Funding approaches for leakage reduction

Report for Ofwat

December 2019

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Abbreviations

ALC	Active leakage control
AMP	Asset management period
CSPL	Customer supply pipe leakage
DD	Draft determinations
DMA	District metered area
(S)ELL	(Sustainable) economic level of leakage
ODI	Outcome delivery incentive
SDB	Supply-demand balance
WRMP	Water resources management plans
TWD	Treated water distribution
WRZ	Water resource zone
WW	Wholesale water

Company abbreviations

AFW	Affinity Water
ANH	Anglian Water
BRL	Bristol Water
DVW	Dee Valley Water
HDD	Hafren Dyfrdwy
NES	Northumbrian Water
PRT	Portsmouth Water
SVE	Severn Trent Water
SEW	South East Water
SSC	South Staffs Water
SWB	South West Water
SRN	Southern Water
SES	SES Water
TMS	Thames Water
UUW (NWT)	United Utilities
WSH	Dŵr Cymru
WSX	Wessex Water
YKY	Yorkshire Water

Executive summary

Introduction

Leakage is defined as treated water lost from the distribution system, and includes water lost from the companies' distribution networks and supply pipe losses from customers' pipes. It is an indication of how well a company maintains and manages its network, and is an indicator of the resilience of the water system.

Since the privatisation of the water sector, companies have made significant gains to reduce leakage in England and Wales, but progress has stalled in recent years. Around 3,170 million litres per day (21%) of water put into public supply is lost through leakage.[1] Maintaining the balance between water supply and demand is becoming an increasingly critical challenge, given the pressures from increasing demand from a growing population, at a time when supply is coming under threat from climate change and increased drought risk, leading to higher risks of water shortages. Addressing leakage, which contributes to lowering water demand, is therefore a high priority for the UK government, Ofwat, companies and customers.

Leakage is therefore a key focus for company business plans and for Ofwat at PR19. In the PR19 final methodology document 'Delivering Outcomes for Customers' Ofwat outlines its expectations for companies to propose stretching performance commitment levels for leakage.[2] It also says that customers should not pay extra for companies to deliver stretching but achievable performance commitments.

At the draft determinations (DD), Ofwat states that it expects companies to achieve their performance commitments from their base allowance. An exception is where the performance commitment is beyond the industry upper quartile threshold leakage level in 2024-25 on both normalised measures of leakage, i.e. leakage per length of mains (expressed in metres cubed per kilometre of mains per day, m^3/km/day) and leakage per number of connected properties (expressed in litres per property per day, l/prop/day). In such case a company can receive an additional cost allowance for leakage reduction.

Companies have raised a number of challenges to Ofwat's approach at DD. First, while companies have agreed to meeting Ofwat's challenge to reduce leakage by at least 15%, they have also requested significant levels of additional funding (£674m based on companies' April 2019 business plans) to meet this challenge on the basis that it requires a more substantial reduction in leakage than has been achieved by the industry in recent history.

However, Ofwat's consideration that leakage reduction is funded through base expenditure and only allow enhancement expenditure only under limited circumstances, has been challenged on the basis that companies believe they are not being sufficiently funded to reduce the level of leakage beyond what companies consider to be base service levels.

Second, companies raised concerns that Ofwat's base econometric models do not account specifically for leakage-specific variables, meaning that model-predicted costs do not sufficiently reflect company-specific differences that drive leakage reduction costs, nor do they account for the increasing marginal cost of reducing leakage.

Ofwat commissioned this study to review the challenges above and consider whether its approach to the funding of leakage reduction is appropriate. We also provide some recommendations for the additional data that could be collected to inform future cost assessments.

Study approach

Our approach is as follows:

- We examine trends in leakage performance over time, and review the drivers of leakage performance and costs across companies.
- We review Ofwat's current policy approach as at DD and the challenges that companies have raised in relation to this.
- We augment Ofwat's econometric models to incorporate leakage more explicitly, validate the results and assess the impact this has on companies' cost allowances.
- We explore other modelling approaches for assessing costs, i.e. modelling leakage performance directly to inform the costs required to drive leakage performance.

[1] Ofwat, *Service Delivery Report 2018-19 Analysis Model*, October 2019.
Ofwat, *PR19 final determinations: Securing cost efficiency technical appendix*, December 2019, page 59.
[2] Ofwat, *Delivering Water 2020: Our methodology for the 2019 price review. Appendix 2: Delivering outcomes for customers*, December 2017, page 65.

- We consider how data and information could be improved to support more robust and accurate assessments of leakage reduction allowances in the future.

Drivers of company leakage performance and costs

Individual companies' leakage performance and costs can differ significantly for a number of reasons, from different challenges in their operating environments, historical investment decisions and their mix of leakage reduction activities.

Companies are at different points of the investment cycle, and the long-lived nature of distribution assets can influence companies' leakage levels (and hence the type and cost of leakage reduction activities) over the long run. However, our analysis suggests that there is a weak relationship between historical reductions in leakage and the share of spend towards investing, maintaining and renewing infrastructure assets.[3] This may be because targeting leakage reduction requires a blend of both capital and operational activities. In addition, companies' spending on investing, maintaining and renewing wholesale water infrastructure assets also appear to exhibit some cyclicality. These observations may be the result of how the costs of leakage activity are presented, with challenges to the consistency and granularity of reported data on leakage activity. It may also reflect changes to leakage reduction and management activities, although the data for which consistent data is available may be too short for definitive conclusions.

We also find some evidence that the **marginal cost of leakage reduction** (for both the cost of maintaining and renewing assets and operational costs) **appears to increase** as companies achieve further gains to reduce leakage.

Companies also face different operating conditions. Companies that face a larger supply-demand deficit and a high cost of water, either as the result of drought risk or other climactic or topographical factors tend to have better leakage performance. These companies face a more pressing challenge to reduce leakage in order to maintain their supply and demand balance.

Companies also respond differently to the location of the leakage challenge, which influences the type of leakage reduction activities. These typically require different responses, and therefore the optimal mix of leakage reduction activities will need to be tailored to these specific conditions. For example, higher levels of customer supply pipe leakage may suggest a greater focus on increasing metering penetration, including installation of smart meters, to drive changes in customer behaviour.

These factors taken together suggest that company-specific factors also influence the costs of leakage reduction and individual company performance.

The impact of incorporating leakage in cost models

We undertake our analysis and investigation into the impact of incorporating leakage into the cost models based on the base model specification that Ofwat are using for final determinations. We augment these models to include a leakage variable, specifically the variance in leakage levels in each year from the industry upper quartile level. Using this variable allows us to capture the progress that companies make over time and how far companies have yet to go to achieve this performance benchmark. Following extensive testing of alternative leakage-related variables and specifications, we find three potential augmented model specifications that meet the criteria of goodness-of-fit, overall significance and robustness tests. We find that these augmented models perform similarly to Ofwat's existing models in terms of explanatory power. These model specifications principally add a leakage variable based on the distance from the 2024-25 upper quartile for leakage normalised by length of mains (m^3/km/d). Note that other normalised measures such as leakage per property per day did not meet our model selection criteria.

Some companies have suggested using the distance from the sustainable economic level of leakage (SELL) as the appropriate driver for the cost modelling. While the SELL – to the extent that it is measured accurately – sets the economically-efficient level of leakage reduction by balancing the cost of water lost through leakage and the cost of reducing it, this measure faces a number of challenges. Notably there are a number of uncertainties in estimating SELL, particularly the social and environmental costs. It is also influenced by companies' own determinations of costs and benefits, such that companies that are more inefficient in reducing leakage will have higher SELL. As a result, the measure is a less significant driver of leakage performance improvements. There is also significant variation in companies' leakage performance relative to SELL, which suggests that there is much heterogeneity in the way in which companies measure SELL. For these reasons we have not used the distance from the SELL as the primary leakage variable.

[3] We use a combined measure that includes the cost of Maintaining the long-term capability of the assets – infra for wholesale water, Renewals expensed in year (Infrastructure) for wholesale water and Demand side enhancements to the supply/demand balance (dry year critical / peak conditions and dry year annual average)

We use the results from our candidate models to triangulate an estimate for efficient base costs over the 2020-25 period for each company and the industry, by taking the average of the predicted values using each candidate model. To this, we overlay a funding scenario where leakage reduction to achieve companies' 2020-25 stretch levels is funded through the base cost allowance.

We find that including a leakage variable in the cost models using our candidate econometric specifications results in **higher estimates of efficient modelled base costs overall for the industry (when Thames Water is excluded)** (see Table 1). The increase in efficient modelled base costs to reduce leakage in line with companies' 2020-25 performance commitments is around £50 million.

We present the results with and without Thames Water as the company appears to be the outlier when comparing normalised leakage volumes. For this reason, we therefore introduce additions to the model to control for its effects. The impact on Thames Water's efficient cost is largely the result of the new models that include specific terms to control for the effect of Thames Water, as well as the result of the non-linear functional form for leakage used in the model. This means that the economies of scale effect dominates, i.e. Thames Water is expected to become more cost-efficient at reducing leakage, which is why the model predicts that Thames Water will face increasingly lower costs per unit of leakage reduction.

Table 1: Comparison of efficient modelled base costs for the modelled scenario against Ofwat's final determination specification

	Ofwat final determination specification	Study modelled scenario
Total WW base cost (£m), excl. TMS	**13,382**	**13,432**
Difference in levels		50
% difference		0.37%
Total WW base cost (£m), incl. TMS	**16,586**	**16,579**
Difference in levels		-6
% difference		-0.04%

Source: PwC analysis

Policy implications and considerations

These results may suggest that Ofwat's final determination funding approach is insufficient for funding more ambitious reductions in leakage, although the overall increase in the base cost across the industry suggested by our models is not materially higher in percentage terms.

However, this overall picture masks **significant distributional effects across the sector** – our modelling of new cost allowances suggest that there are both companies with increases and companies with decreases to their allowances from using our alternative modelling approach. Because our candidate models include a measure based on the difference between leakage levels and the upper quartile industry level based on leakage normalised by length of mains (m3/km/day), as this provides an improved model fit, the new models result in an uplift in the allowance for companies that perform well on this metric. On the other hand, those companies that may perform better with the alternative normalisation per property (litres/property/day) do not benefit as much. The distribution effects are also partly the result of the non-linear effects that are captured in the candidate model specifications, as they account for the higher marginal costs of leakage reduction faced by companies that are already operating close to the 2024-25 upper quartile level.

However, there are a number of limitations to our analysis. First, while including the leakage variable passes our specification tests and performs similarly in terms of its explanatory power, including the leakage variable in Ofwat's model specifications also reduces the statistical significance of the other variables in explaining wholesale water base costs (in particular, the weighted average density variables). Second, the limits on the availability and consistency of historical data means that our analysis is limited to a brief period and so may not sufficiently capture long-term variations in historical spending.

In summary, while including the leakage variable produces a statistically robust model, it also highlights the difficulty of meaningfully incorporating leakage into the cost models, while retaining their validity. For example, it raises distributional issues and a question over how to address the impact on Thames Water, particularly and whether adopting different treatment for Thames Water would be appropriate.

Ofwat may consider our alternative model outputs as a basis for making an adjustment to companies' allowances at final determination rather than adopting a revised form of base model. This would recognise both general high-level indicative outputs of the models but also the issues with leakage data limitations and robustness. Such an adjustment could consider the appropriate increase for 'good' performers and any 'catch-up' funding for companies that are significantly below the expected levels.

We also model leakage directly to understand the impact historical spending on leakage reduction activities has on leakage performance. The results of our leakage models suggest **historical spending, particularly spending associated with maintaining the long-term capability of assets and supply-demand balance demand-side enhancement funding, appears to have a small but statistically significant impact on leakage performance**.

We also find that higher treated water distribution base costs has a delayed effect on reducing leakage. This is a tool that could support future assessments of enhancement funding, if or when better quality data is made available in the future.

We note that at initial assessment of plans there were a number of challenges to using the industry median unit cost of leakage reduction to assess the enhancement allowance. At DD, Ofwat used company-specific unit costs but retain the use of the industry median unit cost as a comparator, applying an efficiency challenge to companies with unit costs higher than the median. In response to DD, a company challenged the use of the industry median as a comparator. **A general observation is the lack of detailed and consistent data across the industry on where leakage occurs and what drives the costs of reducing it**, and the historical cost and impact on performance of leakage reduction activities. We highlight a number of areas that might benefit from having more data and information from the sector to enable a broader understanding of the cost drivers of leakage reduction, namely:

- More consistent data and information on the companies' leakage location (customer and distribution) and drivers;
- More information on where companies are in different points of the investment cycle;
- Increased emphasis on ex-post assessments of the benefits of leakage reduction activities;
- More consistent data on the costs of leakage reduction across the industry to enable benchmarking; and
- Ongoing monitoring of future technological developments.

1 Introduction and our approach

1.1 Background to the study

Leakage is defined as treated water lost from the distribution system. This includes water lost from the companies' distribution networks and supply pipe losses from consumers' pipes.

Leakage is an indication of how well a company maintains and manages its network assets, and the resilience of its water system. Current leakage volumes are the result of historical investment and asset management decisions, which can influence the incidence of leakage, the cost of maintaining the network and reducing leakage in the future.

Broadly, the level of leakage can be affected by a wide range of factors, such as local geographical conditions (e.g. soil type and density of connections), the characteristics of the network (e.g. length, age and health of mains), as well as companies' leakage control strategies.

Around 3,170 million litres per day (Ml/day), or 21% of water put into public supply is lost through leakage[4]. The potential benefits of leakage reduction are significant, including: the environmental benefits of reduced abstraction; increased reliability of water supplies; reduced water-related capital expenditure; and lower operating costs for companies. Conversely, excessive levels of leakage can result in waste of water and energy from unnecessary treatment, significant additional costs for water companies and negative customer experiences. It can also act as a disincentive for customers to save water.

Maintaining the balance between water supply and demand is becoming an increasingly critical challenge, given the pressures from increasing demand from a growing population, at a time when supply is coming under threat from climate change and increased drought risk, leading to higher risks of water shortages. The Water UK report on long term planning identifies the need for more ambitious leakage reduction to respond to increased risk of droughts.[5] Similarly, Parliament also recognises the need for more urgent action in this area.[6]

Addressing leakage, which contributes to lowering water demand, is therefore a high priority for the UK government, Ofwat, companies and customers.

An ambitious long-term strategy to reduce leakage requires active leakage management and effective demand management on the part of companies, and behavioural changes (in reducing consumption) on the part of customers, supported by technological innovation. Therefore, having the right incentives will encourage companies to target leakage effectively and efficiently.

1.2 Objectives of this study

Leakage is therefore a key focus for company business plans and for Ofwat at PR19. In the PR19 final methodology document 'Delivering Outcomes for Customers', Ofwat outlines its expectations for companies to propose stretching performance commitment levels for leakage.[7] It has also motivated a number of changes to Ofwat's approach to funding leakage reduction for 2020-25 – at the draft determinations (DD) stage, Ofwat set additional allowances through enhancement funding, if companies are forecast to meet the industry upper quartile threshold leakage level in 2024-25 on both normalised measures of leakage, i.e. leakage per length of mains (expressed in m3/kilometre/day) and leakage per number of connected properties (expressed in litres/prop/day).[8]

Companies raised a number of challenges to Ofwat's approach at DD. First, while companies have agreed to meeting Ofwat's challenge to reduce leakage by at least 15%, they have also requested significant levels of additional funding (£674m based on companies' business plans) to meet this challenge on the basis that it requires a more substantial reduction in leakage than has been achieved by the industry in recent history.

However, Ofwat's approach to not fund any leakage reduction through base expenditure (and through enhancement expenditure only under limited circumstances), has been challenged on the basis that companies

[4] Ofwat, *Service delivery report 2018-19*, October 2019.
[5] Water UK, *Water resources long term planning framework (2015-2065)*, July 2016.
[6] Environment, Food and Rural Affairs Committee, *Regulation of the Water Industry (HC 1041)*, Eighth Report of Session 2017–19, October 2018.
[7] Ofwat, *Delivering Water 2020: Our methodology for the 2019 price review. Appendix 2: Delivering outcomes for customers*, December 2017, page 65.
[8] As leakage volumes can differ across companies for reasons of size and scale, the normalised measure of leakage (i.e. where leakage is scaled to the length of mains, number of properties or distribution input) is used to facilitate like-for-like comparisons across companies.

believe they are not being sufficiently funded to reduce the level of leakage beyond what companies consider to be base service levels.

Secondly, companies also raised concerns that Ofwat's base cost models do not account specifically for leakage-specific variables, meaning that model-predicted costs do not sufficiently reflect company-specific differences that drive leakage reduction costs, nor do they account for the increasing marginal cost of reducing leakage.

We note that at initial assessment of plans there were a number of challenges to using the industry median unit cost of leakage reduction to assess the enhancement allowance. At DD, Ofwat used company specific unit costs but retained the use of the industry median unit cost as a comparator, applying an efficiency challenge to companies with unit costs higher than the median. In response to DD, a company challenged the use of the industry median as a comparator.

Ofwat commissioned this study to evaluate its approach to leakage cost allowances. The conclusions of this review will support Ofwat in considering and responding to companies' feedback on Ofwat's DD approach to leakage reduction funding, and will help inform Ofwat's approach to the final determinations, as well as shape policy decisions for future leakage reporting, future price controls and funding allowances.

1.3 Our approach

Our approach is as follows:

- We examine trends in leakage performance over time, and review the drivers of leakage performance and costs across companies.
- We review Ofwat's policy approach at DD, and the challenges that companies have raised in relation to this.
- We set out alternative modelling options for assessing the level of funding provided for leakage reduction, by augmenting Ofwat's cost models to incorporate leakage more explicitly, and assess the impact this has on companies' cost allowances.
- We explore other modelling approaches for assessing costs, i.e. modelling leakage performance directly to inform the costs required to drive leakage performance.
- We explore a number of considerations for future leakage funding, by reviewing areas where the availability of data and information could be improved to support more robust and accurate assessments of leakage reduction allowances in the future.

1.4 Structure of this report

Below we set out the structure for the remainder of this report:

- Section 2 sets out companies' performance in leakage reduction and outlines Ofwat's PR19 approach at initial assessment of business plans (IAP) and the changes subsequently proposed at DD to fund leakage reduction, the issues that companies have raised in relation to Ofwat's leakage reduction funding approach, and our observations on the drivers of leakage performance and costs.
- Section 3 sets out our approach to augmenting Ofwat's base cost models to account for leakage specifically. This section also summarises the results from the approach we used to model leakage levels, and the impact of historical spending on leakage reduction on leakage.
- Section 4 sets out the results from our cost modelling and the impact of the alternative leakage model specifications on companies' base cost allowance.
- Section 5 sets out areas where new data may be needed to support leakage cost assessments in the future.

2 Leakage performance and current policy approach

2.1 Section overview

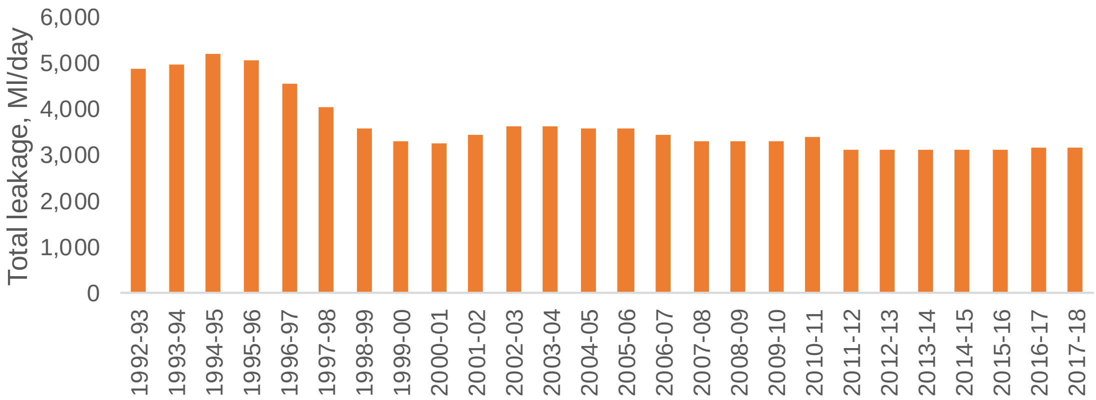
In this Section, we set out Ofwat's policy approach to leakage for PR19 and some of the key challenges highlighted by companies on the approach. The remainder of this section is structured as follows:

- Section 2.2: Leakage performance to date in England and Wales.
- Section 2.3: Drivers of leakage performance and costs.
- Section 2.4: Ofwat's PR19 approach.

2.2 Leakage performance in England and Wales

In the years since privatisation of the water sector in England and Wales, total leakage has reduced significantly by around 30%. Much of this reduction was prompted by drought conditions in 1995 – from that peak, leakage has fallen by more than a third.[9] However, this progress has largely stalled over the past two decades (see Figure 2.1).

Figure 2.1: Historical leakage in England and Wales[10]



Source: PwC analysis of Ofwat data[11]

As can be seen since 2002, leakage levels have declined at a considerably slower rate.

Part of the reason driving this trend was the use of the sustainable economic level of leakage (SELL) measure to determine leakage performance commitment levels in the past. The SELL is the point where the marginal cost of water leakage (i.e. not fixing the leak) would equal the marginal cost of leakage control (i.e. fixing the leak)[12], which theoretically delivers the 'least-cost' level of benefit to customers. Companies use this to inform their strategies in the water resources management plan[13] (WRMP), which companies are legally obliged to produce every five years.

However, over time the company-derived SELL approach has failed to drive efficiency improvements or innovation in leakage reduction. As Table 2.1 shows, companies have historically performed below SELL. Companies with leakage volumes greater than the SELL would be expected to develop strategies to reduce leakage to that point but from an economic perspective, companies already operating below the SELL would have little incentive to reduce leakage any further.

[9] NAO, *Leakage and Water Efficiency*, Report by the Comptroller and Auditor General, HC 971 Session 1999-2000: 1 December 2000.
[10] Ofwat, *Delivering Water 2020: Consulting on our methodology for the 2019 price review*, July 2017.
[11] Ofwat, *Service delivery report 2018-19*, October 2019.
[12] SELL reflects both the private costs (i.e. operating and capital costs of leakage control e.g. developing new water resources to compensate for the water lost through leaks) and the external social and environmental costs of leakage
[13] The WRMP should demonstrate how water companies will manage the needs of future populations, deal with climate change and develop demand management options including water efficiency and leakage management measures.

In addition, the SELL approach does not provide a stretching level to companies that are operating inefficiently due to SELL being calculated from companies' own costs. As noted in the Strategic Management Consultant[14] (SMC) report (2012), '*A key point about SELL is that, if the current active leakage control (ALC) operations are inefficient, the SELL will be higher and therefore the regulatory target will be higher, than if the company has made efforts to increase productivity from its leakage detection and repair teams. There does not seem to be an incentive in the SELL mechanism to promote efficiency and innovation*'.

Table 2.1 below shows there is significant variation in companies' leakage performance relative to their individual SELLs, which suggests that there may be significant differences in how companies have measured SELL.

Table 2.1: Comparison of company leakage performance against SELL, 2018-19

Company	Total leakage 2018-19 (Ml/day)	Volume of leakage above or below SELL (Ml/day)	Volume of leakage above or below SELL (% of total leakage level)
ANH	191.2	-19.8	-10.3%
WSH	169.5	-1.3	-0.8%
HDD	15.3	1.1	7.0%
NES	200.4	-13.7	-6.9%
SVE	424.4	-8.6	-2.0%
SWB	103.6	-24.3	-23.5%
SRN	101.8	14.5	14.2%
TMS	690.4	78.4	11.4%
UUW	456	-149.7	-32.8%
WSX	66.4	-27.7	-41.6%
YKY	289.8	-2.3	-0.8%
AFW	196.1	-7.4	-3.8%
BRL	41.7	-14.3	-34.3%
PRT	28.1	-3.3	-11.7%
SEW	86.9	-21.6	-24.9%
SSC	83.7	-0.3	-0.4%
SES	24.2	-3.2	-13.0%
	3169.5	**-203.5**	**-6.4%**

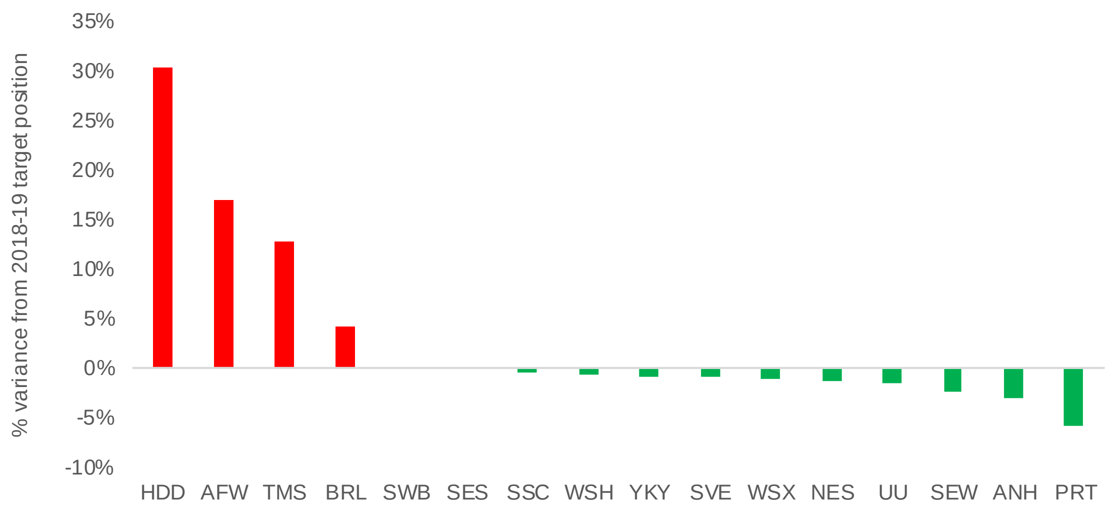
Source: Annual Performance Report 2018-19

Consequently, the importance of SELL in driving leakage reduction strategies has diminished. In addition to broader socio-demographic and environmental challenges facing the water industry, this slowing progress in leakage reduction over time means Ofwat is considering how to adapt existing definitions and methodologies to re-invigorate leakage reduction activity for the industry.

We also assess recent company performance in reducing leakage, specifically their performance in the 2018-19 period against their PR14 performance commitments on leakage. This is shown in Figure 2.2. Most companies appear to have met or slightly exceeded their performance commitment levels, with the exception of Hafren Dyfrdwy, Affinity Water, Thames Water and Bristol Water. This might suggest that in the absence of unexpected external events that might impair companies' abilities to meet leakage performance levels, companies have generally been able to achieve them, which might suggest room for stretch in forward-looking performance levels.

[14] Strategic Management Consultant (SMC), *Review of the calculation of sustainable economic level of leakage and its integration with water resource management planning*, report for the Environmental Agency, Ofwat and Defra, October 2012.

Figure 2.2: Comparison of 2018-19 leakage performance commitment levels vs actual performance



Source: Ofwat, Service delivery report 2018-19, October 2019

2.3 Drivers of leakage performance and costs

Individual companies' leakage performance and costs can differ significantly for a number of reasons, from different challenges in their operating environments, historical investment decisions and their mix of leakage reduction activities. We explore these factors in more detail below.

1. Companies are at different points of the investment cycle

Different companies are likely to operate at different points of the investment cycle, and the long-lived nature of distribution assets can influence companies' leakage levels (and hence the type and cost of leakage reduction activities) over the long-run. For example, reducing leakage purely through active leakage control (ALC), while lower-cost in the short-term, may deliver diminishing returns as this approach only targets visible leakage and does not address the quality and resilience of the underlying assets over the long-term.

As SES Water's cost adjustment claim notes, reducing leakage purely using ALC becomes 'disproportionately more expensive as the increasing number of leaks that need to be detected, located and then repaired'. In addition, 'increasing reliance on operational activity (such as ALC) could reduce resilience … to risks'.[15]

Mains replacement, while relatively expensive in the short-term, can help deliver better value for money than reactive strategies like ALC, as a 'spend to save' initiative that reduces maintenance costs for the majority of the life of the asset and contributes to reducing leakage. The potential benefits of longer-term investment from increasing the resilience of the asset base, e.g. to extreme weather conditions, should also be taken into account. In addition, as the SMC report notes, transitioning from one steady state to another and achieving a step-change in leakage reduction will require investment in increased repairs or asset renewal activities.[16]

This shows that the choice of leakage reduction activities requires careful optimisation that strikes the right balance between maintaining cost effectiveness in the short-term, but also ensuring the longer-term sustainability of infrastructure health and impact on leakage.

To assess companies' investment activities to reduce leakage, we assess the historical cost of leakage-related investments. The lack of specific data relating to capital expenditure on leakage means that we use proxy costs, drawn from Ofwat's Stata dataset:[17]

- *Maintaining the long-term capability of infrastructure assets* for wholesale water: this captures the capital expenditure on infrastructure assets (excluding third party capex) to maintain the long term capability of assets and to deliver base levels of service. Where projects have drivers both of enhancement and capital maintenance, companies are expected to apply a method of proportional allocation to allocate costs between enhancement and capital maintenance.

[15] SES Water, *PR19 Business Plan re-submission Cost adjustment claim for leakage – mains replacement component*, April 2019.
[16] SMC, *Review of the calculation of sustainable economic level of leakage and its integration with water resource management planning, report for the Environment Agency, Ofwat and Defra*, October 2012.
[17] Ofwat, *RAG 4.07 – Guideline for the table definitions in the annual performance report*, November 2017.

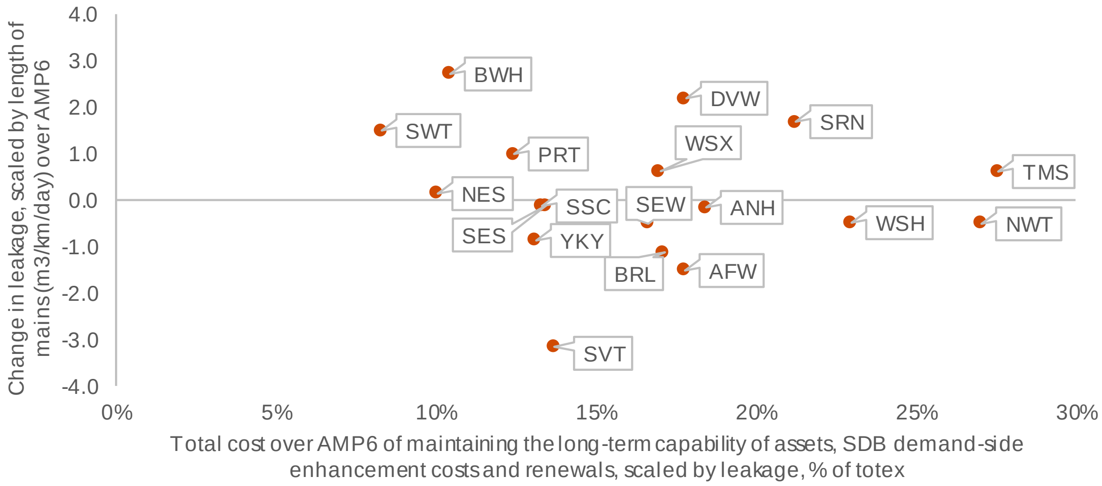
- *Renewals expensed in year (Infrastructure)* for wholesale water: This captures infrastructure renewals that are expensed rather than capitalised in the statutory accounts. 'Renewals' are generally planned activities to replace significant lengths of pipework or parts of an asset. These are targeted at improving network performance or solving ongoing problems and restores an asset to full capability.
- *Demand side enhancements to the supply/demand balance (dry year critical / peak conditions and dry year annual average)*: This captures capital expenditure to enhance the supply-demand balance. This includes expenditure associated with schemes to deliver demand-side (distribution and customer options) enhancements.

These measures consider the costs of maintaining the quality of infrastructure more broadly rather than specifically targeting leakage, however, we consider that capital maintenance activities such as mains renewal directly contribute to leakage reduction.

Figure 2.3 shows the relationship between the change in normalised leakage over 2015-20 (leakage scaled by the length of mains) and the total cost over 2015-20 of maintaining the long-term capability of assets, demand-side enhancement costs and renewals, expressed as a percentage of totex. As Figure 2.3 shows, some companies have increasing levels of normalised leakage over time (i.e. companies above the horizontal axis).

There appears to be no strong association between the share of spend and impact on leakage reduction. This may be because targeting leakage reduction requires a blend of both capital and operational activities. For example, SES Water explains that the reasons behind its low leakage reduction achievements are driven by a combination of capital investment and operational activities.

Figure 2.3: Change in normalised leakage over 2015-20 and the total cost of maintaining the long-term capability of assets as a share of total over 2015-20



Source: PwC analysis, Ofwat Stata dataset

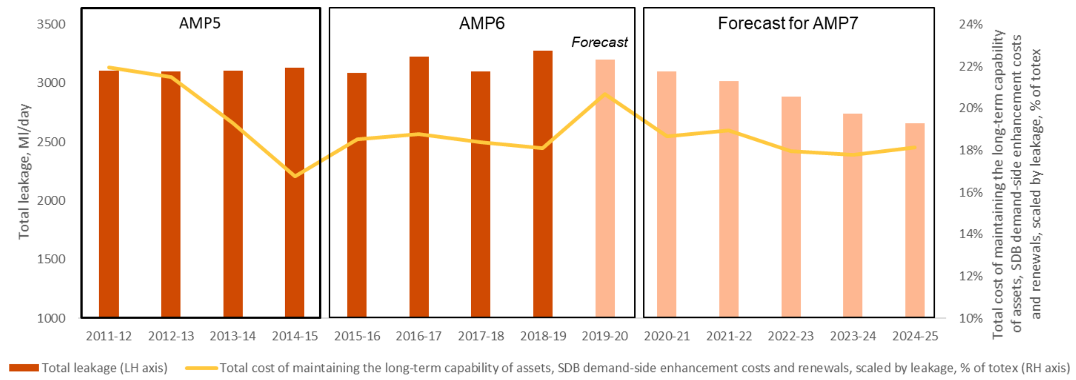
We find that over time, companies' investment in, maintaining and renewing infrastructure assets exhibit some cyclicality (see

Figure 2.4). This spending declined over the 2010-15 period, before rising slightly over 2015-20, and is forecast to decline again over 2020-25. Figure 2.5 shows the ratio of spend to invest, maintain and renew infrastructure assets to leakage over time, with each line representing an individual company and the orange line showing the industry average. Similarly, the lines for individual companies appear to exhibit some cyclicality.

Figure 2.6 shows the relationship between the cost of investing, maintaining and renewing infrastructure assets as a share of totex, and wholesale water opex as a share of totex. It shows that lower levels of spend to maintain and renew the quality of infrastructure is associated with relatively higher levels of wholesale water operating expenditure. Taken together, this might suggest that once companies have made the initial investment to improve the quality of infrastructure assets, the focus shifts to operational leakage reduction activities. For example, Anglian Water, following its investments to maintain the long-term capability of assets and renewing assets over 2015-20, is planning to shift its focus to improving the management of its networks, including through better pressure management and intensive leakage detection over 2020-25.[18]

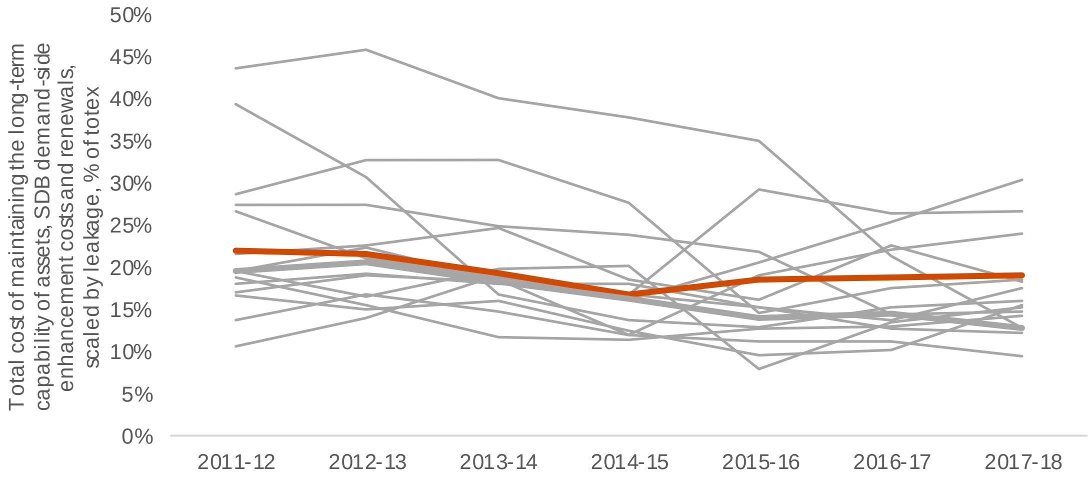
[18] Anglian Water, ODI on leakage, available here: http://ourperformance.anglianwater.co.uk/resilient.html?tab=tab_b

Figure 2.4: Historical level of leakage in England and Wales, compared to the cost of maintaining the long-term capability of assets, demand-side enhancement costs and renewals, % of totex over 2011-2019



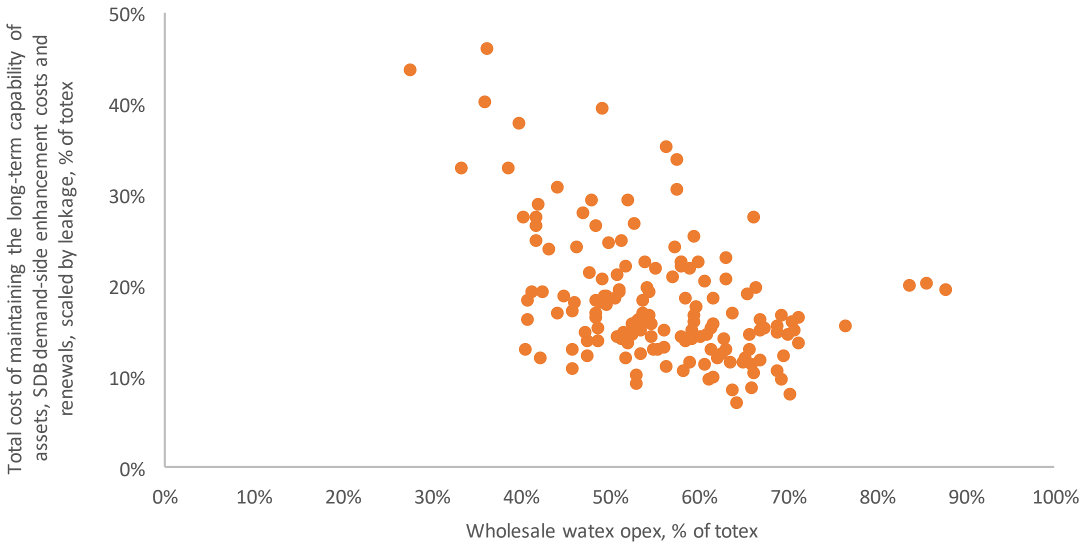
Source: PwC analysis, Ofwat Stata dataset

Figure 2.5: Total cost of maintaining the long-term capability of assets, demand-side enhancement costs and renewals, scaled by leakage, % of totex



Source: PwC analysis, Ofwat Stata dataset. Note each line represents an individual company and the orange line shows the industry average

Figure 2.6: Cost of investing, maintaining and renewing infrastructure assets as a share of totex, and wholesale water opex as a share of totex, 2012-2019



Source: PwC analysis, Ofwat Stata dataset. Each point denotes an observation for each company for one year.

2. **There is some indication that the marginal cost of leakage reduction rises as companies achieve further gains to reduce leakage.**

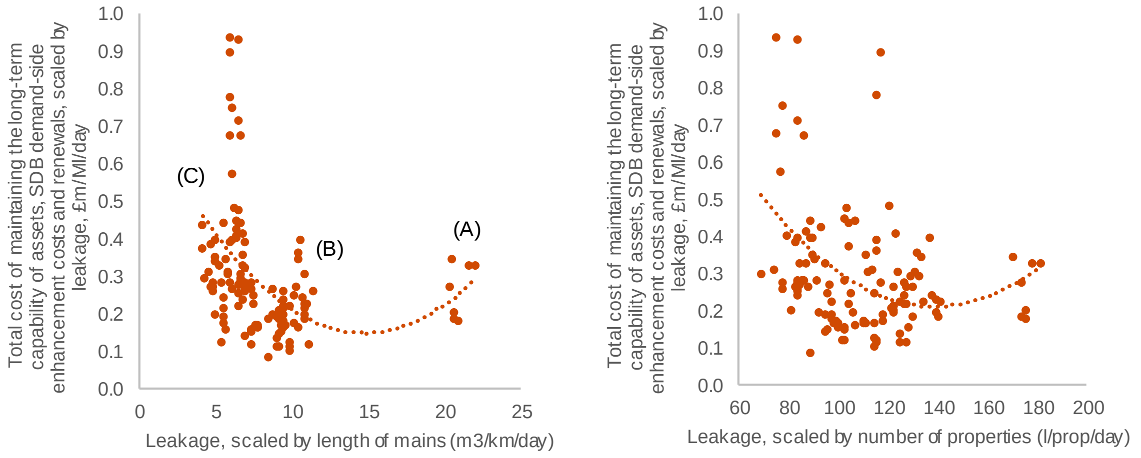
The marginal cost of leakage reduction may increase w ith leakage reduction as 'low hanging fruit' (i.e. leaks that are more easily detected and resolved) is addressed first, or as companies first exhaust lower-cost means of reducing leakage before exploring more costly means of reducing leakage.

We assess this relationship by considering the total cost of investing, maintaining and renew ing infrastructure assets, scaled by leakage, and compare this against companies' leakage performance, scaled to the length of mains (see Figure 2.7).

We find some evidence that the marginal cost of leakage reduction (for both the cost of maintaining and renew ing assets and operational costs) increases as companies further reduce leakage.

There appear to be some efficiency gains from investing to renew and maintain asset quality from improving leakage performance (moving from A to B in Figure 2.7), but the marginal cost of leakage reduction then starts to increase as companies achieve low er levels of leakage (moving from B to C).

Figure 2.7: The total costs of inv esting, maintaining and renewing infrastructure assets, scaled by leakage and normalised leakage (m3/km/day and l/prop/day), 2011-18



Source: PwC analysis of companies' business plan data

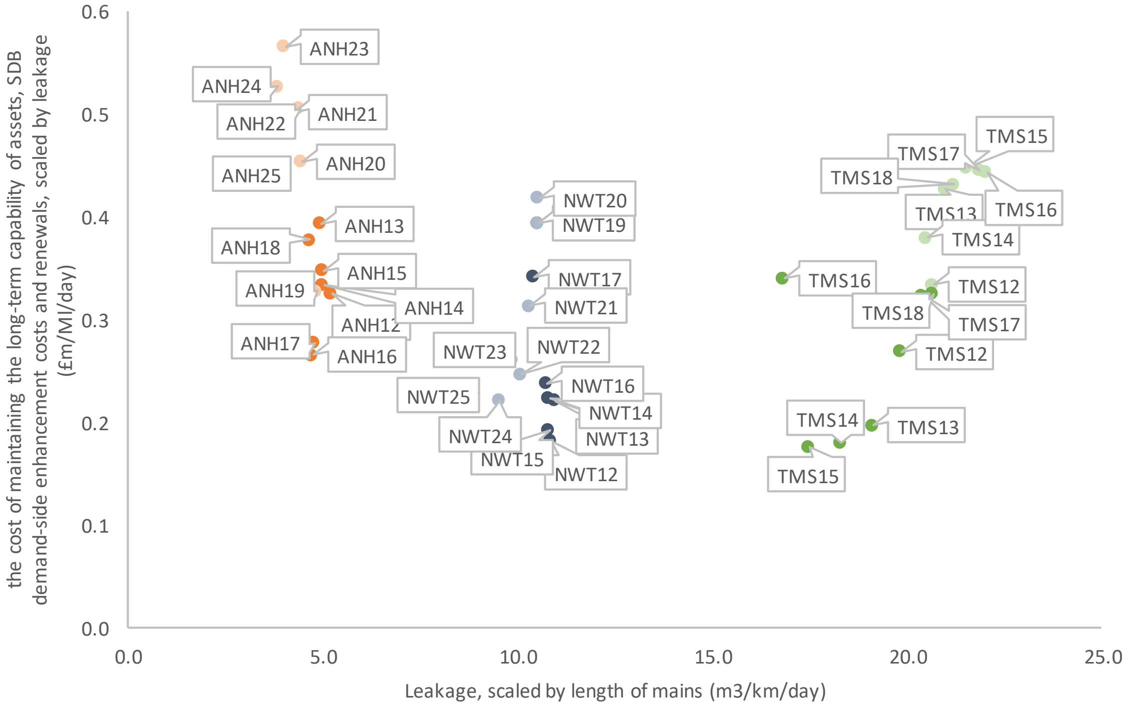
How ever, this also masks considerable differences in costs across companies, which might point to the importance of company-specific characteristics that drive leakage unit costs and performance, be it differences in leakage reduction activities, operating conditions or operational efficiency. In other w ords, companies may be operating on their ow n cost curves that are distinct from other companies. It should also be noted that the pattern observed in Figure 2.7 is largely driven by Thames Water w hich is an outlier (represented by the cluster of points to the right).

To test this, w e also examine trends over time that have taken place w ithin companies. Figure 2.8 show s how unit costs have evolved over time for three companies that vary in leakage performance – w e have selected Anglian Water (ANH) as a high-performing observation for this measure, United Utilities (NWT) as a poor performer and Thames Water (TMS) as a very poor-performing observation. Again we use as a proxy for unit costs the cost of maintaining the long-term capability of assets, supply-demand balance demand-side enhancement costs and renew als, scaled by leakage.

These companies generally exhibit a dow nward-sloping relationship between historical costs and leakage performance, and broadly anticipate unit costs to increase over the 2020-25 period. How ever, it does also appear that companies are moving along their ow n distinct cost curves.

These observations suggest that while the marginal costs of leakage reduction appear to increase w ith performance, company-specific factors also influence the magnitude and profile of costs.

Figure 2.8: Normalised leakage levels and a proxy for leakage unit costs (scaled by length of mains) between 2011-12 and 2024-25 (forecast)



Source: PwC analysis of companies' business plan data. Lighter shade indicates forecast.

3. Companies face different operating environments

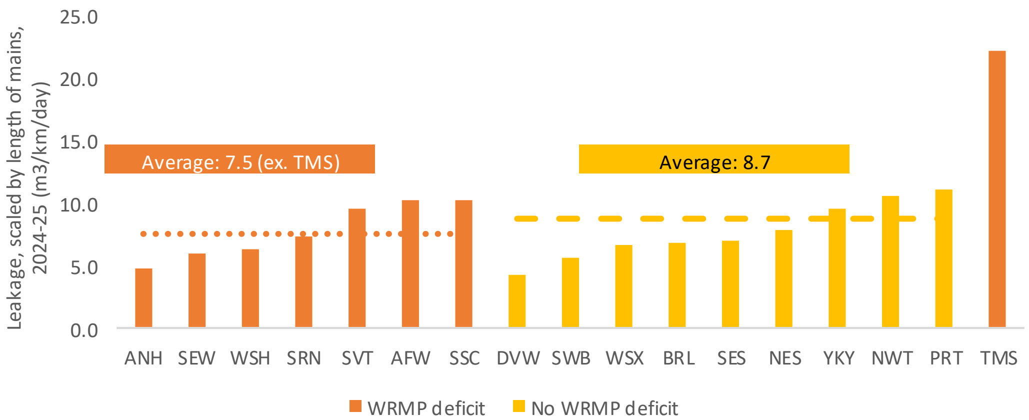
Companies' operating environment and geographical characteristics can influence their performance on leakage.

For example, companies that face a larger supply-demand deficit and a high cost of water, either as the result of drought risk or topographical factors tend to have better leakage performance. As Figure 2.9 shows, companies that have WRMP deficits in the supply-demand balance in 2024-25 tend to have lower relative levels of leakage (when Thames Water is excluded), as captured by the normalised leakage measure (expressed in geometric means). These companies face a more pressing challenge to maintain their supply and demand balance, and one of the means of addressing this deficit is by reducing leakage, which is included in the demand for water.

For example, the area in which Anglian Water (ANH) operates is regarded as an area of severe water stress where the rainfall is below the national average, and it is the leading company in terms of leakage performance. To tackle this, it has invested in smart metering (i.e. installing more than 85,000 smart household meters by 2020) and increased frequency of usage monitoring to drive customer behavioural change.

The exception here is Thames Water, which, while it is expected to have a WRMP deficit, its leakage performance still lags behind the rest of the industry.

Figure 2.9: Comparison of normalised leakage (expressed in geometric means) across companies, 2017-18

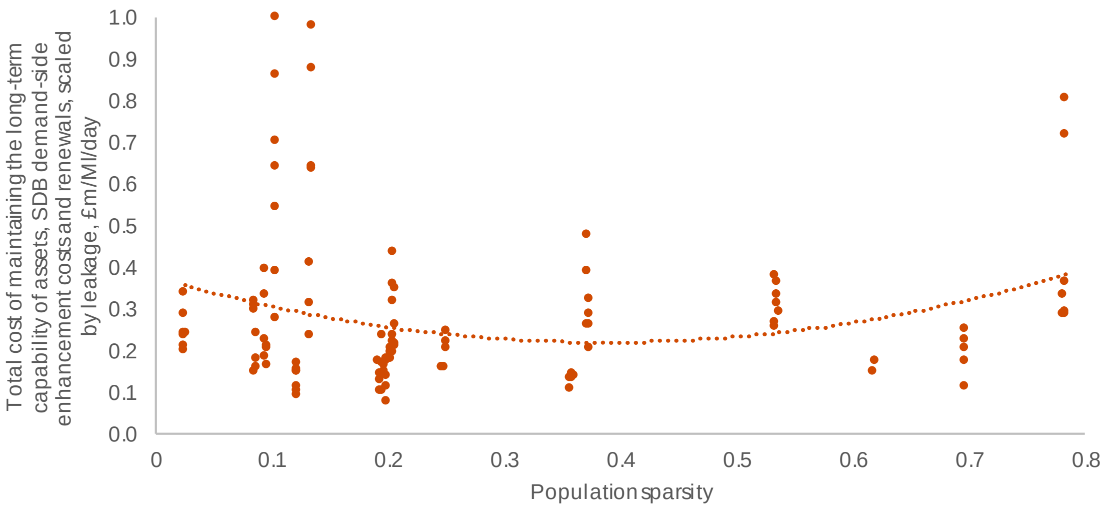


Source: PwC analysis, Ofwat Stata dataset, Ofwat's SDB enhancement models

Differences across supply areas (e.g. denser urban areas vs sparser rural areas) can also influence the cost of leakage reduction activities (see Figure 2.10). The distribution of customers may affect leakage reduction activity and broadly follows a U-shaped curve. At low levels of sparsity (i.e. in more densely-populated areas), leakage reduction activities may be affected by higher levels of traffic congestion or more complex infrastructure networks, which leads to higher costs. In more sparsely-populated areas, parts of the network may be more difficult to access or longer travel times are required which can affect leakage-related and meter reading activities. For this reason, density is included as one of the drivers in Ofwat's base cost models. A similar approach was taken by Ofgem for the RIIO-2 price controls for the network companies running gas and electricity transmission and distribution network. Specific adjustments were made to cost allowances for activities within the M25 (for gas distribution) and within London (for electricity distribution).[19]

These observations provide some support to the importance of company-specific factors in influencing the costs of leakage reduction.

Figure 2.10: The total costs of investing, maintaining and renewing infrastructure assets, scaled by leakage and population sparsity, 2011-18



Source: PwC analysis, Ofwat Stata dataset

4. Companies face different types of leakage

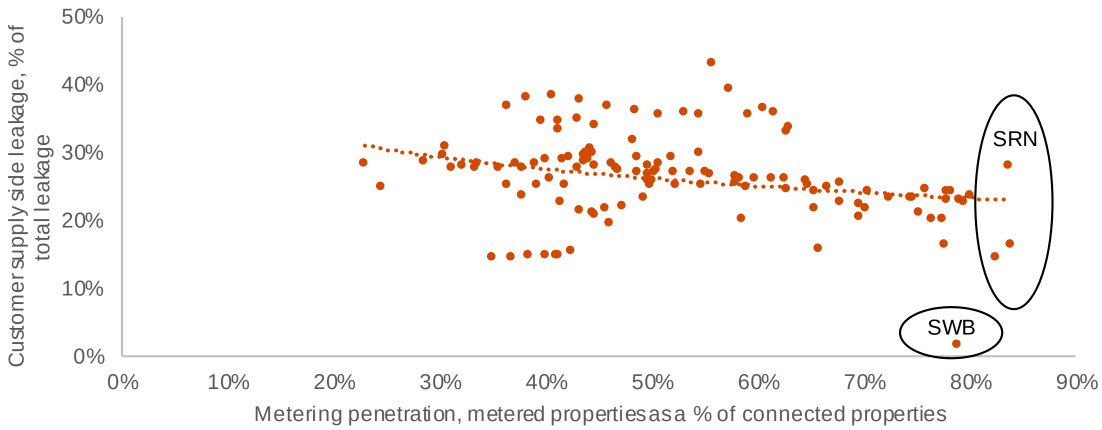
Water companies also need to respond to different leakage types, such as background leakage and bursts, as well as distribution leakage vs customer supply pipe leakage (CSPL). These typically require different responses, and therefore the optimal mix of leakage reduction activities will need to be tailored to these specific conditions.

- **Distribution leakage**: refers to leakage that takes place up to the point of delivery, and includes service reservoir losses and trunk main leakage. This is assessed after customer losses have been deducted from total leakage.
- **CSPL**: there is no statutory definition, but broadly refers to leakage through private water supply pipes that connect a property to water mains and are not in the ownership of water supply companies.[20] However, companies' business plans show that CSPL accounted for nearly a quarter of overall leakage over 2015-20. Companies' total reported leakage includes CSPL, and therefore has a direct bearing on companies' ability to meet their leakage performance commitments.[21]

For example, a company with higher levels of CSPL might opt to focus on increasing metering penetration, while a company with higher levels of background leakage might put greater emphasis on mains renewal activities. As Figure 2.11 shows, higher levels of metering penetration are typically associated with lower levels of CSPL as increasing metering penetration supports customer behavioural changes that lead to CSPL being detected more effectively.

[19] Ofgem, *RIIO-2 tools for cost assessment*, June 2019.
[20] UKWIR, *Issues regarding the potential adoption of supply pipes: costs, customer service and regulatory impacts*, Report Ref. No. 09/CU/01/4. 2009.
[21] SMC, *Review of the calculation of sustainable economic level of leakage and its integration with water resource management planning, report for the Environment Agency, Ofwat and Defra*, October 2012.

Figure 2.11: Correlation between metering penetration and customer supply-side leakage, 2011-2018



Source: PwC analysis, Ofwat Stata dataset

For example, Southern Water has one of the highest levels of metering penetration in England and Wales as it was one of the first companies to roll out a large-scale compulsory metering programme, which ran from 2010 to 2015, and has had a significant impact on reducing water usage (including leakage).

Companies are investing in smart metering, which can collect near real-time information on leakage (every 15 minutes) to improve leakage detection in customers' properties, or upgrading to advanced metering infrastructure (AMI), which integrates smart meters, communication networks, and data management systems to enable two-way communication between utilities and customers. On the other hand, companies that have higher levels of distribution losses, may engage in other activities that target leaks in the underground pipe network. For example, United Utilities, where distribution losses account for around 80-90% of overall leakage, is planning to install around 100,000 'acoustic' loggers across its underground water supply network to detect leaks.[22]

As a result, each company's proposed unit cost is influenced by its proposed mix of leakage reduction activities, ranging from ongoing efforts to find and fix leaks (e.g. through ALC) and pressure management, to metering enhancement, and longer-term capital expenditure such as mains replacement activities. The costs of these activities can vary significantly and are influenced by different cost drivers.

2.4 PR19 approach

The slowing progress achieved in reducing leakage, combined with companies' underperformance in achieving leakage performance commitments over PR14 is the context for the changes to Ofwat's regulatory approach introduced during the PR19 process.

2.4.1 Ofwat approach to funding leakage reduction at IAP

Ofwat has introduced a number of changes to its funding approach for leakage reduction for PR19.

Ofwat's policy position stated that '*customers should not pay extra costs for companies to deliver stretching targets*', and as a result, the delivery of the 15% minimum leakage reduction requirement should be funded from companies base cost allowance.[23] In exceptional circumstances, water companies could make a case for adjustment of their performance commitment if they are not able to deliver stretching performance commitments from base costs.

For enhancement costs, Ofwat's approach during the IAP allowed enhancement funding for companies that committed to leakage reduction in excess of 15% or beyond the industry 2024-25 upper-quartile level. This allowance was determined through a unit cost approach, using the minimum of the level proposed by the company or the industry median forecast unit cost for 2020-25, expressed in £million/Ml/day. This was assessed using a 'gated' approach where enhancement funding was allowed based on the lower of company's own unit costs or industry median unit costs of £1.60million per Ml/day multiplied by the volume beyond the relevant threshold:

- If the company's forecast leakage reduction exceeds the 15% threshold but not the upper quartile performance, it received funding beyond the 15%.
- If the company's forecast leakage reduction exceeds the 2024-25 upper quartile threshold of leakage, it received funding beyond the upper quartile level.

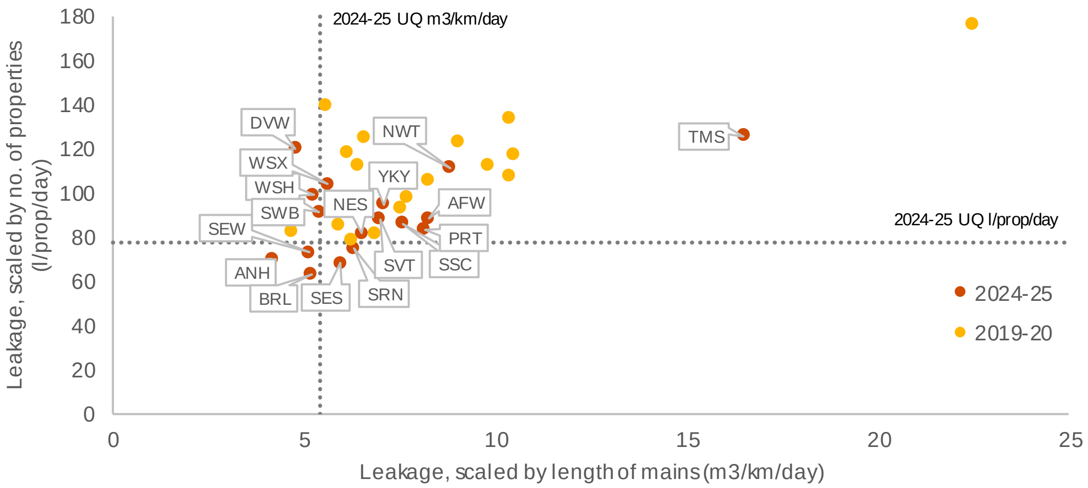
[22] United Utilities, *World's biggest 'listening project' will help save water*, July 2019.
[23] Ofwat, *PR19 Initial assessment of plans, Technical appendix 2: Securing cost efficiency*, January 2019. Ofwat defines base costs as 'routine, year on year costs, which companies incur in the normal running of their business'

- The company received maximum funding under the two tests if both tests are passed.

The £1.60 million per Ml/d unit cost was calculated as a triangulation of the supply-demand balance leakage unit costs, outcomes underperformance payment unit costs and outcomes outperformance unit costs.

In line with Ofwat's expectations, the industry has committed to reduce leakage by 15% over 2020-25 across the industry.[24] The variation in companies' expected performance in 2024-25 is shown in Figure 2.12, and is compared to their performance in 2019-20. The companies that are expected to achieve or exceed the 2024-25 upper quartile industry threshold are Anglian Water, Bristol Water and South East Water.

Figure 2.12: Forecast leakage performance for both leakage normalisations in 2024-25



Source: PwC analysis, Ofwat (January 2019) Supply-demand balance enhancement: Feeder model summaries.

Separate to this funding criteria, Ofwat provided an allowance for metering through the metering enhancement model. Given that increased usage of smart meters should better identify and therefore reduce leakage, Ofwat expects that this will provide further assistance to leakage management, particularly in relation to the installation of smart meters.

2.4.2 Changes for the draft determinations

Ofwat further refined its regulatory approach for the DD, published in July 2019.[25]

Changes in the enhancement funding. The main change between IAP and DD for the enhancement funding was the removal of the 15% leakage reduction threshold and retaining the industry upper quartile threshold to qualify for enhancement allowance.

The new leakage enhancement funding approach was estimated based on the following:

- If leakage performance is not forecast to meet the industry upper quartile threshold in 2024-25 on both normalised measures (by lengths of mains and per property per day), then the request for enhancement funding for leakage reductions was not allowed.
- If companies' leakage performance is forecast to be beyond the industry upper quartile threshold in 2024-25 in both normalised measures, then each Ml/d of leakage reduction beyond this upper quartile level was funded at a unit cost.

At DD, Ofwat's expectations for base service levels is that an efficient company should achieve industry forecast upper quartile performance by 2024-25.[26]

Changes in the industry unit cost to inform the enhancement allowance. As part of the change in approach at the DD, leakage funding was determined through companies' specific leakage unit costs approach rather than by using the triangulation approach at IAP. The new unit cost approach used the company proposed costs, adjusted

[24] Following Ofwat's interventions at the DD, the industry is targeting to reduce leakage by about 17% over AMP7.
[25] Ofwat, *PR19 draft determinations. Securing cost efficiency technical appendix*, July 2019.

[26] Ofwat, *PR19 draft determinations: Securing cost efficiency technical appendix*, July 2019.

for a company-specific efficiency challenge where these costs are above the revised industry median unit cost (£2.0 million per Ml per day)[27]. In contrast, at the IAP, Ofwat capped unit costs at £1.6 million per Ml per day.

The impact of the DD policy change was to reduce the overall allowance. The DD allowance for leakage funding was £76 million, in comparison to £93 million at IAP. The majority of water companies received less funding as a result of the expectation that an efficient company should achieve industry forecast upper quartile performance by 2024-25. [28]

Table 2.3: Leakage enhancement allowance by company during IAP and DD

Company	IAP - leakage enhancement funding (£m)	DD - leakage enhancement funding (£m)	Change from IAP (£m)
ANH	36.48	69.25	32.77
WSH	0.24	0.00	-0.24
NES	2.50	0.00	-2.50
SVE	0.45	0.00	-0.45
SRN	0.00	0.00	0.00
TMS	3.09	0.00	-3.09
NWT	0.00	0.00	0.00
WSX	0.00	0.00	0.00
YKY	39.03	0.00	-39.03
AFW	0.00	0.00	0.00
BRL	2.46	2.39	-0.06
PRT	0.02	0.00	-0.02
SEW	4.91	4.64	-0.27
SSC	3.40	0.00	-3.40
SES	0.00	0.00	0.00
SWB	0.00	0.00	0.00
Industry	92.58	76.28	-16.30

Source: Ofwat, Feeder model SDB enhancement publication, July 2019

2.4.3 Issues raised with regard to Ofwat's approach

14 out of the 17 companies requested enhancement expenditure for leakage reduction to achieve their stretching performance commitment levels. Water companies raised a number of issues with Ofwat's approach to leakage levels and funding approach, as follows:

- Some companies also challenged Ofwat's expectation that an efficient company should achieve industry forecast upper quartile performance by 2024-25, on the basis that this requires reducing the level of leakage beyond what companies consider to be achievable with the base allowance. Calibrating base allowances to historical levels of expenditure may also not capture the allowance required to achieve this far more substantial reduction in leakage than has been achieved historically. Companies therefore challenge that the approach, on the basis that the base allowance is considered insufficient to deliver a step-change in leakage performance.
- Companies raised concerns that Ofwat's base cost models do not account specifically for leakage-specific variables, meaning that model-predicted costs do not sufficiently reflect company-specific differences that drive leakage reduction costs, nor do they account for the increasing marginal cost of leakage. As we set out in Section 2.3 there is some indication of a non-linear relationship between leakage reduction costs and companies' leakage performance.
- Some companies question the merits of using various normalisation measures as the primary measure of leakage reduction performance, as companies may have less control over certain measures (such as leakage per property), than leakage per length of mains. Some companies also suggest that performance on leakage reduction should take into account 'weak spots' in the network, such as connections, joins and diversions.

2.4.4 Ofwat's DD base costs econometric models

Ofwat uses econometric models benchmark wholesale water base costs. We define base costs as operating expenditure (opex), capital maintenance expenditure (capex), plus certain capex enhancement costs categories as specified in Ofwat's cost assessment technical appendix at DD.[29]

[27] Note that leakage benefits associated with metering are assessed implicitly in the metering enhancement model and excluded from this analysis.
[28] Ofwat, *PR19 draft determinations: Securing cost efficiency technical appendix*, July 2019.
[29] Ibid. Enhancement activities include new developments, new connections element of new developments and addressing low pressure costs.

The main cost drivers that Ofwat has included in the base cost models are summarised in Table 2.2, which are consistent with engineering, operational and economic understanding of cost drivers.[30]

Table 2.2: Cost drivers and variables included in Ofwat's base cost models

Cost driver categories	Definition and examples
Scale	These variables measure the size of the network and/or level of output. Examples include: • Number of connected properties • Length of mains The larger the network, the higher the likely costs of managing and operating the network.
Complexity	These variables capture the complexity of required treatment or the complexity of the network. Examples include: • The share of water treated at works of complexity levels 3 to 6. This variable refers to the volume of water treated at treatment works of different complexity levels, ranging from zero (least complex) to six (most complex). It captures the step change in treatment costs between works of complexity level 2 or less (i.e. relatively simply works such as those treating good quality groundwater sources) and works at higher levels of complexity (e.g. works with multiple treatment stages treating lower quality sources). • Weighted average treatment complexity is calculated as the weighted average of the numbers one to seven, each corresponds to a treatment complexity level as defined in the business plan data tables, where the weight for each level of complexity is the proportion of water treated at that level.
Topography	These variables capture the energy requirement for transporting or pumping water. The number of booster pumping stations per lengths of main is the main measure of the topography (costs are associated with the requirement to pump and transport water to customers) in the treated water distribution and wholesale water cost models.
Density	These variables capture the economies of scale at the treatment level and costs resulting from operating in highly dense areas. Examples include: • Weighted average density. The density of an area could have two opposing effects on costs: The density variable captures the potential for a water treatment business to treat water using larger and fewer treatment works incurring lower unit costs. However, dense areas may also be associated with higher property, rental and access costs when distributing water to customers. Ofwat decided to use the weighted average density because it is beyond company control and it is able to reflect relative densities within regions. • Squared term of the weighted average density. This term has been included to capture the non-linear effect of population density on costs.

Ofwat then use a triangulation process to combine different models to produce cost estimates at different levels of aggregation, which are equally weighted to set the efficient cost allowances. These are the water resource plus models (model 1 and model 2), treated water distribution model and wholesale water models (model 1 and model 2).

Leakage[31] is only relevant for the treated water distribution and wholesale water sector and is not relevant to water resources, hence, in the rest of the report we will focus only on the treated water distribution and wholesale water models.

The cost drivers for the treated water and wholesale water models are summarised in Table 2.3.

Table 2.3: Ofwat base cost models

	Base cost models				
Variables	**WRP1**	**WRP2**	**TWD**	**WW1**	**WW2**
Number of connected properties	✓	✓		✓	✓
Lengths of mains			✓		
Water treated at works of complexity levels 3 to 6	✓			✓	
Weighted average treatment complexity		✓			✓
Number of booster pumping stations per lengths of main			✓	✓	✓
Weighted average density	✓	✓	✓	✓	✓
Squared term of the weighted average density	✓	✓	✓	✓	✓

Source: Ofwat, Supplementary technical appendix: Econometric approach, January 2019

[30] The definitions of these variables have all been drawn from the following source: Ofwat, *PR19 Initial assessment of plans, Supplementary technical appendix, Econometric approach*, January 2019.
[31] Total leakage measures the sum of distribution losses and supply pipe losses in mega-litre per day (Ml/day). It includes any uncontrolled losses between the treatment works and the customer's stop tap. It does not include internal plumbing losses. (Business Plan, Tab Wn2 line 25).

The main difference between the two wholesale base cost models - WW1 and WW2 – is the measure used to capture water treatment complexity. For WW1, this is expressed as a percentage of water treated at treatment works with a complexity level between 3 and 6, while for WW2 it is expressed as the weighted average of treatment complexity level.

Ofwat's current position is that the econometric models should be driven by factors that are exogenous and beyond management control, e.g. topography, density. Some of these variables do take into account some exogenous factors that influence leakage, e.g. length of mains and density (high connection densities in urban and semi-urban areas tend to have higher levels of leakage as these tend to occur on service connections that connect properties to mains).

3 Econometric model testing and results

3.1 Section overview

In Section 3 we present our approach to modelling base costs by embedding leakage performance explicitly in the existing model.

The remainder of Section 3 is organised as follows:

- Section 3.1 sets out how we account for leakage in Ofwat's base cost models..
- Section 3.2 describes our modelling approach.
- Section 3.3 summarises the results from our econometric analysis.
- Section 3.4 reports the results of our candidate model specifications.
- Section 3.5 sets out other alternative specifications that were tested to help inform our candidate specifications.
- Section 3.6 sets out our approach for modelling leakage directly to assess the extent to which historical costs has had an impact on leakage reduction.
- Section 3.7 sets out the limitations of our analysis.
- Section 3.8 concludes.

3.2 Accounting for leakage in Ofwat's base cost models

We test the inclusion of variables that capture companies' leakage performance in Ofwat's base cost models in response to the issues raised by companies. Specifically, this allows us to test the extent to which companies' leakage performance (relative to the forecast upper quartile level in 2019-20 and 2024-25) influences companies' base cost.

We use Ofwat's FD Feeder Model datasets, covering the period from 2011 and 2019. We retain Ofwat's base cost model specifications and augment these by testing the incorporation of leakage-related variables.

Specifically, given the change to Ofwat's approach at the DD, the main driver we test is the distance in leakage levels in each year from the industry 2024-25 upper quartile (as used at DD). Using this variable allows us to capture the progress that companies make over time, and how far companies have yet to go to achieve the specified level. This would allow us to test whether the cost allowance increases overall, the closer companies are to the benchmark.

We test this variable using a number of transformations, as follows:

- We use a number of different normalisation measures to derive the industry upper quartile level for leakage, as follows:
  - Leakage per lengths of main (m3/km/day), expressed as the ratio between the total leakage volume and the total length of potable and non-potable mains.
  - Leakage per property (l/property/day), expressed as the ratio between the total leakage volume and the sum of non-household and household connected properties.
  - Leakage per distribution input (%), expressed as the ratio between the total leakage volume and the distribution input (volume of water entering the distribution system).[32]
  - Leakage levels expressed in geometric means. The geometric mean for the upper quartile is calculated as the squared term of the product between the leakage volume normalised by lengths of main (m3/km/day) and the leakage volume normalised by properties per day (l/property/day). This approach has some advantages over taking the arithmetic mean as it is less affected by the presence of very small or very big observations in our sample that might skew the results.

[32] Distribution input is the average amount of potable water entering the distribution network and supplied to customers within the company's area of supply. See Ofwat, *RAG 4.06 – Guideline for the table definitions in the annual performance report*, August 2016.

– These are then expressed as levels (i.e. in Ml/day) for each company using the appropriate company-specific scaling variable (length of mains, number of connected properties, distribution input).

- We test both the distance from the upper quartile level of performance at the start of the 2020-25 period (i.e. 2019-20) and at the end (i.e. 2024-25).
- We also include a squared term of leakage volumes to capture any non-linear effects, i.e. as companies near the 2019-20 or 2024-25 upper quartile leakage level, the costs of reducing leakage increase at an accelerating rate.

In addition to the leakage variables above, we also tested other variables that may indirectly influence costs through leakage, such as:

- Weather factors, such as temperature and rainfall. Large variations in temperature could cause pipes to burst more frequently. We use the minimum monthly temperature in a year for each company's operating region to test this.

Consistent with Ofwat's base cost modelling approach, we focus on variables that are "exogenous", i.e. variables that are not directly within management control in our augmented base cost models. The use of exogenous variables avoids issues of perverse incentives, particularly where companies exert influence. This is the reason that we do not use the deviation from SELL as an input, as this measure is influenced by companies' own determinations of costs and benefits in informing SELL levels, and does not represent an objective and homogenous approach across the industry. Instead, we use a similar approach by using a distance from the upper quartile level measure. This approach is also consistent with Ofwat's regulatory approach to setting price controls more broadly. In addition, as we have seen in Section 2, SELL has failed to drive efficiency in leakage reduction. For this reason, we have also excluded factors like asset age and condition, as these are within management control.

3.3 Description of modelling approach

Our approach to augmenting the existing Ofwat models is based on six steps, described in more detail in Annex B. We augment Ofwat's TWD, WW1 and WW2 models, as leakage costs likely relate to the distribution element of the supply chain and hence may affect these models. However, our results primarily focus on the WW1 and WW2 models as our tests for the TWD model did not produce statistically significant results. We hypothesise that this is because the variance in TWD costs do not capture the effect of leakage but that it may be captured in the variance at the wholesale water level due to how leakage may be impacting costs across the whole supply chain.

The Ofwat dataset we use includes observations for the 17 water and wastewater companies from 2011-12 to 2018-19. We test panel data models, i.e. fixed effect (FE) and random effect (RE), and apply the Hausman test to identify our candidate model specification.[33] The Hausman test suggests that a RE model specification is more appropriate than FE. Our dependent variable is the base cost in treated water distribution and wholesale water (expressed in logs) and the independent variables driving leakage are summarised in Table 3.1.

Following extensive testing of alternative variables and specifications, we find three potential augmented model specifications that meet the model selection criteria, as set out in Ofwat's technical appendix on its econometric approach.

Our three candidate augmented model specifications are defined as follows (and summarised in Table 3.1):

- **Model specification 1:** We augment Ofwat's base specification with a variable capturing the distance from the upper quartile leakage level in 2024-25 (estimated on the basis of m^3/km/day), its squared term, and a variable capturing the interaction between a dummy variable for Thames Water and the distance from the upper quartile leakage level.[34] We include this term to capture the potential specific impact that Thames Water exerts on base costs, as the data in Section 2 showed Thames Water being an outlier on leakage performance.
- **Model specification 2.** We augment Ofwat's base specification with a variable capturing the distance from the upper quartile leakage level in 2019-20 (estimated on the basis of m^3/km/day), its squared term and a dummy variable for Thames Water.

[33] Wooldridge, J. M., *Econometric Analysis of Cross Section and Panel Data*, Cambridge, MA: The MIT Press, 2002.
[34] A dummy variable (or binary variable) is used to indicate the presence or absence (i.e. equal to 1 or 0) of a variable in the sample. It allows us to divide the sample into subgroups and evaluate the impact that each subgroup has on the dependent variable. In this case including a dummy variable for Thames Water allows us to estimate the specific effect exerted by Thames Water on base costs. The interaction term is the product of two variables, which allows us to capture the effect of one variable, conditional on the value of another variable. The interaction term in our model allows us to capture any leakage effects that are specific to Thames Water in explaining base costs.

- **Model specification 3:** We augment Ofwat's base specification with a variable capturing the distance from the upper quartile leakage level in 2024-25 (estimated on the basis of m^3/km/day), its squared term and dummy variable for Thames Water.

Table 3.1: Model specifications

	Ofwat variables	Additional variables
Model specification 1	Ofwat DD cost drivers	• Distance from the upper quartile leakage level in 2024-25 (m3/km/day) • Squared distance from the upper quartile leakage level in 2024-25 (m3/km/day) • Interaction term between the upper quartile leakage level in 2024-25 term (m3/km/day) *Thames Water dummy)
Model specification 2	Ofwat DD cost drivers	• Distance from the upper quartile leakage level in 2019-20 (m3/km/day) • Squared distance from the upper quartile leakage level in 2019-20 (m3/km/day) • Thames Water dummy
Model specification 3	Ofwat DD cost drivers	• Distance from the upper quartile leakage level in 2024-25 (m3/km/day) • Squared distance from the upper quartile leakage level in 2024-25 (m3/km/day) • Thames Water dummy

We present the results of our candidate models in the following section. For completeness we report all the models that we have tested but that we do not include in our candidate specification list in Annex A.

3.4 Results from our econometric analysis

Our results show that two main variables are significant in our model specifications: the distance from the industry upper quartile leakage level at 2019-20 or 2024-25 (normalised based on the length of mains) and the Thames Water dummy.

3.4.1 Model Specification 1

The results for model specification 1 (Table 3.2) show that the Ofwat cost drivers of base costs and the deviation from the upper quartile 2024-25 leakage level variables are statistically significant at the 5% level, apart from the weighted average density variables.

The coefficient on the linear term for the distance from the upper quartile 2024-25 level is statistically significant and has a negative sign implying that the more companies are over-performing relative to the benchmark level, the more positive the impact on base costs. For both the model specifications WW1 and WW2, the squared difference coefficient is statistically significant and with a positive sign, which suggests a non-linear relationship between companies' leakage performance and the marginal cost of reducing leakage. This means that the more companies over-perform relative to the level, the more positive the impact on base costs. However, it also means that companies that are underperforming (and hence where there is a large absolute difference between leakage levels and the upper quartile level of leakage) are expected to have higher costs.

The interaction term between the Thames Water dummy and the upper quartile 2024-25 level is significant for both WW1 and WW2 models, which suggests that there are leakage-specific effects that are idiosyncratic to Thames Water. The negative sign on the coefficient suggests that Thames Water on average should be spending less on leakage reduction compared to the industry. The weighted average density variable and its squared term are statistically significant at the 5% level in WW1 and lower statistical significance in WW2 (weighted average density is significant at 18% and its squared term is significant at 20%). This implies that the denser an area is the higher the impact on costs.

Table 3.2: Results of model specification 1

Model 1	**WW1**	**WW2**
Variable name	**WW botex**	**WW botex**
ln (number of properties)	**1.046***** (0.000)	**1.008***** (0.000)
% of water treated at complexity levels 3 to 6	**0.005***** (0.000)	
ln (weighted average water treatment complexity)		**0.542***** (0.000)
ln (number of booster pumping stations per length of main)	**0.300**** (0.025)	**0.343***** (0.002)
ln (weighted average density)	**-2.180*** (0.081)	**-1.299** (0.184)
(ln(weighted average density))^2	**0.155*** (0.091)	**0.091** (0.207)
Difference from forecast 2024-25 UQ leakage level based on m3/km/day	**-0.002**** (0.040)	**-0.001*** (0.064)
Squared difference from forecast 2024-25 UQ leakage level based on m3/km/day	**7.35E-06***** (0.006)	**7.23E-06***** (0.006)
Thames Water dummy *x* forecast 2024-25 UQ leakage level based on m3/km/day interaction	**-0.002**** (0.046)	**-0.002*** (0.053)
Constant	**-1.218**	**-3.886**
Number of observations	**141**	**141**
Standard errors[35]	**cluster**	**cluster**
R_squared	**0.976**	**0.978**
RESET p_value[36]	**0.364**	**0.234**

****p-value < 0.01, meaning that the variable is statistically significant at 1%; **p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%. P-values in (brackets).*

3.4.2 Model Specification 2

The results for model specification 2 (Table 3.3) show that the Ofwat base cost drivers are significant and with the expected sign, except for the weighted average density variable and its squared term for WW2, which are not significant (statistically significant at 17% and 19% respectively).

The coefficient on the distance from the 2019-20 upper quartile leakage level variable is statistically significant for WW1 and WW2. The linear terms have a negative sign, implying that the more companies are over-performing relative to the 2019-20 upper quartile leakage level, the more positive the impact on base. The squared difference terms are positive, meaning that the more companies over-perform relative to the 2019-20 upper quartile leakage level, the more positive the impact on base. The Thames Water dummy variable is significant, suggesting that Thames Water exerts a specific effect on base. The negative sign on the coefficient indicates that Thames Water is expected have lower costs than other companies, once other factors explaining base costs are controlled for.

[35] For the calculation of the p-values we adjust for clustered standard errors because the variance in our model is correlated ("clustered") by company. We make this adjustment to ensure our results are accurate.
[36] The Ransey RESET test is a general specification test for the linear regression model. Our models pass the test at the 5% level as the RESET p-value greater than 0.05.

Table 3.3: Results of model specification 2

Model 2	WW1	WW2
Variable name	**WW botex**	**WW botex**
ln (number of properties)	**1.039*** (0.000)	**1.003*** (0.000)
% of water treated at complexity levels 3 to 6	**0.005*** (0.000)	
ln (weighted average water treatment complexity)		**0.537*** (0.000)
ln (number of booster pumping stations per length of main)	**0.282** (0.036)	**0.325*** (0.004)
ln (weighted average density)	**-2.248*** (0.069)	**-1.353** (0.169)
(ln(weighted average density))^2	**0.160*** (0.077)	**0.095** (0.190)
Difference from 2019-20 UQ leakage level based on m3/km/day	**-0.001** (0.049)	**-0.001*** (0.092)
Squared difference from 2019-20 UQ leakage level based on m3/km/day	**5.71E-06*** (0.000)	**5.78E-06*** (0.000)
Thames Water dummy	**-0.758*** (0.000)	**-0.745*** (0.001)
Constant	**-0.97**	**-3.711**
Number of observations	**141**	**141**
VCE	**cluster**	**cluster**
R_squared	**0.976**	**0.978**
RESET p_value	**0.495**	**0.302**

****p-value < 0.01, meaning that the variable is statistically significant at 1%; **p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

3.4.3 Model Specification 3

The results for model specification 3 (Table 3.4) show that the Ofwat base cost drivers are significant and with the expected sign, except for the weighted average density variables in WW2 that are not statistically significant at the 5% level.

The coefficients on the distance from the forecast 2024-25 upper quartile leakage level variables appear to be statistically significant for all models. The signs on the linear and squared terms are the same as those observed in model specification 1 and 2. Similar to model specification 2, the Thames Water dummy variable is significant, again suggesting that Thames Water is expected to have lower costs than other companies, once other factors explaining base costs are controlled for. As in model specification 1 and 2, the lower statistical significance on the weighted average density variable can be explained by similar reasons, i.e. the dummy variable for Thames Water has displaced density in terms of explanatory power.

Table 3.4: Results of model specification 3

Model	WW1	WW2
Variable name	**WW botex**	**WW botex**
ln (number of properties)	**1.048*** (0.000)	**1.010*** (0.000)
% of water treated at complexity levels 3 to 6	**0.005*** (0.000)	
ln (weighted average water treatment complexity)		**0.544*** (0.000)
ln (number of booster pumping stations per length of main)	**0.277** (0.039)	**0.324*** (0.004)
ln (weighted average density)	**-2.261*** (0.065)	**-1.362** (0.158)
(ln(weighted average density))^2	**0.161*** (0.074)	**0.095** (0.180)
Difference from forecast 2024-25 UQ leakage level based on m3/km/day	**-0.001** (0.030)	**-0.001** (0.048)
Squared difference from forecast 2024-25 UQ leakage level based on m3/km/day	**5.57E-06*** (0.000)	**5.66E-06*** (0.000)
Thames Water dummy	**-0.731*** (0.002)	**-0.716*** (0.003)
Constant	**-1.052**	**-3.764**
Number of observations	**141**	**141**
VCE	**cluster**	**cluster**
R_squared	**0.976**	**0.978**
RESET p_value	**0.449**	**0.286**

****p-value < 0.01, meaning that the variable is statistically significant at 1%; **p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

3.5 Additional specifications tested

We also tested several additional models using alternative measures of distance from the upper quartile leakage benchmark level. The distance from the upper quartile level of leakage performance using leakage per property per day, percentage of distribution input and geometric mean (of leakage metrics), were found to be significant only in a limited number of models. We also tested these models without the inclusion of the Thames Water dummy (and interaction term), and this diminished the overall goodness-of-fit of the model and overall significance.

We also find that weather factors, i.e. the minimum monthly temperature in a year, do not appear to have a statistically significant impact on costs.

3.6 Leakage model testing

In this Section we model a leakage-specific model to assess the impact of historical expenditure on leakage reduction. The remainder of this Section is structured as follows:

3.6.1 Drivers of leakage

A number of factors motivate our approach to attempt to model leakage directly. As described in Section 2, one of the issues raised by companies is that historical expenditure to reduce leakage (e.g. capital maintenance activities) can be lumpy. Combined with the use of an industry median unit cost during the cost assessment process, costs may therefore be skewed towards companies that are either performing relatively little leakage reduction or are carrying out relatively cost-efficient leakage reduction activities. Modelling leakage directly allows us to assess the extent to which historical spending, particularly capital maintenance activities, have contributed to leakage reduction in the past.

This model could be used as an alternative approach to inform the appropriate cost allowance for funding leakage reduction to support future price determinations, and to some extent enables companies to be benchmarked for efficiency.

We model total leakage as the dependent variable, expressed in Ml/day. The main explanatory variables of interest are expenditure items that relate to leakage, as follows:

- Botex: baseline cost obtained as the sum of operational costs (opex) and capital maintenance costs;
- Totex: this includes the sum of total operational cost and total capital costs (opex plus capex);
- Expenditure associated with maintaining the long-term capability of assets (i.e. infrastructure); and
- Supply-demand balance demand-side enhancement costs for wholesale water. This measure is relevant as leakage reduction (alongside managing customer demand) is a core component of companies' demand-side strategy to maintain the supply-demand balance.

We also test the inclusion of lagged terms of these spend variables, to determine whether spending has a lagged effect on leakage, for example if the effect of last year's capital maintenance activities only becomes clear in the following year's leakage performance. Current levels of leakage are also influenced by the volumes of the previous year, hence we have included the lagged term of leakage to check if this variable is one of the drivers of current leakage volumes.

In addition to these variables, we also include other control variables that are underlying drivers for leakage. These predominantly include the variables used in Ofwat's FD cost models, driving the cost for leakage reduction. The lengths of mains, number of properties connected, the weighted average density (and its squared term) and number of boosting pump stations are certainly variables driving the leakage volumes, hence we have included them in our model specifications.

We also tested the inclusion of exogenous drivers of leakage, such as temperature to capture the effect of climate on leakage performance.

The limitations of historic data for leakage reduction costs (for the period between 2011 and 2017) results in the use of additional, proxies, i.e. expenditure associated with maintaining the long term capability assets.

3.6.2 Description of modelling approach

The Ofwat dataset that we have used for our analysis includes observations of 17 companies from 2011 to 2017 (for a total of 124 observations). We have tested panel data models, i.e. fixed effect (FE) and random effect (RE), and applied the Hausman test to identify our candidate model specification. The Hausman test suggests that a random effect panel data model is preferred over fixed effects.

Using the model selection criteria and modelling principles as specified in Ofwat's econometric technical appendix published in their initial assessment of plans, we find augmented five model specifications to explain leakage. The specifications are summarised in table 3.5 below . .

Table 3.5: Leakage models

		Model 1	Model 2	Model 3	Model 4	Model 5
Spend drivers	**Explanatory variables of leakage**					
	Lagged volumes of leakage (i.e. leakage at time *t - 1*)	✓	✓	✓	✓	✓
	Expenditure in maintaining long term capability asset		✓		✓	
	SDB demand-side enhancement			✓		✓
	TWD botex	✓				
	Lagged TWD botex	✓				
	WW botex					✓
Other leakage drivers	Average annual minimum temperature				✓	
	Number of connected properties		✓		✓	✓
	Lengths of mains	✓		✓	✓	
	Number of booster pumping stations per lengths of main	✓	✓	✓	✓	✓
	Weighted average density	✓	✓	✓	✓	✓
	Squared term of the weighted average density	✓	✓	✓	✓	✓

Source: PwC analysis from Ofwat documents

3.6.3 Results from leakage econometric models

We present the results of our leakage model in Table 3.6. It is worth noting that the sample size reduces due to data availability. Therefore, these results should be treated with some caution.

The model results show that the higher the level of expenditure, the larger the impact on leakage reduction. This is highlighted in our models:

- Model 1 shows that the botex TWD does not appear to have a contemporaneous effect on leakage, but there could be a lagged effect, as the coefficient suggests that the previous year's spend has a negative impact on leakage the following year.
- Model 2 shows that spending on maintaining the long-term capability of infrastructure assets appears to have a negative impact on leakage and is statistically significant. The magnitude of the coefficient suggests that a 10% increase in the expenditure to maintain the long-term capability of assets (specifically infrastructure) will lead to a 0.09% reduction in leakage volumes.
- Models 3, 4 and 5 show that demand-side enhancement expenditure appears to exert a statistically significant impact on leakage, meaning that a 10% increase in demand-side enhancement costs leads to a 0.05% reduction in leakage volumes. However, we should interpret the results of this model with some caution due to the limited number of observations – this is largely because not all companies received SDB demand-side enhancement funding historically. It is also worth noting that some of this expenditure will be funding water efficiency activities (i.e. non leakage demand benefits).

Across all our models, we find the lagged term of leakage to be highly significant, which suggests that leakage demonstrates "persistence", i.e. historical leakage performance appears to drive future performance. We also find that in one of our specifications (model 4), the lower the minimum temperature within a year, the higher the level of leakage observed.

Table 3.6: Results of our leakage models

	Model 1	Model 2	Model 3	Model 4	Model 5
ln (number of properties)		0.089***		0.084***	0.204***
ln (lengths of main)	0.069***		0.227***		
ln (number of booster pumping stations per length of main)	0.048***	0.039***	0.078**	0.045***	0.065**
ln (weighted average density)	-0.273***	-0.240***	-0.754***	-0.202***	-0.572**
ln (weighted average density)^2	0.022***	0.018***	0.059***	0.016***	0.041***
ln (lag of leakage volume)	0.957***	0.923***	0.808***	0.930***	0.826***
Annual minimum temperature				-0.006***	
ln (wholesale water botex)					0.006
ln (treated water distribution botex)	0.009				
ln (lag of treated water distribution botex)	-0.037*				
ln (SDB demand-side enhancement)			-0.005**		-0.005**
ln (capital maintenance expenditure)		-0.009***		-0.009***	
Constant	0.703***	0.103	1.415**	0.016	0.182
Number of observations	105	93	58	80	58
R_squared	0.9984	0.9986	0.9986	0.9991	0.9988

****p-value < 0.01; ** p-value < 0.05; *p-value < 0.1*

3.7 Limitations of the analysis

We have used Ofwat's Feeder Model 1 dataset, covering the period from 2011-12 and 2017-18, to build our models. However, there are a number of limitations to this analysis, mainly that the limits on the availability and consistency of historical data means that our analysis is limited to a fairly brief period, and so may not sufficiently capture long-term variations in historical spending.

The use of historical data to model costs may not sufficiently capture the stretching performance required for 2020-25, particularly if reductions of that magnitude have not been observed in the recent past. This is particularly relevant if the costs shift together with leakage reduction, for example if the marginal cost of leakage reduction increases over time. To some extent this is mitigated by introducing the non-linear leakage term in our specifications, however, future analysis should incorporate data over the next five year period where such reductions are expected to be observed.

It should be noted that while our candidate model specifications have helped contribute to additional explanatory power, the inclusion of the leakage variable in Ofwat's model specifications have also reduced the statistical significance of the other variables in explaining the base cost, and may therefore require a re-examination of Ofwat's model selection.

With regard to the leakage model, due to the limited availability of cost data that directly relates to leakage, we have used alternative proxies to capture this cost, such as the cost of maintaining the long-term capability of infrastructure assets. This measure is focused on the cost of maintaining infrastructure more broadly rather than specifically targeting leakage, however, we consider that capital maintenance activities such as mains renewal also contribute to leakage reduction. These are potential areas for improvement in the future as more data is made available over 2020-25 and future price control periods to enable more robust analysis.

3.8 Conclusions

We augment Ofwat's FD base models to include a leakage variable, specifically the distance in leakage performance in each year from the industry upper quartile level. Using this variable allows us to capture the progress that companies make over time, and how far companies have yet to go to achieve the benchmark. Following extensive testing of alternative variables and specifications, we find three potential augmented model specifications that meet the criteria of goodness-of-fit, overall significance and model specification and robustness tests. We find that these augmented models perform similarly to Ofwat's FD model in terms of explanatory power and robustness.

We find that no single leakage variable can fully explain differences in cost, and so our model specifications include different measures of leakage, i.e. the difference in companies' leakage and the forecast upper quartile level at both 2019-20 and 2024-25. Some companies have suggested using the distance from the sustainable economic level of leakage (SELL) as the appropriate driver for the cost modelling. While the SELL – to the extent that it is measured accurately – sets the economically-efficient level of leakage reduction by balancing the cost of water lost through leakage and the cost of reducing it, this measure faces a number of challenges (as discussed previously). For these reasons we have not used the distance from SELL as the primary leakage variable.

In addition, we also include a dummy variable and interaction terms in our model specifications to account for the idiosyncratic effects that Thames Water exerts on the model.

It should be noted that the inclusion of the leakage variable in Ofwat's model specifications reduces the statistical significance of the other variables in explaining the base cost, but the models are still robust and have a high R-squared.

We also model leakage directly to understand the impact historical spending on leakage reduction activities has on leakage reduction. The results of the leakage models suggest historical spending, particularly spending associated with maintaining the long-term capability of assets and demand-side enhancement funding, appears to have a small but statistically significant impact on leakage. We also find that botex TWD has a delayed effect on reducing leakage. However, data limitations mean that our analysis has been limited to a short time period, which means that it may not sufficiently capture long-term variations in historical spending. This is potentially a tool that could be used to support future assessments of enhancement funding, as better quality data is collected in the future.

4 Impact on base cost allowances

4.1 Section overview

In this Chapter we describe different policy options for funding leakage reduction based on the economic results we have described in Chapter 3.

The reminder of this Chapter is as follows:

- Section 4.2 describes the modelled funding scenario.
- Section 4.3 summarises the key findings from the funding scenario.
- Section 4.4 provides conclusions on the findngs.

4.2 Description of modelled funding scenario

We model the impact of funding leakage reduction in line with companies' 2020-25 forecast leakage levels, as consistent with company performance commitments. On average, companies are expected to reduce leakage by about 17% over 2020-25.

We estimate the impact of the candidate model specifications on the base cost allowance, by replicating the approach used in Ofwat's cost assessment models, but using the coefficients derived from our candidate modelling specifications, as set out in Section 3.4.

We draw on Ofwat's wholesale water cost models, which includes the forecast data for each driver of the cost model over the 2020-25 period for each company. These forecasts are presented as 3-year averages. For the purposes of our modelling, these are expressed in terms of annual averages, using historical actual data to back calculate expected leakage levels each year over 2020-25.

For companies whose leakage levels are expected to fall below the upper quartile at any point during 2020-25, the amount of funding will be capped at the upper quartile level to avoid duplication with the enhancement cost allowance. In addition, for Anglian Water, whose leakage levels from 2019-20 and throughout 2020-25 are expected to be below the upper quartile leakage level (based on m3/km/day), we estimate the cost allowance on the basis that it would maintain leakage levels at the 2019-20 level.

Note that this scenario is assessed against the 'do nothing' option, i.e. the existing allowances estimated using Ofwat's final determination (FD) econometric model specification and the latest available data on companies' cost drivers.

4.3 Summary of results

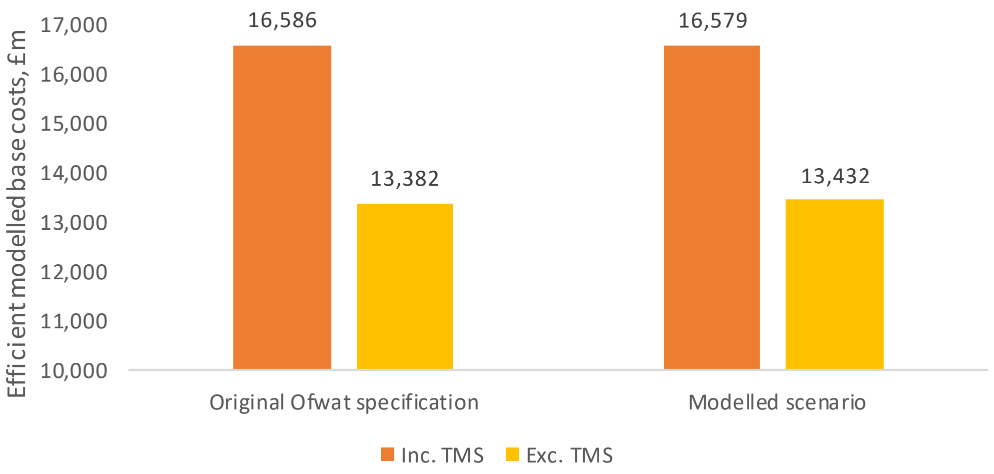
We use the results from our candidate models to triangulate an estimate for efficient modelled base costs over the 2020-25 period for each company and the industry, by taking the average of the predicted values using each candidate model. We consider this approach to be reasonable as the predicted costs from each candidate are broadly similar directionally and in order of magnitude. Note that we present efficient modelled base costs which exclude (i) the efficient unmodelled base costs; (ii) the cost adjustment claims; and (iii) the efficient enhancement costs.

We present the results for efficient modelled base costs and compare this against Ofwat's FD specification in Figure 4.1 and Table 4.1.

We find that the inclusion of leakage in the cost models using our candidate econometric specifications result in a higher efficient base cost allowance overall for the industry (when Thames Water is excluded).[37]

[37] We present the results including and excluding Thames Water as it appears to be an outlier on the basis of its current and future leakage performance compared to the industry.

Figure 4.1: Comparison of efficient modelled base costs for the modelled scenario against the default costs determined using Ofwat's original specification



Source: PwC analysis

Table 4.1: Comparison of efficient modelled base costs of the modelled scenario against the default costs determined using Ofwat's original specification

	Ofwat final determination specification	Study modelled scenario
Total WW base cost (£m), excl. TMS	**13,382**	**13,432**
Difference in levels		50
% difference		0.37%
Total WW base cost (£m), incl. TMS	**16,586**	**16,579**
Difference in levels		-6
% difference		-0.04%

Source: PwC analysis

The results show that using our candidate model specification to account for leakage reduction line with companies' stretch leakage levels would (when Thames Water is excluded) result in higher cost allowances, by about £50 million.

However, this masks significant distributional impacts across companies (see Table 4.2).

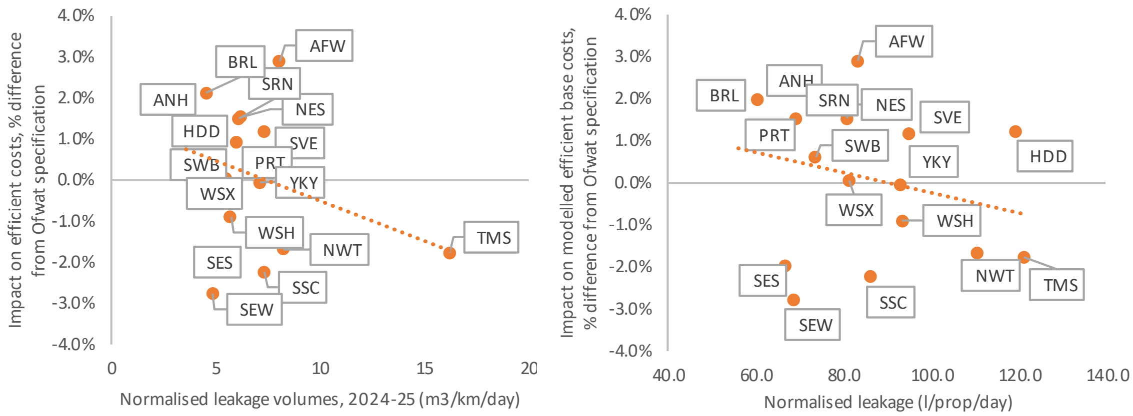
Table 4.2: Impact of modelled scenario on efficient wholesale water base costs

	Company	Impact on efficient wholesale water base costs, £ millions	Impact on efficient wholesale water base costs, % difference
1	AFW	29	2.9%
2	SVE	26	1.2%
3	ANH	25	2.0%
4	NES	17	1.5%
5	SRN	10	1.5%
6	BRL	7	2.1%
7	SWB	4	0.6%
8	PRT	1	0.9%
9	HDD	1	1.2%
10	WSX	0	0.1%
11	YKY	(1)	-0.1%
12	SES	(3)	-2.0%
13	SSC	(9)	-2.2%
14	WSH	(9)	-0.9%
15	SEW	(16)	-2.8%
16	NWT	(33)	-1.7%
17	TMS	(57)	-1.8%

Source: PwC analysis

Figure 4.2 shows the relationship between the impact on efficient base costs under the modelled scenario, compared to companies' normalised leakage performance in 2019-20. Because our candidate models include a measure based on the difference between leakage levels and the upper quartile industry leakage level normalised by length of mains (m3/km/day) as this provides an improved model fit, the new models appear to result in an uplift in the allowance for companies that perform well on this metric. On the other hand, those companies that may perform better with the alternative normalisation of leakage per property (litres/property/day) do not benefit as much. The distribution effects are partly the result of the non-linear effects that are captured in the candidate model specifications, as they account for the higher marginal costs of leakage reduction faced by companies that are already operating close to the upper quartile leakage level.

Figure 4.2: Impact on efficient wholesale water base costs under the modelled scenario vs normalised leakage performance (2019-20) across companies



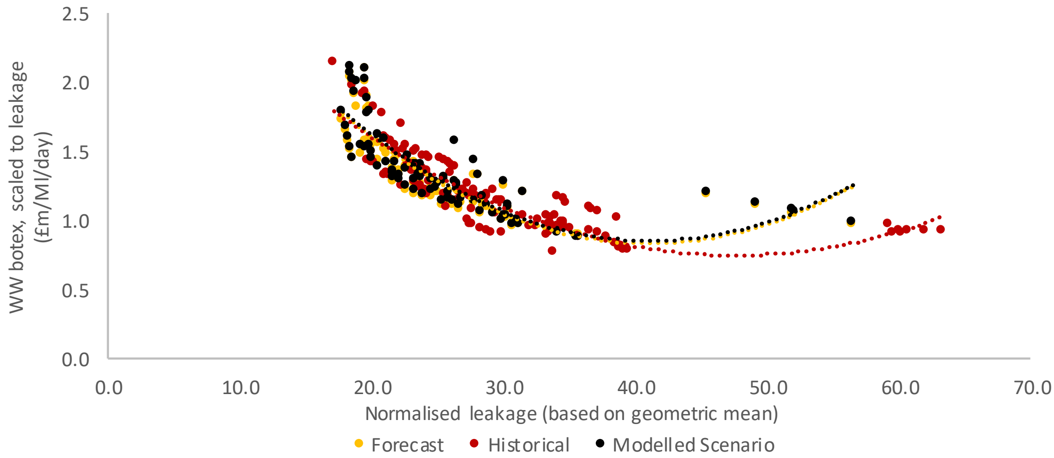
Source: PwC analysis

This downward-sloping relationship reflects to some extent the non-linear effects that are captured in the candidate models, as it accounts for the higher marginal costs of leakage reduction faced by companies that are already operating close to the upper quartile level.

Thames Water appears to be the outlier on comparisons of normalised leakage volumes and we therefore introduce additions to the model to control for its effects. The impact on Thames Water's efficient cost is largely the result of the new models that include specific terms to control for the effect of Thames Water, as well as the result of the non-linear functional form for leakage used in the model. This means that the economies-of-scale effect dominates, i.e. Thames Water is expected to become more cost-efficient at reducing leakage, which is why the model predicts that Thames Water will face increasingly lower costs per unit of leakage reduction.

We also compare funding levels between Ofwat's draft FD forecasts, which incorporates the latest year of data for 2018-19, and our new modelled costs (see Figure 4.3), against a measure of leakage that is normalised using the geometric mean approach for each company and each year. We also include historical costs for comparison. The relationship between wholesale water base costs scaled to leakage and normalised leakage is U-shaped. This is the result of the non-linear functional form we use in our model specification, which suggests that there are some efficiency gains as companies improve their leakage performance, but the marginal costs then start to increase as companies drive further reductions in leakage.

Figure 4.3: Comparison of wholesale water efficient modelled base costs across companies



Source: PwC analysis

4.4 Conclusions

As no single model fully accounts for leakage, w e use a triangulation approach to estimate the impact on base allow ances by taking the average of our three model specifications. We estimate the impact on the base cost allow ance by replicating the approach used in Ofw at's cost assessment models, but using the coefficients derived from our candidate model specifications.

We find that the inclusion of leakage in the cost models using our candidate econometric specifications results in higher efficient base costs overall for the industry (when Thames Water is excluded), assuming that leakage reduction in line w ith companies' 2020-25 forecast leakage levels are funded through the base cost. The increase in efficient base costs is around £50 million.

How ever, this masks significant distributional effects across the sector – our modelling of new cost allowances suggest that there are both companies w ith increases and companies with decreases to their allow ances from using the new modelling approach. Because our candidate models include a measure based on the difference betw een leakage levels and the upper quartile industry leakage level normalised by length of mains (m3/km/day) as this provides an improved model fit, the new models appear to result in an uplift in the allow ance for companies that perform w ell on this metric. On the other hand, those companies that may perform better w ith the alternative normalisation of leakage per property per day (litres/property/day) do not benefit as much. The distribution effects are partly the result of the non-linear effects that are captured in the candidate model specifications, as they account for the higher marginal costs of leakage reduction faced by companies that are already operating close to the upper quartile leakage level.

Thames Water appears to be the outlier on comparisons of normalised leakage volumes and w e therefore introduce additions to the model to control for its effects. The impact on Thames Water's efficient cost is largely the result of the new models that include specific terms to control for the effect of Thames Water, as w ell as the result of the non-linear functional form for leakage used in the model. This means that the economies-of-scale effect dominates, i.e. Thames Water is expected to become more cost-efficient at reducing leakage, w hich is w hy the model predicts that Thames Water w ill face increasingly lower costs per unit of leakage reduction.

5 Considerations for leakage funding

5.1 Section overview

In this section we set out further considerations in relation to data that may help provide more insight on leakage costs in the future.

- Section 5.2 sets out the challenges in identifying the efficient cost of leakage reduction.
- Section 5.3 concludes.

5.2 Challenges in identifying the efficient cost of leakage reduction

As we have seen in Section 2.3, companies' leakage performance and costs can vary for a number of different reasons. In addition, the industry median cost that was used at initial assessment of plans did not really reflect differences in companies' current leakage performance and planned leakage reductions, as the cost profile of achieving a step-change reduction in leakage can be significantly different from achieving incremental gains (again depending on the mix of leakage reduction activity and each company's cost efficiency). At DD, company specific leakage unit costs were used but the challenge of identifying an appropriate benchmark for efficiency remains.

To inform the policy considerations below, we reviewed the following evidence:

- A selection of companies' PR19 business plans, setting out companies' plans for maintaining the supply-demand balance and commentaries, as well as relevant cost adjustment claims for reducing leakage.
- A selection of companies' WRMPs and particularly the availability and consistency of data on leakage, leakage reduction activities and their associated costs.

A general observation is the lack of detailed and consistent data across the industry on leakage profiles and drivers, and the historical cost and impact of leakage reduction initiatives. Below we highlight some areas that might benefit from having more data and information from the sector to enable a broader understanding of the cost drivers of leakage reduction.

More consistent data and information on the companies' leakage types and drivers

Ofwat's PR19 final methodology introduces a new consistent definition of leakage for the industry, along with water companies, UKWIR and Water UK.[38] While this will eventually improve the consistency of reporting by companies and allow better performance comparisons, there are a number of gaps in our understanding of companies' leakage types, specifically:

- **Background leakage**: defined by UKWIR as the minimum historically achieved level of leakage in each district metered area (DMA), and refers to the minimum level that can be achieved by conventional ALC and can be reduced only by pressure reduction or mains renewal. It is assumed that background leakage consists of a large number of very small leaks that are too small or quiet to be detected through conventional leak detection methods.[39] Background leakage is a significant contributor to overall levels of leakage, with estimates from UKWIR showing that it accounts for around half of total leakage.[40]
- **Reported and unreported bursts:** refers to leakage that occurs through bursts on mains, communication pipes and supply pipes. These can either be reported (or referred to as visible leakage), or found through proactive leakage detection.[41]

While companies may report some of the above information in their business plans or WRMPs, it is not typically reported on a consistent basis across industry, much less over time.[42]

There is generally more data on distribution leakage and CSPL, as these are reported in (or can be inferred from) companies' business plan submissions.

In addition, there are a number of attributes of a district metered area (DMA) that may influence leakage levels:

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[38] Ofwat, *Delivering Water 2020: consultation on PR19 methodology Appendix 3: Outcomes technical definitions*, July 2017.
[39] UKWIR, *Achieving zero leakage by 2050: water accounting and quantification methods*, October 2017.
[40] UKWIR, *Long Term Leakage Goals*, March 2011.
[41] UKWIR, *Achieving zero leakage by 2050: water accounting and quantification methods*, October 2017.
[42] For example, SES reports its background leakage to account for 65% of its current total leakage. See SES Water, *PR19 Business Plan re-submission: Cost adjustment claim for leakage – mains replacement component*, April 2019.

- Climate factors (rainfall and temperature)
- Average water pressure
- Number of properties
- Length of mains

Only the last two attributes are currently provided to Ofwat in companies' business plans and are typically aggregated across DMAs.

Additional information that could be provided include leakage-related investments and spending on operational activities. Similar information could be provided at the water resource zones (WRZ) level, which would complement data that companies already collect, such as leakage levels within WRZs.[43] This would enable more granular analysis of the drivers of leakage including local factors. Understanding the individual components that drive companies' performance on leakage is key to understanding how these factors influence companies' choice of leakage reduction activities, and the extent to which leakage reduction is within management control.

More information on where companies are in different points of the investment cycle

As set out in Section 2.3, the historical investment decisions companies make can have longer-term implications for the condition of infrastructure assets and the types and cost of activities that are required to maintain the capability of those assets. Most WRMPs reviewed provide an assessment of preferred and alternative options for leakage reduction, but companies could be encouraged to provide more narrative on how their leakage types influence their choice of leakage reduction activities, and to provide an overview of their investment cycle and activity to reduce leakage.

Increased emphasis on ex-post assessments of the benefits of leakage reduction activities

While companies typically provide an assessment of the expected benefits of leakage reduction initiatives as part of their future plans, they do not appear to perform ex-post analyses consistently. This makes it difficult to draw comparisons across the sector on the relative effectiveness of historical leakage reduction schemes and the drivers of individual firm performance.

One example is the impact of **customer (smart) metering**. Metering penetration can help influence supply pipe leakage[44] and the effects on customer behaviour and consumption are potentially significant. Some companies have reported estimates of benefits from historical experience, e.g. Southern Water, Thames Water and Affinity Water reported significant demand reductions of 8-16.5% from increasing metering penetration over the 2010-15 and 2015-20 periods.[45] However, these do not distinguish between changes in consumer demand driven by behavioural changes, and genuine reductions in leakage.

Recent innovations, such as smart meters (and automated meter readings), can help improve the reliability of leakage estimates as well as speed the detection of leaks in supply pipes. While the efficacy of smart meters depends on the frequency of data collection supported by the infrastructure, smart meters are much more capable of supporting leakage management activities. For example, Thames Water's smart metering programme, which was initiated in 2016, is said to have led to a reduction in customer-side leaks of around 11 Ml/day.[46] Ofwat is currently considering companies' proposals to roll out smart metering separately, with funding provided through the metering enhancement model. However, not all companies have promoted the use of smart meters over the historically installed basic meters.

Companies should be encouraged to provide an ex-post assessment of the effectiveness of leakage reduction initiatives, including ALC, DMA optimisation, pressure management and mains renewals. This would facilitate cross-industry comparisons on the relative effectiveness of leakage reduction schemes, with the added benefit of disseminating best practices.

More granular data on CSPL and changes in customer demand and behaviour, and the metering approach (e.g. type of meter installed, location of installation), would also allow the impact of smart metering on leakage and customer consumption behaviour to be more precisely assessed. This could have policy implications for universal metering policies, and whether to fit meters internally or at the property boundary. At a minimum, companies with smart metering programmes should also provide data on smart meter penetration, as distinct from basic meter coverage. We note that an ongoing research project coordinated by UKWIR on the *Impact of customer-side leakage approaches* may also be relevant to this issue.

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[43] Defined as defined as 'the largest possible zone in which all resources, including external transfers, can be shared, and hence the zone in which all customers will experience the same risk of supply failure from a resource shortfall', source: UKWIR and the Environment Agency, *Definition of key terms for water resources practitioners*, April 2002.
[44] UKWIR, *Quantification of customer supply pipe leakage – a guide for data collection*, December 2013.
[45] Severn Trent, *Draft Water Resources Management Plan*, December 2017.
[46] WWT, *Smartening up: Is UK water metering ready for a smart revolution?*, June 2018.

More consistent data on the costs of leakage reduction across the industry to enable benchmarking

Our overall observation is that companies do not typically provide historical data on leakage unit costs, and the limitations to data availability for this current study precludes more detailed analysis of the cost drivers of leakage reduction activities.

For the reasons set out in Section 5.2, there is a range of drivers that influence individual companies' unit costs. Costs can also differ due to different levels of operating efficiency across companies.

Suggested areas for improvement might include:

- **Historical data on the costs of leakage reduction**. Where possible, companies should provide an assessment of the historical costs of leakage reduction. While companies' plans typically do consider strategic options for reducing leakage, they do not always report the costs of operating at different levels of leakage. Such analysis would be useful in supporting companies' claims that the marginal costs of leakage reduction increase as companies achieve lower levels of leakage, and would allow better understanding of the trade-offs involved in changing the mix of leakage reduction activities. However, we do recognise that there is some uncertainty involved in forecasting levels of expenditure for detection and repair required to operate at different levels of leakage.
- **Unit costs to be provided on a consistent basis to facilitate cross-company comparisons**. The SMC report found that there is significant variation in the costs of ALC, which can vary from £100-600 per repair.[47] There is the potential to improve the granularity and consistency of leakage cost data companies provide in order to enable Ofwat to conduct a more robust benchmarking exercise to compare the relative cost efficiency of leakage reduction initiatives across firms, and provide a stronger basis for the estimation of industry unit costs. A better understanding of companies' leakage types and costs would also enable Ofwat to estimate an industry unit cost curve that would allow a differentiated approach for assessing enhancement funding.

Having a better understanding of leakage unit costs, and historical cost benchmarks for leakage reduction initiatives may be helpful to drive more robust "bottom-up" modelling of funding allowances in the future and enable Ofwat to conduct a more detailed review of cost allowances.

Ongoing monitoring of future technological developments

As the SMC report suggests, 'there is scope in the longer term for companies to find innovative solutions or understand the components of leakage and the effectiveness of alternative techniques'.[48] Innovations such as customer (smart) metering and acoustic sensing, combined with the real-time monitoring of consumption, have helped drive improvements in the speed of leakage detection and management. Better use of data to inform decision-making, combined with further innovation in leakage technologies in the future, can help deliver greater cost savings. Examples of new technology being tested include smart sensors and pipes, 5G technology and Internet of Things (IoT) communications and the use of artificial intelligence (AI) for network automation and control.[49]

The cost of further reducing leakage is constantly evolving as new technology is made available, and this could drive down the cost of leakage reduction in the future. Where such innovations are being trialled by companies, they should be encouraged to share their impact assessments with Ofwat.

5.3 Conclusions

In this section we set out further considerations to inform leakage funding, particularly in relation to the identification of an efficient leakage reduction unit cost to assess the enhancement allowance.

A general observation is the lack of detailed and consistent data across the industry on leakage types and drivers, and the historical cost and impact of leakage reduction initiatives. Below we highlight some areas that might benefit from having more data and information from the sector to enable a broader understanding of the cost drivers of leakage reduction:

- Better understanding of the companies' leakage types and leakage drivers, in particular distinguishing between background leakage and leakage from mains bursts, and more granular data, e.g. DMA- or WRZ-level attributes that drive leakage.

[47] SMC, *Review of the calculation of sustainable economic level of leakage and its integration with water resource management planning, report for the Environment Agency, Ofwat and Defra*, October 2012.
[48] SMC, *Review of the calculation of sustainable economic level of leakage and its integration with water resource management planning, report for the Environment Agency, Ofwat and Defra*, October 2012.
[49] See Water Briefing, *UK water companies trial innovative technologies to tackle leakage and optimise water networks*, May 2019, Birmingham University, Smart wireless sensor network for water leak detection, Servelec Technologies, *Portsmouth Water launches leakage detection system following successful competitive trial*.

- Better understanding of where companies are in different points of the investment cycle. Most WRMPs reviewed provide an assessment of preferred and alternative options for leakage reduction, but companies could be encouraged to provide more narrative on how their leakage types influence their choice of leakage reduction activities, and to provide an overview of their investment cycle and activity to reduce leakage
- Increased emphasis on ex-post assessments of the benefits of leakage reduction activities. Companies should be encouraged to provide an ex-post assessment of the impacts of leakage reduction initiatives, including ALC, DMA optimisation, pressure management and mains renewals in reducing leakage reduction. This would facilitate cross-industry comparisons on the relative effectiveness of leakage reduction schemes, with the added benefit of disseminating best practices.
- Better benchmarking of costs across the industry. Our overall observation is that companies do not typically provide historical data on leakage unit costs, which makes it difficult to assess their levels of operational efficiency and whether the proposed costs are appropriate. We would suggest improving the transparency of historical costs of leakage reduction initiatives and for this data to be available on a consistent basis to facilitate cross-company comparisons.
- Ongoing monitoring of future technological developments. The cost of further reducing leakage is constantly evolving as new technology is made available, and this could drive down the cost of leakage reduction in the future. Where such innovations are being trialled by companies, they should be encouraged to share their impact assessments with Ofwat.

Annex A Further detail on the econometric modelling approach

This Annex sets out in more detail our approach to modelling base costs by embedding leakage performance explicitly in Ofwat's base cost models and additional results from our analysis.

A.1 Final determination models

For our analysis, we use Ofwat's Stata dataset used for the FD.

The coefficients for each econometric model are shown in Table A. 1.

Table A. 1: Base cost models' results on Ofwat dataset

Model 1	WRP1	WRP2	TWD	WW1	WW2
Variable name	WRP botex	WRP botex	TWD botex	WW botex	WW botex
Ln(number of properties)	1.007***	1.007***		1.034***	1.020***
% of water treated at complexity levels 3 to 6	0.008***			0.005***	
Ln(average density of water)	-1.647**	-0.981	-3.120***	-2.220***	-1.789***
Ln(average density of water)^2	0.103**	0.056	0.248***	0.156***	0.125***
ln (weighted average water treatment complexity)		0.486***			0.568***
Ln(lengths of main)			1.049***		
Ln (number of booster pumping stations per length of main)			0.455***	0.231**	0.256**
Constant	-4.274**	-6.607***	5.686***	-1.106	-2.725***
Number of observations	141	141	141	141	141
VCE	cluster	cluster	cluster	cluster	cluster
R_squared	0.934	0.921	0.967	0.975	0.977
RESET_P_value	0.542	0.159	0.124	0.229	0.148

****p-value < 0.01, meaning that the variable is statistically significant at 1%; ** p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

A.2 Further detail on our approach and modelling results for alternative specifications

We take the following steps to investigate the inclusion of leakage variables in the model.

Step 1. Including the level of leakage volumes and its squared term

We test the inclusion of the levels of leakage volumes (expressed in Ml/day) and its squared term in Ofwat's TWD, WW1 and WW2 base cost models. We also express this variable in logs.

We find that leakage volumes (both in levels and log terms) do not have a statistically significant impact on base costs, and it does not improve the overall model fit.

Step 2. Including normalised measures of leakage

Since the volume of leakage variable is not statistically significant we normalise the volumes of leakage by:

- Scaling leakage by the length of mains (expressed in m^3/km/day)
- Scaling leakage by the number of properties served by the company (expressed in l/property/day)
- Scaling leakage by the distribution input (expressed in % of distribution input)
- Taking the geometric mean, i.e. by taking the product of leakage scaled by the length of mains and leakage scaled by the number of properties, and then taking the square root of this term. There are some advantages to using the geometric mean rather than the arithmetic mean as the former is less affected by the presence of very small or very big observations in our sample that might skew the average.

We also tested these variables with their squared terms. We find that these terms do not appear to be statistically significant when included alongside Ofwat's standard variables, as there may be multicollinearity. This is because the denominators used to calculate the normalised measures are also included as explanatory variables in these models. For this reason we exclude these variables from our candidate model specifications.

Step 3. Distance from upper quartile leakage levels

We construct a variable that captures the deviation of the leakage from the industry upper quartile (UQ) leakage level, as follows:

- We first estimate the upper quartile leakage level for the industry using the above normalisation methods, for 2019-20. We use the upper quartile leakage measure for the industry as set at DD for 2024-25.
- These measures are then converted into company-level upper quartile leakage levels, expressed in terms of leakage volumes (Ml/day), by multiplying the upper quartile leakage (expressed in normalised terms) with the appropriate scaling variable (i.e. the upper quartile leakage level based on leakage per length of mains is multiplied by the length of mains for each company to derive company-specific upper quartile leakage levels).
- We then take the difference between the company-specific upper quartile leakage level and expected company performance in each year.

Using the upper quartile leakage level allows us to capture how companies are performing relative to the industry UQ performance. Most UQ measures did not appear to be statistically significant. Table A. 2 shows the results from using the distance from 2019-20 UQ leakage level, and Table A. 3 shows the results from using the distance from 2024-25 UQ leakage level.

Table A. 4 shows the results when we use the distance from the upper quartile leakage level based on the geometric mean. The measure that appears to perform best in our model tests is leakage normalised by the length of mains (m3/km/day), when tested in conjunction with the dummy variable for Thames Water – this is captured in model specifications 1-3 (see Section 3.4).

Step 4. Including a dummy[50] for Thames Water

Our initial assessment of our sample showed the presence of Thames Water as an outlier. We capture its effect through a dummy variable (equal to 1 if the observation refers to Thames Water and 0 otherwise). The Thames Water dummy variable results are significant in most of our model which could imply that Thames Water exerts an idiosyncratic effect on base cost compared to other companies.

We also test the inclusion of an interaction term by multiplying the Thames Water dummy and the distance from the UQ leakage level variable, to see whether there is a "Thames Water" effect that is specific to leakage.[51] We find that this interaction term appears to be statistically significant, which has been included in one of our candidate specifications.

A.3 Other considerations

Another option put forward by companies to account for leakage in Ofwat's cost models is the distance in actual leakage from SELL (see NERA, 2019).

We tested the inclusion of the difference between leakage and SELL. We find that this variable appears to have a statistically significant relationship with base costs, but we have not used this measure as SELL is defined companies, and it is not consistent with Ofwat's updated guidance on measuring and reporting leakage.[52] In addition, for the reasons set out in Section 2.2, the SELL approach has not adequately incentivised leakage reduction. For example Thames Water, which claims that its leakage levels are below SELL, also has the highest levels of leakage (in absolute and relative terms) compared to the rest of the industry. This demonstrates the ambiguity of using this variable as one of the main drivers of leakage reduction. Although this test identified that a SELL variable had some explanatory power in the model, the scale of the impact compared to the Ofwat specification is much lower than proposed in the NERA report.

Instead, we use a similar approach by using a distance from the upper quartile leakage level measure – we consider this to be a more appropriate benchmark as the upper quartile leakage level is an objective measure that

[50] A dummy variable (or indicator variable) is used to indicate the presence or absence (i.e. equal to 1 or 0) of a variable in the sample. It allows to divide the sample into subgroups and evaluate the impact that each subgroup has on the dependent variable. In our case we have that: *i.* the Thames Water dummy coefficient explains by how much the mean base cost of Thames Water differs from the other companies in the sample; *ii.* the constant term measures the mean base cost of other companies in the sample; and lastly *iii.* the average base cost value is given by the sum of the constant term and the dummy coefficient.

[51] The interaction term has the benefit of improving the understanding of the relationship between the variables in the model, which means that the effect of one variable depends on the value of another variable. The interaction term in our model implies that the effect of the distance from the UQ leakage level on base costs varies depending on whether Thames Water is present.

[52] Ofwat: Delivering Water 2020: Our methodology for the 2019 price review (2017).

is linked to industry performance rather than company-specific. This approach is also consistent with Ofwat's regulatory approach to setting price controls more broadly.

Table A. 2: Models incorporating the distance from the industry UQ leakage level in 2019-20, using different normalisation measures

Model	WW1	WW2	WW1	WW2	WW1	WW2
Variable name	WW botex	WW botex	WW botex	WW botex	WW botex	WW botex
Ln(number of properties)	1.029***	1.000***	1.042***	1.000***	1.024***	0.996***
% of water treated at complexity levels 3 to 6	0.005***		0.005***		0.005***	
Ln(average density of water)	-1.58	-0.896	-2.505**	-1.513*	-1.692***	-1.129**
Ln(average density of water)^2	0.110	0.061	0.176**	0.105	0.117***	0.077**
ln (weighted average water treatment complexity)		0.507***		0.549***		0.532***
Ln (number of booster pumping stations per length of main)	0.295**	0.320***	0.208	0.266**	0.282**	0.315***
Leakage UQ20 (m3/km/day)	-0.001	4.66E-04				
Leakage UQ20 (m3/km/day)^2	2.55E-06	2.24E-06				
Leakage UQ20 (l/prop/day)			2.29E-04	0.001		
Leakage UQ20 (l/prop/day)^2			-1.98E-06	-4.15E-07		
Leakage UQ20 (% distribution input)					-0.001	-0.001
Leakage UQ20 (% distribution input)^2					8.99E-06	8.71E-06
Constant	-2.985	-5.144*	-0.349	-3.32	-2.529	-4.332***
Number of observations	141	141	141	141	141	141
vce	cluster	cluster	cluster	cluster	cluster	cluster
R_squared	0.975	0.977	0.975	0.977	0.975	0.977
RESET_P_value	0.198	0.095	0.14	0.073	0.164	0.124

****p-value < 0.01, meaning that the variable is statistically significant at 1%; ** p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

Table A. 3: Models incorporating the distance from the industry UQ leakage level in 2024-25, using different normalisation measures

Model	WW1	WW2	WW1	WW2	WW1	WW2
Variable name	WW botex	WW botex	WW botex	WW botex	WW botex	WW botex
Ln(number of properties)	1.034***	1.001***	1.031***	0.995***	1.039***	1.005***
% of water treated at complexity levels 3 to 6	0.005***		0.005***		0.005***	
Ln(average density of water)	-1.552	-0.864	-1.437	-0.829	-1.580**	-0.979
Ln(average density of water)^2	0.108	0.058	0.099	0.055	0.109**	0.066
ln (weighted average water treatment complexity)		0.507***		0.513***		0.525***
Ln (number of booster pumping stations per length of main)	0.292**	0.320***	0.282**	0.317***	0.283**	0.319***
Leakage UQ25 (m3/km/day)	-0.001	-0.001				
Leakage UQ25 (m3/km/day)^2	2.52E-06	2.24E-06				
Leakage UQ25 (l/prop/day)			-0.001	-0.001		
Leakage UQ25 (l/prop/day)^2			4.12E-06	3.62E-06		
Leakage UQ25 (% distribution input)					-0.002	-0.001
Leakage UQ25 (% distribution input)^2					6.98E-06	6.75E-06
Constant	-3.136	-5.258*	-3.445	-5.283**	-3.075	-4.910**
Number of observations	141	141	141	141	141	141
vce	cluster	cluster	cluster	cluster	cluster	cluster
R_squared	0.975	0.977	0.975	0.977	0.975	0.977
RESET_P_value	0.189	0.097	0.162	0.103	0.172	0.126

****p-value < 0.01, meaning that the variable is statistically significant at 1%; ** p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

Table A. 4: Models incorporating the distance from industry UQ leakage level in 2024-25, using different normalisation measures

Model	WW1	WW2	WW1	WW2
Variable name	WW botex	WW botex	WW botex	WW botex
Ln(number of properties)	1.042***	1.009***	1.030***	1.004***
% of water treated at complexity levels 3 to 6	0.005***		0.005***	
Ln(average density of water)	-1.954***	-1.377***	-2.155***	-1.571***
Ln(average density of water)^2	0.136***	0.095***	0.152***	0.109***
ln (weighted average water treatment complexity)		0.566***		0.574***
Ln(lengths of main)				
Ln (number of booster pumping stations per length of main)	0.249**	0.277***	0.249**	0.269***
Leakage geometric mean UQ20 leakage level	-0.001	-0.001		
Leakage geometric mean UQ20 leakage level^2	2.75E-06	2.30E-06		
Leakage geometric mean UQ25 leakage level			-0.001	-4.45E-04
Leakage geometric mean UQ25 leakage level^2			2.42E-06	1.81E-06
Constant	-2.035	-3.871***	-1.242	-3.211***
Number of observations	141	141	141	141
vce	cluster	cluster	cluster	cluster
R_squared	0.976	0.978	0.975	0.978
RESET_P_value	0.263	0.214	0.256	0.193

****p-value < 0.01, meaning that the variable is statistically significant at 1%; ** p-value < 0.05, meaning that the variable is statistically significant at 5%; *p-value < 0.1, meaning that the variable is statistically significant at 10%*

A.4 Impact of the candidate model specifications on historical modelled costs

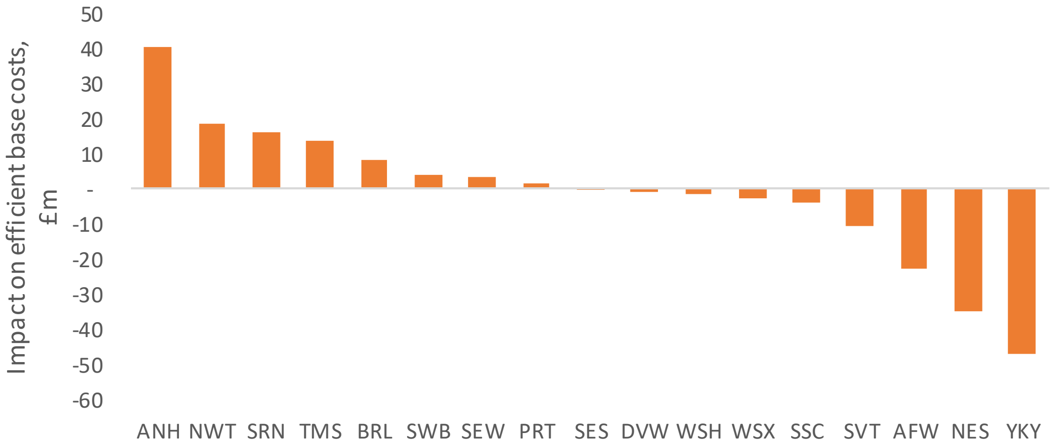
We use our candidate models to estimate the modelled base cost by taking an average across predicted values from each candidate model. We consider this approach to be reasonable as the predicted costs from each candidate are broadly similar directionally and order of magnitude.

The results are shown in Table A. 5. On aggregate, the historical modelled costs for between 2011-12 and 2018-19 do not differ markedly between Ofwat's original specification and the new model specifications, however there are some distributional impacts, as shown in Figure A.1.

Table A. 5: Comparison of efficient historical base costs against Ofwat's original specification

Total, 2011-12 to 2018-19	Ofwat FD specification	Modelled specification
Total WW base cost (£m)	20,909	20,875
Difference in levels		-34
% difference		-0.16 %
Total WW base cost (£m), incl. TMS	25,825	25,805
Difference in levels		-20
% difference		-0.08 %

Figure A. 1: Comparison of companies' modelled costs under the new specification against Ofwat's original specification, 2011-12 to 2018-19

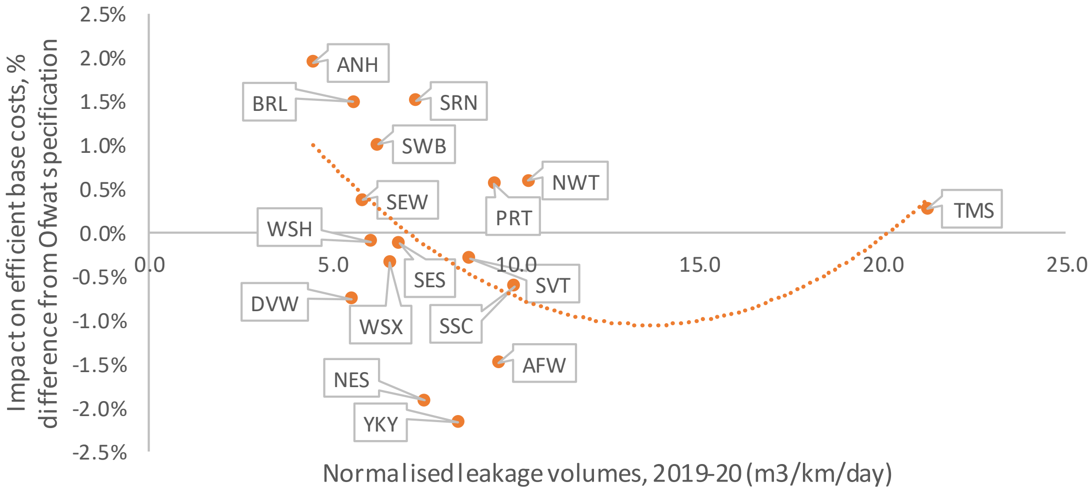


The effect of the squared leakage term in the candidate models dominates only when the value of the difference between leakage and the UQ leakage level is very large in absolute terms. This means that significant underperformers (i.e. TMS) can end up with much higher costs. This also explains the opposing impacts on TMS for AMP5 and AMP6, as Thames Water's performance worsened over AMP6.

As we observed in Section 2, there appears to be a basis for a non-linear relationship between the cost of leakage reduction and leakage performance.

As a result, when we model the base costs using the candidate model specifications that incorporate this non-linear relationship, the modelled base cost is consistent with a U-shaped relationship (see Figure A.2). However, there is some uncertainty as the presence of Thames Water appears to be driving this trend.

Figure A. 2: Impact on efficient base costs under the new model specification (compared to Ofwat's original specification) vs normalised leakage performance (2019-20) across companies



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