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Pathways to long-term PCC reduction

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Executive summary

Context

The Government indicated in last year's 25 Year Environment Plan[i] that it wants to see household water use fall, and that they will work with the water industry to set an ambitious personal consumption target. In July 2019, Defra published a consultation and call for evidence on measures to reduce personal water use[ii].

Previous work by Water UK[iii] had demonstrated a significant and growing risk of severe drought impacts arising in England and Wales from climate change, population growth and environmental drivers. This report called for further research on more extensive measures to reduce water use, in order to increase resilience and reduce the risk of regretted investment.

These findings were also supported by the National Infrastructure Commission (NIC) in their report 'Preparing for a Drier Future'[iv], which recommended reducing the demand for water by around 1,400 million litres per day (Ml/d) by 2050. This would result in a per capita consumption (PCC) rate of 118 litres per head per day (l/h/d) by that year.

In what is thought to be the most comprehensive assessment to date of its kind, this report presents the results from a Water UK study to assess the savings, costs and benefits of 18 water demand reduction interventions. It provides an extensive and detailed response to the Defra consultation and call for evidence.

The central aim of this report is to allow the water sector (both companies and wider stakeholders) to come to a clearer shared view about the possibilities, principles and priorities for reducing household water demand. This will include informing responses to Defra's recent consultation and Water UK's own wider policy position. The intention is to ensure ambitious levels of demand reduction can be achieved over the next thirty to fifty years, thus delivering the resilience required to withstand the challenges ahead.

The results presented in this report clearly demonstrate that the most extensive, cost-effective reductions in household water use, beyond the ambition in current water company plans, are only possible with concerted action by government departments, regulators and water companies. If done right, then this could deliver up to £64 of benefit from each £1 spent.

Key findings

The core findings of the study are that:

The single most cost-effective intervention to save water is a mandatory government-led scheme to label water-using products, linked to tightening Building Regulations and water supply fittings regulations. This would reduce consumption by an additional 31 l/h/d or 2,012 Ml/d by 2065. Of all the interventions analysed, this scores most highly on two key metrics: volume of water saved and benefit-cost ratio, and second overall on marginal cost.

The strongest performing interventions are those that improve the efficiency of all households over time, through technology and behaviour change.

Within that, the role of **tightening building regulations and water supply fittings regulations** is particularly important. **Without changing these regulations, it is not possible to find a way of cost effectively reducing household consumption below 100l/h/d**. On their own (without any labelling initiative), changes to these regulations alone would reduce consumption by 14 l/h/d by 2065, equivalent to a volume of 1,052 Ml/d. They would reduce the marginal cost of a water labelling scheme by over fifty percent to approximately £7/Ml.

The analysis accounts for known uncertainties and presents how these might affect individual results. However, given the scale of societal change implied by the deeper reduction scenarios, **there are some system-wide uncertainties that could also affect predicted results**. It will be important to monitor real-world outcomes from interventions, and not over-rely on individual changes for achieving a concrete demand ambition (e.g. for the purpose wider demand/supply water resource balancing).

The **current ambition** in the latest water company plans will deliver the demand reductions that the NIC recommend, achieving a **national average**[v] PCC of 118 l/h/d by 2050. This is equivalent to a reduction in volume of 1,379 Ml/d from 2020/21. Water companies aim to achieve this level of reduction by increasing the number of metered households and carrying out several hundred thousand water audit visits, amongst other things.

This level of current ambition has been considered when developing the PCC pathway scenarios. To reiterate: going beyond this current ambition in the most cost-effective way requires other water sector stakeholders to become involved in water efficiency.

Household visits, either to deliver water audits or reduce wastage (e.g. from leaky loos) have relatively low marginal costs but save relatively small amounts of water compared to **smart metering**. Extensive smart metering, outside areas of serious water stress could reduce water use by between 368 and 482 Ml/d at a marginal cost of between £2,000/Ml and £3,200/Ml. This is in addition to the increase in metering already planned by water companies.

Smart metering could be delivered by water companies in a 'progressive' programme, followed by either an automatic or voluntary switch to a metered bill, depending on government policy. Smart metering will enable much better customer communication and so will be important in driving customer behaviour change. It also brings a number of key additional benefits associated with water wastage and leakage. A national approach is needed to implement smart metering effectively and efficiently.

A scenario which combines mandatory water labelling scheme (with minimum standards) and smart metering (with voluntary switching) offers the deepest reductions in water use. It is forecast to result in a PCC of 82 l/h/d by 2065, equivalent to a reduction in volume of 2,380 Ml/d. This scenario has a negative cost-benefit of £391 million and a marginal cost of £450/Ml.

In comparison, **without minimum standards for new buildings and products** it is only possible to achieve a PCC of 87 l/h/d by 2065, with a very significantly worse negative cost benefit of £3.34 billion at a marginal cost of £800/Ml.

Note that the analysis presented here is based on national-level estimates of costs and benefits and the actual costs of implementing some interventions (such as metering or home visits) will vary across the country, by region and water company.

Other headline findings

This report contains extensive analysis and assessment of other interventions (18 in total). Overall, none of these measures perform as effectively as a mandatory water labelling scheme (with minimum standards) or smart metering in reducing water use in a cost-effective and cost-efficient manner. With this in mind, other important findings are that:

- On the basis of their potential savings and relative cost-benefits, other interventions which should be developed, tested and evaluated further include innovative tariffs (linked to smart metering), increasing awareness of water issues through media campaigns, incentives for individual and customers to reduce water use, and addressing the problem of water wastage from toilet cisterns which leak.

- Household visits to carry out water audits or reduce water wastage (e.g. from leaking toilet cisterns) have the potential to bring forward savings in time, but cannot compete with water labelling or metering in terms of volumes of water saved. Rainwater harvesting, greywater recycling and community wastewater recycling could be useful interventions in certain situations where other options are limited but are not able to deliver the savings from labelling or metering, and water reuse/recycling is less cost efficient than labelling or metering.

- The marginal cost of some of the PCC reduction scenarios presented in this report are less than those of supply-side schemes. Water labelling with minimum standards has a marginal cost of £7 compared to £633 for the most cost-effective supply-side scheme. Whilst these two sets of marginal costs are not directly comparable, this is an area that merits further exploration, including through the ongoing National Framework process.

- Customer bill impacts have been estimated for scenarios and for individual interventions used in the scenarios. Smart metering has the largest estimated impact on customer bills resulting in an increase of £29 per household per year. This means that the scenarios which include smart metering have a customer bill impact in the range of £25-£30, depending on the mix of other interventions.

Based on these key findings, this report finds that the best strategy for maximising demand reductions involve government and water companies working together to deliver mandatory water labelling and increased smart metering, beyond the current ambition in water company plans.

The two-pronged approach of labelling and metering will reduce water consumption by targeting water-using technology and water-using behaviour respectively.

Implementing water labelling with minimum standards and extending smart metering will contribute to increased resilience in the water sector by reducing demand by an estimated 2,300 Ml/d beyond the current ambition in water company plans. This will mitigate the potential challenges of population growth and climate change, providing secure water supplies whilst protecting the environment for future generations.

Certainty

All long-term planning has uncertainties about the outcome. This report is based on sound evidence wherever possible and applies confidence grades to the savings estimates to take account of the reliability and accuracy of this evidence. Uncertainty has also been accounted for in the modelling of future water use under the scenarios analysed. This shows that more ambitious scenarios (such as Enhanced-03 which is based on labelling and smart metering) are more likely to deliver real world demand reductions.

Sensitivity analysis has been conducted on the costs and benefits of the interventions to determine the changes that would be required to alter the findings of this analysis. This shows that the estimated operational cost of the water labelling intervention with minimum standards would have to increase from an assumed £0.1 per household per year to at least £2.35 to result in a negative cost-benefit value. The sensitivity analysis also shows that 'Enhanced-03' scenario opex costs would only need to reduce by 10% to result in a cost-benefit value of zero. An opex cost reduction of 76% would be required in the Enhanced-04 scenario to achieve the same outcome.

It is important to note that study does not account for 'known unknowns', for example how a mandatory labelling scheme will actually perform in England and Wales, or how consumers or others in society will react to smart water metering. This is beyond the scope of this project.

Despite this, most of the risks associated with water demand reduction uncertainties identified in this project can be mitigated, although this gets more challenging as the levels of water use reduction increase. To mitigate risks, water companies should continue to account for uncertainty in their plans and apply adaptive planning techniques. The progress of PCC reductions should be monitored at a national level, reported on a frequent basis, and a country-wide assessment made of progress towards PCC reduction ambitions. This would enable successful interventions to be accelerated, and less successful ones to be improved or replaced. This will help ensure that the progression towards a lower PCC is maintained to achieve resilience.

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[i] HM Government (April 2018) A Green Future: Our 25 Year Plan to Improve the Environment https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

[ii] https://consult.defra.gov.uk/water/measures-to-reduce-personal-water-use/

[iii] Water UK (2016) Water Resource Long Term Planning Framework https://www.water.org.uk/wp-content/uploads/2018/11/WaterUK-WRLTPF_Final-Report_FINAL-PUBLISHED-min.pdf

[iv] See https://www.nic.org.uk/wp-content/uploads/NIC-Preparing-for-a-Drier-Future-26-April-2018.pdf

[v] It is important to note this is a national average and that different companies will have different starting points depending on their current levels of consumption and what they plan to do to reduce household water use over the coming decades.

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1 Introduction and background

1.1 Context

This is the main report from a study commissioned by Water UK to explore long-term pathways for PCC reduction in England. The findings from this report will inform Water UK policy related to long-term resilience in the water sector with particular regard to the interventions required to meet ambition on reductions in per capita consumption (PCC).

This report builds on previous Water UK research on the Long Term Water Resources Planning Framework published in 2016[1]. This earlier report identified that there is a significant and growing risk of severe drought impacts arising in England and Wales from climate change, population growth and environmental drivers.

The report states:

> ***There is a case for considering more extensive measures to reduce water use, both to give a greater level of resilience and to reduce the risk of regretted investment. The levels of demand management that have been analysed in this report are potentially ambitious and rely on significant behavioural change as well as significant future innovation to reduce costs below their current levels to make the options economically feasible.***

This study will look in more detail at how the demand-side ambition in the 'extended' and 'enhanced' scenarios in that research can be delivered, whilst exploring more stretching levels of PCC reduction. Water UK's previous long-term framework study was also used as the starting point for the National Infrastructure Commission's 'Planning for a Drier Future'[2], which recommended that around one third of the extra 4,000 Ml/d needed to ensure long-term resilience in England should come from demand management.

The evidence in this report will also contribute to PCC ambitions set out in the Government's 25 Year Plan for the Environment and will also feed into the forthcoming call for evidence and consultation on a national PCC target.

> ***We want to see water use in England fall… there is action we can take to ensure we are using our water supply most efficiently. We will work with the industry to set an ambitious personal consumption target and agree cost-effective measures to meet it.***
>
> ***Defra. 25 Year Environment Plan[1]***

Evidence from this report will help to inform the creation of a 'National Framework' for water resources – a process involving the Environment Agency, water companies and water users – to consider the strategic national balance of water supply and demand over coming decades.

[1] https://www.water.org.uk/water-resources-long-term-planning-framework

[2] https://www.nic.org.uk/wp-content/uploads/NIC-Preparing-for-a-Drier-Future-26-April-2018.pdf

Water UK will also use the evidence from this report to consider a number of its own policy positions, including, by providing comparator benchmarks, its commitment to progress an industry position on customer supply pipe leakage.

1.2 Research objectives

A particular focus for this project is to evaluate the relative costs and benefits of demand-side interventions that water companies can control compared to those that require government intervention or regulation. It incorporates recent research into the costs and benefits of mandatory labelling at point of sale of devices that use water.

The scope of work for this project was to address the following six questions:

i) Which real world (physical and behavioural) interventions make the biggest contribution to resilience by reducing demand for the least economic cost? What does a 'marginal-cost curve' look like for achieving an 'extended' and 'enhanced' level of demand reduction, or levels of reduction that go beyond that?

ii) Based on that, what is the net economic cost or benefit of a given level of demand? How does that change if we restrict interventions to those that:

   a. purely affect activities currently measured under Ofwat's definition of per capita consumption;
   b. as (a) but also with the addition of customer side leakage and;
   c. as (b) but reflecting the possible failure of interventions where customer or political acceptability is low.

iii) Given (i) and (ii), and the lead-in times required for different activities, when must we start making a given intervention in order to achieve its required level of demand reduction in time? What, therefore, does the right chronological sequence of activity look like, and how urgently must it take place? What are the dependencies and interactions between different interventions?

iv) Given (iii), comment on and evidence the most important company activities and Government policies currently in place or missing in order to put us on course for achieving a given level of ambition.

v) What are the policy or technological areas where a breakthrough (in take up, public attitudes, significant policy shift or technology) would have the largest impact on overall economic cost?

vi) How might we de-risk the achievement of long-term water demand goals by identifying how we could recalibrate at different points in time our ambition in any individual area to respond to under or over-delivery (or changing overall demand assumptions) in the overall picture? What would a sensible process look like for review and change?

This work was carried out in consultation with a Water UK steering group which included representatives from water companies in England and Wales, the Environment Agency and Defra. This report was also subject to peer review which identified a number of areas for improvement in terms of analysis and presentation, which have been implemented for the final version of this report.

The conclusions and recommendations of this report should not automatically be taken to represent the views of any individual water company or Water UK, unless otherwise noted.

These six questions informed our approach to this project and the following sections, as follows:

- Section 2 describes how the interventions were identified.
- Section 3 presents how the savings, costs and benefits of the interventions were evaluated.
- Section 4 describes the development of the scenarios used to model PCC reductions and costs and benefits these scenarios. This includes the extended and enhanced scenarios from the previous work and additional scenarios, as described. This also takes account of lead times, inter-dependencies and mutual exclusivities.
- Section 5 presents the modelling methods.
- Section 6 presents results of the economic modelling, including cost-benefit analysis and marginal cost curves.
- Section 7 discusses the results of the modelling in terms of points iv), v) and vi) above.
- Section 8 presents the conclusions from this project.

The orange boxes at the start of each section summarise the key points in that section.

2 Interventions

This section sets out the scope and definition of the interventions considered in this project.

We conducted a directed literature review and a review of recent water company plans to collate a draft list of potential interventions. We also used water company plans and feedback from the companies to understand the current level of water efficiency ambition.

The draft list of interventions was grouped according to their type and what kind of organisation would need to lead their implementation. We identified a range of intervention types (e.g. metering, water labelling, home audits). We also determined that interventions would be led by either water companies, government or 'others'.

The intervention list was finalised following review and discussion with the project steering group. A total of 18 interventions were included in the final list.

This section identifies which interventions are dependent on others being implemented, whilst some interventions are mutually exclusive.

Scope and definitions

In this project an 'intervention' is any sustainable real-world effort to reduce potable water consumption in households and therefore the demand on public water supplies. This includes interventions which use or recycle water for non-potable purposes.

This project does not examine interventions for non-households (i.e. businesses and commercial premises).

It does look briefly at customer supply pipe leakage, noting that is not classed as consumption.

2.1 Literature review

A literature review was carried out to identify potential demand reduction interventions. The review included:

- Waterwise strategy for the UK (for context)[3].
- Water UK Long Term Water Resources Planning Framework – relevant for modelling the Extended and Enhanced scenarios in this study[4].

[3] https://www.waterwise.org.uk/resource/water-efficiency-strategy-for-the-uk-2017/
[4] https://www.water.org.uk/water-resources-long-term-planning-framework

- Ofwat's study into the Long-term potential for deep reductions in household water use – this included a range of scenarios with more ambitious interventions[5].
- The water efficiency collaborative fund study to update the evidence base for water efficiency[6].
- The independent review of water labelling costs and benefits[7].

All of the demand-side options from the most recent available versions of WRMP tables 5 and 6 were provided to the project team by the Environment Agency, for use in this project. There are about 500 interventions in total. A tool was developed for viewing, grouping, sorting and analysing these options.

2.2 Defining the level of current ambition

Water companies are planning to deliver a range of demand management interventions in their revised draft or final Water Resources Management Plans, published in 2019 (WRMP19). These plans define the current ambition in the water industry for reducing per capita consumption. The plans extend to at least 2044/45 and some extend as far as 2100. For companies that do not have a forecast after 2045, we have extrapolated properties and occupancy using the 2040/41 to 2044/45 trend.

Where meter penetration reaches 95%, unmeasured occupancy and property numbers stay fixed at this level after the end of the company plan and measured properties increase by new properties only. In some cases, companies' occupancies are kept flat to avoid unrealistic values. Severn Trent Water's unmeasured household population is kept flat when it reaches 99% meter penetration.

The key consumption metrics for the current level of ambition include:

- PCC reduces from approximately 138 l/h/d in 2021 to 113 l/h/d in 2065.
- Metering penetration is at approximately 91% by 2065. It is important to note that this will not be smart metering, therefore potential additional savings remain to be achieved by converting all existing and new meters to smart meters in this time.
- Several companies plan significant levels of household audits, for example:
    - Anglian Water – 135,000 over the next ten years
    - Southern Water – 100,000 over the next five years
    - Wessex Water – 40,000 over the next five years.

2.3 Developing the interventions list

The evidence presented in section 2.1 was used to develop an initial list of 20 interventions. These are presented in Table 1. This initial list was presented to the Project Steering Group (PSG) and then developed and refined further through discussion with the PSG and the project team. A final list of 18 interventions was determined following this, as presented in Table 2. Interventions in italics in Table 1 were added from the initial list.

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5 https://www.ofwat.gov.uk/publication/long-term-potential-deep-reductions-household-water-demand-report-artesia-consulting/

6 https://www.waterwise.org.uk/resource/water-efficiency-evidence-base-statistical-analysis-2015/

7 https://www.waterwise.org.uk/wp-content/uploads/2019/02/Water-Labelling-Summary-Report-Final.pdf

Some of the interventions are dependent on others being implemented first, whilst others are mutually exclusive. The relationship between the interventions is presented in Figure 1.

Supply pipe losses are not part of consumption; this is part of leakage; however, Water UK were keen to understand the relative costs and benefits of supply pipe losses compared to interventions that reduce household consumption. A high-level review of potential savings from reducing supply-pipe losses, and its costs and benefits is presented in section 6.5.2. This section also considers the savings and benefits that smart metering brings to reducing supply pipe losses.

Table 1: Initial list of interventions

Intervention group	Ref	Intervention type	Led by
Smart metering	1	Progressive metering by region – automatic switching	Water company (with government support)
Smart metering	2	Progressive metering by region - voluntary switching	Water company
Smart metering	3	Full universal metering across England & Wales	Government
Tariffs	4	Innovative tariffs	Water company
Home visits	5	Non targeted assisted audits	Water company
Home visits	6	Targeted assisted audits	Water company
Home visits	7	Leaky loo find and fix	Water company
Market transformation	*8*	*Market Transformation Programme - water using devices*	*Government*
Market transformation	*9*	*Water labelling*	*Government*
Market transformation	*10*	*New technology development - new tools and devices*	*Other*
New homes	11	New homes standards - mandatory	Government
New homes	12	New homes standards - voluntary	Other
New homes	*13*	*Water neutrality*	*Government*
Behaviour change	*14*	*Behaviour change national initiative - purchasing choices*	*NGO*
Behaviour change	*15*	*Behaviour change national initiative - water use*	*NGO*

Intervention group	Ref	Intervention type	Led by
Behaviour change	*16*	*Behaviour change local - purchasing choices*	*Water company*
Behaviour change	*17*	*Behaviour change local - water use*	*Water company*
Recycling	18	Community rainwater harvesting (RWH)	Other
Recycling	19	Community wastewater recycling	Other
Recycling	20	Home retrofit RWH/Greywater recycling (GWR)	Other

2.3.1 Justification for smart metering interventions

Smart metering was chosen as the preferred metering intervention for this project because it provides a clear additional benefit over meter technology used by most water companies at present and is likely to become the 'default' approach to household metering over the next 20 years. Therefore, variations in meter interventions were considered by assessing ways to increase the proportion of households with a smart meter (also known as meter penetration).

Smart metering is also a definitive step-change from current metering approaches, therefore, is more amenable to analysis for the purpose of this study. We have quantified water savings and the costs and benefits of smart metering in section 3. We also provide a qualitative assessment of smart metering benefits that are harder to quantify in section 3.3.

Smart metering has no clear and agreed definition but is characterised by:

1) measurement of consumption in greater detail.
2) communication via networks and allowing data to be used by customers and utilities.
3) storage of data at predefined intervals.
4) enabling communication between the supplier and the consumer[8].

[8] Based on Foundation for Water Research (2015) Smart meters and domestic water usage. FR/R0023. May 2015.

2.4 Final list of interventions

Progressive smart metering by region – automatic switching
Progressive smart metering by region – voluntary switching
Full universal metering across England and Wales
Innovative tariffs
Non targeted assisted audits
Targeted assisted audits
Leaky loo find and fix
Change WC standards
Mandatory water labelling – associated with Building Regulations and minimum standards
Mandatory water labelling - No association with other schemes
New homes standards - mandatory
New homes standards - voluntary
Community rainwater harvesting
Community wastewater recycling
Home retrofit RWH/GWR
Increased media campaigns and school education
National co-ordinated programme
Individual and community incentives

Table 2: Final list of interventions and descriptions

Intervention group	Ref	Intervention type	Led by	Description
Smart metering	1	Progressive metering by region – automatic switching	Water company with government support	Smart water meters are installed by water companies at up to 90% of homes. Homes are encouraged to switch to a meter using bill comparisons over a 2-year period. After this period homes are automatically switched to a metered bill. Enhanced customer support is offered during this period e.g. home visits and higher levels of telephone support. There are safeguards for vulnerable and low-income customers. At present, only water stressed areas can implement compulsory switching from an unmetered bill to a metered bill, therefore this option would require government support. This option would be in addition to the metering planned by water companies in their current water resource management plans. It would include retrofitting all existing household meters to be smart meters. See section 3.2 for further details of the analysis associated with this.
Smart metering	2	Progressive metering by region - voluntary	Water company	Smart water meters are installed by water companies at up to 63% of homes. This reflects the percent of households which are likely to have lower water charges on a metered bill, compared to an unmetered bill. Homes are encouraged to switch to a meter using bill comparisons over a 2-year period. Enhanced customer support is offered during this period e.g. home visits and higher levels of telephone support. There are safeguards for vulnerable and low-income customers. Switching is voluntary; therefore, this option does not require government support. Companies are still able to meter customers when there is a change in property ownership. This option would be in addition to the metering planned by water companies in their current water resource management plans. It would include retrofitting all existing household meters to be smart meters. See section 3.2 for further details of the analysis associated with this.
Smart metering	3	Full universal metering across England & Wales	Government led, implemented by water companies.	Smart meters are installed at all homes in England and Wales. Effectively, this is a compulsory metering intervention, so would require a change in policy and regulation. The aim would be to include flats and other difficult to meter properties in this intervention. This will require

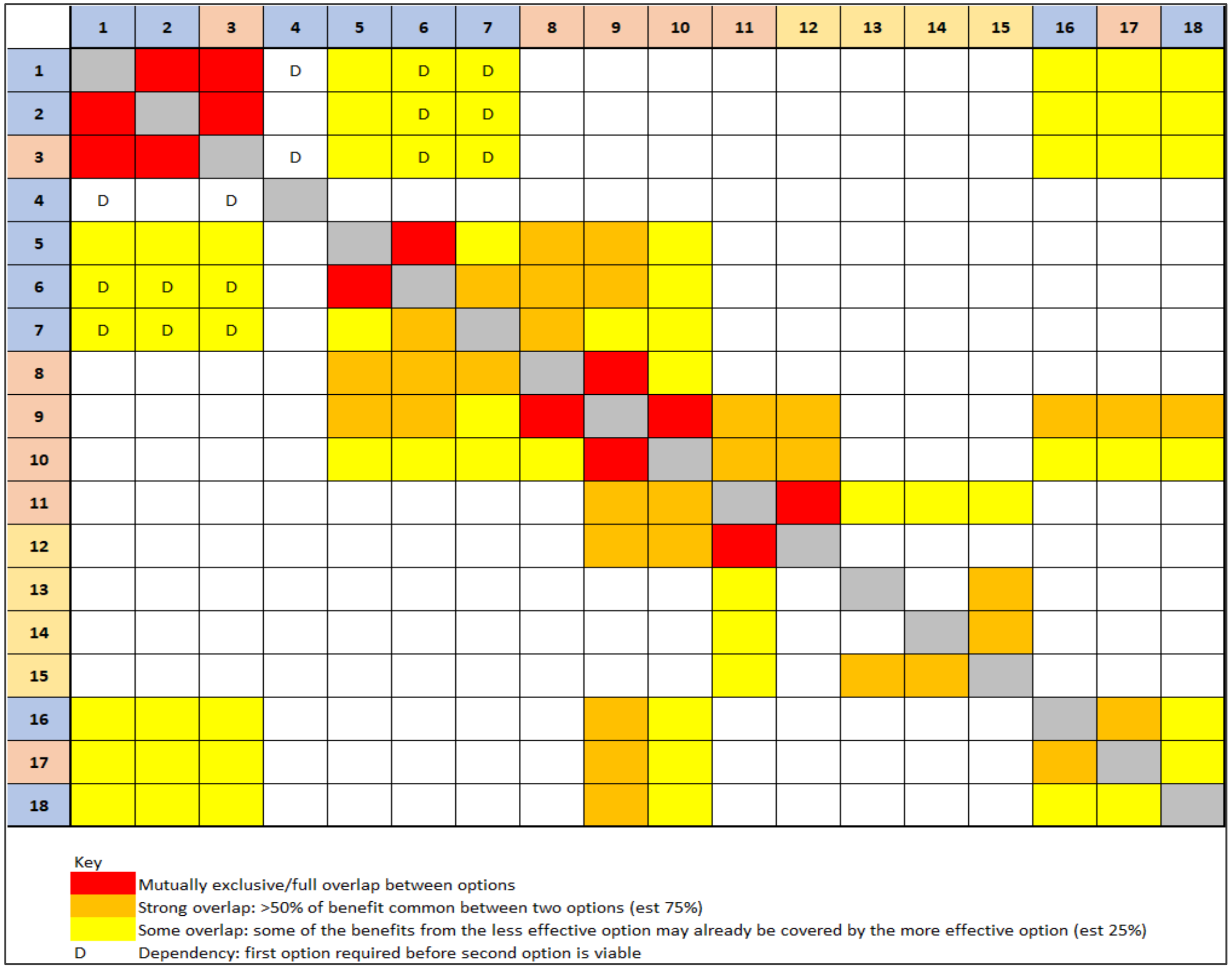
Intervention group	Ref	Intervention type	Led by	Description
				technology innovation or extensive (and expensive) pipework separation to meter 'difficult properties' (such as flats) cost effectively. This option would be in addition to the metering planned by water companies in their current water resource management plans. It would include retrofitting all existing household meters to be smart meters. See section 3.2 for further details of the analysis associated with this.
Tariffs	4	Innovative tariffs	Water company (with support from regulators)	This intervention assumes smart metering as a pre-requisite. New tariffs are developed and introduced to encourage water saving behaviours through price incentives. Tariffs can be targeted to deliver reductions in consumption based on individual household consumption patterns. The definition of 'innovative tariffs' has been left deliberately loose because there is a lack of research and evidence on smart meter tariffs and their effectiveness. The framework for tariffs for water services are determined by Ofwat. This intervention would therefore also require input from this regulator.
Home visits	5	Non targeted assisted audits	Water company	Water companies have extensive plans to carry out water audits in households in their current water resources management plans. This intervention would build on these plans by delivering audits in more homes. Homes are selected for a water efficiency audit based on factors such as location and are not targeted to the properties that are likely to save the most water. Water saving showerheads, WC flush retrofits and water efficient taps are provided as appropriate. The audit will also include behavioural advice. This intervention takes account of home audits planned by water companies as part of their current ambition.
Home visits	6	Targeted assisted audits	Water company	As per intervention 5 but in this case, homes are selected for a water efficiency audit based on high potential for water saving (approaches to identify such houses are currently being trialled at

Intervention group	Ref	Intervention type	Led by	Description
				several companies using a range of methods including meter data and freely available socio-demographic information).
Home visits	7	Leaky loo find and fix	Water company	An intervention to find and fix leaky loos using data from metered customers, and through awareness campaigns and initiatives for unmetered customers. Customers would be able to identify leaky loos using simple measures such as leak strips or drops of food dye in the cistern. Water companies would then arrange for repair or replacement of the faulty cistern mechanism at no cost to the customer. The effectiveness of this intervention will be proportional to smart meter penetration, as smart meter data will indicate which households have high levels of continuous flow.
Home visits	8	Change WC standards	Government	This intervention is a specific change to water supply fitting regulations for WCs that would prevent future installation of potentially leaky loos. This could include a return to only using siphonic flush cistern mechanisms. There is a link between this and intervention 9, which associates water labelling with tightening building regulations and water supply fitting regulations.
Market transformation	9	Mandatory water labelling – associated with Building Regulations and minimum standards	Government	In this intervention water labelling of relevant products is legislated as mandatory and managed by government. The scheme would be operated in association with Building Regulations and minimum standards (i.e. based on changes to The Water Supply (Water Fittings) Regulations 1999). This would mean that only products performing at a baseline level will be allowed on the market and referenced in the Building Regulations. This would require not only the development of the labelling policy but also the development and agreement on the baseline standard and the amendment of the relevant Building Regulations. It is assumed that there would be 3 minimum standard intervention years over an 11-year period with the first minimum standard coming into force in year 5, then year 8 and finally year 11.

Intervention group	Ref	Intervention type	Led by	Description
Market transformation	10	Mandatory water labelling - No association with other schemes	Government	In this intervention water labelling of relevant products is legislated as mandatory (for manufacturers and retailers similar to the current energy label regulations) and managed by government. The scheme would be operated in isolation with no specified intensive marketing campaign(s) and is not referenced in any other government legislation or scheme.
New homes	11	New homes standards - mandatory	Government	A requirement for developers to install devices to meet specific standards. These would be linked to minimum standards in intervention 9, therefore there is some overlap between these two interventions.
New homes	12	New homes standards - voluntary	Other	A voluntary scheme for developers to install devices to meet specific standards. These would be linked to minimum standards in intervention 9, therefore there is some overlap between these two interventions.
Recycling	13	Community Rainwater Harvesting (RWH)	Other	Similar to the exemplar North West Cambridge scheme, this would be an intervention for new developments where water collected through roof runoff and a sustainable drainage system is collected in a lake on the development. This water then undergoes basic treatment before being supplied through a separate supply system for toilet flushing, outside use and potentially clothes washing.
Recycling	14	Community wastewater recycling	Other	This intervention is based on the Albion Water approach of providing 'green water' supplies (non-potable water) to new developments sites which is used for toilet flushing, garden watering and vehicle washing. The water comes from rainwater runoff and treated wastewater.
Recycling	15	Home retrofit RWH/Greywater Harvesting (GWR)	Other	This intervention would require a widespread programme to encourage the retrofitting of rainwater or greywater systems to existing housing stock. Rainwater systems are likely to be more successful at present due to the maturity of the technology and lower maintenance requirements. Retrofit options for greywater recycling products are less popular, more complex and require more maintenance.

Intervention group	Ref	Intervention type	Led by	Description
				There are many products available, however take up is extremely limited at present because there is no incentive to do so. There is also a relatively large degree of uncertainty associated with the savings and costs for these interventions.
Awareness	16	Increased media campaigns and school education	Water company	This intervention would build on the baseline activity that companies already undertake, but would be higher profile, more consistent and co-ordinated at a regional and national level.
Awareness	17	National co-ordinated programme	Government	A government-led intervention to deliver suitable messages to target different customer groups via mainstream media (TV, radio) as well as social media using behavioural economics and social science principles.
Awareness	18	Individual and community incentives	Water company	This would be a water company-led intervention. Companies would deliver behaviour change campaigns where homes are encouraged to change their water use behaviours and practices. The incentives could be either individual or community based. Individual schemes could be similar to a loyalty scheme where customers receive a reward if they achieve a certain percentage reduction in consumption. Community schemes could provide towns, villages or neighbourhoods with a reward e.g. match funding towards a new community resource – based on consumption across that area.

Figure 1: Intervention dependencies and mutual exclusivities



2.5 Proposed interventions versus current ambition

The PSG was aware of the potential that some of the interventions set out in this section were already being delivered, at least to some extent, by water companies as part of their current ambition, as described in their latest water resources plans.

A survey of water companies was therefore carried out to determine if this was true. Emails were sent to the PSG and to appropriate colleagues in other water companies, each containing a company-specific spreadsheet of the draft scenarios with details of the number of households targeted in each company's region, for each intervention, but particularly focused on metering and household audits.

Table 3 presents a summary of the responses received. Based on these responses the scenarios have been adapted to reflect water company current ambition with regard to metering and home audits

Table 3: Water company responses on potential double counting versus current ambition

Company	Response
Affinity Water	We do see potential double counting when including our "concerted action on water efficiency" option. This option includes revisiting properties for audits similar to "targeted assisted audits" and believe significant amount of double counting potentially here. Elements of water labelling and increased media campaigns are also covered by this initiative.
Anglian Water	Potential double counting with Bits and Bobs campaign
Portsmouth Water	It is quite likely that the 'Targeted assisted audits' are the same as our water efficiency schemes C046a and C046b. These schemes include audits and the rollout and expected results are quite ambitious – so I don't believe there is much room for extra benefit over the final plan.
SES Water	Potential double counting with large scale home water efficiency visits.
South Staffs Water (including Cambridge Water)	No obvious overlap
South East Water	These [interventions] will already be included within our WRMP19 final plan forecast figures, so to include these would be double counting.
Severn Trent Water	Metering in the scenarios is delivered a lot earlier than current progressive metering programme. AMP 7 progressive metering but not forcing customers to switch. Revisit this in AMP8.

Company	Response
	Implication is that scenario [with audits] would increase households audited to 33%. Not sure this is possible due to low uptake. Is 33% achievable? Would need big change in perception etc. It is a big risk
Southern Water	The figure for water saving home visits is massively ambitious both in terms of actual numbers and in ability to reach the right houses in the next five years
South West Water (including Bournemouth Water)	Progressive metering – During AMP7 we're looking to install meters at almost all of the unmeasured properties we can, and dual bill to allow customers to see if a measured bill would be cheaper. So additional benefits from this would be hard to justify Community incentives – extensive in plan for AMP7, with a similar PCC saving. New schemes haven't been included from AMP8 onwards. Some social housing audit activity in included throughout the planning horizon, giving an overall saving of around 1 l/h/d (new activity largely balances decay).
United Utilities	No issues
Wessex Water	Risk of double counting measures in the scenarios that are already accounted for in our final plan relate to the home audits and the incentives programmes
Yorkshire Water	The only area of potential overlap is metering as we continue with our DMO programme. We are currently carrying out water audits as 'business as usual' and there is no additional activity in our preferred solution in the WRMP so no double counting there.

3 Estimating savings, costs and benefits

This section sets out the evidence and analysis of the savings, costs and benefits of the interventions, as follows:

Savings – the most likely, upper and lower water savings that will result from each intervention, taking account of the intervention characteristics and interactions with water companies' current ambition, as described in section 2. All sources of evidence are presented, and key assumptions are discussed. Estimated water savings are assigned a confidence grade based on the reliability and accuracy of evidence.

Costs – these include new or additional capital and operational expenditure (capex and opex), as well as any known environmental and social costs associated with interventions.

Benefits – these include the positive social and environmental impacts of reducing the amount of water taken from the environment, as well as any deferred capital investment in water resource schemes.

This section also includes a qualitative assessment of some of the key benefits that it has not been possible to quantify, relating to smart metering and peak demand.

This section also describes how the costs and benefits of interventions have been brought together to feed into the scenario modelling outlined in subsequent sections.

It is vital there is a reliable evidence base for the interventions investigated in this study – these will provide a strong foundation to the results. Section 3.1 outlines the evidence related to water savings associated with the interventions considered, whilst the remainder of Section 3 outlines the evidence related to costs and benefits. In compiling the evidence base for the interventions, we have considered a range of factors including:

- The reliability of data sources for interventions;
- The accuracy of savings due to estimated uncertainty ranges for interventions;
- Modelling uncertainty for savings for interventions and scenarios; and
- Sensitivity analysis for costs and benefits.

3.1 Quantifying water savings

Water savings are based either on:

- A predicted trend in water savings from a start year (e.g. the effect of water labelling on consumption over time).
- A predicted saving per property (e.g. home visits) and a number (or proportion of) properties with successful visits.
- A change in billing status from unmetered to metered bill with assumptions about savings per meter and maximum meter penetration.

We have produced a lower, and upper saving estimate, either as a percent of PCC or in litres per person per day. We have also produced an estimate of lower and higher coverage rate (i.e. what percent of households will end up with the intervention). This coverage rate is applied to all interventions except for water labelling, where all properties are assumed to be included over time, as per the EST report. A mid savings rate and mid coverage is taken as the midpoint between the upper and lower values.

Based on this we have assigned a confidence grade to each intervention, using the definitions presented in Table 4. The confidence grades for each intervention are presented in section 6.

Table 4: Confidence grade definitions

Reliability score	
A	Strong recent and local evidence, widespread application
B	Good evidence, published trials
C	Some evidence from smaller trials or overseas
D	No substantial evidence
Accuracy score	
1	within ± 15%
2	within ± 30%
3	within ± 80%
X	Outside 80%, unknown or unquantified

Table 5 presents the savings estimates and coverage estimates for each intervention with data sources and calculations where appropriate. The coverage ranges presented in Table 5 reflect what is feasible based on consultation with water companies, and in particular taking account of the current ambition of water companies, presented in section 2.5. The savings for the water labelling interventions are taken from the EST report and presented in Table 6.

Table 5: Saving estimates for interventions

Ref	Intervention type	Delivered by	Lower estimate saving	Mid estimate saving	Upper estimate saving	Savings units	Lower take up	Mid take up	Higher take up	Data sources
1	Progressive metering by region - auto-switched	Water company	12%	17%	22%	% of PCC	70%	90%	95%	Ornaghi & Tonin (2017)[9]; Orr et al (2018)[10], UKWIR (2019)[11]
2	Progressive metering by region - voluntary	Water company	4%	6%	7%	% of PCC	70%	90%	95%	
3	Full universal metering across England & Wales	Government	12%	17%	22%	% of PCC	80%	90%	100%	
4	Innovative tariffs	Water company	2	4	6	l/h/d	100%	100%	100%	Wessex Water (2012)[12]
5	Non targeted assisted audits	Water company	9	13	17	l/h/d	5%	13%	20%	Orr et al (2018)[10], WEFF Collaborative fund (2015)[13]
6	Targeted assisted audits	Water company	13	17.5	22	l/h/d	5%	13%	20%	
7	Leaky loo find and fix	Water company	3	4.5	6	l/h/d	10%	30%	50%	Based on 212 + or - 25% l/prop/day leaky loo at 5% of properties and occupancy of 2.4. High level of

[9] Ornaghi C. & Tonin, M. (2017) The Effect of Metering on Water Consumption - Policy Note https://www.waterwise.org.uk/wp-content/uploads/2018/08/The-Effect-of-Metering-on-Water-Consumption_June2017.pdf

[10] Orr, P., Papadopoulou, L. and Twigger-Ross, C. (2018) Water Efficiency and Behaviour Change Rapid Evidence Assessment (REA) FINAL REPORT

[11] UKWIR (2019) USING SMART METERS TO DELIVER SAVINGS FOR CONSUMERS reference CU02D206

[12] Wessex Water (2012) Towards sustainable water charging. Interim findings from Wessex Water's trial of alternative charging structures and smart metering

[13] Dŵr Cymru Cyfyngedig on behalf of the water efficiency collaborative fund (2015) Water efficiency evidence base statistical analysis. Final report. https://www.waterwise.org.uk/wp-content/uploads/2018/08/Collab-Fund-WEFF-stats-analysis-FINAL.pdf

Ref	Intervention type	Delivered by	Lower estimate saving	Mid estimate saving	Upper estimate saving	Savings units	Lower take up	Mid take up	Higher take up	Data sources
										coverage based on a 'find and fix' of targeting households.
8	Change WC standards	Government	3	4.5	6	l/h/d	20%	55%	90%	Based on 212 + or - 25% l/prop/day leaky loo at 5% of properties and occupancy of 2.4. High level of coverage based on a 'find and fix' of targeting households.
9	Water labelling - with minimum standards	Government		See Table 6		l/h/d		100%		EST (2018)[14]
10	Water labelling - No minimum standards	Government		See Table 6		l/h/d		100%		
11	New homes standards - mandatory	Government	15	20	25	l/h/d	100%	100%	100%	Based on 125 l/person/d - 110 l/person/d or - 100l/person/day
12	New homes standards - voluntary	Other	15	20	25	l/h/d	20%	35%	50%	Based on 125 l/person/d - 110 l/person/d or - 100l/person/day
13	Community Rainwater Harvesting (RWH)	Other	24	30	36	l/h/d	10%	30%	50%	Upper figure based on 87.5 l/prop/d figure from Ofwat divided by occupancy of 2.4. Lower figure is 2/3 of this, reflecting potential reduction due to lack of storage. Upper level of coverage is based on mandatory support and 50% of new houses in community developments.

[14] EST (2018) Independent review of the costs and benefits of water labelling options in the UK. Technical Report

Ref	Intervention type	Delivered by	Lower estimate saving	Mid estimate saving	Upper estimate saving	Savings units	Lower take up	Mid take up	Higher take up	Data sources
14	Community wastewater recycling	Other	30	35	40	l/h/d	10%	30%	50%	40 l/person/day estimate provided by Albion Water (pers. Comm.)
15	Home retrofit RWH/GWR	Other	8	23.5	39	l/h/d	5%	8%	10%	Savings based on Melville-Shreeve et al (2016)[15]
16	Increased media campaigns and school education	Water company	1.38	4.14	6.90	l/h/d	25%	38%	50%	Saving estimate of between 1% and 5% assumed, given lack of evidence[16].
17	National co-ordinated programme	Government	1.38	4.14	6.90	l/h/d	25%	38%	50%	This would be a concerted national behaviour change programme. There is limited evidence on the effectiveness of behaviour change alone. Most useful reference is Ross (2015) which estimates a 7 l/h/d or approximately 5% saving per household from analysis of Essex and Suffolk Water (ESW) H2eco programmes[17]. Another ESW behaviour change project – Challenge Twenty:12 was shown not to deliver any savings[13]

[15] Melville-Shreeve, P., Ward, S. & Butler, D. (2016) Rainwater Harvesting Typologies for UK Houses: A Multi Criteria Analysis of System Configurations https://www.mdpi.com/2073-4441/8/4/129/htm
[16] For example, Waterwise (2012) 'Investigating the impact of water efficiency educational programmes in schools: a scoping study' found limited quantitative results on the effectiveness of education programmes.
https://www.waterwise.org.uk/wp-content/uploads/2018/02/Investigating-the-impact-of-water-efficiency-educational-programmes-in-schools_final.pdf
[17] https://www.waterwise.org.uk/wp-content/uploads/2018/11/H2eco-Research-Phase-10-Final-Report.pdf

Ref	Intervention type	Delivered by	Lower estimate saving	Mid estimate saving	Upper estimate saving	Savings units	Lower take up	Mid take up	Higher take up	Data sources
18	Individual and community incentives	Water company	1.38	4.14	6.90	l/h/d	25%	38%	50%	South West Water GreenRedeem Pilot in Exeter. 3,200 households with 1.5 to 4.7% reduction in consumption at DMA level.[18]

[18] https://www.southwestwater.co.uk/siteassets/document-repository/business-plan-2020-2025/engaging-customers.pdf, see page 14

Table 6: Water saving for labelling option (l/h/d)

Year	Water labelling - with minimum standards			Water labelling - No minimum standards		
	Lower estimate saving	Mid estimate saving	Upper estimate saving	Lower estimate saving	Mid estimate saving	Upper estimate saving
1	0	0	0	0	0	0
2	0.708	0.833	0.958	0.338	0.398	0.458
3	1.417	1.667	1.917	0.676	0.796	0.915
4	2.125	2.500	2.875	1.015	1.194	1.373
5	2.833	3.333	3.833	1.353	1.591	1.830
6	3.542	4.167	4.792	1.691	1.989	2.288
7	4.250	5.000	5.750	2.029	2.387	2.745
8	5.738	6.750	7.763	2.739	3.223	3.706
9	7.225	8.500	9.775	3.449	4.058	4.667
10	8.713	10.250	11.788	4.159	4.893	5.628
11	10.200	12.000	13.800	4.870	5.729	6.588
12	11.688	13.750	15.813	5.580	6.564	7.549
13	13.175	15.500	17.825	6.290	7.400	8.510
14	14.663	17.250	19.838	7.000	8.235	9.471
15	16.150	19.000	21.850	7.710	9.071	10.432
16	17.638	20.750	23.863	8.420	9.906	11.392
17	19.125	22.500	25.875	9.131	10.742	12.353
18	19.628	23.091	26.555	9.370	11.024	12.678
19	20.130	23.683	27.235	9.610	11.306	13.002
20	20.633	24.274	27.915	9.850	11.589	13.327
21	21.135	24.865	28.595	10.090	11.871	13.652
22	21.638	25.456	29.275	10.330	12.153	13.976
23	22.140	26.048	29.955	10.570	12.435	14.301
24	22.643	26.639	30.635	10.810	12.718	14.625
25	23.146	27.230	31.315	11.050	13.000	14.950
30	23.146	27.230	31.315	11.050	13.000	14.950
45	23.146	27.230	31.315	11.050	13.000	14.950

3.2 Key assumptions

3.2.1 Start dates for water company driven interventions

Water company investment plans for AMP7 are unlikely to change, therefore water company led interventions, such as metering, audits and behaviour change, will start from 2025.

3.2.2 Water labelling

We have fully reviewed the assumptions behind the savings (and costs) in the recent water labelling report by the Energy Saving Trust (EST)[7], and believe that they are all broadly appropriate. The EST report has been subject to peer review and scrutiny from the PSG so is considered sufficiently robust for use in this project.

3.2.3 Household water audits – versus current ambition

We canvassed the water companies and asked whether the assumptions we have made for the number of home audits that could be completed in potential PCC pathway scenarios could potentially double count what is in the water companies' current ambition (i.e. the level of home audits in the current ambition would make the target for home audits in the intervention difficult or impossible to reach). The following companies are likely to be affected by this:

- Severn Trent
- South East
- Portsmouth
- Anglian
- Affinity
- South Staffs
- Cambridge
- Southern
- Wessex
- SES Water
- Thames.

For these companies the target for home audits in the intervention has therefore been reduced from 12.5% to 5%.

3.2.4 Household water audits – decay in savings

In order to account for the observed decay in savings related to home audits we have implemented the following:

- For the home audit interventions, the savings will be sustained in full for 5 years and then reduce.
- Where the scenario includes water labelling, we have assumed that the home audit saving will then go to zero (as the saving will be maintained by the water labelling take up).

- Where the scenario does not include water labelling, we have assumed the saving reduces to 20% of the original value after 5 years (as the replacement devices are likely to be more water efficient through existing technology improvements).

We have assumed that water companies will carry out 'one round' of water audits in this study. This reflects steering group feedback about the potential for water audit uptake and the challenge of modelling the savings and costs of repeated rounds of audits. This would require extensive assumptions.

3.2.5 Smart metering

We have taken account of water company current ambition for metering in the analysis of the smart metering interventions, including increasing penetration of normal meters (e.g. through change of ownership initiatives) and the smart meter roll out ongoing in Thames Water and planned roll out in Anglian Water.

We have included different meter costs and savings to account for two different types of property: those receiving a meter for the first time (these attract a higher cost and higher saving), and one for properties upgrading from 'dumb'/simple automatic meter reads (AMR) to smart (these attract a lower cost (meter upgrade) and a lower saving). All metered properties (regardless of whether they are metered in the intervention) will then have a smart fixed network cost added at £8 per household per year (with the exception of TW who have one already).

For the voluntary switching intervention (2), we have assumed that the maximum of 60% of customers will voluntarily switch to a metered bill (based on the approximate reported winners and losers in terms of bills: about 60% of users are better off[9]), plus all new builds and change of ownership (people moving into different property). New builds are about 0.75% of total properties. Calculating the numbers of movers who would change bill status (from unmetered household to metered household) is complex; so, as a proxy we have used the number of house sales in 2014 (Trends in the United Kingdom Housing Market, 2014[19]), which is 1 million for a household stock of about 27 million, about 3.7 %.

Therefore, we have assumed that the maximum metered household percentage will reach 63% under this metering option.

Note: if a company's meter penetration increases above this within their current ambition, we have assumed the higher number.

3.2.6 Analysis method

We translate the intervention savings at the household level into savings per micro-component, by assessing which micro-components will be affected by the interventions and how they will be affected in terms of ownership, volume per use or frequency of use.

This is analysed per company to derive a mean PCC. The uncertainty associated with this is computed using a stochastic model (100,000 runs) which produces zonal PCC estimates using occupancy, meter penetration and micro-component distributions, as described in section 5.

[19] https://www.bl.uk/collection-items/trends-in-the-united-kingdom-housing-market-2014

We then use this to model the savings for each intervention to construct different scenarios, as presented in section 4.

3.3 Costs and benefits overview

We have reviewed and analysed available evidence relating to the range of costs and benefits associated with interventions:

- Costs include new or additional capital and operational expenditure (capex and opex), as well as any known environmental and social costs associated with interventions (e.g. carbon, loss of utility from reduced water use). These are considered further in section 3.4.
- Benefits include the positive social and environmental impacts of reducing the amount of water taken from the environment, as well as any deferred capital investment in water resource schemes. These are considered further in section 3.5.
- The quantified costs and benefits are brought together in section 3.6.
- Section 3.7 includes a qualitative assessment of some of the key benefits that it has not been possible to quantify, relating to smart metering and peak demand.

Our initial screening assessment of the different costs and benefits likely to be associated with the interventions outlined in Section 2, is shown in Figure 2.

Some, but not all, of the costs and benefits identified can be monetised (partly depending on whether information relevant to the impact of the intervention is available and can be quantified). In Section 3.5, we outline how the costs and benefits of interventions have been brought together to feed into the scenario modelling outlined in subsequent sections.

3.3.1 Baseline

Costs and benefits are considered and assessed relative to the 'current ambition baseline', which is based on water company WRMP19 plans for demand management[20]. This includes interventions that have been funded in Ofwat 'draft determinations' and are expected to be implemented during AMP7. This also includes ongoing smart meter rollout by Thames Water, smart metering by Anglian Water (AMP7 and AMP8) and a range of other programmes such as major home audit initiatives described in section 2.2. The baseline assumption also implies that some potential impacts from interventions are not considered to be additional to 'business as usual' and hence are not assessed (e.g. product development costs[21]).

Under water companies' current ambition, the national average PCC reduces from approximately 138 l/h/d in 2021 to 113 l/h/d in 2065.

[20] We have used the latest available version of these plans, which did vary by company at the time of this work between 'revised draft' and 'final' versions.

[21] The EST report on labelling effectively assumes that product development would apply to conventional as well as water efficient interventions, and hidden costs (e.g. maintenance) may be no higher than those for existing fittings.

Figure 2: Initial screening assessment of costs and benefits associated with interventions

			Costs				Benefits		
			Capex	Opex	Carbon	Utility loss	Reduced abstraction	Resource saving	Hot water savings
Intervention_group	Int_ref	Intervention_type	Capital cost of intervention.	Operational cost of intervention.	Greenhouse gas emissions arising from construction (e.g. embodied) and operation (e.g. vehicle usage) of interventions, as well as emission savings from avoided investment or sequestration.	Where impacts occur, likely to be negative, as water use is reduced. However, only significant where a degree of compulsion or forced behaviour change is involved.	Benefit from water saved. Linked to estimate of water saving.	Avoided cost of investing in new resources. Linked to estimate of water saving.	Energy bill savings. Linked to estimate of water saving, but aplpicable to heated water only.
Metering	1	Progressive metering by region - forced	--	-	-	-	++	++	++
Meeting	2	Progressive metering by region - voluntary	-	-	-	0	+	+	+
Metering	3	Full universal metering across E&W	--	-	-	-	++	++	++
Tariffs	4	Innovative tariffs	0	-	+	0	+	+	+
Home_visits	5	Non targeted assisted audits	0	-	-	0	+	+	+
Home_visits	6	Targeted assisted audits	0	-	-	0	+	+	+
Home_visits	7	Leaky loo find and fix	0	-	-	0	+	+	0
Home_visits	8	Change WC standards*	0	-	0	0	+	+	0
Market_transformation	9	Water labelling - with minimum standards	-	-	+	-	++	++	++
Market_transformation	10	Water labelling - No minimum standards	-	-	0	0	+	+	+
New_homes	11	New homes standards - mandatory	-	-	+	-	++	++	++
New_homes	12	New homes standards - voluntary	-	-	0	0	+	+	+
Recycling	13	Community RWH	--	-	-	0	+	+	0
Recycling	14	Community wastewater recycling	--	-	-	0	+	+	0
Recycling	15	Home retrofit RWH/GWR	--	-	-	0	+	+	0
Awareness	16	Increased media campaigns and schools	0	-	0	0	+	+	0
Awareness	17	National co-ordinated programme*	0	-	0	0	+	+	0
Awareness	18	Individual and community incentives*	0	-	0	0	+	+	0

Key to symbols

++	Significant positive impact expected
+	Small positive impact expected
0	No impact expected
-	Small negative impact expected
--	Significant negative impact expected

3.4 Costs

Costs include capex, opex and any known negative environmental and social impacts associated with the interventions.

3.4.1 Capex and opex costs

Capex and opex cost estimates have been derived by the project team based on demand-side option evaluation work, completed for a selection of companies in WRMP19. These costs have therefore been reviewed by the Environment Agency and subject to internal and external audit as part of the business planning process. Table 7 presents the unit cost estimates (capex and opex) for each intervention.

Table 7: Summary of intervention unit costs

Ref	Intervention type	Promoted by	Capital Costs	Capex Costs (£/hh)	Operational costs	Opex Costs (£/hh/year)
1	Progressive metering by region – auto-switch	Water company	Meter cost, meter survey, meter installation, analytic set up	**243.66**	Meter replacement, Analytic annual charge, Network Annual charge/ Mobilisation fee	**10.51**
2	Progressive metering by region - voluntary	Water company	Meter cost, meter survey, meter installation, analytic set up	**243.66**	Meter replacement, Analytic annual charge, Network Annual charge/ Mobilisation fee	**10.51**
3	Full universal metering across England and Wales	Government	Meter cost, meter survey, meter installation, SPL repair, analytic set up	**293.02**	Meter replacement, Analytic annual charge, Network Annual charge/ Mobilisation fee	**10.51**
4	Innovative tariffs	Water company	Set up tariff	**1.44**	Billing system (marginal cost for bespoke tariffs), Evaluation costs	**0.10**
5	Non targeted assisted audits	Water company	Devices: (including ecoBeta, Tap, LFSH, Outdoor) Survey cost/ installation cost, campaign	**102.00**	Evaluation costs	**0.10**
6	Targeted assisted audits	Water company	Devices: (including ecoBeta, Tap, LFSH, Outdoor), survey cost/ installation cost, campaign	**102.00**	Evaluation costs, Identification of properties to target	**0.10**

Ref	Intervention type	Promoted by	Capital Costs	Capex Costs (£/hh)	Operational costs	Opex Costs (£/hh/year)
7	Leaky loo find and fix	Water company	Devices: (including ecoBeta), survey cost/ installation cost, campaign	**87.00**	Evaluation costs, Identification of properties to target	**0.10**
8	Change WC standards	Government	No capital cost	**0.00**	Campaign, incentives, Evaluation costs	**2.10**
9	Water labelling - with minimum standards	Government	No capital cost	**0.00**	Evaluation costs	**0.10**
10	Water labelling - No minimum standards	Government	No capital cost	**0.00**	Campaign, Evaluation costs	**0.11**
11	New homes standards - mandatory	Government	More efficient devices (marginal cost)	**406.00**	Campaign, Evaluation costs	**2.10**
12	New homes standards - voluntary	Other	More efficient devices (marginal cost)	**406.00**	Campaign, Evaluation costs	**2.10**
13	Community RWH	Other	Build, fit out cost, storage, pipe network	**1,847.67**	Maintenance, sampling, treatment, operation (Electricity, etc.), evaluation	**64.30**

Ref	Intervention type	Promoted by	Capital Costs	Capex Costs (£/hh)	Operational costs	Opex Costs (£/hh/year)
14	Community wastewater recycling	Other	Build, fit out cost, storage, pipe network	**890.00**	Maintenance, sampling, treatment, operation (Electricity, etc.), evaluation	**9.40**
15	Home retrofit RWH/GWR	Water company	Fit out cost, storage, plumber, installation	**2,000.00**		**0.00**
16	Increased media campaigns and school education	Water company	No set up cost assumed	**0.00**	Campaign, steering group for scheme	**2.10**
17	National co-ordinated programme	Government	No set up cost assumed	**0.00**	Campaign, steering group for scheme	**2.10**
18	Individual and community incentives	Water company	No set up cost assumed	**0.00**	Campaign, steering group for scheme, incentives	**2.10**

3.4.2 Carbon emissions

The main environmental impact identified in WRMPs is carbon, which can relate to:

a) greenhouse gas emissions arising from construction (e.g. embodied) and operation (e.g. vehicle usage) of interventions (a cost relative to the baseline);

b) emission savings from reduction in operational emissions (e.g. pumping and treatment of water) (a benefit relative to the baseline); and

c) savings from household consumption of energy (due to cold and hot water use) (a benefit relative to the baseline)

There is some information relating to a), for example Decker (2018)[22] provides estimates of the amount of carbon embedded in meter installation, reading and replacement. However, estimates are not available for all interventions and other information reviewed (e.g. average incremental social costs (AISCs) of carbon in WRMPs) was found to be inconsistent and highly variable. We therefore concluded that embodied carbon (materials) and operational carbon (e.g. vehicle use) emissions could not currently be reliably quantified across all interventions to ensure a consistent treatment in the cost benefit analysis.

Carbon impacts relating to b) and c) are assessed based on an estimation of energy use and carbon emissions from water supply and from using water in the home, produced by Artesia. Carbon is valued in accordance with UK Government non-traded carbon price schedule[23].

Reduced carbon costs (due to water savings) take account of water temperatures, hot water use, device types (e.g. electric showers versus showers using gas heated water), per capita consumption, boiler type and the energy efficiency of boilers. The result is a total carbon emission per household per day of 2.63 kgCO2e/prop/day (around 1 tonne CO2e/prop/year)[24]. This is based on a PCC of approximately 138 l/h/d. Table 8 shows the calculated reduction in emissions from household water use as PCC falls.

Note that this carbon emission value is applied to all interventions except for leaky loo find and fix and change in WC standards and the recycling options. This is because no hot water is used in these interventions.

[22] Analysis of the Costs of Water Resource Management Options to Enhance Drought Resilience, Final Report for the National Infrastructure Commission.

[23] https://www.gov.uk/government/collections/carbon-valuation--2

[24] This is made up of: water delivered to the home (0.12 kg); water centrally heated in home 1.30kg); water heated by electric showers (0.78 kg); washing machine (0.26 kg); dishwasher (0.16kg); wastewater treated (0.05 kg). No allowance is made for grid decarbonisation or alternative domestic heating technology (e.g. heat pumps). See section 6.2.3.1 for sensitivity analysis.

Table 8: Calculated carbon emissions due to household water use

PCC (l/h/d)	Carbon emissions (kg CO_2e)
138	2.64
130	2.51
120	2.34
110	2.19
100	2.10
90	1.87
82	1.74

Source: Artesia

3.4.3 Social costs

Social costs include the potential negative effect on household utility due to the implementation of water saving measures. Current evidence, in the form of water company marginal benefit values for PCC reductions (see for example Ofwat PR19 IAP[25]), suggest households have a net preference for water savings from current PCC levels (i.e. social and environmental benefits are greater than costs). This is considered in more detail in section 3.5. Whether this 'result' holds for deeper PCC reductions (delivered for example through more stringent standards for fittings) is not quantitively evidenced.

3.5 Benefits

Benefits considered here include:

- Any known positive environmental and social impacts associated with the interventions (as a result of reducing the amount of water taken from the environment);
- Any deferred capital investment in water resource schemes;
- Any other significant but unquantified benefits – which are considered to be limited to smart metering for the purposes of this study.

3.5.1 Social and environmental benefits

We reviewed three potential sources of valuations for the social and environmental benefits of reducing the amount of water taken from the environment. Each is linked to a separate water sector strategic planning process, as outlined below.

[25] https://www.ofwat.gov.uk/regulated-companies/price-review/2019-price-review/initial-assessment-of-plans/

1) **WRMP: using the social and environmental costs/benefits featured in AISC estimates (present value (PV); in terms of Pounds per cubic metre, £/m3).** [26]

- Despite being the conventional source for environmental and social values for water resource planning, the evidence base from water company plans is limited, due to reduced emphasis on monetary valuation in the Defra (2016) Guiding Principles for Water Resources Planning.
- Overall there is uneven coverage of AISC estimates across companies' feasible and preferred option lists; present value calculations are opaque; and there is no reliable process establishing which aspects of environmental & social values are captured within different companies' estimates (including carbon).
- The materiality of AISC values is also low – e.g. even for resource development options environmental & social costs are comparatively low compared to total costs (average incremental costs (AIC) is approximately 10% of total AISC; based on Decker, 2018 for NIC).

2) **Water Industry National Environment Programme (WINEP) or River Basin Management Plan (RBMP) waterbody improvements valued at catchment level (marginal value; £/km/yr. for Water Framework Directive status change).**

- In principle this should include assessment of benefits for water company measures that retain water in the environment (e.g. sustainable abstractions) that could be a proxy for impacts of water savings associated with demand measures.
- However, values in RBMPs are assessed for a bundle of measures at the catchment level. Identifying and utilising these values therefore requires an understanding and quantification of the pathway linking the water saving to a given WFD status change within a specific catchment. This level of location specific assessment is challenging and beyond the feasible scope of this project.

3) **PR19: water company values for changes in service levels (e.g. PCC, leakage, security of supply), which are typically based on customer research (e.g. stated preference willingness to pay studies) and applied to Performance Commitment (PC) assessments and Outcome Delivery Incentives (ODIs) (marginal benefits; £/unit/yr.).**

- PC marginal benefit values and ODI payment rates should reflect customers' (society's) values for outcomes – i.e. saving water – which likely includes a mix of motivations related to environmental (e.g. reduced pressure on the water environment) and social (e.g. better water efficiency in the home) benefits.
- The Ofwat IAP (Jan 2019) and published PR19 data tables reports marginal benefit values and ODI rates for each company. A number of companies have also published the original source material for valuations (e.g. companies' customer research results, including WTP studies).

Water company marginal benefit (MB) values are reported in £ per change in PCC per household per year terms (£/ΔPCC/hh/yr.). This represents the most consistent source of monetised benefit estimates for use in this project. They are assumed to represent a bundle

[26] AISCs (average incremental social costs) are calculated by dividing the net present value of the capital (including maintenance, replacement and financing), operating, environment and social costs of the option, by the net present value of the extra water available for use.

of benefits, but not overlap with valuations applied in relation to carbon savings from reduced household energy consumption for cold and hot water use, as summarised in section 3.4.2.

In the cost benefit analysis, we apply an average value of £0.36 per l/h/d per household per year (median = £0.24). This is based on the calculation of marginal benefit values from ODI rates reported in the Ofwat IAP[27]. This indicates that, on average, households value the benefits of reducing water consumption by 1 l/h/d by £0.36 per year. Table 9 summarises the source data and calculation of the marginal benefit values.

Table 9: Water company PCC marginal benefit values

Company	PCC (l/h/d) (average household)	ODI rate (£/l/h/d/hh) (out-performance)[a]	Marginal benefit (£/l/h/d/hh)[b]
AW	137.1	0.08	0.17
BW	144.5	0.03	0.05
NRW	152.3	0.06	0.11
PW	141.5	0.01	0.01
SEW	132.6	0.15	0.30
SSW	147.5	0.09	0.18
SWW	130.3	0.26	0.52
SW	139.5	0.17	0.33
SES	138.5	0.55	1.10
TW	155.5	0.54	1.08
UU	142.3	0.06	0.13
WW	134.5	0.16	0.31
Mean			0.36
Confidence interval (95%)			0.12 – 0.59
Median			0.24

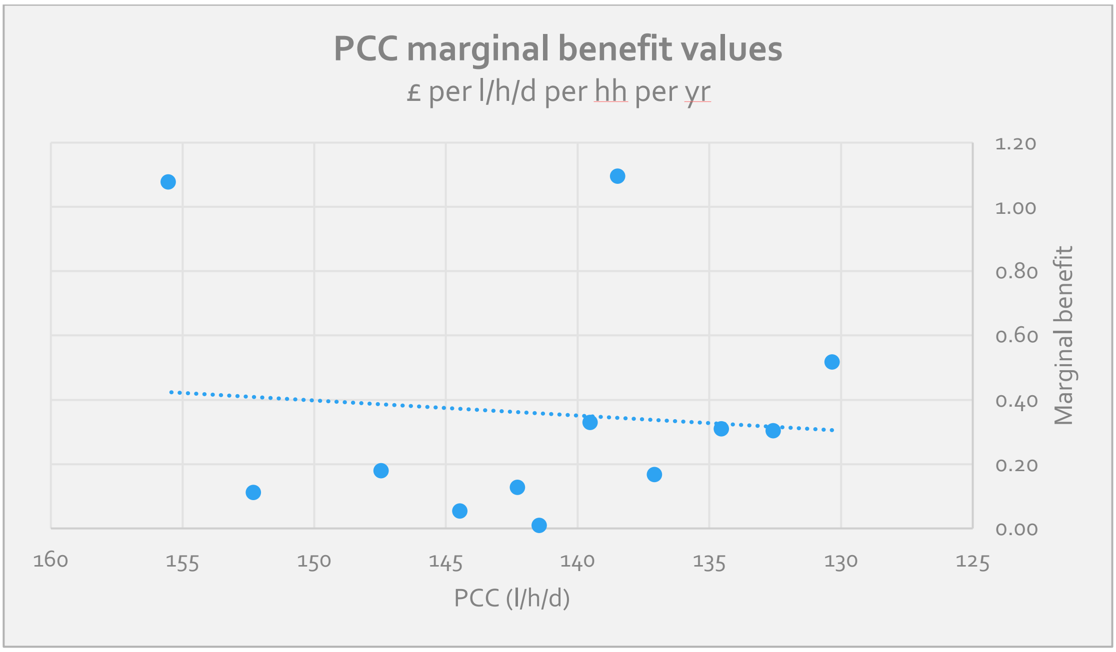
Notes: [a]ODI rates as reported in Ofwat IAP documents (Technical Appendix 1 – Delivering Outcomes for Customers Final). Valuations for AFW, DCWW, STW and YW excluded due to incomparability as noted by Ofwat. [b]Marginal benefit values calculated using standard Ofwat ODI out-performance formula [ODI rate = marginal benefit x (1-p); where p = 50% as prescribed by Ofwat in the PR19 Final Methodology, Appendix 2 Outcomes].

The marginal benefit unit value applied in the cost benefit analysis is assumed to be constant over the range of PCC reduction based on a relatively flat relationship that is observed between marginal benefit and consumption, as illustrated in Figure 3. This does, however, extrapolate the valuation beyond the range of PCC reductions that are proposed in

[27] Marginal benefit values are calculated from reported ODI rates for out-performance since the Ofwat IAP presents company valuations in a consistent set of units ((£/ΔPCC/hh/yr). Valuations reported by companies in PR19 (draft) Business Plan submissions (App1 data tables) are in a range of units and metrics.

companies PR19 Business Plans. As suggested in section 3.4.3, deeper cuts in PCC could have a net negative impact on households (see further below).

Figure 3: Marginal benefit values for PCC reductions

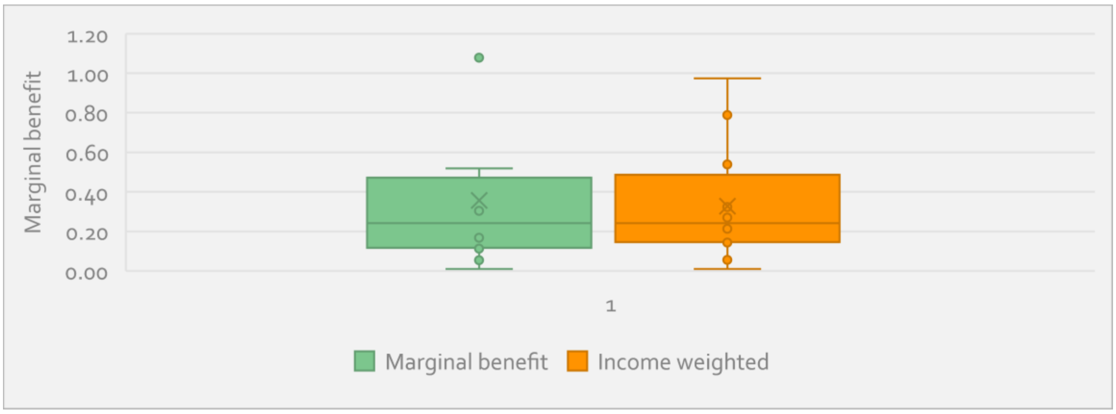


Notes: Calculated marginal benefits values (Table 7) plotted against current PCC for each company. Trendline is reported to show linear 'best fit' across the 12 data points. Notwithstanding the very small sample size, this suggests that on average marginal benefit is relatively invariant to changes in PCC level; hence use of a constant unit value within this range is appropriate.

For reference, Figure 4 shows the results of a sensitivity test for the (mean) average marginal benefit value, comparing the result to a set of values weighted by average household income for each water company region. This accounts for a potential factor that could cause marginal values to vary between company regions. In particular, customer valuations should be constrained by household income; so that regions with lower household income would on average have lower willingness to pay for PCC reductions, compared to regions with higher household income on average (assuming all else is equal).

Mean (£0.36 vs. £0.34) and median (£0.24 vs. £0.24) values are stable across the comparison, suggesting that differences observed between values in Figure 2 are due to other factors – e.g. the relative importance that households place on water savings in different company regions versus other priorities for investment (e.g. reducing sewer flooding, reducing CSOs/pollution incidents, improving the aesthetic quality of tap water). In summary, the results suggest that applying the mean value is a reasonable approximation for the marginal benefit of water savings, given evidence that can be drawn on.

Figure 4: Comparison of marginal benefit values – unweighted vs. weighted



Notes: unweighted values as reported in Table 9. Income weight values scale marginal benefit by ratio of gross disposable household income (GDHI) for the water company region to national average GDHI, using ONS data (Regional gross disposable household income (May 2018): https://www.ons.gov.uk/economy/regionalaccounts/grossdisposablehouseholdincome/datasets/regionalgrossdisposablehouseholdincomegdhi).

However, the marginal benefit values applied in the cost benefit analysis should be interpreted broadly, representing the household preference for water conservation and associated benefits (e.g. reduced abstraction; less pressure on water environment), from current observed PCC levels across companies (approximately 155 to 130 l/h/d). This is because there is limited reporting on: (a) specific definitions in source studies (customer WTP) and; (b) water company PR19 assumptions to calculate per l/h/d value.

Note also that the constant unit value assumption is likely to be a reasonable assumption for initial reductions in PCC in the water savings scenarios (e.g. down to current ambition levels). It may be that, as consumption falls, the marginal benefit decreases. This is likely to tend towards zero and could eventually be a negative value – i.e. net social and environmental cost, as households place an increasing weight on the potential inconvenience associated with reduced water use.

Such an effect is not quantitatively evidenced, hence any assumption of a declining marginal benefit value over the PCC reduction range considered in this report would not be supported by any evidence. In addition, applying a lower marginal benefit value would also affect all aspects of the economic analysis equally, so the results would not change in relative terms.

Finally, reduced consumption reduces the risk of other measures (e.g. temporary use bans) that comparatively may have a greater negative impact on household utility. As such, it is more appropriate to consider switching values as part of sensitivity testing, rather than assuming arbitrary lower values past some PCC level.

3.5.2 *Deferred investment benefits*

One potential benefit of interventions that reduce PCC is a reduction in the need to invest in new supply-side water resource options. In reality, it may be that the investment in such options is deferred by a number of years (or to an alternaitve future planning period), rather than avoided altogether. The Decker (2018) report for the NIC provides estimates of average incremental cost (AIC) for different types of infrastructure option. These estimates are presented in Table 10, converted to £ per Ml values.[28]

Table 10: AIC estimates for (feasible) infrastructure options (from Decker, 2018[29])

Option	AIC (p/m³)	AIC (£/Ml)
Aquifer recharge	113.7	1,137
Bulk supply	83.9	839
Conjunctive use	105.1	1,051
Desalination	128.3	1,283
Effluent reuse	128.2	1,282
Groundwater	67.1	671
Reservoir	172.9	1,729
Surface water	63.3	633
WTW capacity	86.4	864
All infrastructure options	98.1	981

This benefit is only relevant where supply-side options would, in the absence of demand reductions, be needed, i.e. those companies with a current or projected supply-demand deficit. A full comparison of interventions considered in this report with supply side measures for such companies would require determining company-specific values from WRMP19 reports and tables and converting average costs to marginal costs. This would be an involved process which would potentially require work approaching the level of a new supply-demand balance, so is not undertaken as part of this project.

Alternatively, another option could be to develop an average value based on national levels of deficit and apply this to all companies. However, this would provide benefits to companies which do not have a deficit or any planned investment, so is also not appropriate.

The recommended option is therefore to apply the high-level estimates in Table 10 to companies with a projected deficit. This would ideally need to consider the time period over which the investment is delayed and, in order to compare the resulting estimates to PCC reduction interventions, the relationship between average and marginal costs.

[28] Note that AICs cannot be directly compared to the marginal cost of interventions to reduce PCC, since the former includes fixed costs.

[29] Decker (2018) Analysis of the costs of water resource management options to enhance drought resilience. Final Report for the National Infrastructure Commission. Regulatory Economics. February 2018.

The EST Water Labelling report includes capex and opex estimates for avoided supply-side investment[30]. Whilst it is not clear how these estimates have been derived, the report states that deferred investment benefits "…*are significant figures and although not included in any of the key metrics it should be noted that this would be a significant benefit*."

3.6 Bringing costs and benefits together

The costs and benefits of interventions can be compared to produce a high-level cost-benefit analysis. Results are reported in section 6.2 including a set of sensitivity tests based on the scenarios developed and outlined in section 4. Costs and benefits are assessed against the 'current ambition' baseline, with PCC reductions and associated water savings profiled over time in accordance with the interventions and timings for implementation that are specified in the scenarios. Costs and benefits do not start to accrue until after AMP7.Costs and benefits are assessed over a 47-year time horizon commencing in 2019 (year 0) running through to 2065 (year 46). Cost and benefits are discounted using HM Treasury standard declining long-term discount rate (3.5% for years 0-30; 3.0% for years 31-46)[31]. All monetary values are reported in current prices (2019).

Due to limited regional information, costs and benefits are estimated at a national level. Therefore, caution should be exercised when using the estimates at a company or regional level where some impacts (e.g. benefits of reduced abstraction) may differ. Note also that whilst the cost benefit analysis shows the comparative position of different scenarios, it does not show how a specific PCC reduction should be optimised from an economic perspective.

In addition to the cost benefit analysis results, section6 also reports the calculated marginal abatement cost for each intervention and scenario, summarising the £ cost per Ml water saved.

3.7 Qualitative benefits assessment

3.7.1 Smart metering benefits

The main benefit that has been quantified within this study for smart metering is the volume of water saved in the home. However, smart metering has a number of additional potential benefits that extend to different parts of the business and to customers. The purpose of this section is to highlight these potential benefits, but not to quantify them. These would need to be quantified specifically for each company when making a business case for smart metering.

The potential operational benefits rely on collecting data at higher frequencies, processing that data and using the information to provide insights that can be used to deliver increased business efficiency. These benefits include:

- Meter reading savings.

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[30] For example, for the mandatory labelling option with minimum standards (option 2 in the EST report), the saving is £397 billion avoided supply side investment over 10 years and £1.6 trillion over 25 years. This is based on capex of £1.76 m/Ml and opex of £1.44 m/Ml.

[31] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

- More efficient customer supply pipe leakage reduction.
- More efficient distribution system leakage reduction.
- Improvements to customer service, through greater understanding of customers' consumption.
- Improved network operations and the ability to manage the meter stock more efficiently.
- The ability to spot internal losses more quickly and provide services to reduce these.
- The ability to integrate household consumption data into smart networks.

In addition to the operational savings for water companies, there are also additional potential benefits to customers. These include customers' having the ability to decide to reduce water and energy bills through further water savings, and the ability to take advantage of other potential 3rd party services such as receiving automated leak alarms.

3.7.2 Benefits of interventions on peak demand

The analysis in this report focuses on the dry year annual average savings that are achieved by a range of interventions and scenarios. Recent work on a collaborative study looking at the peak water demand experienced in summer 2018[32] has shown that a number of interventions considered in this project will also deliver benefits to peak demand. For example, metering will reduce the baseline demand (thus reducing the absolute size of peak demand), and also reduces the weather-driven response in consumption. Interventions such as water labelling were not considered in the 2018 peak demand report but will deliver similar results by reducing the baseline demand and suppressing the peak response due to weather.

The benefits of the interventions on peak demand have not been quantified but could be significant in increasing the resilience of water supplies. The peak demand report recommends that the benefit of interventions such as metering on peak demand reduction and resilience should be quantified and factored into the water resource planning option evaluation process.

[32] Artesia (2019 – in preparation) Water demand insights from summer 2018. Collaborative Study

4 Scenarios

In this section we summarise how we developed the scenarios used to assess long-term pathways for PCC reduction.

This includes the method for deciding which interventions to use in each scenario.

The scenarios with their constituent interventions are presented.

The scope of work for this project required that the following scenarios be explored:

- Extended demand reduction scenario from the Water UK Long-term water resources planning framework;
- Enhanced demand reduction scenario from the Water UK Long-term water resources planning framework; and
- A level of ambition that reduces consumption below that.

It was also necessary to present a scenario which reflected the current ambition of the water companies, so that the pathways towards long-term PCC reduction can be compared against what is currently planned.

Scenario development went through several iterations using the deterministic modelling process described in section 5. During this process, the following considerations were made:

- Interventions could not be mutually exclusive;
- Dependent interventions had to proceed in the correct order;
- Some scenarios were to be based on interventions that could be led and delivered only by water companies;
- Some scenarios were also to be based on interventions that could be led and delivered by government; and
- There should be a mix of scenarios based on a few (potentially only one) intervention(s), and ones that require several interventions.

These considerations were used to determine the most appropriate interventions for each scenario. Not all interventions were used in the scenarios but section 6 presents water savings, cost/benefit and marginal cost results for all interventions individually, for comparison.

Table 11 presents the scenarios and the interventions used.

Table 11: Scenarios and interventions

Scenario	Int. ref	Intervention name	Led by	Implementation date
Extended	2	Progressive smart metering with voluntary switching	Water Company	2025 to 2031

Scenario	Int. ref	Intervention name	Led by	Implementation date
	7	Leaky loo find and fix	Water Company	2025 to 2031
	16	Increased media campaigns and school education	Water Company	2025 to 2031
Enhanced-01	10	Mandatory water labelling with no minimum standards	Government	2021
Enhanced-02	2	Progressive smart metering with voluntary switching	Water Company	2025 to 2031
	4	Innovative tariffs	Water Company	2031
	6	Target assisted audits	Water Company	2025 to 2031
	14	Community wastewater recycling	Other	2021
	16	Increased media campaigns and school education	Water Company	2025 to 2031
Water labelling only	9	Mandatory water labelling with minimum standards	Government	2021
Enhanced-03	2	Progressive smart metering with voluntary switching	Water Company	2025 to 2031
	9	Mandatory water labelling with minimum standards	Government	2021
Enhanced-04	1	Progressive smart metering with auto switching (compulsory)	Water Company/ Government	2025 to 2031
	4	Innovative tariffs	Water company	2031
	6	Target assisted audits	Water company	2025 to 2031
	7	Leaky loo find and fix	Water company	2025 to 2031
	10	Mandatory water labelling with no minimum standards	Government	2021
	14	Community wastewater recycling	Other	2021
	16	Increased media campaigns and school education	Water company	2025 to 2031

The scenarios cover a range of potential outcomes as well as highlighting the relative roles of water companies and government in delivering the interventions[33]. For example, the scenarios involving water labelling would require government intervention, whereas the Extended and Enhanced-03 scenarios can be delivered wholly by water companies (a company like Albion Water, who deliver community wastewater recycling schemes are a water company).

The two variations of the water labelling intervention – with and without minimum standards (Enhanced-01 and the water labelling only scenario respectively) – will provide an indication of the different costs and savings associated with these two options.

[33] As part of this study we considered the role of other organisations, including NGOs and product suppliers, but in all cases, we concluded the input from these other parties would be led and/or encouraged by either water companies or government.

5 Modelling method

This section describes how and why per capita consumption (PCC) varies between water companies and describes the challenge this poses for analysing and reporting consumption at a national level.

We then describe the modelling method which uses a two-step approach based first on a deterministic analysis of the impact of interventions on consumption, then a stochastic model which describes the inherent uncertainty in assessing the demand reduction.

Each of these steps is then described in more detail. Both approaches start by analysing the current water efficiency ambition of water companies.

The deterministic approach is used to determine the interventions to be used in each scenario. The results of this were provided to each water company for review, to ensure no double counting compared to current ambition. Outputs for PCC, property numbers and household occupancy are produced.

The stochastic modelling uses a proven relationship between meter status, occupancy and the micro-components of water use to produce consumption forecasts. These forecasts reflect the change in household occupancy and metering over time, the effect of these variables on consumption and importantly the effect of the interventions on micro-components.

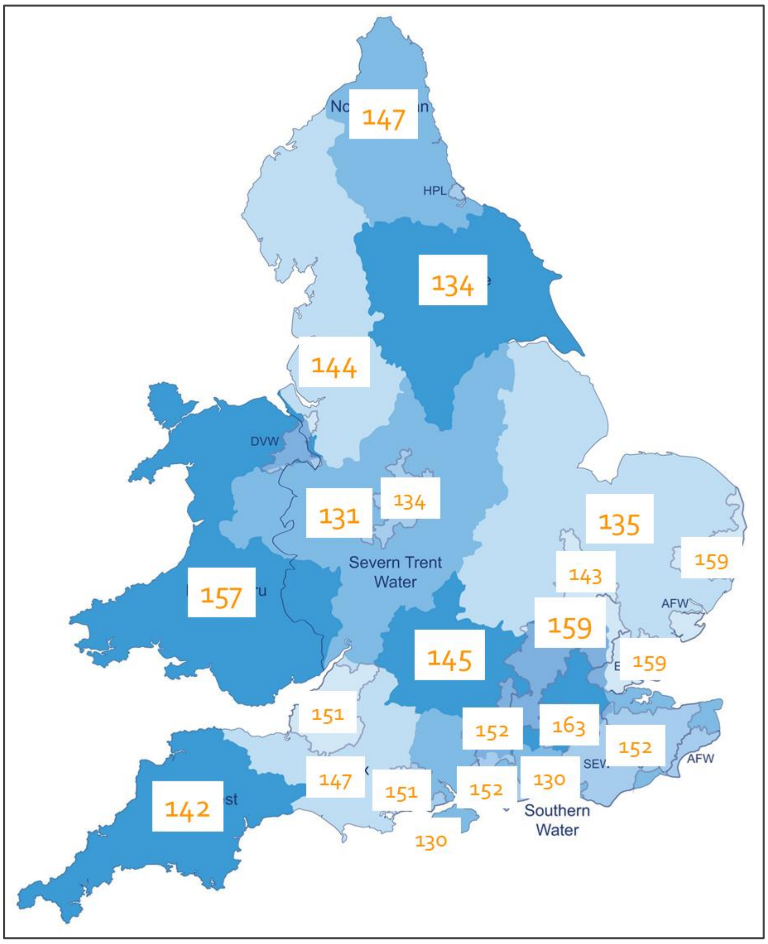
The stochastic model is run 100,000 times to produce an uncertainty range for the interventions and scenarios. This is combined with the savings uncertainty for each intervention to produce an overall uncertainty.

5.1 Introduction

In order to assess the impact of different water saving scenarios on the level of PCC that can be achieved and the impact on costs and benefits, we need to be able to forecast the different pathways to a lower PCC from the current ambition of water companies around England and Wales. There is a high geographic variation of PCC around England and Wales and this illustrated in the graphic in Figure 5. This is based on reported PCC for 2017/18 taken from the 'Discover Water' website[34].

[34] https://discoverwater.co.uk/amount-we-use

Figure 5 Regional variations in PCC (reported figures 2017/18, l/h/d)

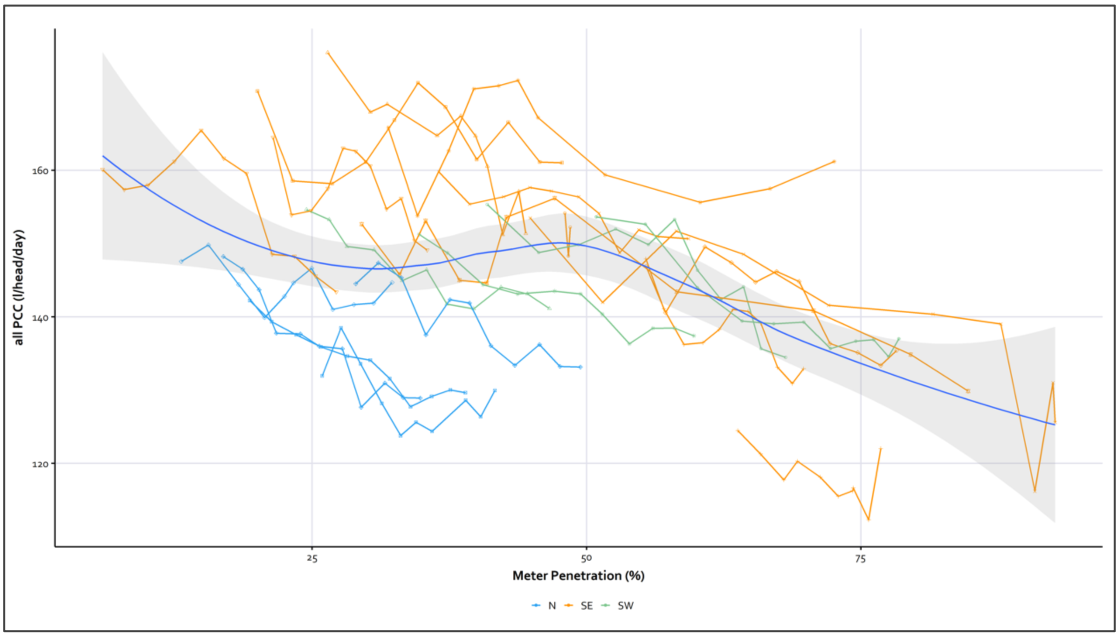


The reported values in Figure 5 will be different to values used in water resources management plans and will of course be superseded over time, particularly as new methods for estimating PCC are implemented. This will change the PCC values for some companies more than others. However, there will always be variations in consumption across the country. The reasons for the variations in PCC are reasonably well understood[35], but difficult to predict[36].

Figure 6 presents PCC against meter penetration, based on reported values up to 2017/18. Each individual line on the graph represents a single water company. The thick blue line (with uncertainty band around it) shows the overall trend for England and Wales. This indicates that average PCC decreases overall, as meter penetration increases. This observation broadly holds true for each of the individual company lines, although each line has ups and downs and slightly different gradients.

[35] Artesia (2017): Planning for the future: a review of our understanding of household consumption. Ref: AR1170, Artesia Consulting 2017.
[36] Variation in Per Capita Consumption Estimates by Ofwat (2007).

Figure 6: PCC versus meter penetration by water company



The interesting observation from Figure 6 is that there is a clear separation between water companies in the north (blue lines) and water companies in the south-east (orange lines). Consumption is consistently lower in the north than in the south-east. This clear geographical difference suggests that the variation in PCC is due to a range of factors and these include:

- Occupancy;
- Age of occupants;
- Property type;
- Socio-demographic factors (social status, levels of affluence, culture, religion, lifestyles, and household or individual values towards water use);
- Whether households pay for water via a meter; and
- Weather.

The methods used to measure and estimate PCC will have a bearing on consumption, but this does not explain the clear north-south split apparent in Figure 6.

One of the implications for this project is that the impact on PCC from water saving measures and demand management will need to be modelled at company level and aggregated proportionally up to England or England and Wales level. Not all the factors listed above can currently be modelled regionally (for example fully quantifying the differences in behaviours, attitudes or practices) but some, such as meter penetration and occupancy, can be quantified at regional level and used to differentiate regions.

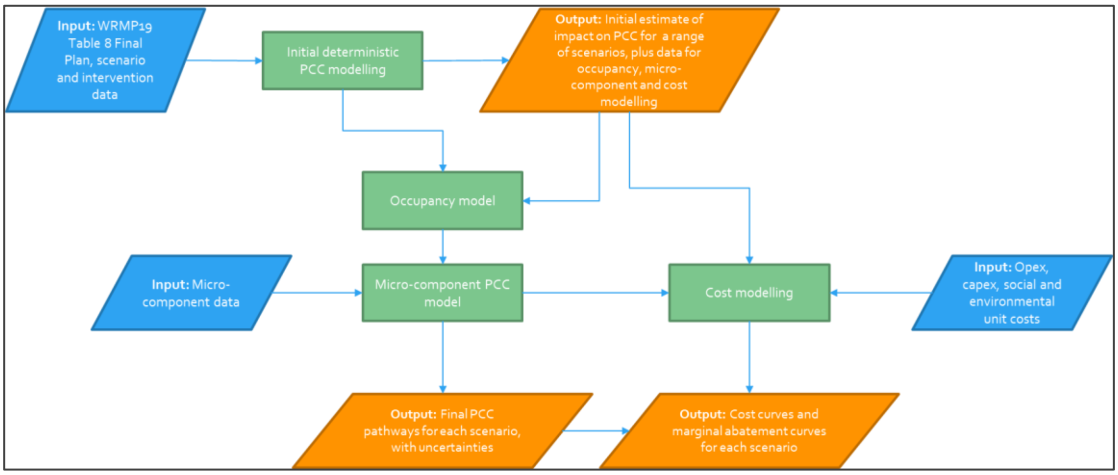
The other main implication the regional variation in PCC values relates to whether an intervention can deliver the same saving for the same cost if starting from two different PCC values. This raises the question as to whether there should be elasticities in the intervention cost curves between areas. At the moment there is no evidence to support this logical argument, however it potentially opens up a challenge to using standard behavioural or household assumptions that could fundamentally affect the impact of interventions between different areas. There is some evidence from Northumbrian Water who have applied the same assisted home audits in their north and south regions and achieved similar savings. Therefore, we currently assume that all interventions can be applied equally to all areas. Metering interventions obviously will take account of the prevailing level of meter penetration.

In order to further quantify some of the variation and uncertainty in response to water saving measures a stochastic approach has been used to model the variation in responses. A stochastic approach differs from a deterministic model, since the model possesses inherent randomness which will lead to an array of results from which uncertainties can be derived. The model therefore produces outputs with defined confidence intervals, which will indicate how variable a specific scenario outcome is.

The model has to forecast the impact from multiple concurrent or sequential interventions in one scenario. We also need to be able to get early indicative outcomes quickly in order to investigate different permutations of interventions.

Therefore, we start the forecast process with a deterministic step to get an initial estimate forecast and to quantify the number of households that are impacted by each intervention. The outputs of this are then fed into the stochastic model, which allows us to assess the inherent randomness in the scenario outcomes and produce distributions of PCC for key points in the forecast or PCC pathway. An overview of the process is shown in Figure 7.

Figure 7: Overview of modelling process for PCC and the cost impacts



5.2 Modelling approach

This process is broken down and described in more detail in Figure 8 and in the next sections.

5.2.1 *Initial deterministic calculations*

The starting point for investigating the potential PCC pathways is the current PCC ambition of each company as described in the revised draft water resource management plans 2019. We abstracted data from WRMP Table 8 Final Planning tables as follows:

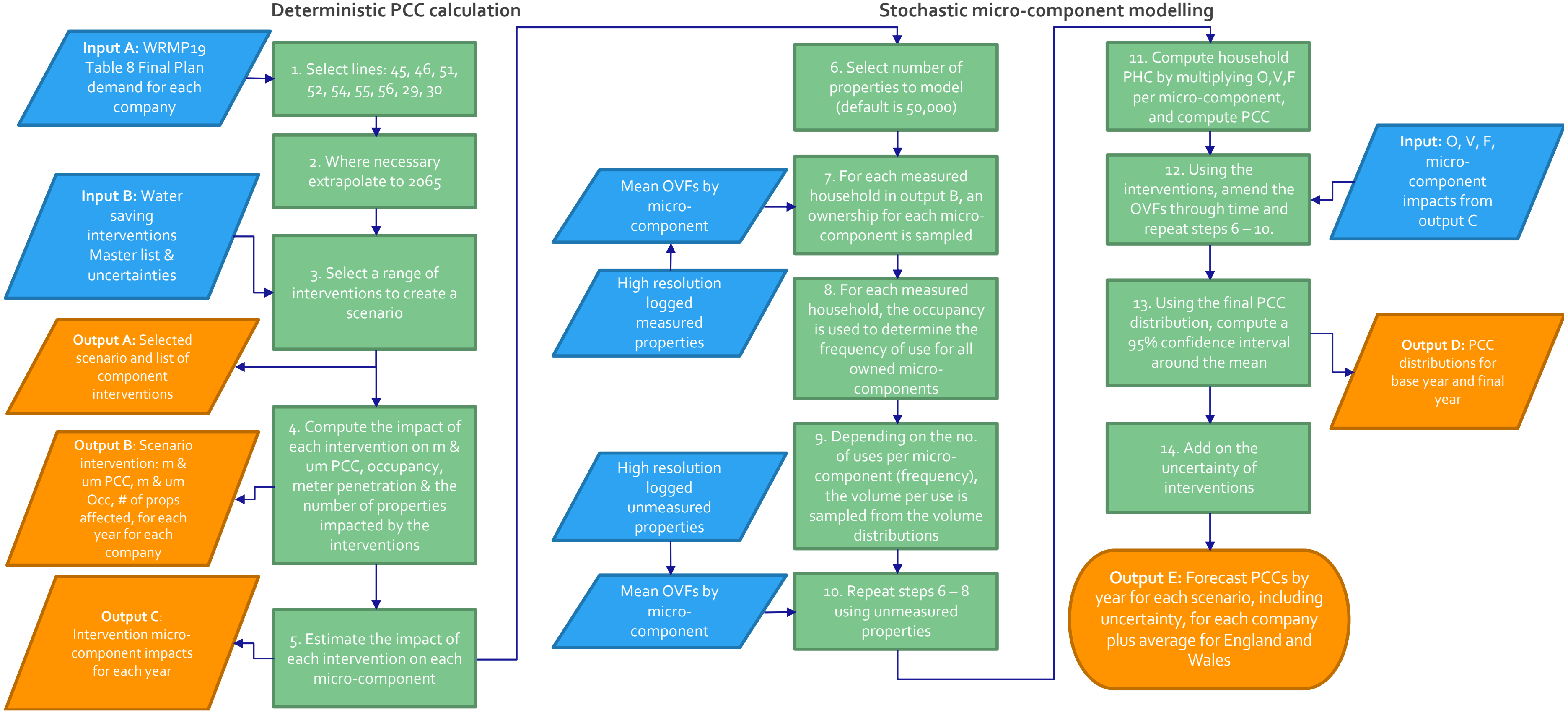
- 29FP- Measured Household - PCC (l/h/d)
- 30FP- Unmeasured Household - PCC (l/h/d)

- 45FP- Measured Household - Properties (excluding voids)
- 45.1FP- New properties
- 46FP- Unmeasured households - properties (excluding voids)
- 51FP- Measured Household - Population
- 52FP- Unmeasured Household - Population
- 54FP- Measured Household - Occupancy Rate (average) (excluding voids) (h/prop)
- 55FP- Unmeasured Household - Occupancy Rate (h/prop)
- 56FP- Total Household Metering penetration (excl. voids) (%)

The consumption values are Dry Year Annual Average figures for consistency, and these are used throughout the modelling. An estimate of normal year PCC values can be calculated at the end of the process. Because we wish to produce PCC pathways out to 2065, some of the WRMP Table 8 data has been extrapolated forward to 2065 using simple linear regression.

Data on interventions (demand management measures) is fed into the process, and this is described in section 2.3.

Figure 8: Flowchart of modelling process



The first step is an iterative process of applying interventions and computing the resulting PCC values for the following years:

- 2021 (starting year)
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
- 2065.

The percentage of properties covered by each intervention and the impact on PCC for each property impacted are described in the intervention list Table 5.

The final list of interventions selected for each scenario was based on judgment, considering the following points:

- The target end point PCC agreed with the PSG.
- The feasibility of implementing the interventions (are they likely to be achieved).
- Any overlap or mutual exclusivities between interventions.
- The inclusion of a range of interventions that are to some degree within the control of water companies and others that require stakeholder input.

Each scenario is described by one or more interventions. The scenarios used are described in section 4.

Summary data (number of households impacted and mean PCC) was output for each scenario and its component interventions for each company. These were circulated to each company to allow each company to review the interventions and provide feedback on whether there was any double counting of interventions between the scenarios and the companies' water resource plans. The results of that feedback are described in section 2.5.

The output from the deterministic stage are:

- Measured Household - Properties
- Unmeasured households - properties
- Measured Household - Population
- Unmeasured Household - Population
- Measured Household - Occupancy Rate
- Unmeasured Household - Occupancy Rate
- Measured Household - PCC
- Unmeasured Household - PCC
- Average household PCC

These are produced for each company, each year, for each scenario. These are taken forward to the stochastic PCC modelling phase.

5.2.2 Stochastic micro-component modelling

The stochastic modelling produces a PCC value for each property in the model. For each company 100,000 properties are modelled (50,000 unmeasured and measured).

First, a probability distribution is assigned to occupancy making it possible to produce household level occupancy values which have a mean occupancy equal to that using all data combined. Producing household level data in this way will allow individual homes to be modelled, producing the final PCC distributions which can be used to derive confidence intervals.

The basis for modelling PCC stochastically is predicated on an understanding of micro-component usage in the home (WC flushing, showering, clothes washing, drinking, etc.), conditional on meter status and occupancy.

At this point household level occupancy has been output from the model, therefore the first stage of the consumption model is to analyse a large number of individual unmeasured and measured household's micro-component data. Using this, we can calculate current and future PCC using a micro-component model. Each end-use is calculated using values for ownership, frequency of use and volume per use (O, V, F) which will differ by occupancy, and measured or unmeasured meter status. This deep understanding allows us to make assumptions about how each scenario will impact each element of water use in the home, which is important in the final stage of the model.

The basis for the model for household consumption (PHC) is:

$$PHC = \sum_{i=1}^{n} (O_i + V_i + F_i) + phr$$

Where:

O is the proportion of the households using the appliance or activity, per micro-component '*i*'

V is the volume per use for '*i*'

F is the frequency per use (per household) for '*i*'

phr is the household residual

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 will average household consumption.

The '*phr*' term represents the consumption that is not explained by the O, V and F parameters. This is the amount by which the model is calibrated in the base year. This assumes that future years' '*phr*' is proportionately the same as the base year, if this is not the case then there will be an additional error in the forecast that cannot be quantified.

Thus far, consumption will vary with changing occupancy and meter status, as well as varying within the parameters of the individual O, V and F micro-component distributions for each end use.

However, by varying the ownership, volume and frequency distributions based on the interventions identified in <section ref>, it is possible to output PCC distributions for each scenario revealing the effect on average household consumption, with an accompanying confidence level.

Building a stochastic model requires various assumptions about the micro-components, distributions, and scenarios. Firstly, the assumptions about the micro-components are set out in Table 12.

Table 12: Micro-component modelling assumptions

Assumption	Impact
Micro-components can be well described as well-known distributions	With the exception of losses and external use, the micro-components are assumed to be well described by probability distributions. This allows the mean and standard deviations to be altered in the scenarios but may not fully show the randomness of some micro-components.
Frequency of use only depends on occupancy	Mean frequency of use has been determined per micro-component.
Volume per use varies per household, and is not fixed per micro-component	A single household may have differing toilet flush volumes; however, this means that multiple appliances can be modelled, and reduces the probability of over-sampling from the extremes of the distribution
The OVF distributions do not change in the scenarios, the mean and standard deviations do.	The micro-components are assumed to behave in the same way probabilistically, when considering scenarios, however they may have altered means and different variance.
All measured properties can be treated as one group	The model currently only considers measured and unmeasured populations due to the high-resolution data available. However, optants and compulsorily metered properties may behave differently, which are not modelled here.
Losses are assumed to be independent of occupancy	This is largely true, however larger occupancy households are likely to be larger homes with more appliances. Having more appliances may mean a higher probability of an internal leak, which is not currently modelled.
External use is assumed to be independent of occupancy	Within the data set analysed to derive the OVFs, this seems to be the case. However, if external use is related to occupancy, then this is not currently modelled.

Selecting the distributions for ownership, volume and frequency (for each micro-component and billing type) was finalised only after analysis of micro-component data taken from real properties logged over a number of weeks. This enabled the distributions parameters to be optimised, as well as their dependency on other variables known.

For example, it was discovered that frequency of use (F) is dependent on occupancy and is not a linear relationship for lots of micro-components. Therefore, this distribution has been adapted to include its dependence on the number of occupants. This increases the variability in the outputs, much like what is expected to be seen in reality.

Table 13 shows the micro-components used in the model, as well as the distribution used to describe the volume per use. Note that the distribution of ownership is binomial for all micro-components, and the frequency is an adaptation of the Poisson distribution which is reliant on occupancy. Finally, occupancy is modelled as a Poisson distribution.

Table 13: Micro-component distributions used in the model

Micro-component	Volume
Tap	Lognormal
Toilet	Normal
Bath	Normal
Shower	Lognormal
Washing Machine	Normal
Dishwasher	Normal
External use	Custom
Losses	Custom

When modelling occupancy, a Poisson distribution was used, with mean occupancy for the area/company used as the distribution variable.

The model was built in the programming language R and requires the following inputs in order to produce an output distribution:

- The number of properties to be modelled each year (measured and unmeasured households).
- The mean occupancy for measured and unmeasured households each year.
- The change in each micro-component in response to the water efficiency measures under each scenario.

The outputs from the modelling process are:

- PCC pathways for the current ambition and each of the scenarios.
- PCC distributions for the start year and the end year of the scenarios.

6 Modelling results

This section describes presents the results of the modelling carried out for this project, showing:

- The per capita consumption savings associated with each scenario and intervention
- The costs-benefit for each scenario and intervention
- The marginal costs for each scenario and intervention

The results show that government -led interventions, particularly a mandatory water labelling scheme associated with minimum standards for fittings regulations, reduce demand by the largest amount.

Smart metering interventions, which could be led by government or water companies, are the next most effective ways of reducing consumption. Innovative tariffs will provide further benefits to smart metering.

Metering and labelling work well because, over time, they will deliver reduced consumption across all households.

These interventions are generally cost beneficial and have some of the lowest marginal costs.

Sensitivity analysis of the cost benefit analysis and marginal costs demonstrates that the central results presented in this section are robust and are not sensitive to small to moderate variations in the estimates and assumption made here.

6.1 PCC results

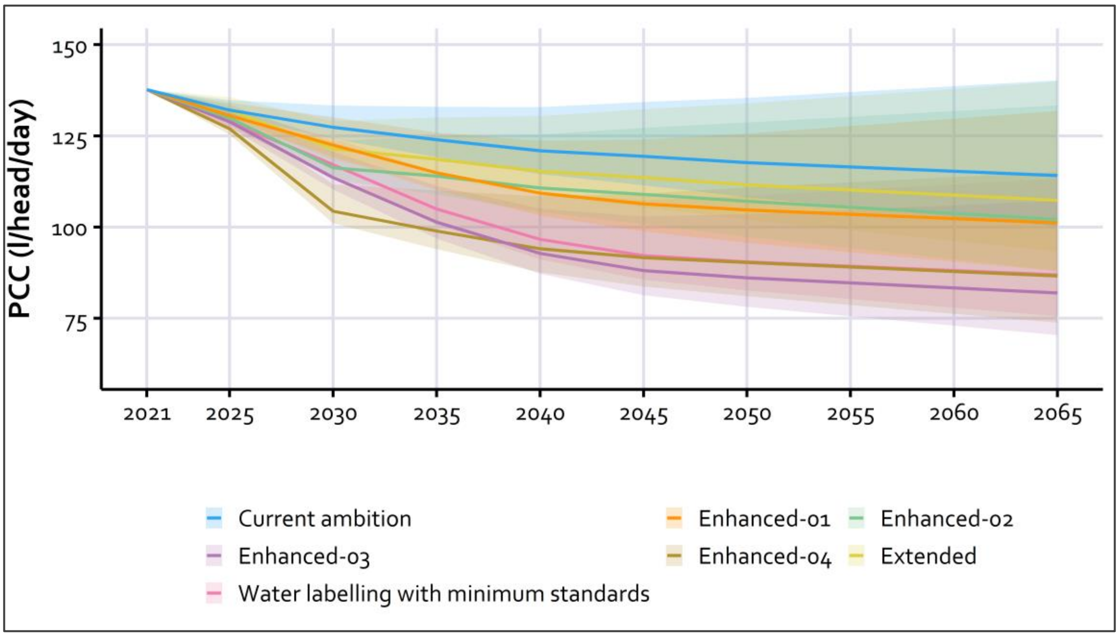
Figure 9 shows the PCC pathways for the current ambition and each of the 6 scenarios as a mean PCC for England and Wales from 2021 through to 2065. The shaded area around each of the lines represents the total uncertainty in the modelled outputs.

The uncertainty has been calculated by combining the uncertainties from the following sources:

- Model error;
- Covariance between frequency of use and occupancy (in the model);
- Intervention uncertainties (from Table 5); and
- Covariance between interventions and model error (specifically, the micro-components)

The errors have been combined using error propagation theory and are non-symmetric in nature. This is due to the precaution that the interventions are likely to result in a reduced saving as opposed to a higher saving, per property. Therefore, the uncertainties in the following plots are skewed towards a higher PCC.

Figure 9: Summary of modelled mean PCC pathways for England and Wales



The same information is presented in tabular form in Table 14.

Table 14: PCC values for each scenario

	PCC (l/head/day)				
Scenario	04/2021	**04/2025**	**04/2035**	**04/2045**	**04/2065**
Current ambition	137.7	132.1	124.0	119.4	114.2
Extended	137.7	132.0	118.6	113.6	107.3
Enhanced-01	137.7	130.6	114.9	106.4	101.2
Enhanced-02	137.7	129.9	114.0	109.0	107.1
Enhanced-03	137.7	128.9	101.4	88.1	81.9
Enhanced-04	137.7	127.0	99.0	91.6	86.6
Water labelling with minimum standards	137.1	128.9	105.0	92.2	86.9

For each scenario, three graphs are presented below:

- A waterfall plot showing which interventions contribute to the savings achieved in each scenario, and by how much. These plots order the interventions by their standalone cost-benefit ratio, as presented in section 6.2. The plots also present the confidence grade for each intervention, indicating the likely reliability and accuracy of the savings presented.
- A time series plot of the mean PCC for the current ambition and the new scenario. This shows how the PCCs vary over time in relation to the current ambition. This graph also shows the uncertainty around the mean with the shaded area around each line.
- A distribution of PCC values for the start year (2021), the current ambition in 2065 and the new scenario in 2065. This shows how the shape of the PCC distributions changes as a result of the new scenario compared to the current ambition. This effectively represents the distribution of PCC across the population.

Graphs for each scenario are plotted individually against the current ambition in Figure 10 to Figure 27. When uncertainty is accounted for, it is clear that more ambitious scenarios have greater likelihood of delivering long term reductions in consumption, compared to less ambitious ones. For example, the uncertainty associated with the Extended scenario (Figure 10) shows a significant likelihood that the outcome will be greater than the forecast mean savings from the current ambition.

In contrast, there is less 'overlap' between the uncertainties associated with water labelling (Figure 19) and the Enhanced-03 scenario (Figure 22), indicating that it is more likely that these scenarios will deliver reductions in PCC.

Figure 10: PCC pathway for the Extended scenario – waterfall plot

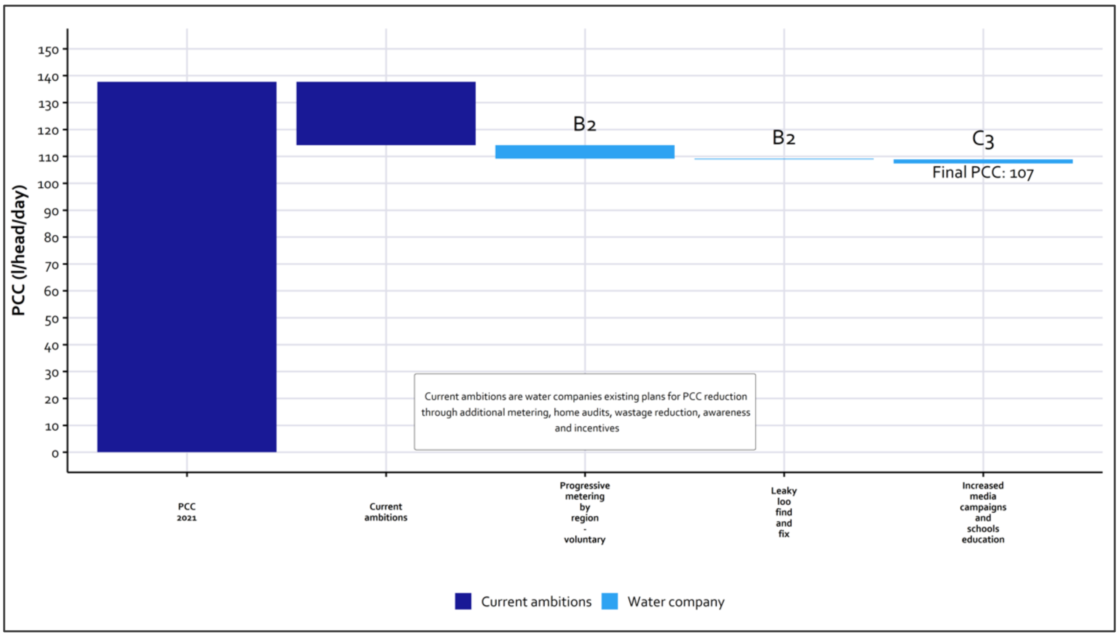


Figure 11: PCC pathway for the Extended scenario – time-series plot

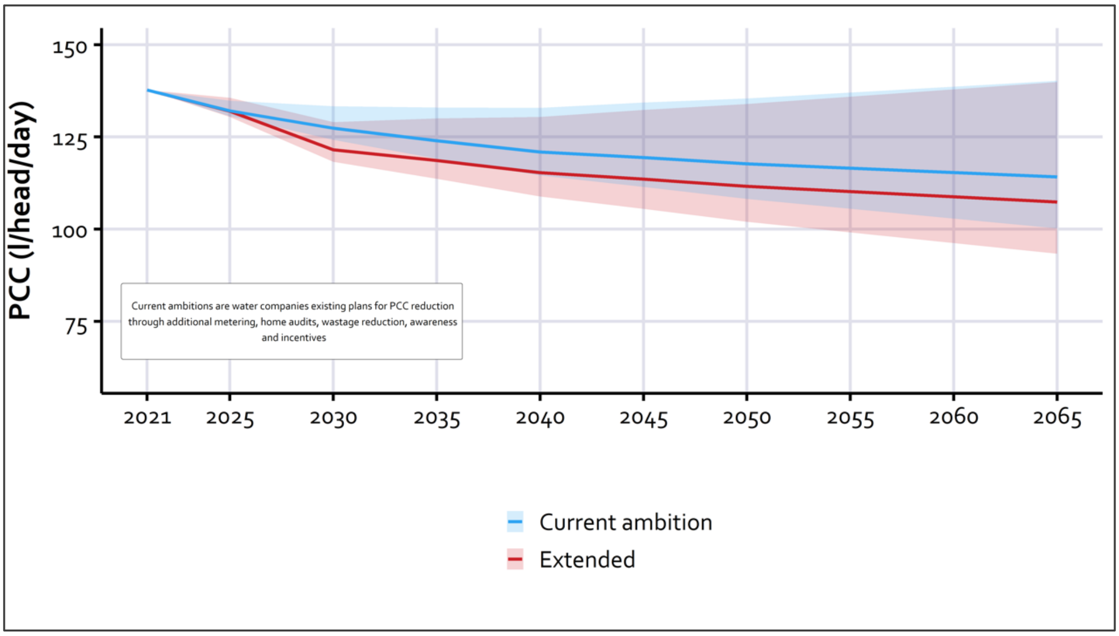


Figure 12: PCC distributions for Extended scenario versus current ambition

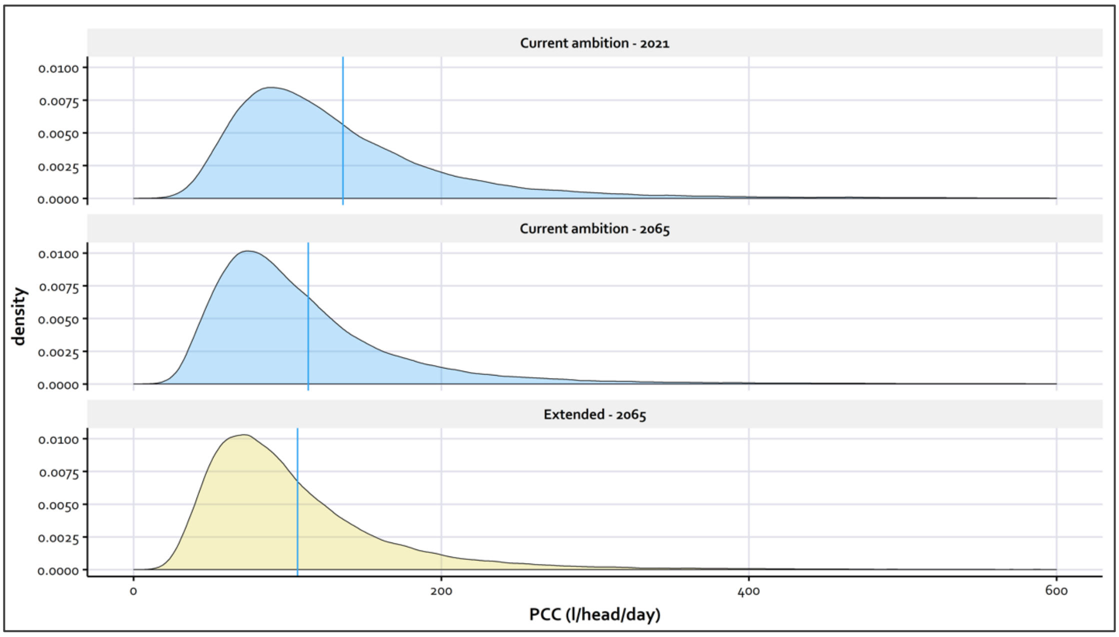


Figure 13: PCC pathway for the Enhanced-01 scenario – waterfall plot

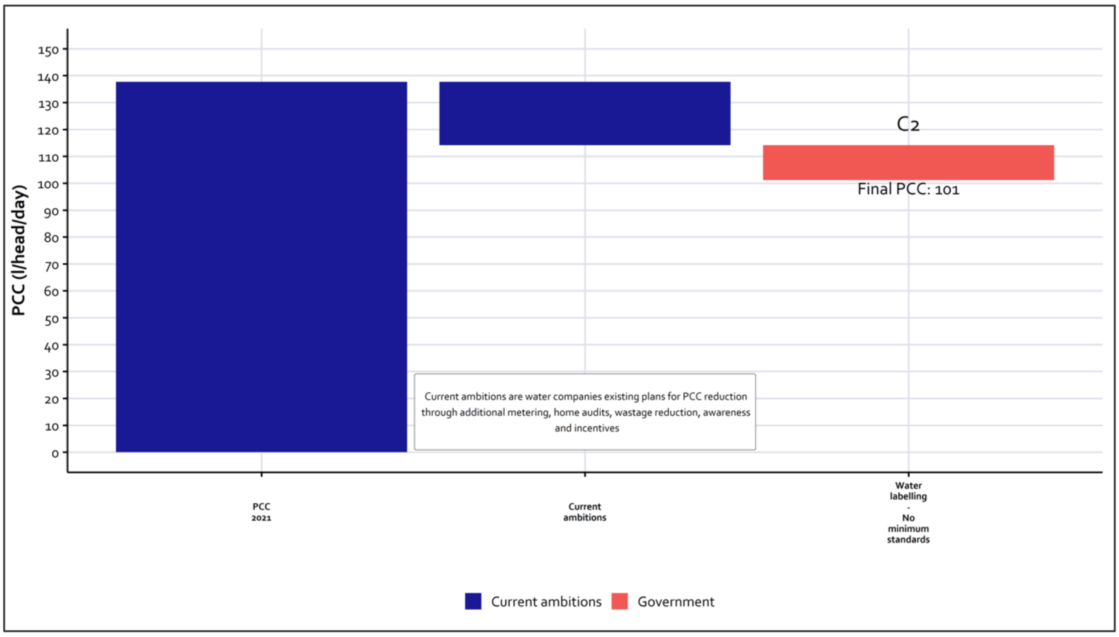


Figure 14: PCC pathway for Enhanced-01 scenario – time-series plot

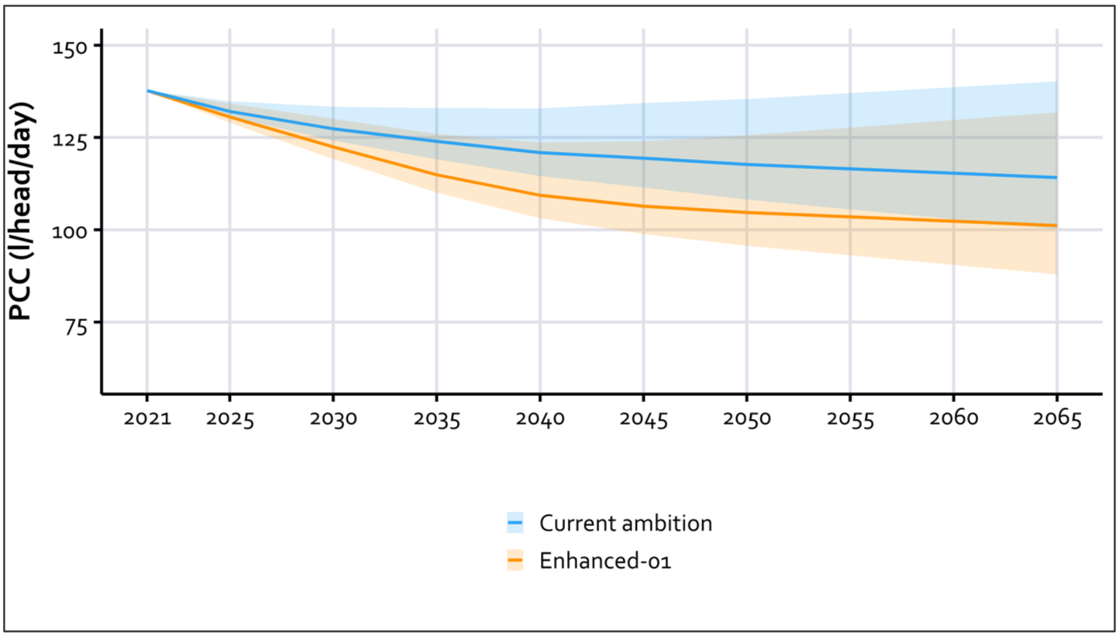


Figure 15: PCC distributions for Enhanced-01 scenario versus current ambition

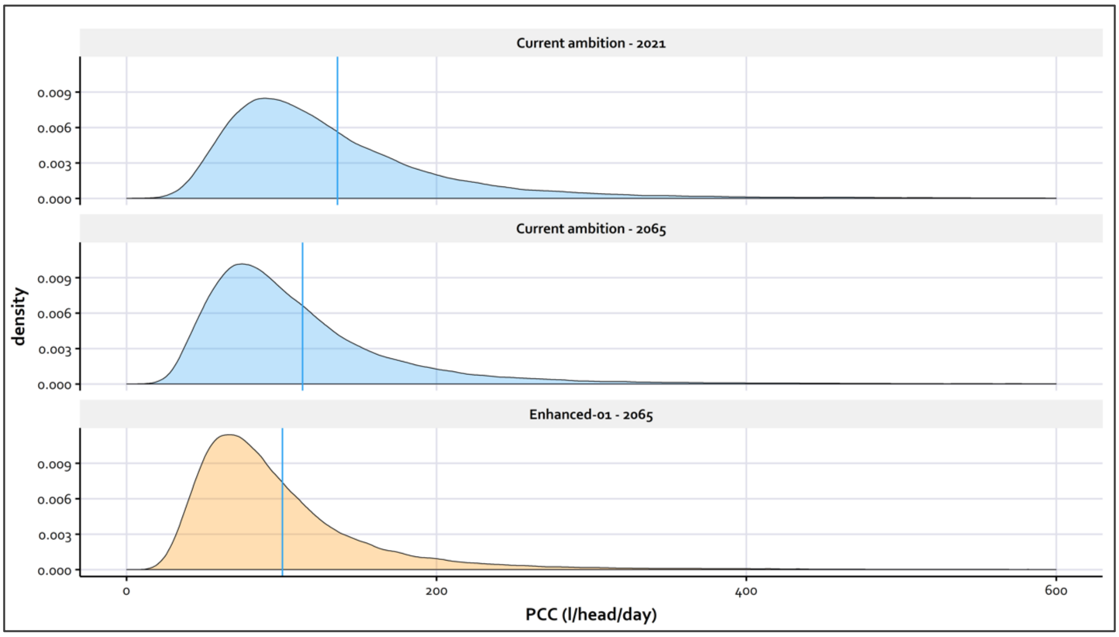


Figure 16: PCC pathway for the Enhanced-02 scenario – waterfall plot

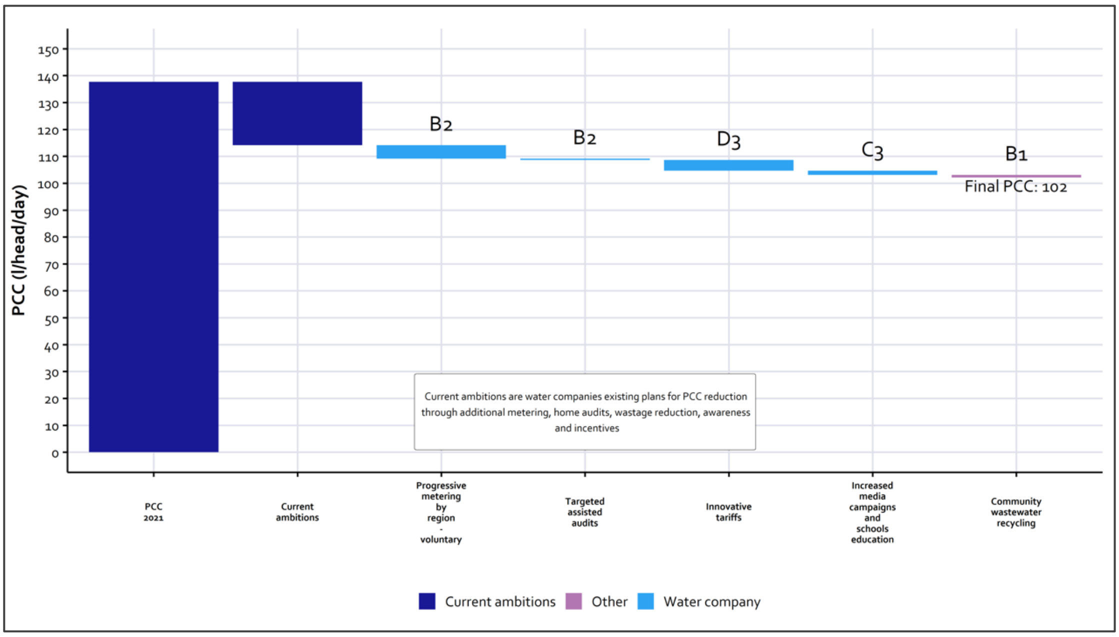


Figure 17: PCC Pathway for the Enhanced-02 scenario – time-series plot

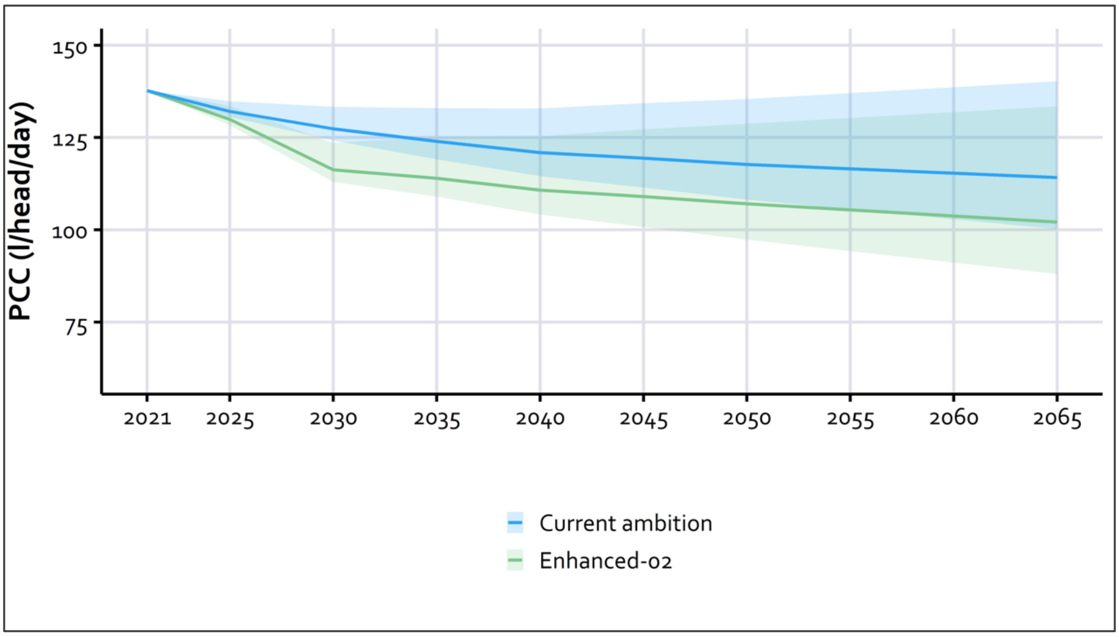


Figure 18: PCC distributions for Enhanced-02 scenario versus current ambition

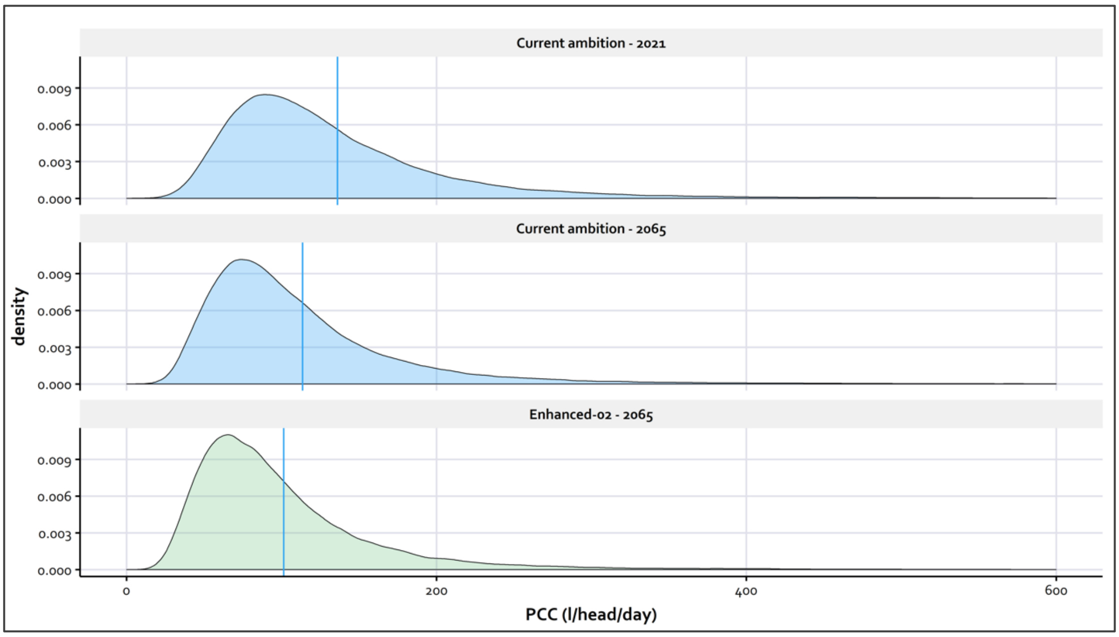


Figure 19: PCC pathway for the Water labelling only (with minimum standard) scenario – waterfall plot

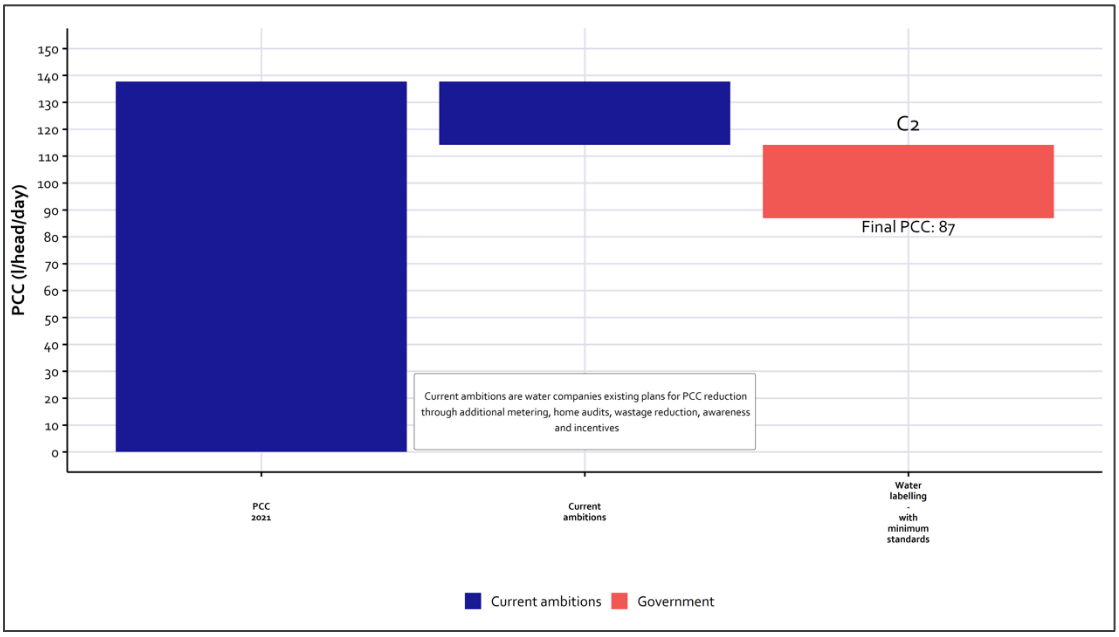


Figure 20: PCC Pathway for Water labelling only (with minimum standards) scenario – time-series plot

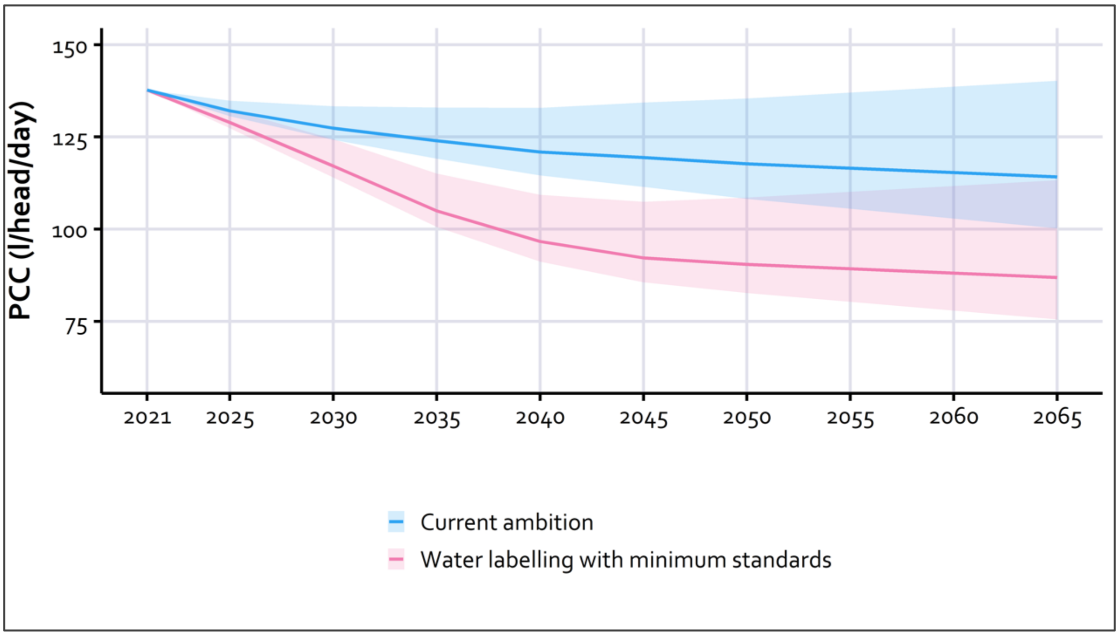


Figure 21: PCC distributions for Water labelling only (with minimum standards) scenario versus current ambition

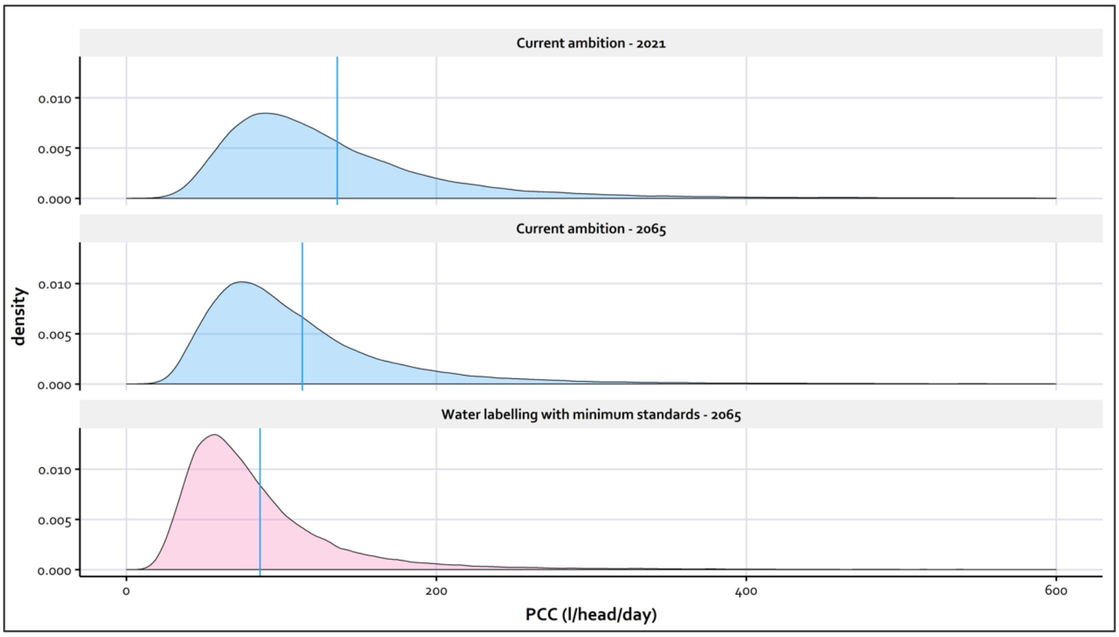


Figure 22: PCC Pathway for the Enhanced-03 scenario – waterfall plot

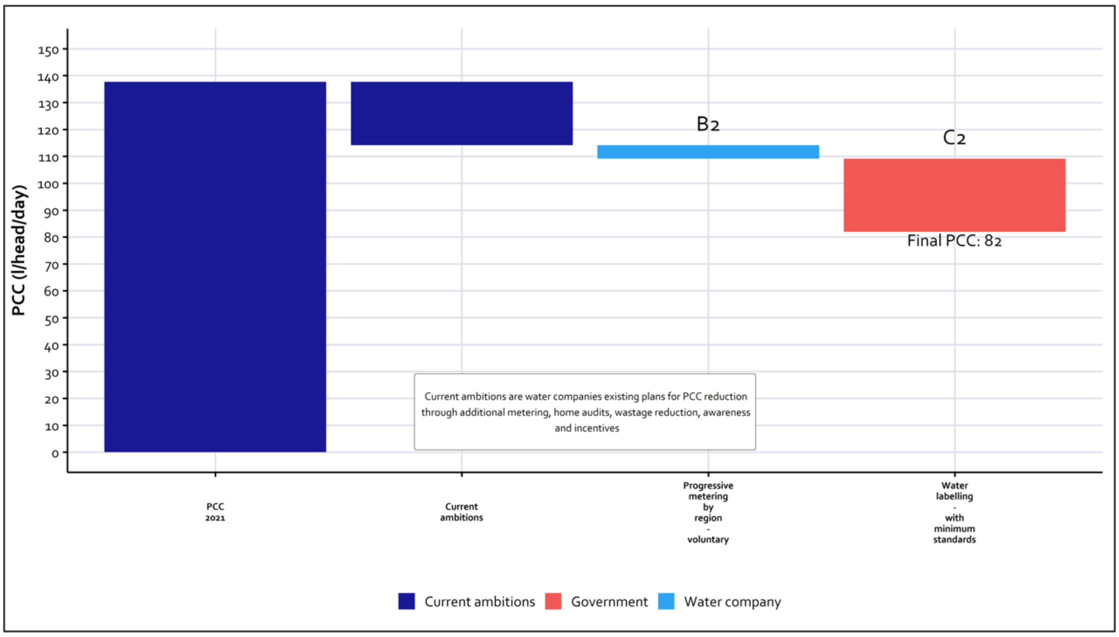


Figure 23: PCC Pathway for Enhanced-03 scenario -time-series plot

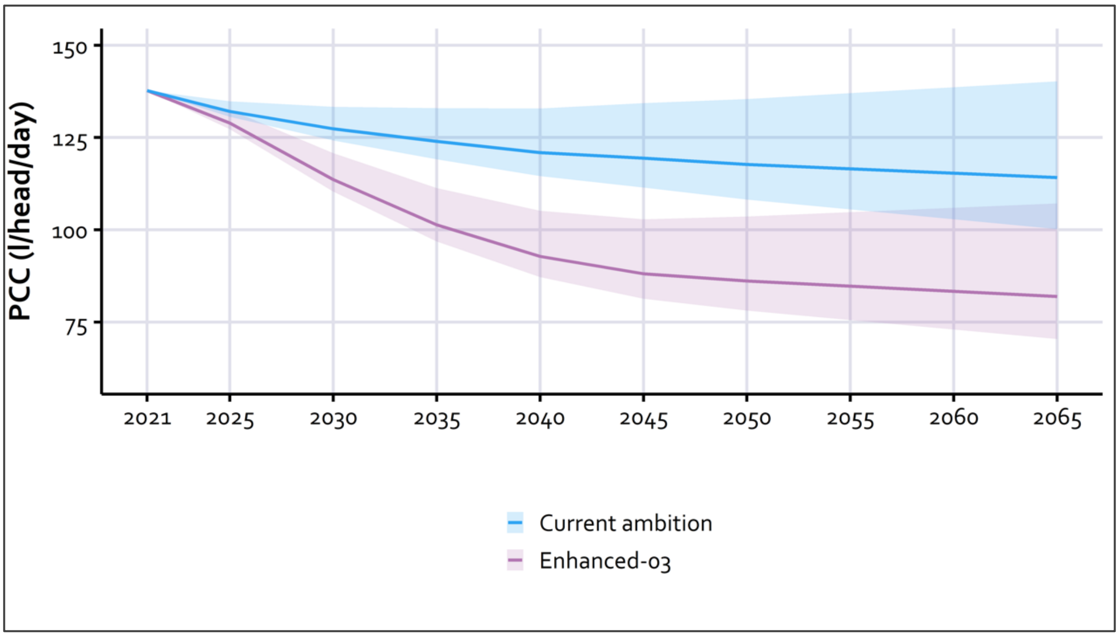


Figure 24: PCC distributions for Enhanced-03 scenario versus current ambition

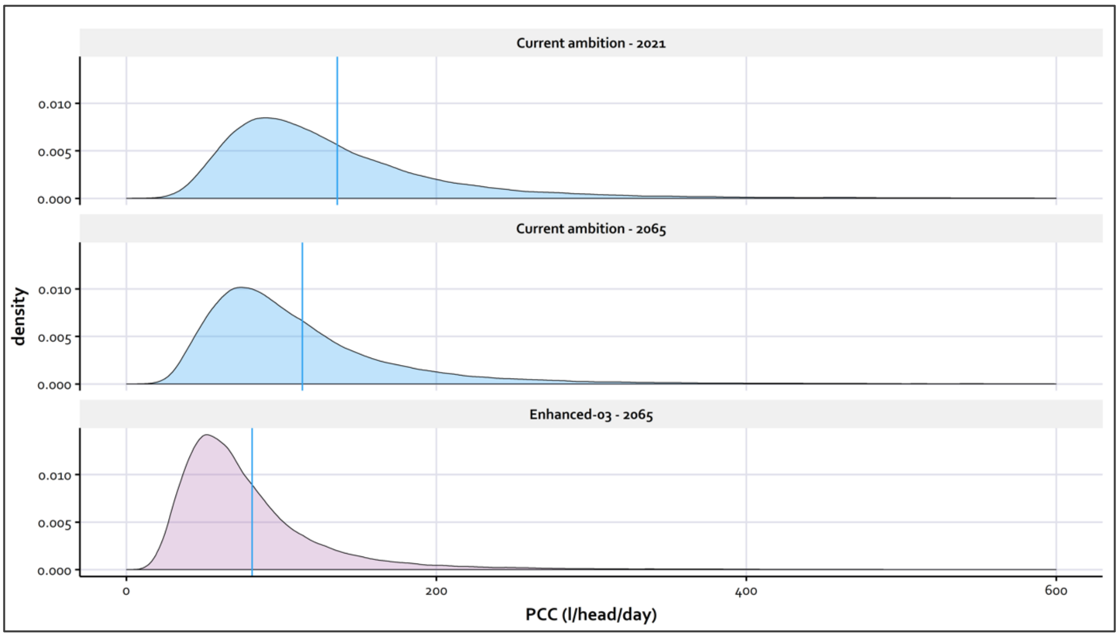


Figure 25: PCC Pathway for the Enhanced-04 scenario – waterfall plot

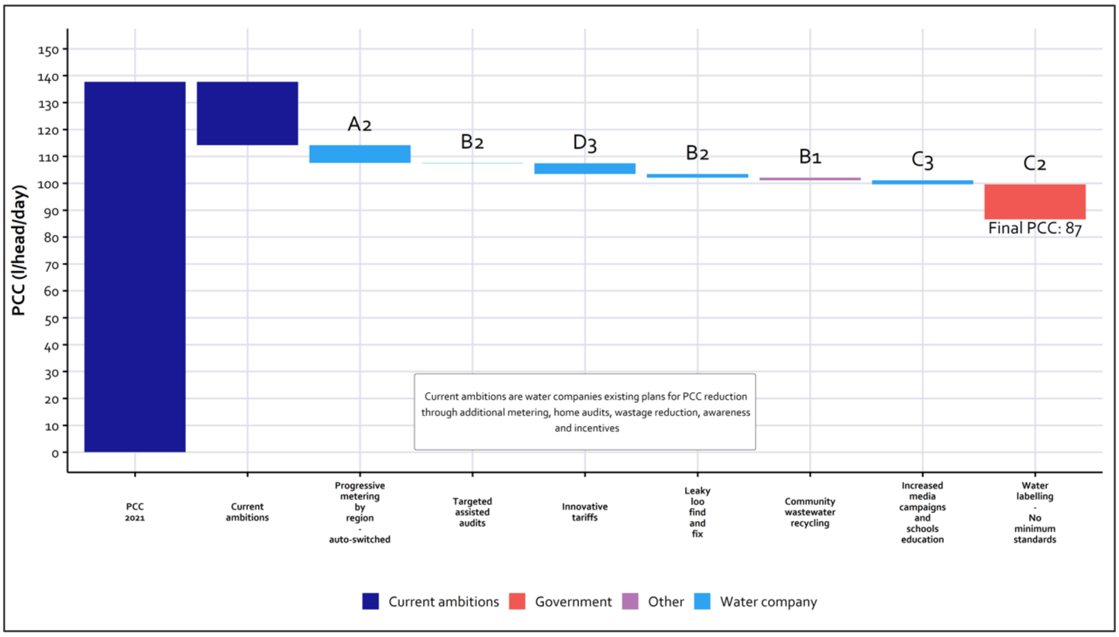


Figure 26: PCC Pathway for Enhanced-04 scenario -time-series plot

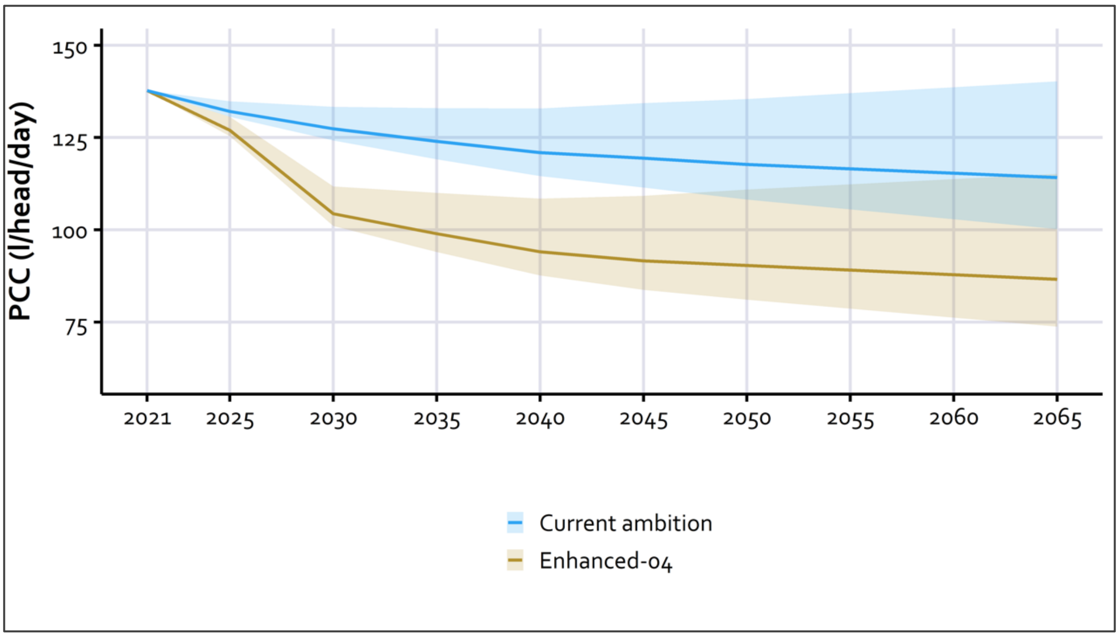
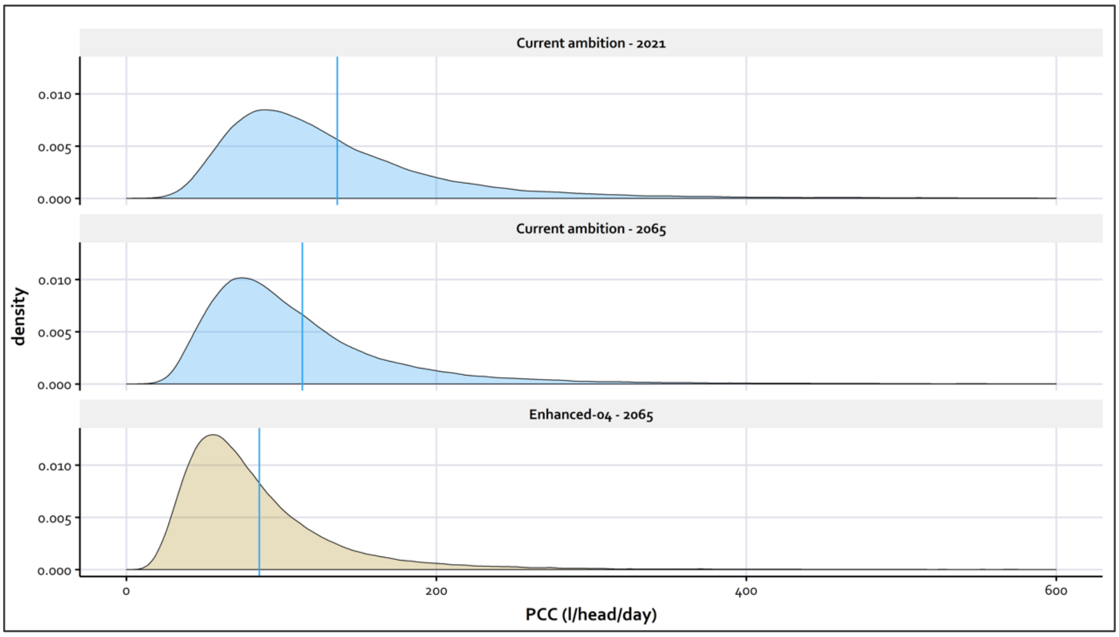


Figure 27: PCC distributions for Enhanced-04 scenario versus current ambition



6.1.1 Interventions

The reduction in consumption from each intervention is presented in Figure 28. Interventions are presented in order of their estimated savings. This 'waterfall' plot includes interventions that are mutually exclusive and dependent, so the total reduction in consumption that is shown from left to right across the graph cannot be achieved in reality. It does show the relative PCC reduction for every intervention and alongside the confidence grade.

Figure 29 to Figure 31 show waterfall plots for government-led, water company-led and 'other-led' interventions respectively. Even though these plots also contain mutually exclusive interventions, they can be compared to provide an overall view of the size of savings available from each group. Government-led interventions provide the biggest reduction in consumption, then water industry-led interventions, then finally interventions led by others.

Figure 28: PCC reduction for all interventions

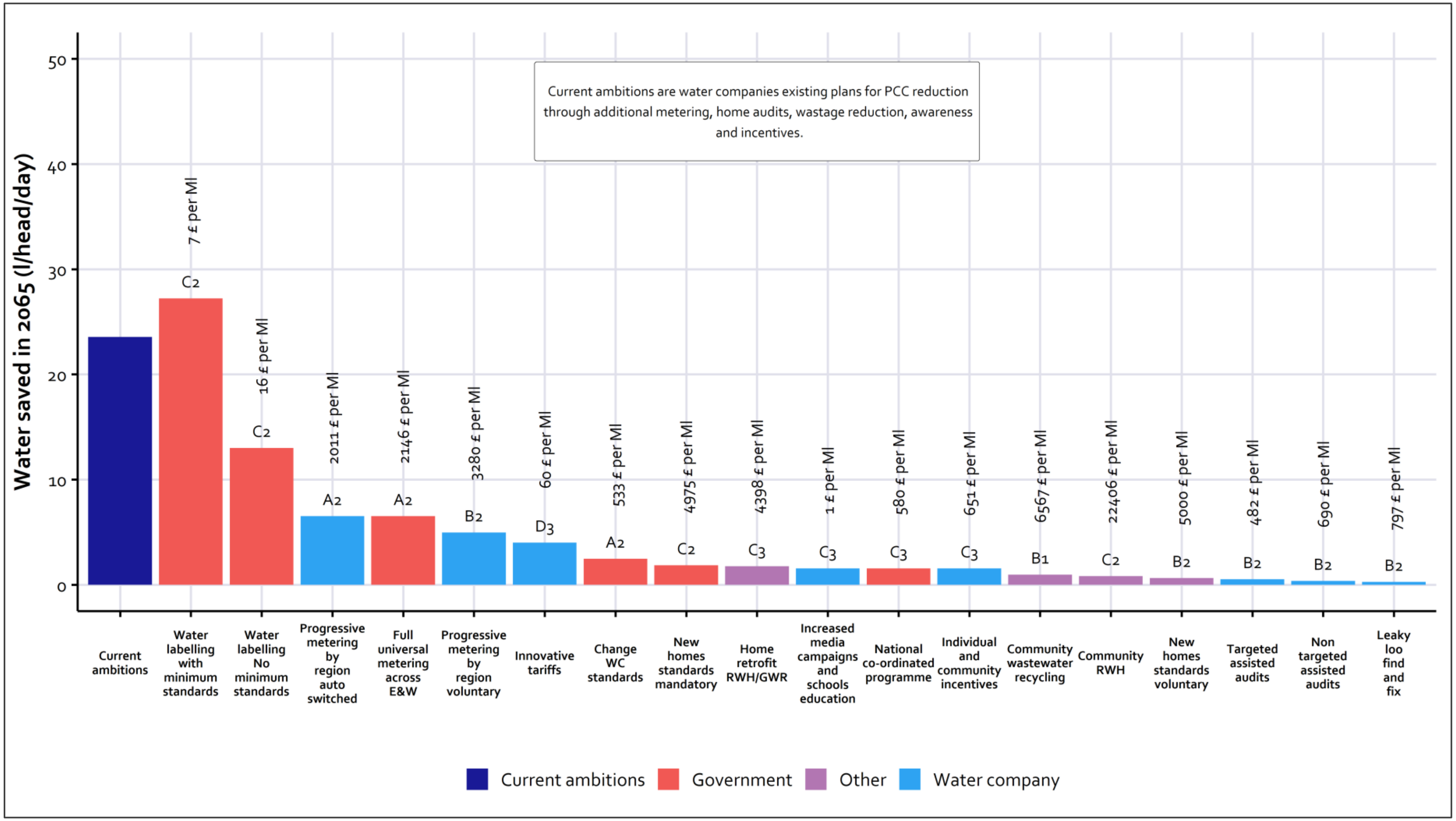


Figure 29: PCC reduction for government interventions

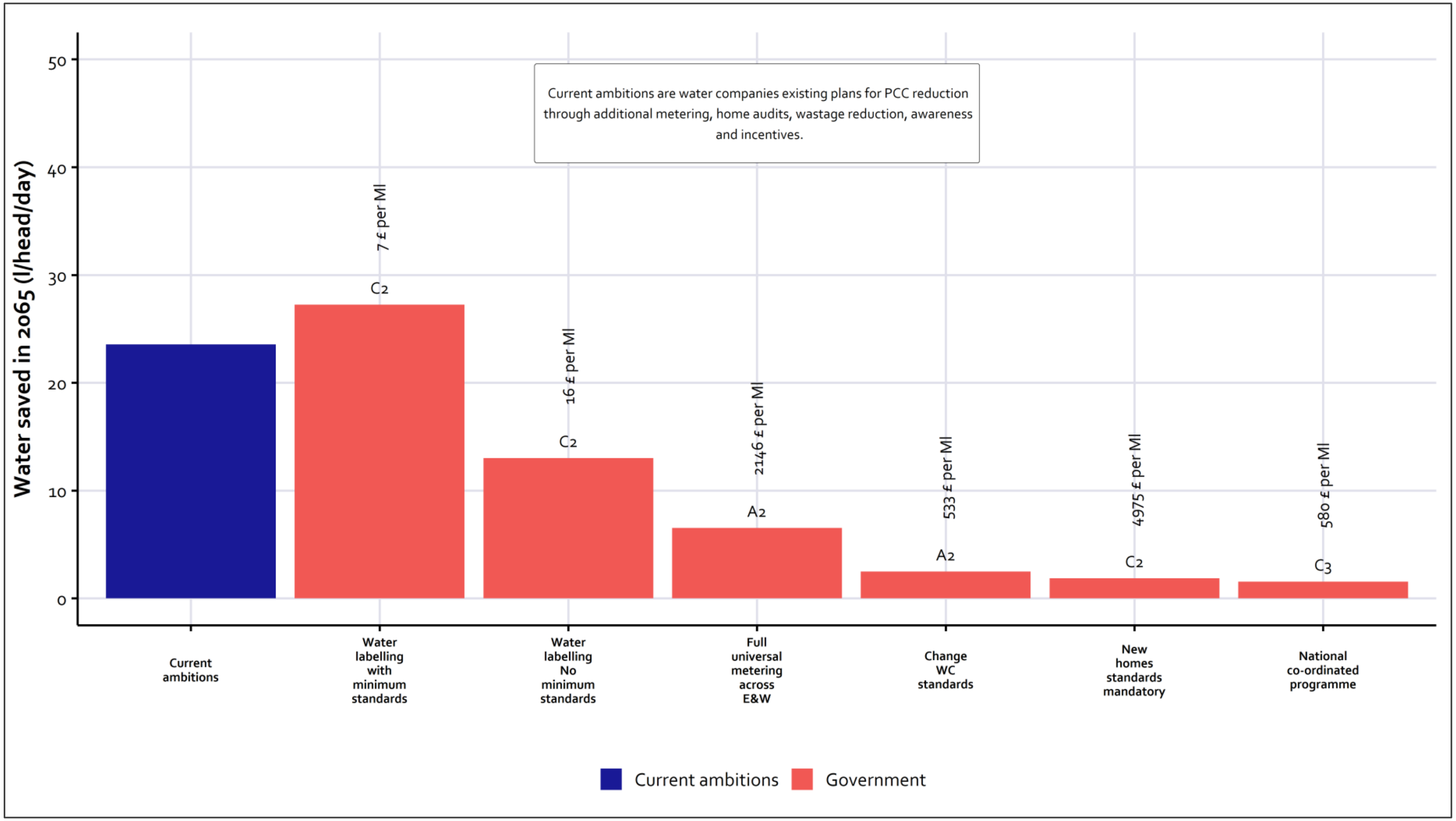


Figure 30: PCC reduction for water company interventions

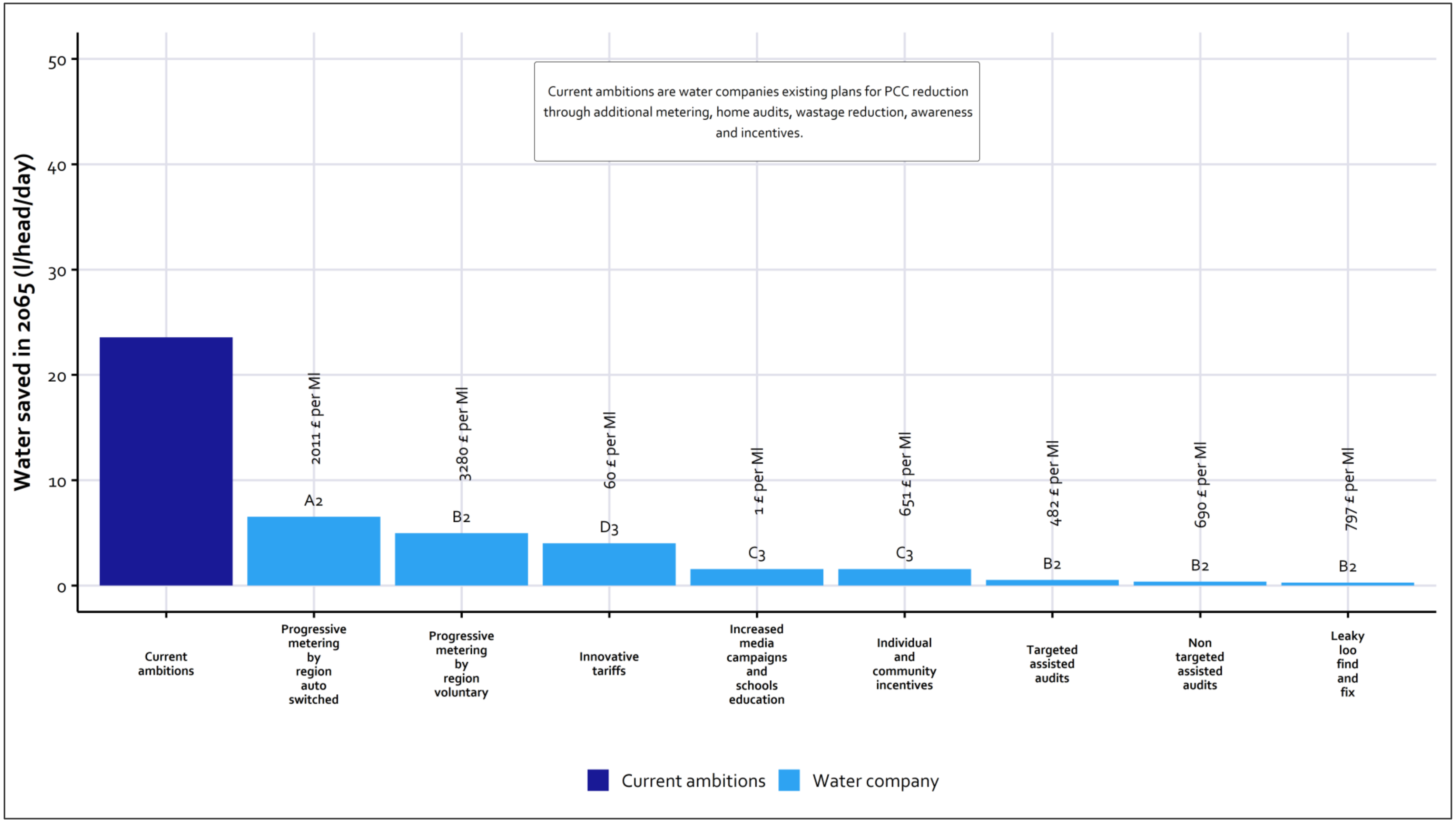
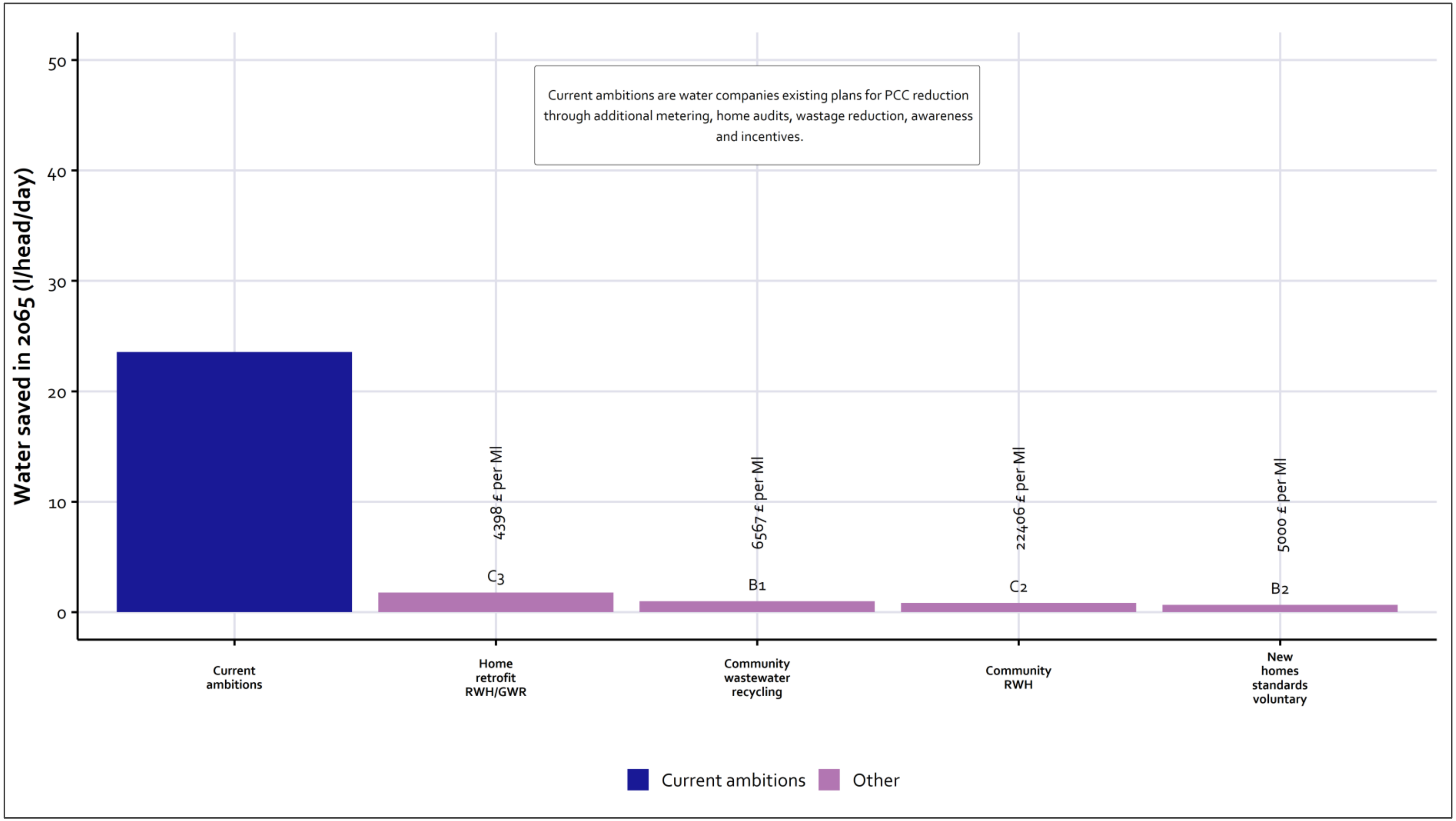


Figure 31: PCC reduction for other interventions



6.2 Cost-benefit analysis

6.2.1 Input data

The cost-benefit analysis assesses the net benefit of the set of PCC reduction scenarios described in section 4 (Table 11). The objective of the analysis is to present an England and Wales view of the relative performance (ranking) of the scenarios, in terms of monetised costs and benefits (i.e. net present value). Costs reflect the resource costs (capex and opex) associated with interventions. They are estimated at the individual intervention level and aggregated to the national level based on the composition of each scenario. Social welfare benefits are estimated at the scenario level in-line with the calculated reduction in national average PCC. The main data inputs for estimating costs and benefits in terms of the change in PCC over time, the number of properties impacted by interventions, and the water saving against the current ambition baseline come from the modelling approach described in section 5.

Table 15 outlines the principle components of the aggregate cost and benefit estimates for each scenario.

Table 15: Cost-benefit analysis – scope of aggregate costs and benefit estimates for each scenario

Component	Scope	Data
Capex	Devices, installation, set-up, fit-out, etc.	Number of. properties impacted Unit costs per intervention
Opex	Meter reads, analytics, evaluation, campaign, etc.	Properties impacted per year Unit costs per intervention
Water savings	Mix of environmental and social outcomes resulting from reduced household consumption of water	Customer base Marginal benefits calculated from Ofwat IAP – Table 7
Carbon emissions (CO_2e)	Reductions in operational emissions (water company pumping and treatment) and household consumption of energy (cold and hot water use)	Properties impacted per year CO_2e emissions Non-traded price of carbon schedule

Note that carbon 'costs' of interventions – i.e. emissions arising from construction (e.g. embodied) and operation (e.g. vehicle usage) – are not accounted for in the analysis. Readily available data is inconsistent and highly variable, as highlighted in section 3.4.2. Therefore, it has not been possible to estimate changes in these carbon costs in emissions relative to the current ambition baseline.

Deferred investment benefits are also excluded from the analysis (section 3.5.2. Appropriately accounting for reduced supply-side water resource investments requires an assessment of the supply-demand balance at the water company level, which is beyond the scope this project. Estimated benefits for each scenario can therefore, to a certain extent, be interpreted as conservative, since for some regions water savings by households will delay the need for capex and opex for new water resource interventions.

6.2.2 Cost benefit analysis results

Table 16 summarises the cost benefit analysis (CBA) results in terms of net present value (NPV) over a 47-year period for the six scenarios, comparing aggregated capex and opex to social welfare benefits. Benefits associated with reduced carbon emissions are excluded. These are presented as part of the sensitivity testing (section 6.2.3). Costs and benefits are assessed over a 47-year time horizon commencing in 2019 (year 0) running through to 2065 (year 46) and using the HM Treasury standard declining long-term discount rate (3.5% for years 0-30; 3.0% for years 31-46)[31]. All monetary values are reported in present value (PV) terms in current prices (2019).

Table 16: Cost benefit analysis results

Scenario (2065 PCC)	Interventions*	PV benefits	PV costs	NPV	CBA rank
Extended (107 l/h/d)	Smart metering (vol. switching) Leaky loo fix Increased media campaigns	£1,030m	£5,019m	-£3,989m	5
Enhanced-01 (101 l/h/d)	Water labelling (no min. standards)	£1,819m	£68m	£1,752m	2
Enhanced-02 (102 l/h/d)	Smart metering (vol. switching) Innovative tariffs Target audits CWR Increased media campaigns	£1,871m	£6,519m	-£4,648	6
Water labelling only (87 l/h/d)	Water labelling (with min. standards)	£3,936m	£61m	£3,875m	1
Enhanced-03 (82 l/h/d)	Smart metering (vol. switching) Water labelling (with min. standards)	£4,483m	£4,873m	-£391m	3
Enhanced-04	Smart metering (auto-switching) Innovative tariffs	£4,706m	£8,046m	-£3,340m	4

Scenario (2065 PCC)	Interventions*	PV benefits	PV costs	NPV	CBA rank
(87 l/h/d)	Target audits Leaky loo fix Water labelling (no min. standards) CWR Increased media campaigns				

Notes: *Abbreviated summary – see Table 10 for full description. All values rounded to nearest £1m. Profiles of discounted costs, discounted benefits, and net benefit over the time horizon for the analysis are provided in Annex 1

Overall, the water labelling only (with minimum standards) scenario is estimated to produce the greatest net social benefit (NPV = approx. £3.9bn). Whilst the scenario does not generate the greatest total benefit (PVB = approx. £3.9bn), its comparatively lower total cost (PVC = approx. £0.06bn) means that it is the best performing by a significant margin on a net benefit basis.

In contrast, Enhanced 03 (PVB = approx. £4.5bn) and Enhanced 04 (PVB = approx. £4.7bn) are estimated to generate higher total benefits due to greater reductions in PCC, but at substantially greater cost (PVC = approx. £4.9bn and £8.0bn, respectively). These scenarios are ranked 3 and 4, respectively in terms of NPV, but there is an order or magnitude different in the net benefit (NPV = approx. -£0.4bn vs. -£3.3bn).

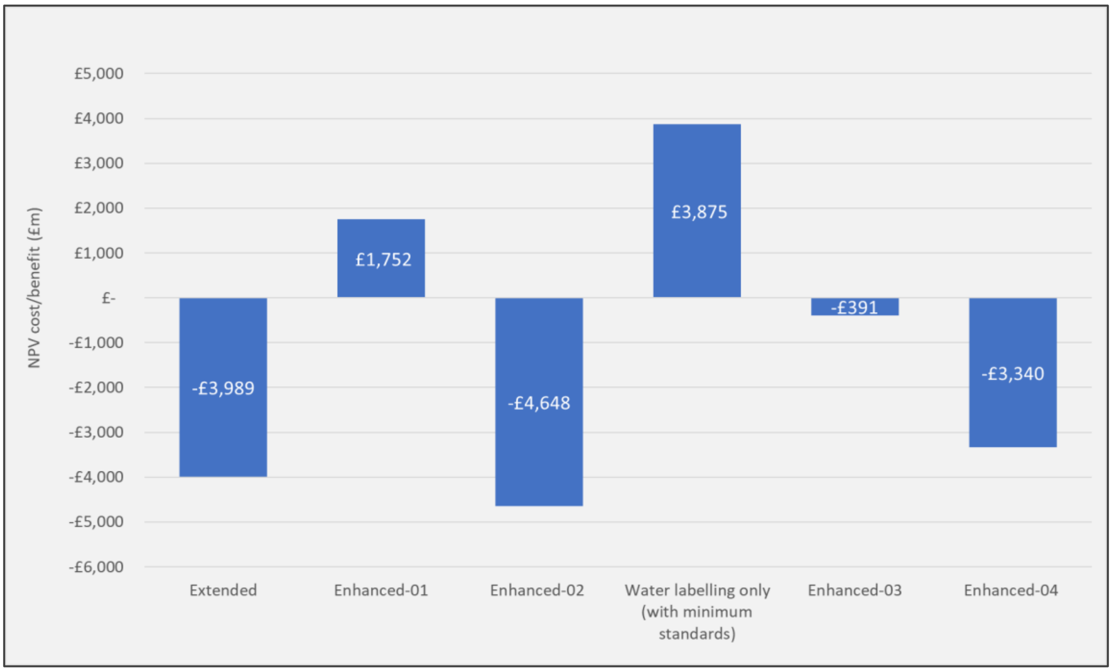
Enhanced 01 (water labelling without minimum. standards) is the second-ranked scenario in terms of net-benefit (NPV = approx. £1.8bn). It has marginally higher aggregate cost but achieves roughly 50% of the benefit of the labelling scenario with minimum standards (PVB = approx. £1.8bn).

In comparative terms, £1 of expenditure for the Enhanced 01 scenario return approx. £27 in benefits; for the water labelling only (with min. standards) scenario, £1 of expenditure returns approx. £64 in benefits.

The two worst performing scenarios are Extended (NPV = approx. -£4.0bn) and Enhanced 02 (NPV = approx. -£4.6bn). In monetary terms, the benefits that are delivered by these scenarios are around 1/5 to 1/3 of the costs incurred.

Figure 32 summarises the NPV ranking for the six scenarios, providing a visual comparison of the net benefit estimates.

Figure 32: Cost benefit analysis results for PCC reduction scenarios (excluding carbon)



6.2.3 Sensitivity analysis

Sensitivity analysis of the cost benefit analysis and marginal costs demonstrates that the central results presented in this section are robust and are not sensitive to small to moderate variations in the estimates and assumption made here.

The main parameters that can be considered for sensitivity testing in the CBA include the savings estimates for interventions, scenarios, the current ambition baseline and their profile over time, cost and benefit values, the time horizon for the analysis, and the discount rate.

Uncertainty in relation to PCC reductions and the effectiveness of individual interventions in delivering water savings is addressed in the modelling approach (Section 5.2; Table 4), whilst aspects such as time horizon and discount rate are pre-determined, in relation to the scope of the analysis and HM Treasury Green Book guidance[31]. For costs and benefits, however, it is useful to consider a set of sensitivity tests in order to explore how the CBA results change with different assumptions. The following sensitivity tests were carried out and are reported in the following sections:

6.2.3.1 Inclusion of carbon saving benefits for all scenarios

6.2.3.2 Switching values for marginal benefit estimates for negative NPV scenarios

6.2.3.3 Effect of declining marginal benefit on water labelling scenario NPV

6.2.3.4 Switching values for scenario costs

6.2.3.1 *Inclusion of carbon saving benefits for all scenarios*

The inclusion of carbon saving benefits due to reductions in operational emissions (water company pumping and treatment) and household consumption of energy (cold and hot water use) is treated as a sensitivity in the analysis since there are a number of caveats associated with the analysis:

- It is not possible to estimate the net carbon impact for each scenario because reliable data for embodied carbon (materials) and operational carbon (e.g. vehicle use) emissions over the baseline are not available (Section 3.4.2). Therefore, estimates of carbon saving benefits are likely to be over-estimated, but it is not possible to quantify the scale of the uncertainty.
- It has also not been possible to account for the expected decarbonisation of energy generation at the national level within the time horizon for the analysis (47-years). Emissions factors that applied to estimate the carbon intensity of water supply/treatment/use in the near term are unlikely to be appropriate over a longer term, especially given the Government's 2050 net zero emissions target. Within the analysis, however, the emissions factors are assumed to be constant over time, rather than trending down in line with national level greenhouse gas (GHG) targets. This is a further source of uncertainty that results in an over-estimate of carbon saving benefits for each scenario, but again, it is not possible to quantify the likely scale of the over-estimation.
- Some interventions will not result in reduced hot water consumption (e.g. leaky loos find and fix), however no differentiation is made in the assessment of benefits. This uncertainty however, is expected to have a less material impact on the over-estimation of benefits compared to those outlined above, due to the relative scale of water savings involved.

The carbon saving benefits should therefore be treated as indicative and subject to a greater level of uncertainty compared to the wider benefit estimates for reduced household consumption of water. The supplemental CBA results are reported in Table 17, which shows the addition of the present value benefits for carbon savings to the main results presented in Table 16.

Table 17: CBA results including estimated carbon saving benefits

Scenario	Present value benefits			PV costs	NPV	NPV rank
	Social and environmental	Carbon	Total			
Extended	£1,030m	£128m	£1,158m	£5,019m	-£3,861m	5
Enhanced-01	£1,819m	£5,640m	£7,459m	£68m	£7,391m	2
Enhanced-02	£1,871m	£256m	£2,128m	£6,519m	-£4,391	6
Water labelling only	£3,936m	£11,914m	£15,850m	£61m	£15,789m	1

Scenario	Present value benefits			PV costs	NPV	NPV rank
	Social and environmental	Carbon	Total			
Enhanced-03	£4,483m	£112m	£4,594m	£4,873m	-£279m	3
Enhanced-04	£4,706m	£771m	£5,477m	£8,046m	-£2,569m	4

Notes: All values rounded to nearest £1m.

Including indicative carbon saving benefits does not materially alter the conclusions of the CBA in terms of the relative performance of each scenario. The balance in terms of scenarios that show positive NPV (Water labelling only and Enhanced-01) versus negative NPV (Extended, Enhanced-02, Enhanced-03, Enhanced-04), remain unchanged.

This result is driven by the way in which carbon saving benefits are estimated, which is proportional to PCC reduction and number of properties impacted, and therefore the marginal benefits estimate. Hence, scenarios that have the least relative cost to implement but the greatest saving exhibit the greatest benefit values.

Note that whilst the Enhanced 03 and Enhanced 04 scenarios also feature water labelling within their set of interventions, the water saving benefits are attributed to the metering components in the modelling; which therefore reduces the effectiveness of the labelling intervention in terms of water saved at the national level. As a result, smaller carbon saving benefits are estimated.

6.2.3.2 Switching values for marginal benefit estimates for negative NPV scenarios

A switching value refers to the value an input variable would need to take for a scenario to switch from a negative NPV to a positive NPV, or vice versa. We can use switching values to determine the minimum marginal benefit value that would need to be assumed in order for the scenarios with negative NPV in Table 16 to switch to a net positive outcome .

Results are summarised in Table 18. All CBA parameters are unchanged except for the marginal benefit estimate applied to household water savings. Note that in the main CBA results, a value of £0.36 per l/h/d per household per year is used for the marginal benefit of reducing water consumption.

Table 18: Marginal benefit switching values for negative NPV scenarios

Scenario	Net present value (£m; 47 years) [Ranking]	Switching value (£/l/h/d/hh)	Percentage change in marginal benefit value*
Extended	-£3,989m [5]	£1.73	+381%
Enhanced-02	-£4,648 [6]	£1.25	+247%

Scenario	Net present value (£m; 47 years) [Ranking]	Switching value (£/l/h/d/hh)	Percentage change in marginal benefit value*
Enhanced-03	-£391m [3]	£0.39	+8%
Enhanced-04	-£3,340m [4]	£0.62	+72%

Notes: *Percentage change = [(switching value – 0.36)/0.36] x 100.

The smallest switching value is required for the marginal benefit estimate applied to the Enhanced 03 scenario. An 8% increase in the marginal value (+£0.03) would switch the scenario NPV from negative to positive (with all else equal). This value is within the calculated 95% confidence interval for the marginal benefit estimate (£0.12 to £0.59); hence the main analysis NPV result is somewhat marginal and only a small uplift in the assumed unit value for benefits is required for a conclusion that on balance, cost and benefits are least roughly equal.

For Enhanced 04, the switching value is £0.62, which is a 72% increase in the marginal benefit unit value. This value is just outside of the upper end of the calculated 95% confidence interval, but within the range of values observed across companies (see Figure 3). Therefore, whilst a more optimistic assessment of benefits is required in order for this scenario to return a positive NPV result, it is not outside of the observed range of values. In contrast, the calculated switching values for the Extended and Enhanced 02 scenarios are outside of the observed range of values, requiring uplifts of 381% and 247% respectively to balance costs and benefits.

6.2.3.3 Effect of declining marginal benefit on water labelling scenario NPV

Another important assumption in the assessment of benefits is that benefit values are constant over the time horizon for the analysis. In reality this is a fairly strong assumption, but an effect of declining marginal benefit as water savings increase is not quantitatively evidenced. Accounting for this effect to any degree would decrease the PV benefit estimates for each scenario, but since unit values are not differentiated between scenarios the relative rankings would not change.

Given this, it may instead be useful to demonstrate a selective sensitivity test for the water labelling only (with minimum standards) scenario, which is estimated to generate the greatest net social benefit based on the constant unit value assumption (Table 16). A declining marginal benefit value schedule is presented in Table 19, which is primarily specified using statistical results from the analysis of water company marginal benefit values (see Table 9). The schedule should be interpreted as illustrative and is specified only for the purposes of testing the materiality of the constant unit value assumption to the water labelling scenario.

Table 19: Illustrative declining marginal benefit value schedule

PCC (l/h/d)	Marginal benefit (£/l/h/d/hh)	Notes
130 – 139	£0.36	Mean value applied in main CBA

120 – 129	£0.24	Median value (Table 8)
110 – 119	£0.20	Interpolated
100 – 109	£0.16	Interpolated
90 – 99	£0.12	95% CI lower bound (Table 8)
80 - 89	£0.10	Extrapolated

Applying the declining marginal benefit value schedule reduces the water labelling scenario aggregate benefit estimate by approximately 62%. The estimated net present value, however, remains positive (NPV = approx. £1.4bn). Comparative results are summarised in Table 20. In the sensitivity case, £1 of expenditure for the scenario returns around £24 in benefits. This is compared to the 1:64 ratio for the constant unit value assumption.

Table 20: Sensitivity analysis of marginal benefits for water labelling with minimum standards

Sensitivity	Present value benefits	Present value costs	Net present value
Constant unit value MB = £0.36 per l/h/d per hh per year	£3,936m	£61m	£3,875m
Declining unit value MB = £ per l/h/d per hh per year schedule (Table 19)	£1,493m	£61m	£1,432m

Notes: All values rounded to nearest £1m.

6.2.3.4 Switching values for scenario costs

The main reason why water labelling (with minimum standards) is cost beneficial is the low operational cost of this intervention/scenario at £0.1 per household per year. Therefore, it is useful to determine the switching value for this cost, i.e. how much would this cost need to increase by for the costs of the intervention/scenario to exceed the benefits. This is presented in Table 21 for two instances: with a constant marginal benefit and with a declining marginal benefit.

Table 21: Opex switching values for water labelling only scenario

Marginal benefit	Net present value (£m; 47 years)	Switching value (£/hh/yr)	Percentage change in marginal benefit value*
Constant	£3,875m	£6.50	+6,400%
Declining	£1,432m	£2.35	+2,250%

In the case of a constant marginal benefit value – i.e. the main CBA result – the opex switching value is approximately £6.50. Therefore, in this instance, water labelling would result in an overall reduction in social welfare if there was an additional annualised cost of £6.50 per household per year, compared to the assumed value of £0.10 per household per year.

For the declining marginal benefit value sensitivity case, the opex switching value is approximately £2.35 per household per year.

This result can be interpreted in general terms in relation to the cost to householders, for example if retailers passed on any additional costs associated with more efficient products, or if there was a decrease in the level of utility experienced by households (e.g. if showers or washing machines were less effective, enjoyable, etc.).

Selected switching value results are shown for the mid-ranked Enhanced 03 and Enhanced 04 scenarios (Table 22). This focuses on the resource costs for the smart metering component of the scenarios, assessing the uniform percentage reduction in the unit values that are applied for capex and opex in the main analysis that would result in NPV = 0.

Table 22: Smart metering cost switching values for Enhanced 03 and Enhanced 04 scenarios

Scenario	Net present value (£m; 47 years) [Ranking]	Switching values - smart metering intervention	Reduction in unit value costs
Enhanced-03	-£391m [3]	capex: £219.30/hh opex: 9.46/hh/yr	10% reduction
Enhanced-04	-£3,340m [4]	capex: £63.35/hh opex: 2.73/hh/yr	76% reduction

For the Enhanced 03 scenario, a 10% reduction in capex and opex costs for progressive smart metering would result in roughly a balance of overall costs and benefits (i.e. NPV = 0) (all else being equal). This is a relatively modest reduction that could be consistent with efficiency savings over a widespread roll-out and implementation. For Enhanced 04 a significantly greater reduction is required in capex and opex costs (approx. 76%) to reach the same position in terms of NPV (all else equal).

6.3 Marginal costs

Marginal abatement cost (MAC) calculations show the effectiveness of interventions in terms of the cost per total volume of water saved over the time horizon of the analysis in pounds per megalitre (£/Ml). They are calculated with the following parameters:

- Time horizon: 47-years
- Intervention cost (£): whole life cost (CAPEX + OPEX); present value, 47-years
- Intervention saving (£): none
- Water saved (Ml): total water saving over 47-years; discounted).

6.3.1 Scenarios

Marginal costs for each scenario are presented in Table 23. The scenarios with the lowest marginal costs are Enhanced-01 (which only includes the water labelling with no minimum standards intervention) and the water labelling with minimum standards scenario/intervention. Enhanced-03 also includes water labelling with minimum standards, combined with voluntary progressive metering. This approach delivers the largest savings of the scenarios presented in this report: over ten billion litres of water (discounted) over 47 years for the lowest (discounted) whole life cost of all the scenarios.

Table 23: Marginal costs for scenarios (present value; 47 years)

Intervention	Whole life cost (£m)	Water saved (000's Ml)	MC (£ per Ml saved)	MAC Ranking
Extended	4,680	2,077.4	2,250	6
Enhanced-01	64	3,929.3	16	2
Enhanced-02	6,170	3,850.5	1,600	5
Water labelling only (with min. stds.)	58	8,803.9	7	1
Enhanced-03	4,640	10,201.2	450	3
Enhanced-04	7,450	9,338,.3	800	4

Enhanced-03 would require government involvement to deliver water labelling. Water companies would be able to deliver voluntary progressive metering. This scenario therefore demonstrates what is possible when government and the water industry work together.

The Enhanced-04 scenario aims to maximise water saved without tightening regulations for new buildings and water supply fittings. This costs significantly more than Enhanced-03 and delivers less, resulting in a marginal cost of almost twice as much as Enhanced-03. This demonstrates that minimum standards for new buildings and water supply fittings are required in order to cost-effectively reduce PCC below 100 l/h/d in the long-term.

Figure 33 to Figure 38 show the marginal abatement cost (MAC) plots for each of the scenarios. These plots show the cost per mega-litre saved in £ on the y-axis, and the total water saved to 2065 (in million mega-litres) on the x-axis, with each intervention presented as a different coloured rectangle.

Figure 33: MAC plot for the Extended scenario

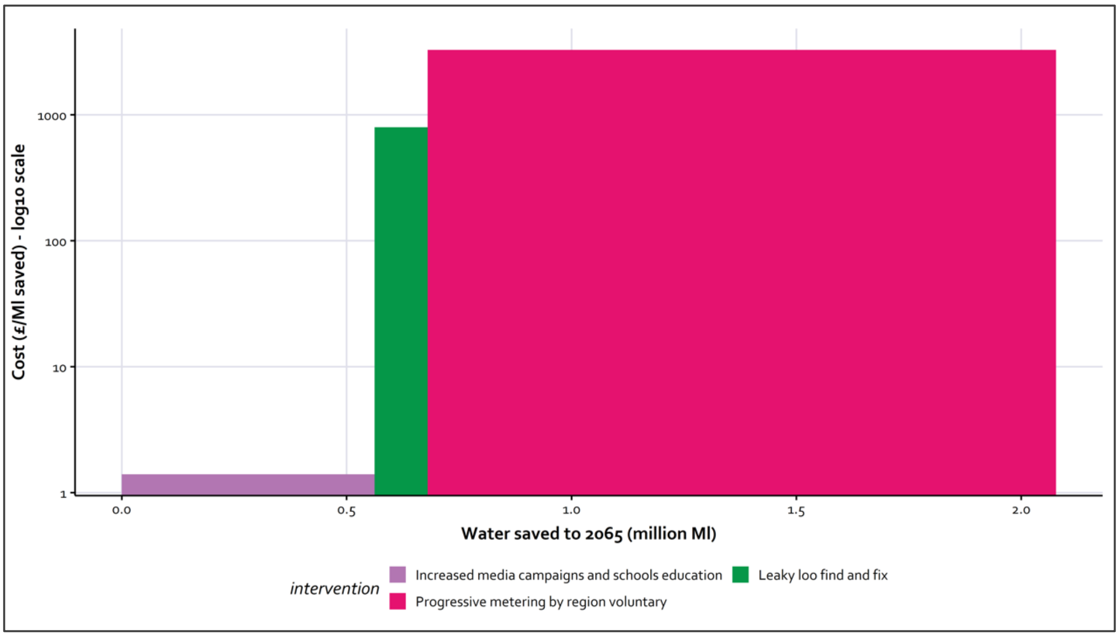


Figure 34: MAC plot for the Enhanced-01 scenario

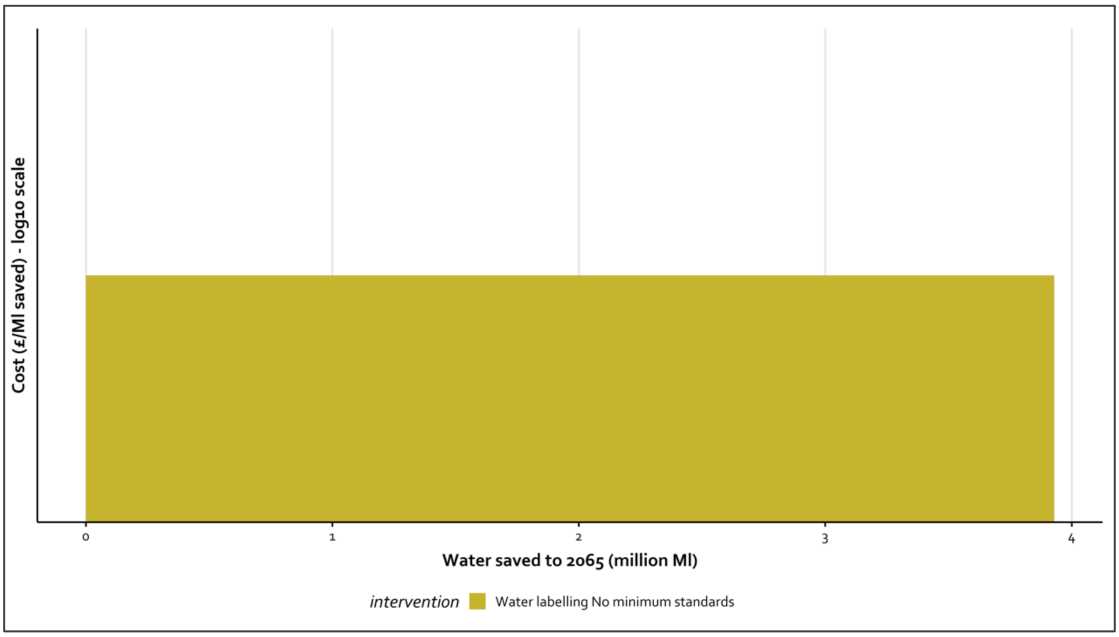


Figure 35: MAC plot for the Enhanced-02 scenario

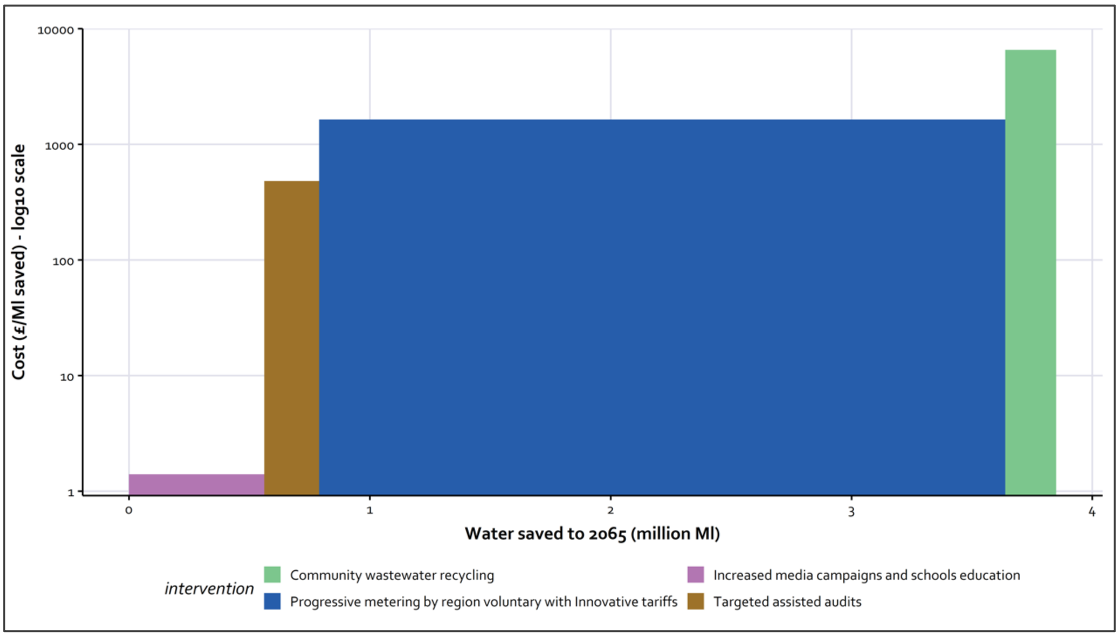


Figure 36: MAC plot for the Water labelling only (with minimum standards) scenario

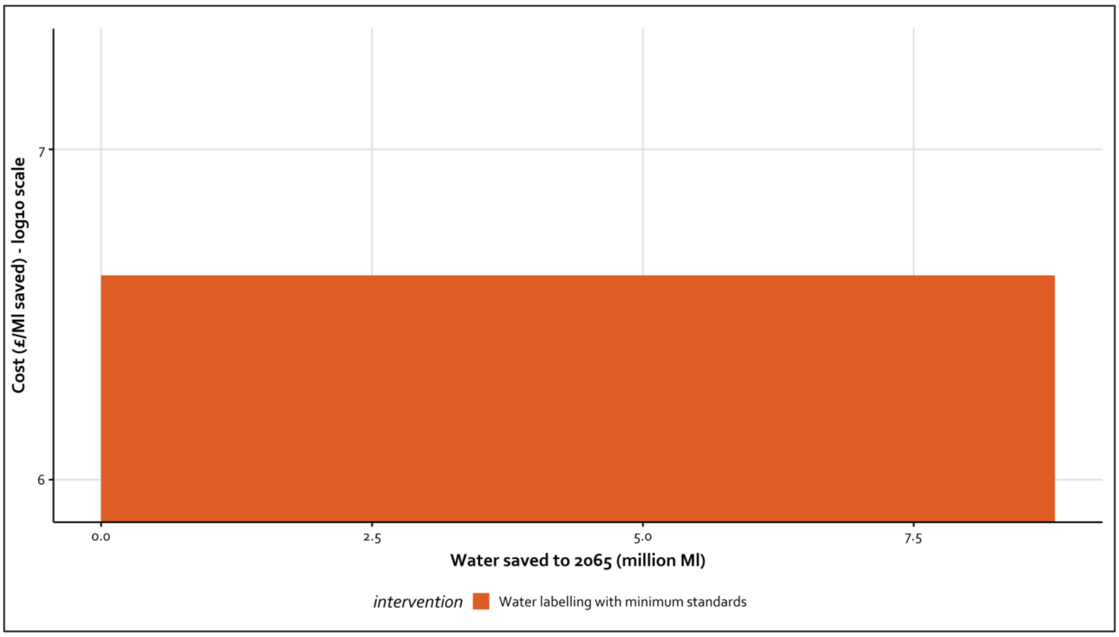


Figure 37: MAC plot for the Enhanced 03 scenario

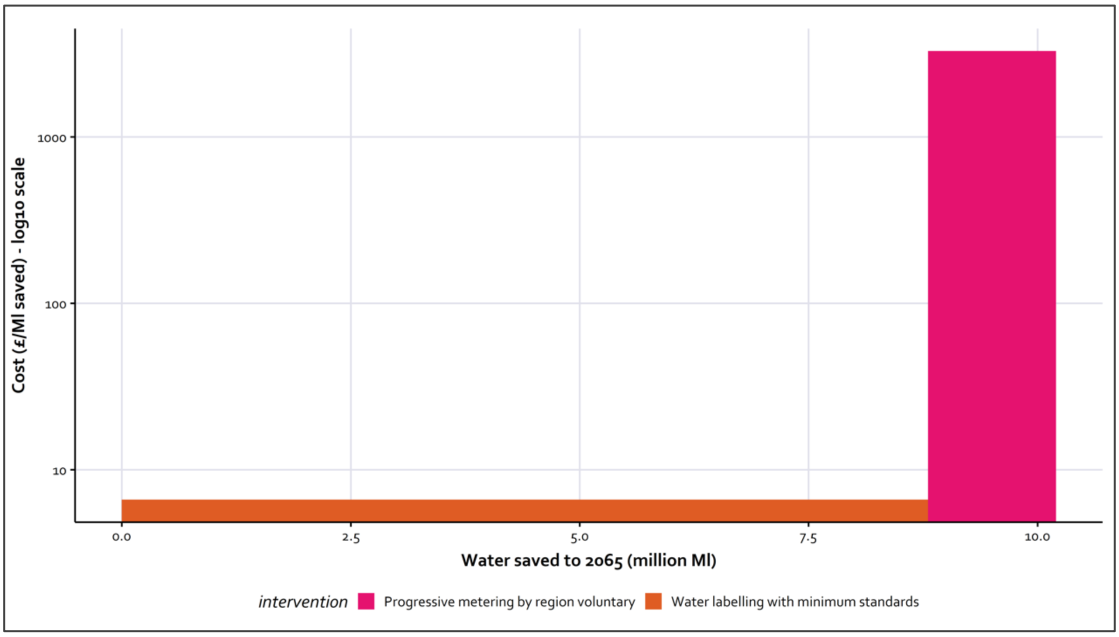
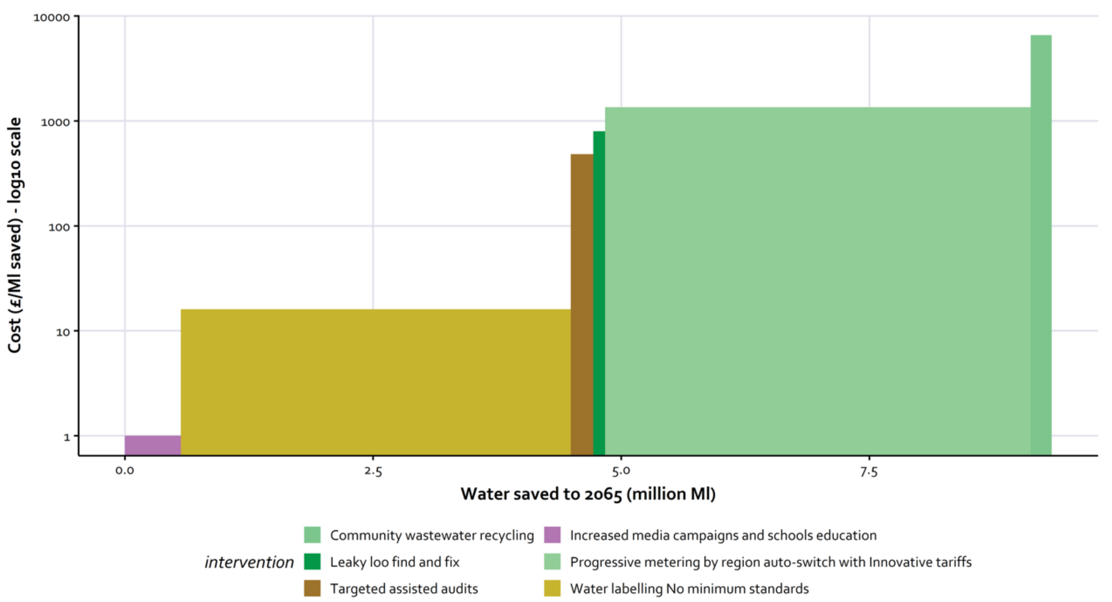


Figure 38: MAC plot for the Enhanced 04 scenario



6.3.2 Interventions

Table 24 reports marginal costs (MC) results for the individual interventions. Results have been rounded to the nearest integer value. Costs and water saved are present values, discounted over 47 years. The rank of each individual intervention is also presented.

Table 24: Marginal costs for individual interventions (present value; 47 years)

Intervention	Whole life cost (£m)	Water saved (000's Ml)	MC (£ per Ml saved)	MAC Ranking
Progressive metering by region - auto-switch	5707	2,837.9	2,011	11
Progressive metering by region - voluntary	4,583	1,397.3	3,280	13
Full universal metering across E&W	6089	2,837.9	2,146	12
Innovative tariffs	87	1,451.4	60	4
Non targeted assisted audits	110	158.9	690	9
Targeted assisted audits	110	227.5	482	5
Leaky loo find and fix	94	117.8	797	10
Change WC standards	656	1,229.3	533	6
Water labelling - with minimum standards	58	8,803.9	7	2
Water labelling - No minimum standards	64	3,929.4	16	3
New homes standards - mandatory	2011	404.2	4,975	15
New homes standards - voluntary	704	140.8	5,000	16
Community RWH	4077	182.0	22,406	18
Community wastewater recycling	1392	212.0	6,567	17
Home retrofit RWH/GWR	3848	875.0	4,398	14
Increased media campaigns and schools education	1	562.3	1	1
National co-ordinated programme	447	770.6	580	7

Intervention	Whole life cost (£m)	Water saved (000's Ml)	MC (£ per Ml saved)	MAC Ranking
Individual and community incentives	366	562.3	651	8

The 'increased media campaigns and schools education' has the lowest marginal cost at £1/Ml, delivering just under 600,000 Ml (or 0.6 billion litres) of water (discounted to present values). Water labelling with minimum standards has the next lowest marginal cost at £7/Ml but delivers significantly more (discounted) water savings compared to increased media campaigns and schools education: 8.8 billion litres compared to 0.6 billion litres. Water labelling with no minimum standards delivers around half that amount of (discounted) water at a marginal cost of £16/Ml.

This highlights the benefit of tightening minimum standards for building regulations and water supply fittings. On their own these interventions are estimated to deliver just under five billion litres of water. These regulations drive most of the difference in whole life costs between the two water labelling interventions: without the regulations we have assumed that money will be required to promote the labelling scheme and encourage consumers to buy more water efficient products. This happens by default when tightening minimum standards are included in the intervention.

Innovative tariffs have the next lowest marginal cost (£60/Ml) after the water labelling interventions but it is important to note that tariffs cannot be introduced without one of the metering interventions. The next few interventions by marginal cost rank either include household visits ranging in marginal cost from £480 (targeted assisted audits) to leaky loo find and fix (£800/Ml). These save from 0.1 to 1.3 billion litres of water each (changing WC standards saves the most) however these are generally mutually exclusive.

Metering interventions have the next highest marginal costs. For example, progressive metering with automatic switching has a marginal cost of £2,000/Ml, saving just over two billion litres of water (discounted).

The remaining interventions, with the highest marginal costs are either rainwater/greywater retrofit or relate to new development.

6.4 Assessment of potential customer bill impacts

An assessment of the potential impact on household customer bills has been undertaken. This is presented at the national level in terms of an indicative cost per household per year. The unit financial cost of each intervention is calculated using the capex and opex unit costs (Table 7) and the following high-level formula:

Intervention cost (£/yr) = opex (£/yr) + (capex /asset life) + (capex x WACC)

Asset lives of up to 15 years are assumed for installed equipment and devices (e.g. meters). The weighted average cost of capital (WACC) is applied at 2.40% following Ofwat's IAP[37].

The unit value for the intervention cost is then scaled to an aggregate level by the number of properties in England and Wales that are assessed to be impacted; i.e. have a smart meter installed, participate in a home audit. This gives an annual aggregate cost for the intervention. The impact on customer bills is then estimated by dividing the annual aggregate cost by the number of households in England and Wales:

Customer bill impact (£/hh/yr) = Intervention cost (£/yr) x no. impacted households ÷ total no. households in E&W

Note the calculation of the bill impact in this way assumes that all water company customers will pay for the implementation of the interventions, regardless of whether they are actually impacted by it. This is consistent with the current funding regime for investments in water services via water companies.

Table 25 summarises for the calculated bill impact for each intervention that features in the CBA scenarios. For the purposes of the analysis, the customer bill impact is calculated based on the forecast total number of households in England and Wales in 2030.

Table 25: Indicative customer bill impact for scenario interventions

Intervention	Assumed asset life	Intervention unit cost (per year)	Customer bill impact (per hh/yr)	Notes
1. Progressive smart metering with auto switching (compulsory)	15 years	£32.60	£28.74	-
2. Progressive smart metering with voluntary switching	15 years	£32.60	£25.56	-
4. Innovative tariffs	N/A	£0.40	£0.02	-
6. Target assisted audits	7 years	£17.12	£0.92	-
7. Leaky loo find and fix	15 years	£7.99	£0.50	-
9. Mandatory water labelling with minimum standards	N/A	N/A	-	Not funded by customer bills

[37] Ofwat (2019), PR19 Initial assessment of plans - Technical Appendix 3: Aligning risk and return. Available at: https://www.ofwat.gov.uk/regulated-companies/price-review/2019-price-review/initial-assessment-of-plans/

Intervention	Assumed asset life	Intervention unit cost (per year)	Customer bill impact (per hh/yr)	Notes
10. Mandatory water labelling with no minimum standards	N/A	N/A	-	Not funded by customer bills
14. Community wastewater recycling	N/A	N/A	-	Not funded by customer bills
16. Increased media campaigns and school education	N/A	£2.10	£0.79	opex cost only

Table 26 presents the associated indicative customer bill impact for each of the six scenarios. Enhanced 04 is estimated to have the greatest impact, at approximately £30 per household per year. The lowest cost is for Enhanced 03 scenario, which is approximately £26 per household per year. Enhance 01 and water labelling only do not include interventions that are funded via customer bills, hence there is zero-bill impact in these cases.

Table 26: Indicative customer bill impact for PCC reduction scenarios

Scenario	Interventions	Customer bill impact (£/hh/yr)
Extended	2,7,16	£26.85
Enhanced-01	10	-
Enhanced-02	2,4,6,14,16	£27.29
Water labelling only	9	-
Enhanced-03	2,9	£25.56
Enhanced-04	1,4,6,7,10,14	£30.18

The various caveats associated with the calculated bill impacts, and as noted, the results are presented as indicative, suggesting the potential scale of cost to bill payers. This is based on a broad national level calculation that does not account for any differences in capex and opex between companies, nor any differences in the WACC that is applied.

The results are also sensitive to the assumed asset life. For example, if the asset life for metering is doubled to 30 years, the resulting bill impact for consumers for interventions 1 and 2 are in the range £19 - £22 per household per year, which reduces the overall cost for the set of scenarios with these interventions in Table 26 to £19 - £23 per household per year. Changes in WACC have a more marginal effect; increasing the WACC to 3% increases the bill impact for metering by around £1, to a range of £27 – £30 per household (vs. £26 - £29 per household at 2.40%).

In addition, the bill impacts should not be interpreted as increases or additional amounts on customer bills. No account is made for the overall bill that households pay for water services and how this will change over time, which depends on range of other factors. The results are instead the cost that would be included within bills. Nevertheless, it is also important to recognise the potential for a disproportionate impact on some water company customers, such as those with low incomes, or with high consumption for health reasons. Measures that are funded via general taxation or other sectors will likely have different distributional effects, compared to customer funded measures, and should also be considered alongside the economic efficiency implications examined in the project.

6.5 Comparison with other types of intervention

6.5.1 *Supply-side schemes*

The marginal cost of supply-side schemes were presented in section 3.5.2 and the values in £/Ml are repeated in Table 27 (highlighted in blue), alongside the marginal costs for the scenarios presented in section 6.3.1 (highlighted in green). All scenarios and options are ranked in ascending order of marginal cost.

Table 27 illustrates that three of the PCC reduction scenarios/interventions have significantly lower marginal costs than supply-side schemes. Water labelling with minimum standards has a marginal cost of £7/Ml, which is two orders of magnitude lower than the most cost-effective supply-side scheme (surface water schemes at £633/Ml).

In this ranking, four of the top six scenarios/options presented in Table 27 include water labelling in some form. The two PCC scenarios with the highest marginal cost do not include water labelling and these are in the bottom three scenarios/options presented.

Table 27: Comparison of marginal costs for supply-side schemes and PCC pathway scenarios

Scenario /option	Interventions /description	Marginal cost (£/Ml)
Water labelling only	Water labelling with tightening minimum standards for building regulations and water supply fittings	7
Enhanced-01	Mandatory water labelling with no minimum standards	16
Enhanced-03	Progressive smart metering with voluntary switching Mandatory water labelling with minimum standards	450
Surface water	River abstraction	633
Groundwater	Abstraction from aquifer	671

Scenario /option	Interventions /description	Marginal cost (£/Ml)
Enhanced-04	Progressive smart metering with auto switching (compulsory) Innovative tariffs Target assisted audits Leaky loo find and fix Mandatory water labelling with no minimum standards Community wastewater recycling Increased media campaigns and schools education	800
Bulk supply	Supply of agreed volume of water between water companies	839
WTW capacity	Increasing the capacity of existing water treatment works (WTW)	864
Conjunctive use	Improving links in existing supply systems to increase supply capacity	1,051
Aquifer recharge	Pumping water into aquifers for abstraction later	1,137
Effluent reuse	Reuse of wastewater effluent	1,282
Desalination	Generation of potable water from brackish or salty water (e.g. seawater)	1,283
Enhanced-02	Progressive smart metering with voluntary switching Innovative tariffs Target assisted audits Community wastewater recycling Increased media campaigns and schools education	1,600
Reservoir	Impounding reservoir for the storage of raw water	1,729
Extended	Progressive smart metering with voluntary switching Leaky loo find and fix Increased media campaigns and schools education	2,250

This is a straightforward comparison of the results from this study and the work by Decker (2018) for the NIC[29]. It is not possible to draw too many conclusions from this comparison because supply-side option includes fixed costs and the PCC scenario ones do not. However, the difference in scale between the water labelling and supply-side options is notable and merits further investigation.

6.5.2 Customer supply-pipe losses

An alternative intervention for reducing total demand is to reduce the amount of water lost through customer supply pipe leaks (CSPL). At the start of the next AMP (2021), customer supply pipe leakage is predicted to be approximately 590 Ml/d, with total leakage predicted to be 2,770 Ml/d. The current ambition is for water companies to reduce total leakage by about 1,100 Ml/d by 2045, and within this reduction water companies estimate they will reduce customer supply pipe leakage by 134 Ml/d (about 12% of the leakage reduction will be due to CSPL repairs or replacement).

The water sector has an ambition to halve leakage by 2050, which would mean approximately a further 300 Ml/d reduction in leakage, with about 35 Ml/d of this being from CSPL reduction (at the current proportions of CSPL reduction). Therefore, in halving total leakage we might expect CSPL to drop from 590 to about 420 Ml/d. These savings assume that there is no change in customer supply pipe policies.

A change in policy such as supply pipe ownership, might change the cost effectiveness for supply pipe options, making it more attractive to carry out CSPL reduction. Assuming supply pipe leakage could be halved in line with total leakage, the total saving over the current ambition would be about 160 Ml/d.

7 De-risking the PCC pathways

This section describes the factors that contribute to uncertainty when forecasting PCC for the interventions and scenarios presented.

It sets out an approach to de-risking based on an adaptive planning approach. We propose that risks can be managed both at a national level and by individual water companies.

At a national level the options for de-risking scenarios have been considered based on the uncertainty associated with the scenario, whether additional interventions are available, and whether these would need further regulatory drivers.

It should be feasible to meet the risks associated with the extended and water label only (with minimum standard) scenarios with either no or only relatively minor regulatory changes. More extensive regulatory changes would be required to cover the risk associated with the enhanced-01 and -02 scenarios. It is possible that the risks of delivering the enhanced-03 and-04 cannot be mitigated.

At an individual company level, the uncertainty around interventions that are led by water companies should be dealt with in the normal target headroom-type approach as part of the water resources planning process. Uncertainties that relate to whether or not new government-led interventions will be introduced should be considered through adaptive planning or scenario analysis.

7.1 Introduction

As shown in Section 6, the range of uncertainty in the forecasts of PCC is very large across all scenarios. That comes from a combination of factors, as described in the following sections.

7.1.1 *'Natural' uncertainty in PCC*

This is a significant driver of uncertainty and reflects the fact that future consumption, before interventions are considered, varies considerably depending on occupancy rate and frequency of use calculations (frequency of use partly reflects societal changes).

7.1.2 *The nature of the interventions*

Many of the interventions have relatively limited data to support the assumed savings, and others have been tested on a large scale, but not in a similar environmental and societal context. For example, the costs, savings and benefits from mandatory water labelling with minimum standards appear to make this intervention an obvious way of reducing long-term household consumption, and the forecast for water labelling is comparable to what has been achieved by the WELS scheme in Australia.

However, it is not known how social or economic factors in the UK might affect the level of savings achieved by a labelling scheme. This is partly reflected in the 'C2' confidence grade assigned in section 3.1 – in this case the evidence would suggest a range of uncertainty just over the 15% threshold between accuracy grade 1 and accuracy grade 2. However, the 'C' grade indicates that there are unknowns that make this option inherently more uncertain than the 'B' graded options. In general, the reliability of options tends to increase where they are better known, more evidence based and represent specific physical interventions (e.g. savings from metering programmes are relatively well known, and there is a degree of evidence of the benefits from different types of household water audits).

7.1.3 The ability of water companies to implement the interventions.

The availability of interventions will depend on the degree of regulatory change that is implemented to support demand management measures. Many of the more extensive proposed interventions require legislative support (e.g. progressive metering with automatic switching), so the scope of PCC reduction and risk mitigation will vary depending on government policy.

7.1.4 The interdependency of risks

At a high level there is a risk of 'double counting' of intervention benefits. This has been addressed through the matrix assessment and scenario development described in Figure 1 and Section 4. Beyond that there is a 'covariance' risk, where societal response to one type of intervention may tend to be reflected in other types of interventions, meaning that if one initiative is performing badly, then others will as well. Conversely good performance could be widespread if societal changes gain traction. This has been addressed through the covariance elements of the PCC modelling contained in Section 5.2.2.

7.2 Approach to de-risking

'De-risking' the PCC reduction strategy therefore requires that these risks are considered when any targets are being set, either nationally or through individual Water Resources Management Plans. The range of risk has been evaluated within the modelling described in section 5.2.2. This covers the uncertainties in PCC/customer behaviour, uncertainties over the benefits of the interventions, and the covariance risks represented by general societal response to PCC reduction strategies. In order to manage these risks, it is therefore necessary to:

- Understand the options that are available on a national level to manage the risks under each given scenario (i.e. 'reserve' initiatives that can be deployed if interventions are not delivering as expected).
- Understand the level of regulatory change required to both deliver the expected scenario and manage risks of under-delivery if they occur.
- Understand the implications of 'unknowns' in this context, particularly around societal and environmental responses to water labelling.

Although such risk mitigation is required for the purposes of planning, at the same time, it is important that the uncertainties around the interventions do not stifle ambition or innovation. An adaptive approach is therefore recommended for both national level initiatives and individual water companies. The nature and scope of such adaptive risk mitigation is provided separately for national level initiatives and water company water resources planning in the sections below.

7.3 National Level de-risking

On a national level there are two potential consequences if under-delivery risks materialise:

1) The cost/benefit ratio of initiatives is not as favourable as indicated in this report.
2) Any targets or planning assumptions are missed without further interventions.

With regards to the first point, variability in benefits is unlikely to change the general conclusions shown in section 6.2 – this has been illustrated by the sensitivity testing in section 6.2.3. The most significant consideration is therefore when demand management strategies are being compared against alternative investments – i.e. if the balance between supply side infrastructure development and demand management is being considered. The levels of uncertainty involved in that case can be readily drawn from the ranges of the interventions presented in Section 3.1. It is important to note that it should not be assumed that benefit risks for individual interventions are independent.

When national level strategies are being considered in terms of the PCC targets (point 2 above), 'de-risking' can be accounted for in two ways:

1) The likely PCC outcome is ascribed a level of uncertainty as detailed in Section 6.

2) Each scenario can be considered in relation to the level of mitigation and hence adaptation that is available and required to deliver the levels of PCC that are expected from that scenario.

The second option is more ambitious and can be considered in terms of the risk and mitigation analysis presented in Table 28. This includes the following risk attributes for each scenario.

- The 'expected' PCC in 2050 and the range of variability that could reasonably occur around that central estimate.
- Whether or not new regulations are required to deliver the central estimate.
- Whether the range of variability can be managed through alternative 'shortlisted' interventions, and whether or not such alternatives would require additional regulatory changes to support that mitigation.

Table 28: Risk mitigation considerations for each scenario

Scenario	PCC Central Estimate @ 2050 (l/h/d)	Potential PCC Risk @2050 (l/h/d)	New regulations required to deliver central estimate[1]	Can risk shortfall be made up *without* substantive regulations?[2]	Can risk shortfall be made up *with* further substantive regulations?[2]
Current ambition	118	18	None	Yes	Yes
Extended	112	22	None	Probably[3]	Yes
Enhanced 02	107	21	Minor	No[3]	Yes
Enhanced 01 (water labelling without min standards)	105	21	Minor	No	Yes
Water labelling (min standards)	91	18	Substantive	No	Possibly[3]
Enhanced 03	86	17	Substantive	No	Possibly
Enhanced 04	90	21[4]	Minor[4]	No	No

Notes:

1. New regulations cover extended mandatory metering, water labelling with or without minimum standards, more stringent water efficiency regulations in new homes and innovative tariffs. Mandatory water labelling without new standards and innovative tariffs are considered to represent minor new regulations as the burden on other sectors (manufacturers and developers) is minimal.
2. These columns indicate whether additional regulations will be required to make up the shortfall against PCC expectations if PCCs and benefits from the scenario planned interventions tend towards the upper end of the risk envelope.
3. For the extended scenario, there are circa 19l/h/d of alternative options that only require minor regulatory change, so most of the risk shortfall can be covered. For the water labelling-minimum standards scenario there are around 12l/h/d of interventions that are not related to minimum standards for water using devices, so only 2/3 of the potential risk could be covered. The only significant alternative intervention available that does not require substantive change for the Enhanced 02 scenario is water labelling without minimum standards, which would only cover 12 out of the potential 21l/h/d shortfall.
4. The Enhanced 04 scenario seeks to deliver maximum savings without substantive regulation changes, but it is noted that there is a high risk of double counting in the figures, particularly between 'leaky loos find and fix', 'targeted household audits' and 'water labelling – no minimum standards'. This upside risk is in the order of 5-10l/h/d.

As part of the adaptive approach, it is assumed that further mitigating initiatives would not be started until 2030, as there would be a lag associated with appropriate monitoring and evaluation to determine how well the initiatives are progressing. In the above analysis the savings from water labelling, if it is used as a mitigation, have therefore only been attributed the year 20 benefit for the 2050 time-horizon.

Based on the above, the following conclusions can be drawn about 'de-risking' any nationally based target setting process:

- It should be feasible to meet the current and extended scenarios with only relatively minor regulatory changes to cover the risks. This assumes that water labelling without mandatory standards can be introduced if trends are not looking favourable, and able to deliver the 9l/h/d savings over the period 2030 – 2050 (20 years) referred to in section 6.1.
- If substantive regulatory changes are implemented, then it should be feasible to cover risks up to and including the enhanced 01 and 02 scenarios.
- It may be possible to meet the expected reductions under the water labelling intervention with minimum standards scenario through additional interventions, even if PCCs and intervention benefits do not go as expected. However, it may not be possible to mitigate all of the risks associated with the enhanced 03 and 04 scenarios, even if all feasible interventions are considered. This is particularly the case for enhanced scenario 04, as there is a high risk of double counting of the benefits across a number of interventions, in the order of 5-10l/h/d, on top of the uncertainty range of 21l/h/d.

7.4 Water Company Planning

Each company has a different level of overlap with the individual interventions contained within each of the scenarios *and* the actions that might be available from a national perspective to address risks and meet targets if intervention responses or PCC trends prove to be unfavourable. The actual figures involved in de-risking will therefore be company specific.

On an intervention-only basis the level of uncertainty contained within the scenarios can be estimated as ranging between 2% and 6% of PCC, depending on the scenario. Where there is overlap then this risk will still exist; the company will have to adjust its central estimate of expectations under a given scenario, but the level of risk will be the same.

The following general approach can be used to allow water companies to incorporate risks into an adaptive planning-type framework.

1) Non-policy related uncertainties can be accounted for using conventional 'target headroom' or other risk-based methods in long term forecasts, as described in UKWIR water resources planning guidance. When PCC performance targets are being proposed through the business planning process, then it is likely the central estimate of savings will need to be used, as these initiatives are more within water company control, and hence the incentive and reward mechanisms will be used to encourage efficiency and innovation.

2) For those initiatives that require substantive regulatory changes (primarily progressive metering with automatic switching in non-water-stressed areas, water labelling, mandatory standards for new homes), then these can be handled using adaptive planning until the relevant policy decisions have been taken. Because regulatory changes will tend to be either/or decisions, then the risks involved are not appropriate for simple Monte-Carlo risk modelling, as it is difficult to sensibly combine such large, binary decisions with other risks and uncertainties in headroom analysis. Such uncertainties are therefore best examined as key components of different 'futures' within an adaptive pathways framework. By examining the investment needs under the different demand futures, water companies can

determine whether the uncertainty involved is a significant driver of near-term investment. If the demand uncertainty means supply side schemes need to be started within the next 5 to 10-year period, then investigations, monitoring and possible initial scheme development will be required to manage that risk. If not, then the risk can simply be noted and resolved during the next round of planning.

3) Once regulatory support is in place, then there may still be residual uncertainties that are beyond the bounds of 'normal' Final Plan target headroom allowances. This is particularly relevant to water labelling, where the demographic and environmental differences between Australia and the UK, and the fact that the degree of success will be highly dependent on the way that the scheme is implemented, means that actual outturn uncertainties could be beyond the range expressed in section 3. If scenarios involving water labelling are being considered, then it is recommended that an adaptive pathways analysis is used, whereby the implications of doubling the range of uncertainty described in Table 6 are considered to determine if there are any short-term investment decisions that might changes as a result of that range. This can then be handled through adaptive planning and monitoring if that is the case.

8 Summary and conclusions

8.1 Summary

8.1.1 Context

The Government indicated in last year's 25 Year Environment Plan[vi] that it wants to see household water use fall, and that they will work with the water industry to set an ambitious personal consumption target. In July 2019, Defra published a consultation and call for evidence on measures to reduce personal water use[vii].

Previous work by Water UK[viii] had demonstrated a significant and growing risk of severe drought impacts arising in England and Wales from climate change, population growth and environmental drivers. This report called for further research on more extensive measures to reduce water use, in order to increase resilience and reduce the risk of regretted investment.

These findings were also supported by the National Infrastructure Commission (NIC) in their report 'Preparing for a Drier Future'[ix], which recommended reducing the demand for water by around 1,400 million litres per day (Ml/d) by 2050. This would result in a per capita consumption (PCC) rate of 118 litres per head per day (l/h/d) by that year.

In what is thought to be the most comprehensive assessment to date of its kind, this report presents the results from a Water UK study to assess the savings, costs and benefits of 18 water demand reduction interventions. It provides an extensive and detailed response to the Defra consultation and call for evidence

The central aim of this report is to allow the water sector (both companies and wider stakeholders) to come to a clearer shared view about the possibilities, principles and priorities for reducing household water demand. This will include informing responses to Defra's recent consultation and Water UK's own wider policy position. The intention is to ensure ambitious levels of demand reduction can be achieved over the next thirty to fifty years, thus delivering the resilience required to withstand the challenges ahead.

8.1.2 About this project

This study was commissioned by Water UK to explore long-term pathways for PCC reduction. The findings from this report will inform Water UK policy related to long-term resilience in the water sector with particular regard to the interventions required to meet ambition on reductions in per capita consumption (PCC).

A particular focus for this project is to evaluate the relative costs and benefits of demand-side interventions that are in the control of the water companies; compared to those that require government intervention or regulation. This includes recent research into the costs and benefits of the labelling of water using devices at the point of sale.

A literature review was carried out to identify potential demand reduction interventions. Water company plans published in 2019 define the current ambition in the water industry for reducing per capita consumption. These plans (with extrapolation where relevant) indicate that per capita consumption is forecast to reduce from approximately 138 litres per head per day (l/h/d) in 2021 to 113 l/h/d in 2065. Companies also plan to extend metering and deliver several hundred thousand home water audits.

Evidence from the literature review and water company plans was used to identify 18 potential interventions that could contribute to long-term reductions in PCC. These were a mix of water company-led and government-led initiatives. Costs, benefits and water savings for these interventions were estimated and six scenarios for delivering long-term reductions in PCC were developed. Modelling was carried out to determine the costs, benefits and water savings of the scenarios, including the uncertainties around the water savings.

8.1.3 Results

The results presented in this report clearly demonstrate that the most extensive, cost-effective reductions in household water use, beyond the ambition in current water company plans, are only possible with concerted action by government departments, regulators and water companies. If done right, then this could deliver up to £64 of benefit from each £1 spent.

The core findings of the study are that:

The single most cost-effective intervention to save water is a mandatory government-led scheme to label water-using products, linked to tightening Building Regulations and water supply fittings regulations. This would reduce consumption by an additional 31 l/h/d or 2,012 Ml/d by 2065. Of all the interventions analysed, this scores most highly on two key metrics: volume of water saved and benefit-cost ratio, and second overall on marginal cost.

The strongest performing interventions are those that improve the efficiency of <u>all</u> households over time, through technology and behaviour change.

Within that, the role of **tightening building regulations and water supply fittings regulations** is particularly important. **Without changing these regulations, it is not possible to find a way of cost effectively reducing household consumption below 100l/h/d**. On their own (without any labelling initiative), changes to these regulations alone would reduce consumption by 14 l/h/d by 2065, equivalent to a volume of 1,052 Ml/d. They would reduce the marginal cost of a water labelling scheme by over fifty percent to approximately £7/Ml.

The analysis accounts for known uncertainties and presents how these might affect individual results. However, given the scale of societal change implied by the deeper reduction scenarios, **there are some system-wide uncertainties that could also affect predicted results**. It will be important to monitor real-world outcomes from interventions, and not over-rely on individual changes for achieving a concrete demand ambition (e.g. for the purpose wider demand/supply water resource balancing).

The **current ambition** in the latest water company plans will deliver the demand reductions that the NIC recommend, achieving a **national average**[x] PCC of 118 l/h/d by 2050. This is equivalent to a reduction in volume of 1,379 Ml/d from 2020/21. Water companies aim to achieve this level of reduction by increasing the number of metered households and carrying out several hundred thousand water audit visits, amongst other things.

This level of current ambition has been considered when developing the PCC pathway scenarios. To reiterate: going beyond this current ambition in the most cost-effective way requires other water sector stakeholders to become involved in water efficiency.

Household visits, either to deliver water audits or reduce wastage (e.g. from leaky loos) have relatively low marginal costs but save relatively small amounts of water compared to **smart metering**. Extensive smart metering, outside areas of serious water stress could reduce water use by between 368 and 482 Ml/d at a marginal cost of between £2,000/Ml and £3,200/Ml. This is in addition to the increase in metering already planned by water companies.

Smart metering could be delivered by water companies in a 'progressive' programme, followed by either an automatic or voluntary switch to a metered bill, depending on government policy. Smart metering will enable much better customer communication and so will be important in driving customer behaviour change. It also brings a number of key additional benefits associated with water wastage and leakage. A national approach is needed to implement smart metering effectively and efficiently.

A scenario which combines mandatory water labelling scheme (with minimum standards) and smart metering (with voluntary switching) offers the deepest reductions in water use. It is forecast to result in a PCC of 82 l/h/d by 2065, equivalent to a reduction in volume of 2,380 Ml/d. This scenario has a negative cost-benefit of £391 million and a marginal cost of £450/Ml.

In comparison, **without minimum standards for new buildings and products** it is only possible to achieve a PCC of 87 l/h/d by 2065, with a very significantly worse negative cost benefit of £3.34 billion at a marginal cost of £800/Ml.

Note that the analysis presented here is based on national-level estimates of costs and benefits and the actual costs of implementing some interventions (such as metering or home visits) will vary across the country, by region and water company.

This report contains extensive analysis and assessment of other interventions (18 in total). Overall, none of these measures perform as effectively as a mandatory water labelling scheme (with minimum standards) or smart metering in reducing water use in a cost-effective and cost-efficient manner. With this in mind, other important findings are that:

- On the basis of their potential savings and relative cost-benefits, other interventions which should be developed, tested and evaluated further include innovative tariffs (linked to smart metering), increasing awareness of water issues through media campaigns, incentives for individual and customers to reduce water use, and addressing the problem of water wastage from toilet cisterns which leak.

- Household visits to carry out water audits or reduce water wastage (e.g. from leaking toilet cisterns) have the potential to bring forward savings in time, but cannot compete with water labelling or metering in terms of volumes of water saved. Rainwater harvesting, greywater recycling and community wastewater recycling could be useful interventions in certain situations where other options are limited but are not able to deliver the savings from labelling or metering, and water reuse/recycling is less cost efficient than labelling or metering.

- The marginal cost of some of the PCC reduction scenarios presented in this report are less than those of supply-side schemes. Water labelling with minimum standards has a marginal cost of £7 compared to £633 for the most cost-effective supply-side scheme. No analysis has been performed on the relative certainty in the delivery of supply versus demand interventions and this is an area that merits further exploration, including through the ongoing National Framework process.

- Customer bill impacts have been estimated for scenarios and for individual interventions used in the scenarios. Smart metering has the largest estimated impact on customer bills resulting in an increase of £29 per household per year. This means that the scenarios which include smart metering have a customer bill impact in the range of £25-£30, depending on the mix of other interventions.

Based on these key findings, this report finds that the best strategy for maximising demand reductions involve government and water companies working together to deliver mandatory water labelling and increased smart metering, beyond the current ambition in water company plans.

The two-pronged approach of labelling and metering will reduce water consumption by targeting water-using technology and water-using behaviour respectively.

Implementing water labelling with minimum standards and extending smart metering will contribute to increased resilience in the water sector by reducing demand by an estimated 2,300 Ml/d beyond the current ambition in water company plans. This will mitigate the potential challenges of population growth and climate change, providing secure water supplies whilst protecting the environment for future generations.

8.1.4 Certainty

All long-term planning has uncertainties about the outcome. This report is based on sound evidence wherever possible and applies confidence grades to the savings estimates to take account of the reliability and accuracy of this evidence. Uncertainty has also been accounted for in the modelling of future water use under the scenarios analysed. This shows that more ambitious scenarios (such as Enhanced-03 which is based on labelling and smart metering) are more likely to deliver real world demand reductions.

Sensitivity analysis has been conducted on the costs and benefits of the interventions to determine the changes that would be required to alter the findings of this analysis. This shows that the estimated operational cost of the water labelling intervention with minimum standards would have to increase from an assumed £0.1 per household per year to at least £2.35 to result in a negative cost-benefit value. The sensitivity analysis also shows that 'Enhanced-03' scenario opex costs would only need to reduce by 10% to result in a cost-benefit value of zero. An opex cost reduction of 76% would be required in the Enhanced-04 scenario to achieve the same outcome.

It is important to note that this study does not account for 'known unknowns', for example how a mandatory labelling scheme will actually perform in England and Wales, or how consumers or others in society will react to smart water metering. This is beyond the scope of this project.

Despite this, most of the risks associated with water demand reduction uncertainties identified in this project can be mitigated, although this gets more challenging as the levels of water use reduction increase. To mitigate risks, water companies should continue to account for uncertainty in their plans and apply adaptive planning techniques. The progress of PCC reductions should be monitored at a national level, reported on a frequent basis, and a country-wide assessment made of progress towards PCC reduction ambitions. This would enable successful interventions to be accelerated, and less successful ones to be improved or replaced. This will help ensure that the progression towards a lower PCC is maintained to achieve resilience.

8.2 Conclusions

This study has shown that the greatest savings in water use result from government-led mandatory water labelling interventions, following by progressive metering, using smart meters. Both these types of interventions will require government input, to set up and manage a labelling scheme, and to enable companies outside areas of serious water stress to automatically switch customers to metered billing after a period of time.

These interventions achieve large savings and benefits because they are assumed to apply to nearly all households over time. The water labelling scheme will drive changes to purchasing behaviour and smart metering is expected to influence water using behaviour through improved communication and targeting of customers by water companies.

Interventions that can be led by water companies, without any specific government input are less cost effective. These include individual and community incentives and assisted household audits. These interventions are harder (i.e. more costly) to apply to all households and therefore are less cost-effective.

This report recommends a strategy for reducing demand which involves government and water companies working together to deliver mandatory water labelling and increased smart metering, beyond the current ambition in water company plans.

The two-pronged approach of labelling and metering will reduce water consumption by targeting water-using technology and water-using behaviour respectively.

This will increase the resilience of the sector to the challenges of population growth and climate change, providing secure water supplies whilst protecting the environment for future generations.

[vi] HM Government (April 2018) A Green Future: Our 25 Year Plan to Improve the Environment https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf

[vii] https://consult.defra.gov.uk/water/measures-to-reduce-personal-water-use/

[viii] Water UK (2016) Water Resource Long Term Planning Framework https://www.water.org.uk/wp-content/uploads/2018/11/WaterUK-WRLTPF_Final-Report_FINAL-PUBLISHED-min.pdf

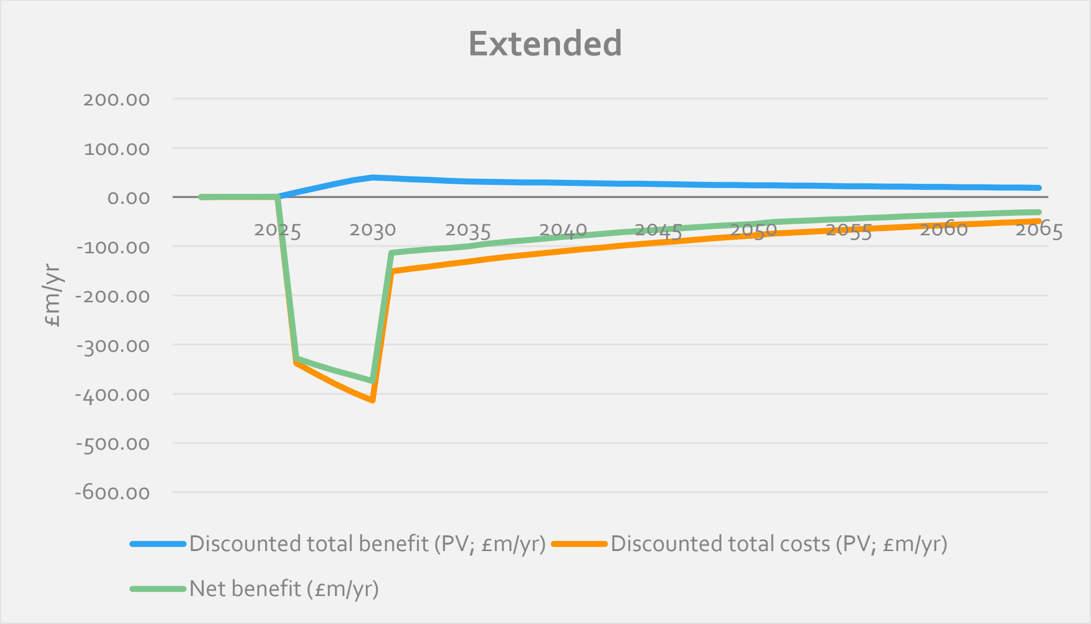
[ix] See https://www.nic.org.uk/wp-content/uploads/NIC-Preparing-for-a-Drier-Future-26-April-2018.pdf

[x] It is important to note this is a national average and that different companies will have different starting points depending on their current levels of consumption and what they plan to do to reduce household water use over the coming decades.

Annex 1

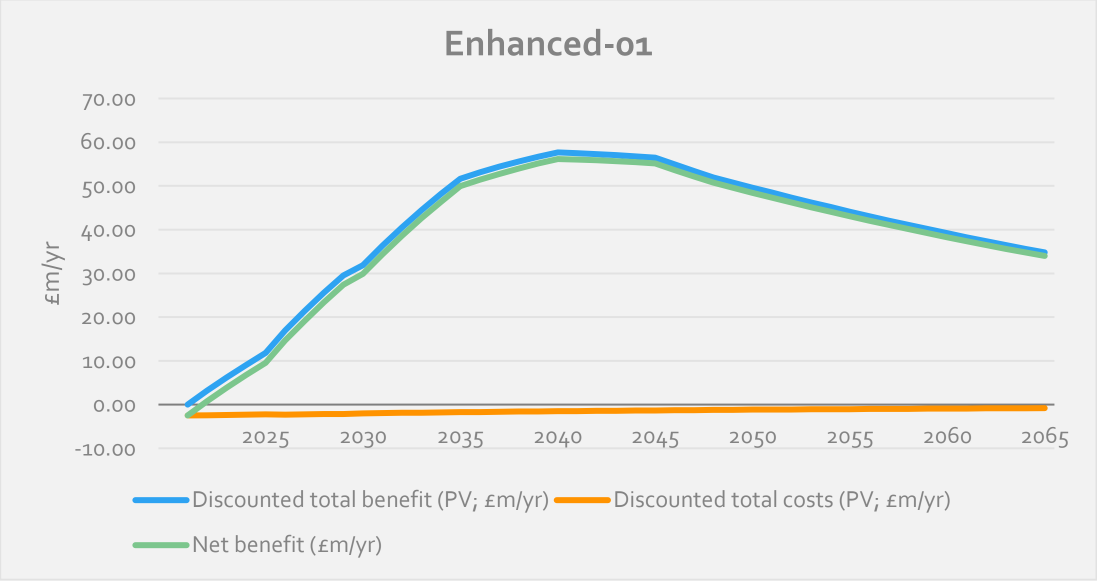
Extended Scenario

Discounted benefit, cost and net benefit profile for Extended Scenario.



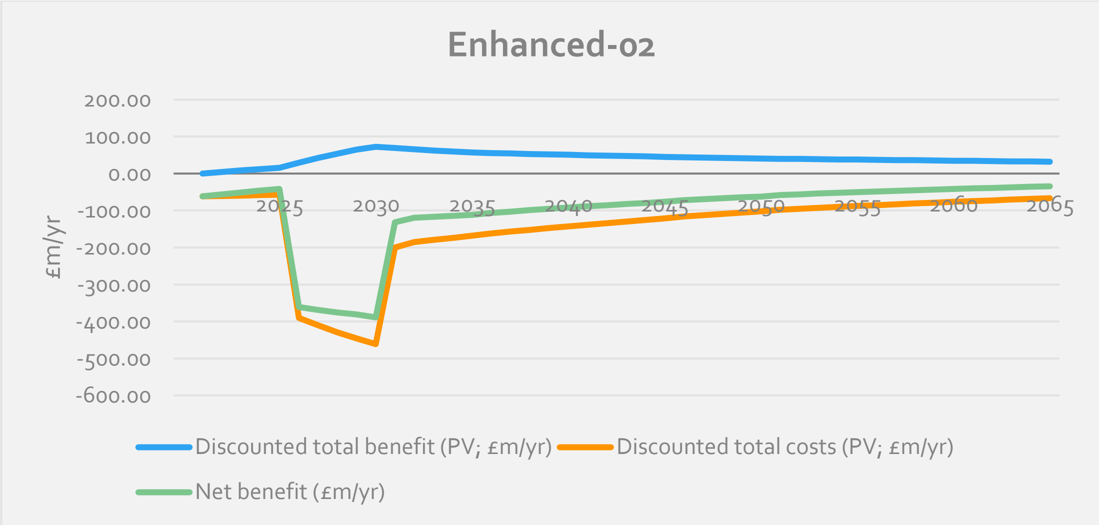
Enhanced-01

Discounted benefit, cost and net benefit profile for Enhanced-01 Scenario.



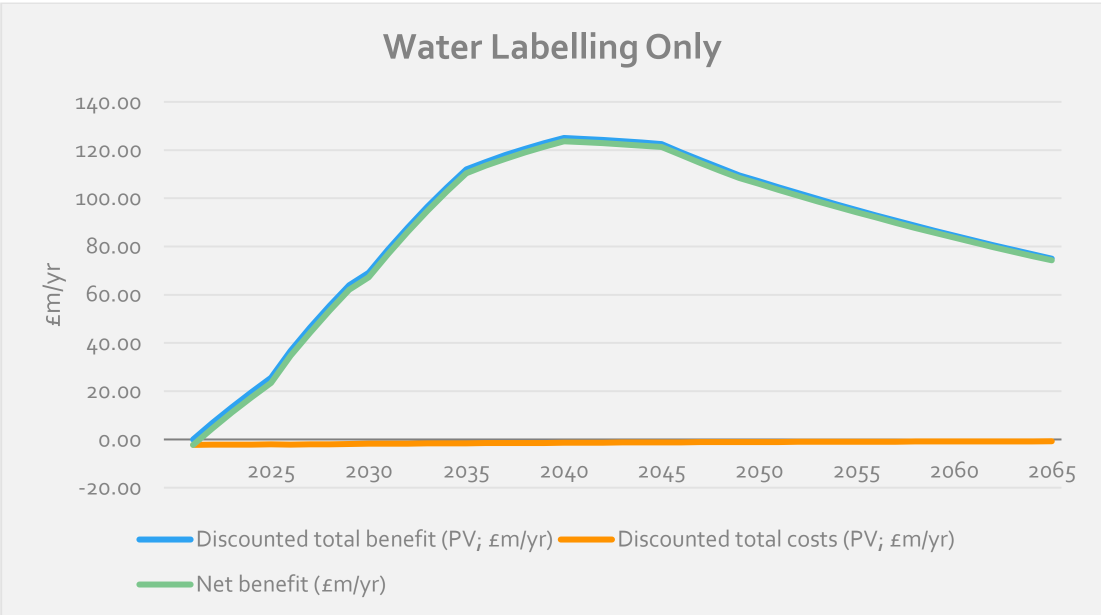
Enhanced-02

Discounted benefit, cost and net benefit profile for Enhanced-02 Scenario.



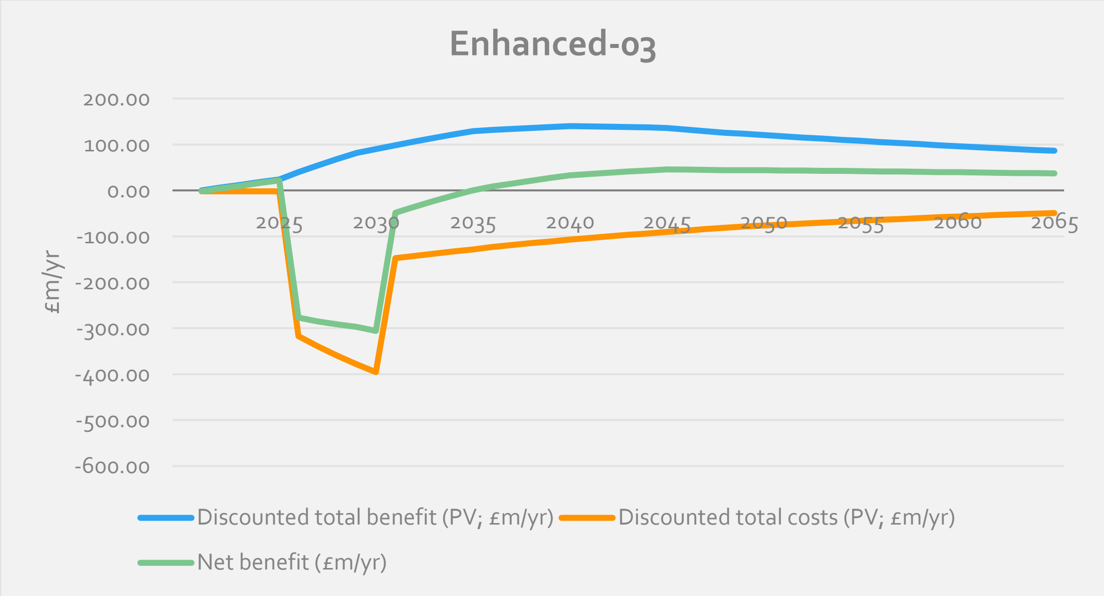
Water labelling only

Discounted benefit, cost and net benefit profile for Water Labelling Only Scenario.



Enhanced-03

Discounted benefit, cost and net benefit profile for Enhanced-03 Scenario.



Enhanced-04

Discounted benefit, cost and net benefit profile for Enhanced-04 Scenario.