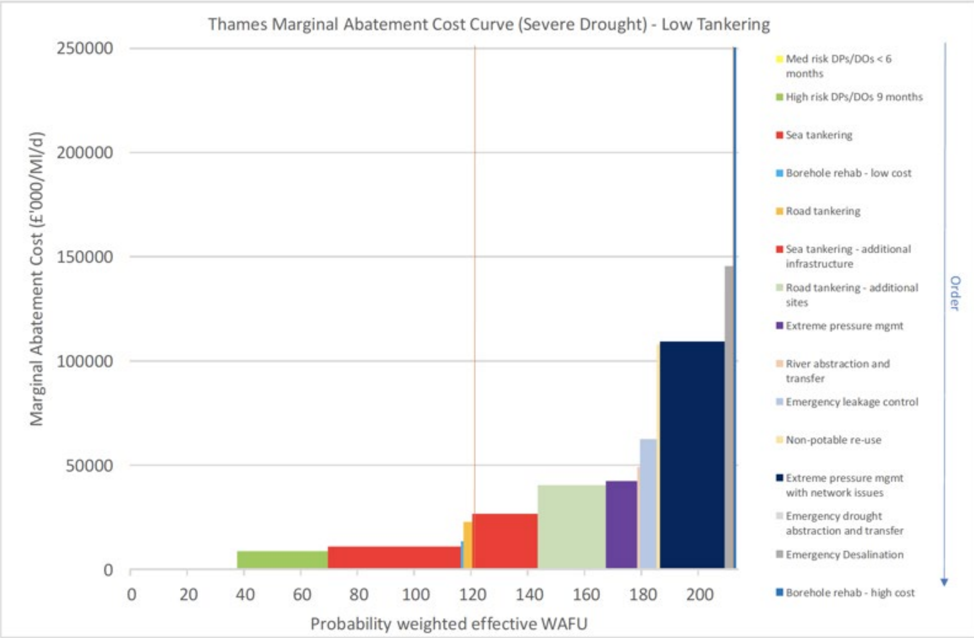
- The regional availability of drought permits is important and has significant impacts on lowering overall emergency costs; however, drought permits may be less reliable for longer duration droughts.
- Some low capacity groundwater options are feasible but do not provide significant yields.
- There is a requirement for enabling works in advance of any severe or extreme drought to allow rapid implementation of other temporary treatment and transfer options.
- There could be supply chain issues emerging during a drought due the availability of equipment and staff resources.
- Water quality constraints are significant for both drinking water quality and at river abstractions.
- Further abstraction from the environment could be required *in extremis*, but this is likely to have significant environmental impacts; the magnitude, extent and duration of damage caused by temporary increased abstraction is not well understood.

available as water quality compliance is currently so high) from PR14 for reduced water quality, this resulted in an estimated cost of over £2,000 per m^3 saved for the 'stretch' distribution zones.

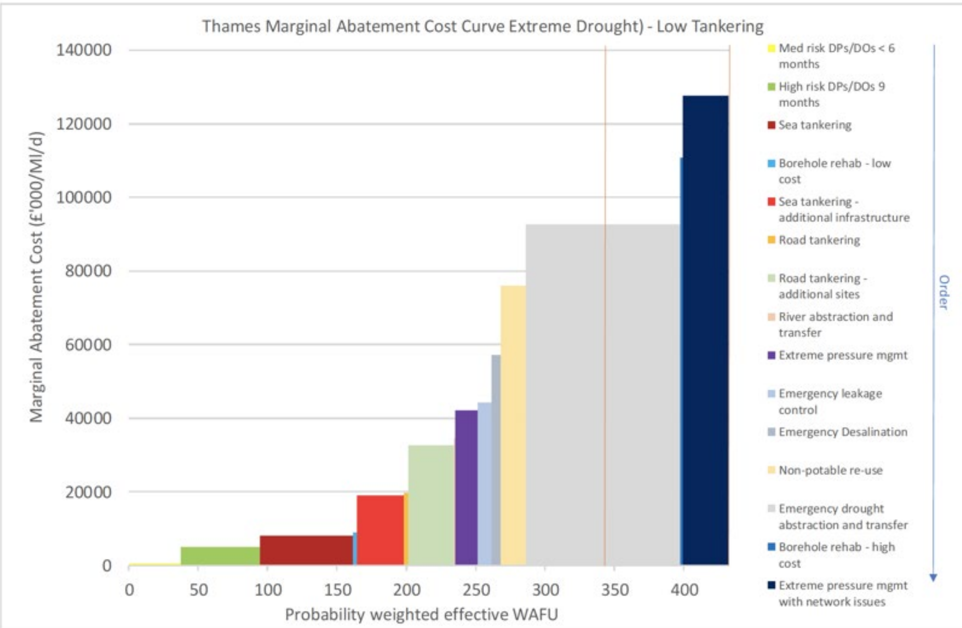
Thames Basin – cost curves of emergency response measures

Marginal Abatement Cost curves (MACs) show cumulative benefit on the x-axis and costs per Ml/d on the y-axis. The model presents both the Water Available for Use (WAFU) and 'effective capacity' data. Without significant investment in the WRMP process, the Thames including London is threatened by water shortages in 'severe' and 'extreme' droughts where supply shortfalls are up to 432 Ml/d. This region would require large amounts additional abstraction in extreme drought situations with consequent environmental impacts.

Severe Drought (WAFU results) in Thames (supply shortfalls 122 Ml/d to 206 Ml/d with "dry climate change" and no WRMP investment)



Extreme Drought in Thames (WAFU results) (supply shortfalls 348 Ml/d to 432 Ml/d with "dry climate change" and no WRMP investment)



** The vertical lines in the graphs indicate the potential water shortfalls under a drought with no climate change and with climate change respectively. They do not represent the actual deficits during a drought event but only the change in Water Available for Use.*

The analysis carried out by Atkins was used by the National Infrastructure Commission (NIC), which estimated that the total costs between 2020 and 2050 of implementing emergency measures to provide household water supply during a 0.5% drought, weighted by the occurrence probability, range between £13 and £16 billion. The total costs over the same period of implementing emergency measures against a 0.2% drought range between £21 and £27 billion (costs on a present value basis (2018 prices) weighted by the occurrence probability).

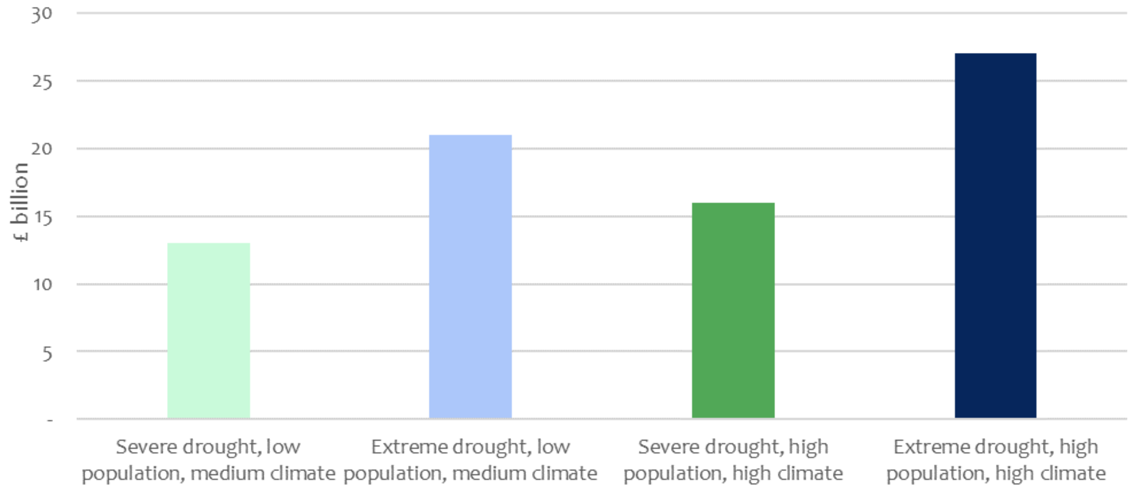


Figure 9 Costs for the period 2020-2050 of supplying emergency measures to provide household water supply during a drought

According to the NIC Assessment (2018, Technical Annex), in England, maintaining current levels of resilience until 2050 in the face of rising population, environmental and climate pressures, would require additional capacity of about 2,700-3,000 million litres per day (Ml/day). The Commission's analysis shows that the costs of providing proactive long-term resilience are less than those for relying on emergency response. To do so the NIC compared the short-term emergency costs of providing water during a drought, weighted by their probability of occurrence in the 2020 to 2050 period, with the whole-life costs of building long-term resilience to an equivalent event.

The figure below shows the comparison between these two costs, including those of maintaining the current level of drought resilience through proactive long-term measures to manage demand and provide additional supply through infrastructure. The results show that at a national level, the cost of responding to a drought emergency are consistently higher than those of building long-term resilience to the same event.

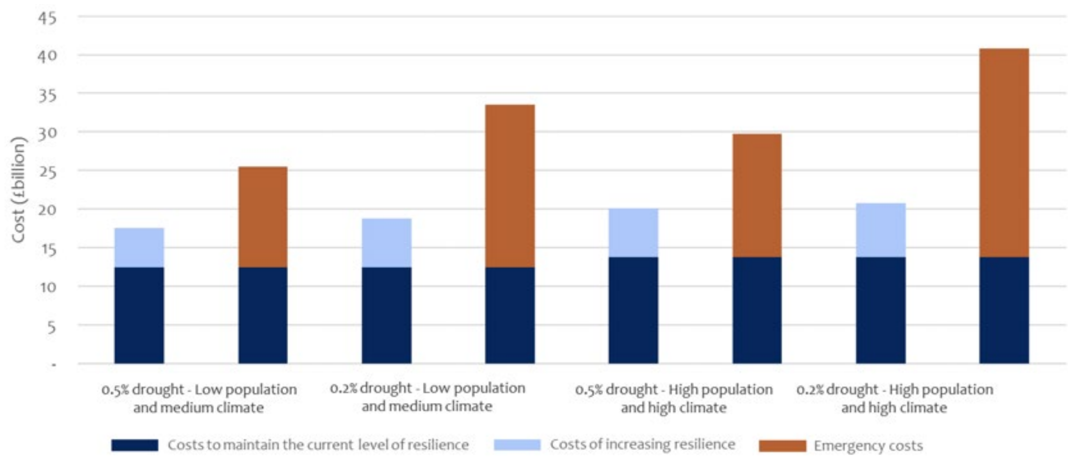


Figure 10 Comparison between emergency costs and resilience costs

However, more adaptation might be required under more severe climate scenarios as projected by UKCP18.

Impacts on the economy

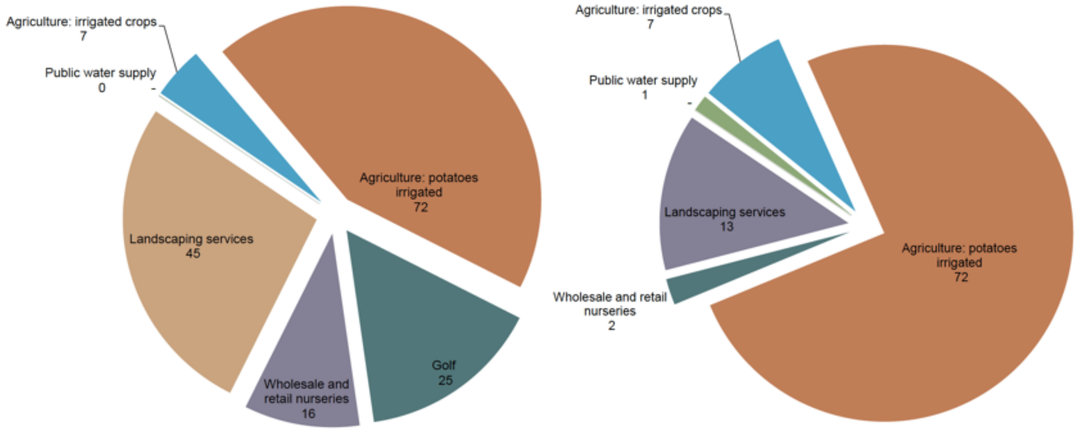
Emergency plans during droughts have consequences on businesses and households. Water is used by households and non-households for a wide range of purposes, examples of which are (Defra, 2013):

- Industrial processes (including power generation) for cooling, where a reduction in water volume would mean that the process capacity has to be de-rated or shut down;
- Cleaning, sometimes for essential hygiene or safety purposes, for control of nuisance (such as dust suppression), or for aesthetics of clean vehicles and buildings;
- Irrigation to improve the yield and quality of crops (for example scab control on potatoes);
- Drinking, by both people and animals, and for food preparation, for both people and animals, within the home and within industry and catering; and
- Navigation in canals and rivers, and for fish husbandry.

In a report prepared by Vivid Economics for Defra in 2013, the impacts of the 2012 drought in England were estimated (Defra, 2013). During that drought, water companies introduced temporary use bans to restrict demand. These restrictions applied in some areas in the second quarter of 2012. As the main target of temporary use bans, households were affected, together with businesses offering services to domestic customers, in particular landscaping services and the horticultural trade. The report shows that significant water savings were achieved thanks to the restrictive measures: cumulative 170,000 megalitres for the period starting from the first quarter of 2011 and ending with the second quarter of 2012.

However, in terms of economic impacts, about £165 million in revenue and £96 million in profit were forgone by some firms and sites in the second quarter of 2012 (Defra, 2012). Contractions in both turnover and profit were highest in the irrigated potatoes sector. The graphs below show the estimated reduction in turnover in the five sectors which experienced drought management actions applied in Q2 2012. These are "first order" impacts on those adversely affected, before considering offsetting gains in other locations and sectors[7]. On this basis, about £165 million in turnover was lost, just under half of which was in irrigated potatoes. Landscaping services lost revenue amounting to about £45 million in turnover and the golf sector £25 million. Public Water Supply (PWS) companies were the least affected, with lost revenue amounting to £0.08 million.

[7] Electricity sector impacts are not quantified in the model. In this particular sector it is likely that reduction in output by one plant which loses the right to abstract water due to HoFs or otherwise would be offset by increases in another, as the electricity supply across the country will always meet demand other than in very exceptional circumstances. However, there could be an impact on profits and prices as the costs of supply from the substitute producer may be higher than for the curtailed producer (Defra, 2013).



Note: *The left hand-side chart presents reductions in turnover, whereas the right-hand chart looks at foregone profit. In irrigated agriculture, costs were assumed to be constant, which means that the reduction in turnover translated into an equivalent reduction in profit.*
Baseline profits are not estimated for the golf sector whose profit level is set at zero in the absence of restrictions on water use (private communication from the English Golf Union). Therefore golf does not appear in the right hand side chart.

Source: *Vivid Economics*

Figure 11 First-round turnover reduction and foregone profit in the second quarter of 2012, GBP million (before considering offsetting increases)

Vivid Economics (for Defra, 2013) further estimated the impact that an extended drought scenario would have had on key sectors (which is they assumed the drought had continued into a third dry winter). By assuming that management actions taken during the 2011/12 drought would have been applied for the extended period, the study estimated that cumulative "first round‟ turnover losses would have amounted to just under £2.9 billion over the two year period, equivalent to 6% of the total turnover under business as usual; and cumulative first round profit losses amount to just under £1.46 billion over the two year period, equivalent to 7 per cent of the total profit under business as usual.

During droughts, extreme heat and dry ground can also cause damage to infrastructure. For example, some roads and parts of the rail network can be affected by ground shrinkage. Ground shrinkage over the summer regularly affects the southeast of England where there are extensive alluvial clay formations and embankments. Uneven changes in the ground affect the geometry of the track above it. The widespread drought of 2012 caused rail track geometry to deteriorate to its worst levels since 2003 (EA, 2017).

Impacts on people and the environment

Failing to ensure an appropriate level of resilience to water stresses would have direct and indirect consequences for people. As described above, during droughts, households can be targeted by temporary use bans to restrict demand (as during the 2012 drought); and/or be subjected to supply restrictions. These measures have a number of implications which can briefly described as follows:

- *Health.* Some emergency measures carry a high risk of water contamination. This is the case for boil water notices, for example. For every 2000 customers affected by a boil water notice there is anecdotal evidence (based on interviews) that one customer would fall ill and require hospital admission (Atkins 2018 for NIC). The willingness to pay elicited from the available literature to avoid Level 4 restrictions have been estimated between £40 and £160 per day of Level 4 per household (Water UK, 2016). Stress-related impacts have not been estimated but should also be considered.

- *Increase costs of basket of goods/spikes in prices.* Impact on profits of business caused by droughts, as seen above, could increase costs for certain goods and services.
- *Impacts on the environment and ecosystem services provided*. Droughts affect key ecosystem processes in terrestrial ecosystems and aquatic systems. Further, drought management actions affect ecosystems, and the water ecosystem the most. In terrestrial systems, these effects are brought about in two ways: by a lowering of the water tables and by the drying of the top soil layer in which plants are rooted and microbial processes take place. In aquatic systems (rivers and wetlands) reduced flows and water levels can result in a reduction in fish biomass, drastic decreases in bird populations, changes in the populations of invertebrates, and altered composition of plant populations (EA, 2017).

Further, costs of inaction or mal-adaptation could be significant. The Environment Agency estimates that 13% of all rivers in England are at risk of not meeting good ecological status due to over-abstraction (HRW for CCRA2). The deficit or surplus situation for individual water bodies within each catchment may be different to the catchment as a whole. However, there are some catchments where abstraction demand is already in excess of the available resource in average low flow conditions. This is particularly the case in the south and east of England, but also in a small number of catchments in the north-west of England. Given the complexity of freshwater ecology, adaptation choices are not going to be simple, and might require the right enabling environment (regulatory framework) to ensure a well-adapted water sector in England.

Step 4. What are the potential additional adaptation options to address climate impacts on the outcome?

Measures to reduce the current risks have already been described in the previous section as those included in the draft WRMPs produced by water companies. These are expected to deliver a higher level of resilience than would otherwise be the case. However, several studies have showed that an increase in the level of investment to enhance resilience is needed to address the potential challenges of future climate change.

The costs of reactive adaptation, in this case, correspond to the costs of emergency measures described in the previous section, even though a certain degree of planning would be needed for such measures to be effective.

An adaptation objective has been set by the National Infrastructure Commission (2018) in terms of maintaining the current levels of resilience until 2050 in the face of rising population, environmental and climate pressures. The Commission estimated that this would require additional capacity of 4,000Ml/day (NIC, 2018). This could be achieved, according to the NIC, through a twin-track approach: a minimum of 1,300Ml/day additional supply infrastructure, combined with demand reduction, including addressing leakage, to deliver the remaining 2,700Ml/day.

Lock-in risk

The water companies' approach to ensuring a certain level of resilience is met is already planned in advance and phased, typically using a triggers system. The main lock-in risk in this case could stem from failing to plan the further investment necessary to increase resilience above current levels. As seen above, measures to deal with extremely dry scenarios are typically expensive and investment is usually left until high drought levels are triggered. However, this might be too late for measures to be effective. One solution could be to defer some or even all the cost for several decades, adopting a phased-approach to investment. Water UK (2016) report that in South Australia, effluent re-use schemes have a much better cost/benefit ratio if the initial construction is confined to enabling infrastructure, and the more expensive, lower asset lower asset life M&E equipment is not procured or installed until it is required during the drought (Water UK, 2016).

Type I: No/Low regret measures.
These include those measures that have been proven to have benefit-to-cost ratios higher than one (or cost-benefit ratios lower than 1), i.e. they generate benefits higher than costs over their lifetime. For example, recent work by Wood Plc (2019) for CCC shows that end-of life upgrades and measures installed in new builds are more cost-efficient compared to retrofits: the former have zero installation cost and would deliver significant benefits both from a household and societal perspective.

Type ii) Early decisions with a long life-time.
These include decisions that will need to be taken today particularly around the storage infrastructure that are deemed to be necessary to maintain the current level of resilience (NIC recommendation). The timing of such investments will need to be carefully considered, along with the implications for the environment and ecosystem services.

Type iii) Early actions to address long-term risks
These include research and monitoring programmes to fill in the current knowledge gaps e.g. on trends of take up rates of water efficiency measures, drivers of behavioural change – e.g. is the water price too low? Etc.

Step 5. What are the benefits and potential costs of adaptation?

The final stage of the case study is to examine the costs and benefits of adaptation.

Water UK (2016) estimated that a 'twin track' approach of demand management coupled with appropriate development of new resources and potential transfers is the most suitable strategy for providing drought resilience in the future.

They estimated that total costs per annum for all potential future scenarios (under the BAU base demand management strategy) to maintain resilience at existing levels in England and Wales are between £50 million and £500 million per annum in demand management and new water resource options. If resilience to 'severe drought' is adopted, this increases to between £60 million and £600 million and for resilience to extreme drought (greater than the 1 in 100 considered historically), between £80 million and £800 million per annum.

In terms of costs per household, there is considerable variation between regions, if costs are allocated to households within the region where deficits occur. Nevertheless, Water UK estimated that the costs of maintaining resilience to 'severe' events are less than £4/customer/annum (which only increases to £5/customer/annum under drier climates, as the relative cost increases). The 'central estimate' of the benefit:cost ratio is greater than 10:1 in all cases and remains greater than 4:1, even if lower bound estimates of the benefits are assumed.

There is a strong economic argument for considering a strategy that provides resilience to 'extreme' drought (central estimate benefit:cost ratio of greater than 5:1); this would typically cost less than £8/customer/annum (£10 under drier climates), compared with the 'baseline' worst historic drought resilience.

However, there are some limitations in the analysis, described by the authors as follows:

- The levels of demand assumed in their analysis are deemed by the authors as potentially ambitious and rely on significant behavioural change as well as significant future innovation to reduce costs below their current levels to make the options economically feasible (Water UK, 2016). As reported in CCC (2019), further progress is needed to reduce the demand for water, given the potential risk of water scarcity in in the future. Building Regulations have included water efficiency standards in new developments since 2014. Household water consumption per person in England and Wales has declined from 155 litres per person per day (l/p/d) in 2003/04 to 141 l/p/d in 2017/18. However, the overall consumption of water per person is still high compared to what is needed to cope with future deficit projections, which is more in the region of 100 l/p/d or less.

- Inter-regional transfers have been identified as a possible, potentially cost effective, component of a resilient supply system. However, the analyses of the potential for inter-regional transfers do not take into account key constraints that could limit the feasibility of those options, which primarily relate to existing, complex abstraction, storage and regulation arrangements, quality considerations (including potable water quality and environmental risks), and the ability of the parties involved to evaluate the levels of resilience risks and hence agree appropriate operational, institutional and financial arrangements.

The table below prepared by Atkins et al. for Water UK (2016) shows that the economic case for improving resilience is very strong, even when lower bound estimates of household WTP are considered and no benefit is assumed to the level of restrictions that would be placed on non-PWS users as a result of improvements in the frequency of restrictions on public water supplies[8]. The analysis also shows that there are potentially significant benefits to non-public water supply business users if resilience in public water supplies is increased, as this will tend to reduce stress on abstraction in comparison to lower investment approaches, and hence reduce the risks that 'blanket' restrictions are placed on water bodies to preserve resources during a drought. The upper bound of this, which assumes that non- PWS users will experience restrictions as a direct result of 'failures' of the public water supplies, indicates that benefits of the public water supply increasing resilience to a 'severe' drought level could be in the order of £250m to £500m in each of the larger sub-Regions that were analysed (Water UK, 2016).

[8] The analysis of the cost/benefit ratios for increasing the levels of drought resilience was based on an PV analysis of the expected costs versus the expected benefits from adopting different polices between now and 2040. This was calculated based on the difference in the expected probability weighted consequence of adopting a 'conventional' or 'standard' planning approach (i.e. planning for median climate change, medium growth and baseline environmentally-driven abstraction changes) that incorporates different levels of drought resilience (i.e. worst historic, 'severe' or 'extreme' resilience) into the Portfolio. Because these are calculated based on the consequence associated with the risks of experiencing those futures that are 'worse' than the 'conventional' planning assumption, they have been compared against the average NPV of the associated Portfolios for those 'worse' futures (Water UK, 2016).

Table 7 Cost/benefit ratio analysis for increasing drought resilience (to 2040)

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

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

At a micro (household) level, a study by ARUP (2008) looked at a range of water saving measures, and estimated costs and pay-back times as show in the tables below. Again, this identifies a large number of measures that have quick payback times and would be low regret in nature.

Table 8 Option, costs and saving for a range of water-saving measures, per person (Cost bands: Low £1-100; Medium £101-1000; High £1001+)

Water-saving device	Cost band	Potential water saved, per person per year (l)	Metered value of water saved, per year (£)	Water saving - elemental
Low flow shower or shower head	L-M	8176	16	Reducing flow from 10.8l/min to 8l/min
Ultra low flush toilet replacement	M	7884	15	Reducing from 9l to 4.5l per flush
Cistern displacement device	Free from water companies	Up to 5256	10	Reducing flush volume by up to 3l
Variable flush retrofit kit	L	Up to 7884	15	Reducing flush volume by up to 4.5l
Low flow bathroom taps (1.7l flow)	L	5087	10	reducing flow from 6.5l to 1.7l
Repair dripping taps	L	4745	9	saving 90l/week
Garden watering	L	5000	10	water garden using water from water butts. 5.3l/butt/day
Car washing	L	15643	31	Filling bucket from water butt eliminates use of 300l mains water/wash
Low flow kitchen tap adapter	L	7727	15	from 12 to 6l/min
Water-efficient dishwasher	M	1205	2	reducing from 25l/load to 14l/load
Water-efficient washing machine	M	4592	9	reducing from 80l/load to 43l/load

Item	Change made	Potential annual water saving for family of five (litres)	Sample cost (including professional fitting)	Typical payback time for a metered home (item cost/ water cost saved)
Toilet	Replace old toilet (9l cistern) with new 4.5l toilet	41,000	£290	Four years
Shower	Replace old gravity-fed shower with new, lower flow electric shower	39,000 (assuming eight-minute showers)	£140	Two years based on cold water costs - one year if you take into account the energy saved on water heating
Bathroom taps	Replace old models with new monoblock taps	Up to 25,000	£80	18 months
Washing machine	Replace with water-efficient version	23,000	£380 (similar to standard machine)	No additional cost if you are replacing a worn-out machine
Dish-washer	Replace with water-efficient version	6,000	£380 (similar to standard machine)	No additional cost if you are replacing a worn-out machine
Kitchen taps	Fit a low-flow adapter	Up to 39,000 (depending on tap usage)	£20 (DIY)	As little as four months
Garden watering and car washing	Install and use water butts	Up to 20,000	£40 each (DIY)	One year (if water used for both garden watering and car washing)

A recent study prepared by Wood Plc (2019) for CCC has updated a 2011 study (Davis Landgon, 2011), and estimated measures with cost-benefit ratios<1 for different house types, comparing new-built vs discretionary retrofit. The study provides unit-cost estimates for different measures, and calculated cost-curves to show their relative cost-efficiency. The findings are presented in the tables below. When considering wider benefits from societal perspective (avoided carbon costs), the list of low-regret adaptation measures also includes installation of low flow shower during discretionary retrofits. Generally, end-of life upgrades and measures installed in new builds showed to be more cost-efficient compared to retrofits: the former have zero additional installation cost and deliver significant benefits.

Table 9 Unit cost of water-efficiency measures (WOOD Plc, 2019)

Adaptation Measure		Unit costs (£ per property, one-off) – discretionary retrofit					
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
WC water efficiency	Dual flush WC	264	264	463	463	463	662
Shower water efficiency	Low flow shower	293	293	293	293	293	516
Washroom tap water efficiency	Low flow tap (pair)	117	117	199	199	199	281
Kitchen tap water efficiency	Click lock kitchen tap	117	117	117	117	117	117
Washing machine water efficiency	Low water washing machine	571	571	571	571	571	571
Dishwasher water efficiency	Low water dishwasher	644	644	644	644	644	644
Garden water efficiency	Water butt	59	n/a	59	n/a	59	59
Rainwater system	Low volume, gravity RW system	1172	n/a	1172	n/a	1172	1172
Greywater system	Short retention GW system	2639	2639	2939	2939	2939	2939
		Unit costs (£ per property, one-off)– end of life					
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
WC water efficiency	Dual flush WC	0	0	0	0	0	0
Shower water efficiency	Low flow shower	0	0	0	0	0	0
Washroom tap water efficiency	Low flow tap (pair)	0	0	0	0	0	0

Kitchen tap water efficiency	Click lock kitchen tap	0	0	0	0	0	0
Washing machine water efficiency	Low water washing machine	124	124	124	124	124	124
Dishwasher water efficiency	Low water dishwasher	174	174	174	174	174	174
Garden water efficiency	Water butt	0	0	0	0	0	0
Rainwater system	Low volume, gravity RW system	0	0	0	0	0	0
Greywater system	Short retention GW system	0	0	0	0	0	0
			Unit costs (£ per property, one-off) - newbuild				
		<70m² semi- or terrcd	<70m² flat	70 - 110m² semi- or terrcd	70 - 110m² flat	70 -110m² dtchd	>110m² dtchd
Washing machine water efficiency	Low water washing machine	112	112	112	112	112	112
Dishwasher water efficiency	Low water dishwasher	157	157	157	157	157	157
Garden water efficiency	Water butt	53	n/a	53	n/a	53	53
Rainwater system	Low volume, gravity RW system	1055	n/a	1055	n/a	1055	1055
Greywater system	Short retention GW system	2375	2375	2645	2645	2645	2645
New build water efficiency package							
110 L/person/day standard	all	0	0	0	0	0	0
105 L/person/day standard	flat, semi & trcd, dtchd	281	281	281	281	338	338
90 L/person/day standard	flat, semi & trcd, dtchd	4502	2181	4502	2181	4924	4924
80 L/person/day standard	flat, semi & trcd, dtchd	5852	2405	5852	2405	6274	6274

Source: Davis Langdon (2011) in WOOD Plc (2019). Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector. London: Adaptation sub-committee, Committee on Climate Change inflated to current prices.

Table 10 Residential adaptation cost curve – _low-regret water efficiency measures (wider benefits) – Household and Societal perspective

	Household perspective, to 2030s			Household perspective, to 2060s		
Measure description & application	**15-year household benefits (£m)**	**15-year, household CBR**	**Cumulative 15-year household benefits (£m)**	**45-year household benefits (£m)**	**45-year, household CBR**	**Cumulative 45-year household benefits (£m)**
Low flow shower – end-of-life upgrade	374	0.00	374	599	0.00	599
Low flow tap (pair) – end-of-life upgrade	62	0.00	435	122	0.00	721
Dual flush WC – end-of-life upgrade	24	0.00	459	47	0.00	768
110 L/person/day standard – newbuild	22	0.00	481	35	0.00	802
Click protect kitchen tap – end-of-life upgrade	23	0.00	503	45	0.00	847
Low flow shower – discretionary retrofit	470	0.47	973	470	0.47	1,317
*Low flow tap (pair) – discretionary retrofit**	*103*	*0.97*	*1,077*	*109*	*0.97*	*1,426*

	Societal perspective, to 2030s			Societal perspective, to 2060s		
Measure description & application	**15-year societal benefits (£m)**	**15-year, societal CBR**	**Cumulative 15-year societal benefits (£m)**	**45-year societal benefits (£m)**	**45-year, societal CBR**	**Cumulative 45-year societal benefits (£m)**
Low flow shower – end-of-life upgrade	623	0.00	623	998	0.00	998
Low flow tap (pair) – end-of-life upgrade	103	0.00	725	204	0.00	1,202
Dual flush WC – end-of-life upgrade	39	0.00	765	78	0.00	1,279
110 L/person/day standard – newbuild	22	0.00	786	35	0.00	1,314
Click protect kitchen tap – end-of-life upgrade	38	0.00	824	75	0.00	1,389
*Low flow shower – discretionary retrofit**	*784*	*0.87*	*1,608*	*784*	*0.87*	*2,173*

Several barriers currently exist which prevent people and businesses from taking the appropriate adaptation actions. For example, in CCC (2019) it is reported that there are policy gaps in supporting the uptake of cost-effective measures to reduce climate- related risks in the housing sector, including water efficiency devices. Often, these measures are not considered or installed by home owners or housing developers, because of a lack of appropriate regulation and guidance and communication with householders (CCC, 2019):

- While efforts are being made to improve water efficiency, further ambition to reduce per capita consumption levels is needed to reduce the risks of water deficits in a changing climate.
- Building standards are not sufficiently ambitious; they are overly complex and compliance is poor. Compliance is weak, and there is indifference around build quality and confusion over roles and responsibilities. Improve water efficiency performance in homes.

There is a need for a more coherent water management plan able to address existing barriers as well as address human and environmental water needs under future climate change. The CCC (2019) recommends that Defra set an ambitious per capita consumption target for water to be met through water efficiency measures, increased metering, compulsory water efficiency labelling, improved behaviours and more ambitious Building Regulation standards. Water efficiency should be included in energy retrofit programmes as standard. There is a need for further research to understand how the design water efficiency level compares to the actual water efficiency of homes once built and occupied (CCC, 2019). Importantly, given the complexity of freshwater ecology, adaptation choices are not going to be simple, and will require the right enabling environment (regulatory framework) to ensure a well-adapted water sector in England.

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