Ofwat

Assessment of growth-related costs at PR24

Final Report

Ref: 285594-00
May 2022

Executive Summary

Growth expenditure relates to costs driven by population growth and increased business activity, such as offsite reinforcement assets and costs associated with meeting additional demand at wastewater treatment works from new and existing customers. At PR19, Ofwat referred to growth-related costs in a broader sense and included costs to reduce risk of sewer flooding to properties.

At PR19, Ofwat assessed growth-related costs and costs to reduce risk of sewer flooding to properties as part of the base cost econometric modelling,[1] complemented with a growth unit cost adjustment and deep dives of business plan evidence where relevant.

In preparation for PR24, Ofwat has indicated in the December 2021 base cost assessment consultation that it would like to revisit the extent to which growth-related costs and costs to reduce risk of sewer flooding to properties can be assessed independently from base costs.[2]

To that end, in January 2022, Ofwat commissioned Arup to assess whether analysis of causal narratives combined with modelling techniques of available data would suggest that separate assessments of growth-related costs are appropriate and feasible at PR24.

The objective of this report is to produce recommendations on proportionate and feasible methods for assessing the following cost lines at PR24:[3]

- Growth-related water network reinforcement;
- Growth-related wastewater network reinforcement;
- Growth at wastewater treatment works; and
- Reducing risk of sewer flooding to properties.

Of the cost lines in scope, costs to reduce the risk of sewer flooding to properties is by far the most material. Half of the companies reported expenditure against this line equivalent to at least 5% of their base costs in the 10 years ending in 2020-21. Industry-level cumulative costs with sewer flooding reached £1.5bn (2017-18 prices) over the 10-year period ending in 2020-21, equivalent to 4% of industry-level cumulative base costs over the same period. By comparison, cumulative costs with growth at wastewater treatment works represented 2.5% of industry-level base costs. The corresponding figures for network reinforcement costs were 2.5% for water and 1.5% for wastewater. We explore materiality of costs and interactions with base costs later in the report.

The findings and recommendations presented in this report result from the work of Arup's multidisciplinary team of engineers, data analysts and regulatory economists who worked independently, but in close contact with Ofwat, from January to April 2022.

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[1] Ofwat, 'PR19 final determinations: Securing cost efficiency appendix', December 2019, chapter 3.1.

[2] Ofwat, 'Assessing base costs at PR24', December 2021.

[3] We note that on-site developer costs such as new connections, requisition mains and diversions are outside the scope of this work.

We arrive at our recommended assessment options by following the six-step approach outlined in the figure below. Initially, we analysed whether costs are suitable candidates for assessment separately from base costs. We then identified plausible cost drivers and variables which form hypotheses that are then tested in econometric models. Following an assessment of model robustness and root cause analysis of insufficient model robustness (when applicable), we drew recommendations on proportionate and feasible assessment options.

Figure E-1: Framework for choosing suitable assessment approaches

1. Suitability for separate assessment

- Growth-related costs are suitable candidates for separate assessment if:
  - a. They are material at industry level and for most companies, ideally at or above at least 2.5% of base costs;
  - b. Site and/or scheme-specific factors are important drivers of expenditure;
  - c. Complementarities/interactions with base costs are minimal; and
  - d. Cost data is not subject to significant changes in reporting/allocation practices.

2. Cost drivers

- Through causal narratives, idenitfy plausible cost drivers at company level, as opposed to site level, to align with Ofwat data collection and cost assessment practices.
- Cost drivers should be exogenous, i.e. outside company control, and avoid creating perverse incentives to companies.
- Use technical insights to describe likely magnitude of impacts and expected direction of impacts.
- Causal narratives frame hypotheses that are then tested through econometric models in Step 4.

3. Variables

- Select variables to measure potential cost drivers from readily available sources.
- Select variables that measure multiple drivers by accounting for multiple causal narratives.

4. Model testing

- Test significance of plausible drivers in explaining costs through econometric model suites, including:
  - a. Cumulative models over the whole sample period (10 years) using regression techniques; and
  - b. Year-on-year panel econometric techniques.
- Test models for capex over the 10-year period and for totex* over the sub-periods available.

5. Model assessment

- Model assessment and selection using Ofwat's model selection criteria for cost assessment:
  - a. Estimated coefficients are of the expected sign and of plausible magnitude according to engineering narratives;
  - b. Model statistical validity across a range of diagnostic tests (VIF, RESET);
  - c. Predictive power of the model above the minimum threshold of 75% to 80%;
  - d. Parsimonious, i.e., simple and sensible;
  - e. Predicted vs actual costs ratio within a plausible range; and
  - f. Estimated model results are robust to changes in the data, e.g., different time span.

6. Recommended options

- Recommend assessment options based on:
  - a. Model robustness; and
  - b. Root cause analysis of why models are insufficiently robust (when/if applicable).

Source: Arup analysis Note: * Totex for 2019-20 is calculated using opex business plan rather than outturns (low materiality).

Our recommended options for assessing the cost lines in scope at PR24 are summarised in the table below. Although the analysis covered each cost line separately, it resulted in similar recommendations for assessing water and wastewater network reinforcement costs related to growth. Therefore, these are presented combined in the summary table. The main report explains the separate process that led to the same recommendations for these two cost lines.

Reconciliation mechanisms are not part of the proposed options. Where relevant, Ofwat will need to consider any appropriate reconciliation mechanisms at PR24.

Table E-1: Summary of recommendations

Cost line	Recommended assessment options at PR24

Water network reinforcement
 	
Wastewater network reinforcement
	Based on historical data and variables currently available, it has not been possible to develop a robust standalone econometric model to assess water network reinforcement costs at PR24 within this study.
	
	Root cause analysis suggests that this is likely a reflection of:
	
	• Localised factors, which affect the way the drivers identified through causal narratives impact costs, and such effects are difficult to capture through company-level variables currently available. These include:
	    • The same company may have capacity headroom in part of its network but not in other parts where growth is concentrated.
	    • The same volume of growth may trigger different spending levels depending on whether growth:
	        ▪ Is concentrated in a small part of the network or spread across a larger area;
	        ▪ Results from a few big developments vs several small developments, or a few large business facilities vs several small ones.
	• The historical data shows evidence of substantial differences in cost allocation practices across companies between growth-related network reinforcement and other cost lines. There are also some synergies between asset replacement (base costs) and network reinforcement (see Table 3).
	
	Therefore, Arup recommends the following:
	
	• **Option 1, preferred option if cost allocation issues can be mitigated: separate assessment from base costs through comparative assessment using information that better reflects localised features of growth and mitigates differences in allocation practices.** This option would need to be supported by:
	    • <u>Additional data collection that reflects the localised features of growth</u>. We recommend Ofwat to work with the water industry to identify plausible localised variables that can realistically be collected ahead of PR24. Examples of plausible variables include:
	        ▪ Local capacity of the network;
	        ▪ Length of new mains/sewers laid;
	        ▪ Diameter of new mains/sewers laid;
	        ▪ Additional pumping station capacity.
	    • <u>Improved data collection to minimise differences in cost allocation practices</u>. One possibility could be benchmarking with the use of company business plan forecasts, if it minimises differences in cost allocation practices. However, we note that this could lead to some double counting of network

Cost line	Recommended assessment options at PR24

	reinforcement allowances, because some of these costs are included in historical base costs.
	• **Option 2, preferred option if cost allocation issues cannot be mitigated**: **keep as part of base costs**. This option would also take advantage of synergies with base costs through asset replacement. If kept with base costs, it is recommended that Ofwat considers:
	    • Testing a driver to capture growth as part of the base cost econometric models. Population growth is a strong candidate for such a driver. It is supported by causal narratives, is exogenous (i.e. outside of company control) and minimises risks of perverse incentives to companies.
	    • If adding a growth driver to the base cost models proves unfeasible, Ofwat could consider applying a post-modelling growth adjustment to the base models, similar to the approach used at PR19.[4]
	    • Alongside these, Ofwat could consider having a cost adjustment claim process similar to that used at PR19. Through this process, companies with unique growth circumstances driving higher efficient costs would have an opportunity to claim an adjustment to their modelled allowances. The assessment of cost adjustment claims would be facilitated if Ofwat requested the following evidence from companies as part of their submissions:
	        ▪ Local capacity of the network;
	        ▪ Magnitude of growth and its features (e.g., large vs small residential developments; industrial/commercial vs household);
	        ▪ Evidence of impact on the network, namely, laying of new mains/sewers and additional pumping capacity requirements; and
	        ▪ Evidence that the higher costs claimed are efficient, e.g., through quotes from prospective bidders, quotes from bidders for comparable works carried out in the recent past and, where applicable, evidence of industry benchmarking.

Growth at wastewater treatment works	Growth at wastewater treatment works costs lend themselves to assessment separate from base costs through econometric models. Costs are fairly distributed across companies, they are sufficiently material and site-specific drivers are considered to be of less relevance.
	The modelling results suggest that an econometric model is a viable option for assessing growth at wastewater treatment works costs at PR24.
	Therefore, Arup recommends the following:
	• **Standalone econometric model** with the following features:
	    • Drivers: 'change in population equivalent served by wastewater treatment works' and 'treatment intensity'; and
	    • Cumulative model summing costs and drivers over a long time period to mitigate the lack of a variable for capacity headroom and smooth the lumpiness in the data.
	• **Supplement the econometric model with a cost adjustment claim process, similar to that used at PR19.** Through this process, companies for which unique circumstances drive higher efficient costs can claim an adjustment to their modelled allowed costs.

[4] Ofwat, 'PR19 final determinations: Securing cost efficiency appendix', December 2019, chapter 3.1.

Cost line	Recommended assessment options at PR24
	Evidence that Ofwat may consider requiring as part of the cost adjustment claim submission include: • Demonstration of the need for the upgrade, how it relates to any existing capacity headroom and assumed time horizon; • Identification of the expected impacts of additional load in terms of type of treatment required (primary, secondary or tertiary); • Description of the upgrade needed including the assets and/or technological solutions chosen; • Description of site-specific constraints that impact on upgrading costs, e.g. ground conditions; and • Evidence that the higher costs claimed are efficient, e.g., through quotes from prospective bidders, and, where applicable, evidence of industry benchmarking.

Reduce sewer flooding risk to properties	Standalone econometric models based on historical data and reflecting the causal narratives are insufficiently robust.
	This is likely a reflection of:
	• Substantial synergies with base costs through:
	  • Regular inspection and maintenance of the network (base costs), which also reduces the risk of sewer flooding.
	  • Customer education and awareness raising initiatives (base costs) prevent the build-up of waste in the network and contribute to reduced sewer flooding risks.
	  • Replacement of old assets (base costs) reduces sewer flooding risks, as older assets and assets in poorer condition are likely to be more prone to blockages.
	• Lack of a suitable variable measuring the number of properties at risk, as a result of hydraulic inadequacy of the network, to account for:
	  • Volume and severity of rainfall, including impacts of climate change.
	  • Location of properties, both legacy properties at risk and new properties that may become at risk as a result of more intense storms caused by climate change.
	Therefore, Arup recommends the following:
	• **Option 1: keep sewer flooding costs with base costs and consider testing a drainage driver as part of the base cost models**. This may be appropriate considering the substantial synergies with base costs. Base costs already account for a number of drivers of sewer flooding as identified through causal narratives, including:
	  • Total number of properties connected, which causal narrative and modelling results suggest being an important, albeit imperfect, indirect measure for properties at risk;
	  • Population density, as a measure of urbanisation; and
	  • Pumping capacity per length of sewers, which is a measure for topography.
	However, base costs lack drainage of surface water, which causal analysis has identified as a driver of 'potential major significance', hence the recommendation to consider testing drainage driver as part of the base cost models. Surface water runoff is arguably also a driver for greater maintenance and inspection of the network and, thereby, a driver that captures many of the synergies between reducing risk of sewer flooding to properties and base costs.

Cost line	Recommended assessment options at PR24

	• **Option 2, appropriate if a suitable variable for quantifying the number of properties at risk is found:**
	  • Work with the industry (e.g., through DWMPs) to develop a suitable variable for quantifying properties at risk of sewer flooding as a result of hydraulic inadequacy of the network. Such variable should account for the following factors, all of which are outside management control:
	    • Volume and severity of rainfall, including impacts of more intense storms caused by climate change.
	    • Location of properties. This needs to consider legacy properties at risk of sewer flooding because they were built under less stringent planning standards. But it also needs to include newer properties which, whilst built in accordance with new and more stringent planning permits, may become at risk of sewer flooding as a result of more intense storms caused by climate change.
	  • Separate assessment of sewer flooding costs based on unit cost model with properties at risk as a driver.
	  • Consider testing drainage driver as part of base cost models to account for synergies with base costs.

Source: Arup analysis

Table of Contents

Acronyms

Acronym	***Description***
AMP	Asset Management Period
ANH	Anglian Water
AFW	Affinity Water
APR	Annual Performance Report
BOD	Biological Oxygen Demand
BPDT	Business Plan Data Templates
BWH	Bournemouth & West Hampshire Water
CBA	Cost Benefit Analysis
CMA	Competition and Markets Authority
CSO	Combined Sewer Overflow
DG5	Sewer Flooding Register
DNO	Distribution Network Operator
DSRA	Developer Service Revenue Adjustment
DVW	Dee Valley Water
EJP	Engineering Justification Papers
FSE	Food Service Establishments
HDD	Hafren Dyfrdwy
IWM	Integrated Water Management
Ml/d	Megalitre per day
Ml/yr	Megalitre per year
MVA	Mega Volt Ampere
N	Number of observations
NBS	Nature-Based Solution
NES	Northumbrian Water
NWT	United Utilities
OLS	Ordinary Least Squares
ONS	Office for National Statistics
PCC	Per Capita Consumption
PE	Population Equivalent
PHE	Public Health England
PR	Price Review
PRT	Portsmouth Water
R^2	R-squared
RAG	Regulatory Accounting Guidelines
RESET	Regression Equation Specification Error Test
RIIO-ED2	Revenue, Incentives, Innovation, Outputs – Electricity Distribution 2
RSF	Risk of Sewer Flooding
SES	Sutton and East Surrey Water plc
SEW	South East Water
SRN	Southern Water
SSC	South Staffs Water
SVE	Severn Trent England
SVH	SVH=SVT+DVW+SVE+HDD
SVT	Severn Trent
SWB	South West Water (starting from 2016-17)
SWH	SWH = SWT+BWH+SWB
SWT	South West Water (up to and including 2015-16)
SuDS	Sustainable Drainage System
TMS	Thames Water Services
UM	Uncertainty Mechanism
VIF	Variation Inflation Factor

W	Water
Ww	Wastewater
WINEP	Water Industry National Environmental Programme
WNR	Water Network Reinforcement
WwNR	Wastewater Network Reinforcement
WSH	Welsh Water
WSX	Wessex Water
WTW	Water Treatment Works
WwTW	Wastewater Treatment Works
YKY	Yorkshire Water
yr	year

List of figures

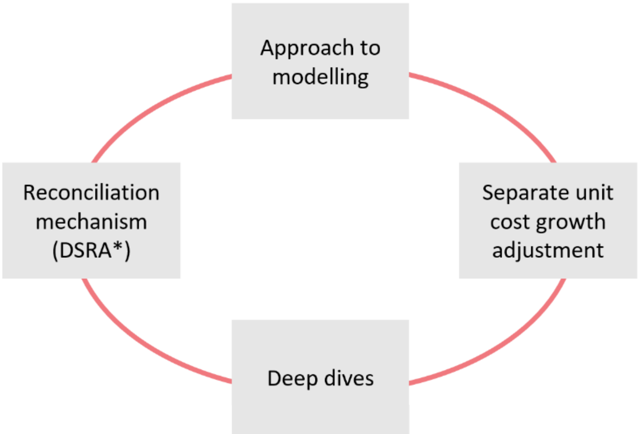
List of tables

1. Introduction

Growth expenditure relates to costs driven by population growth and greater business activity, such as offsite reinforcement assets and costs associated with meeting additional demand at wastewater treatment works (WwTWs) from new and existing customers. At PR19, Ofwat referred to growth-related costs in a broader sense and included costs to reduce risk of sewer flooding to properties.

At PR19, Ofwat assessed growth-related costs and costs to reduce risk of sewer flooding to properties as part of the base cost econometric models,[5] complemented with a separate growth unit cost adjustment, deep dives of business plan evidence and a developer service revenue adjustment (DSRA) mechanism. Ofwat's approach at PR19 is depicted in Figure 1.

Figure 1: Ofwat approach to growth expenditure assessment at PR19



Source: Ofwat. Note: DSRA – Developer service reconciliation mechanism.

In its December 2021 consultation on base costs assessment,[6] Ofwat indicated that it is open to consider options for conducting separate assessments of growth-related costs and sewer flooding costs at PR24. In the consultation, Ofwat also indicated that separate assessments of any of these costs would need to meet certain exclusion criteria, which are listed in Table 1. They show that being able to identify robust standalone econometric or unit cost models and improved data reporting are necessary, albeit insufficient, conditions for carrying out separate assessments.

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[5] Ofwat, 'PR19 final determinations: Securing cost efficiency appendix', December 2019, chapter 3.1.

[6] Ofwat, 'Assessing base costs at PR24', December 2021.

Table 1: Ofwat's proposed criteria for adjusting scope of base cost models at PR24

Criterion	Candidate for exclusion / separate assessment
1	Companies have not incurred these costs in the past.
2	Variations in costs between companies and over time cannot be explained by the cost drivers in the wholesale base cost models.
3	Costs can be clearly identified and data reporting inconsistencies and/or interactions/complementarities with wholesale base costs are minimal (necessary but not sufficient condition for separate assessment).
4	Robust standalone econometric / unit cost models can be developed (necessary but not sufficient condition for separate assessment).
5	Costs are largely outside of company control.

Source: Ofwat, 'Assessing base costs at PR24', December 2021, p.22.

In January 2022, Arup was commissioned by Ofwat to analyse whether separate assessments of growth-related costs, including sewer flooding, are appropriate and feasible at PR24. Arup's multidisciplinary team of engineers, data analysts and regulatory economists worked independently, but in close contact with Ofwat throughout the first quarter of 2022. Arup subject matter experts supported the team through a series of peer reviews.

1.1 Objective and scope of this report

The objective of this report is to produce recommendations on proportionate and feasible methods for assessing the cost lines in scope, listed in the table below, at PR24. We note that site-specific developer costs, such as new connections and requisition mains, as well as diversions, are outside the scope of this work.

Figure 2: Cost lines in scope

Water network reinforcement	Expenditure related to the provision or upgrading of network assets (e.g. water mains, tanks, service reservoirs) to provide for new customers with no net deterioration of existing levels of service.
Wastewater network reinforcement	Expenditure related to the provision or upgrading of infrastructure network assets (e.g. sewers and pumping stations) to provide for new customers with no net deterioration of existing levels of service.
Growth at WwTWs	Expenditure to meet or offset changes in demand from new and existing customers at sewage treatment works.
Reduce sewer flooding risk to properties	Expenditure for the purpose of enhancing the public sewerage system to reduce the risk to properties and external areas of flooding from sewers. It excludes expenditure with maintenance of asset capability.

Source: Ofwat, 'RAG 4.09 RAG – Guideline for the table definitions in the annual performance report', February 2021, p.65.

It is outside the scope of this work to develop new variables. Hence the analysis, findings and recommendations are reflective of historical data readily available.

Detailed investigation of possible new variables or new data to be collected is also outside the scope of this work. Nevertheless, some of the recommendations suggest, at a high-level, a number of potential new variables and information that Ofwat may consider collecting in preparation for PR24.

1.2 Structure of the report

The report is structured as follows:

- **Section 2** presents the approach followed to set recommendations on whether the cost lines in scope could be robustly assessed separately from base costs at PR24.
- **Sections 3 to 6** set out the recommendations for assessing each cost line in scope at PR24:
  - Water network reinforcement (Section 3);
  - Wastewater network reinforcement (Section 4);
  - Growth at wastewater treatment works (Section 5); and
  - Reduce the risk of sewer flooding to properties (Section 6).

2. Approach

This section presents the approach used to set recommendations on whether the cost lines in scope can be robustly assessed separately from base costs at PR24. It starts by setting out the options for cost assessment applicable to the cost lines in scope. It then develops a framework which informs the process followed to draw recommendations on suitable assessment approaches.

2.1 Cost assessment options

Growth-related costs and costs to reduce sewer flooding can be assessed through one or a combination of cost assessment options, which are listed in Table 2. The extent to which an option is viable depends on whether the cost line meets certain criteria, which are also indicated, at high level, in the table below.

Table 2: Cost assessment options applicable to cost lines in scope

	Assessment option	Criteria for application
1	**Standalone econometric/unit cost model**	• Costs are material. • Costs can clearly be identified and data reporting inconsistencies and/or interactions/complementarities with base costs are minimal. • Companies undertake comparable work. • Models are sufficiently robust.
2	**Deep and shallow dive of business plan evidence**	• Site and/or scheme-specific factors are important drivers of costs. • Costs are material at company level for some companies, and immaterial for others. • Deep dive of business plan evidence for companies for which costs are material. • Shallow dive of business plan evidence for companies for which costs are immaterial.
3	**Add growth-specific drivers to base cost models**	• Complementarities/interactions with base costs are significant. • Costs share similar characteristics and are explained by some but not all the drivers used in the base cost models. • Variables measuring additional cost drivers that account for growth-specific factors are available. The choice of such drivers needs to ensure that they are outside management control, and their estimated coefficients are of the expected sign and of plausible magnitude, according to engineering and economic rationale.
4	**'Do nothing' – keep growth-related costs included in the base cost models**	• Complementarities/interactions with base costs are significant. • Costs share similar characteristics and are explained by drivers included in the base cost models.

Source: Arup analysis

2.2 Framework for determining suitable assessment options

Determining assessment options suitable for each cost line is a step-wise process as indicated in the figure below.

Figure 3: Framework for choosing suitable assessment approaches

1. Suitability for separate assessment

- Growth-related costs are suitable candidates for separate assessment if:
  - a. They are material at industry level and for most companies, ideally at or above at least 2.5% of base costs;
  - b. Site and/or scheme-specific factors are important drivers of expenditure;
  - c. Complementarities/interactions with base costs are minimal; and
  - d. Cost data is not subject to significant changes in reporting/allocation practices.

2. Cost drivers

- Through causal narratives, idenitfy plausible cost drivers at company level, as opposed to site level, to align with Ofwat data collection and cost assessment practices.
- Cost drivers should be exogenous, i.e. outside company control, and avoid creating perverse incentives to companies.
- Use technical insights to describe likely magnitude of impacts and expected direction of impacts.
- Causal narratives frame hypotheses that are then tested through econometric models in Step 4.

3. Variables

- Select variables to measure potential cost drivers from readily available sources.
- Select variables that measure multiple drivers by accounting for multiple causal narratives.

4. Model testing

- Test significance of plausible drivers in explaining costs through econometric model suites, including:
  - a. Cumulative models over the whole sample period (10 years) using regression techniques; and
  - b. Year-on-year panel econometric techniques.
- Test models for capex over the 10-year period and for totex* over the sub-periods available.

5. Model assessment

- Model assessment and selection using Ofwat's model selection criteria for cost assessment:
  - a. Estimated coefficients are of the expected sign and of plausible magnitude according to engineering narratives;
  - b. Model statistical validity across a range of diagnostic tests (VIF, RESET);
  - c. Predictive power of the model above the minimum threshold of 75% to 80%;
  - d. Parsimonious, i.e., simple and sensible;
  - e. Predicted vs actual costs ratio within a plausible range; and
  - f. Estimated model results are robust to changes in the data, e.g., different time span.

6. Recommended options

- Recommend assessment options based on:
  - a. Model robustness; and
  - b. Root cause analysis of why models are insufficiently robust (when/if applicable).

Source: Arup analysis

Note: * Totex for 2019-20 is calculated using opex business plan rather than outturns (low materiality).

While tailored to the scope of this work, the framework followed is consistent with Ofwat's principles of cost assessment set out in its December 2021 consultation,[7] which are:

- Consistent with engineering, operational and economic rationale;
- Sensible, simple and transparent;
- Focused on exogenous cost drivers;
- Robust econometric cost models;
- Setting a stretching but achievable cost efficiency challenge; and
- A coherent cost assessment approach.

2.3 Modelling approaches

As set out in Steps 4 and 5 of the framework (see Figure 3), econometric modelling is an important component in determining whether robust models can be developed to assess the growth-related costs separately from base costs.

Our modelling uses historical data covering the 10-year period from 2011-12 to 2020-21, the period for which Ofwat cost data and drivers are available. Capex costs are available for the 10-year sample period. However, up to recently, opex costs related to each of the growth-related cost lines in scope were part of base costs. This means that totex costs are only available for a sub-sample period, as follows:

- Water and wastewater network reinforcement totex costs are available only for 2020-21, the last year in the sample.
- Growth at WwTWs totex and sewer flooding totex costs are available from 2017-18 to 2020-21, the last four years in the sample.

Therefore, the modelling approach used in this work was to test the same model specifications with two types of cost data:

- **Capex cost models**, covering the full 10-year period from 2011-12 to 2020-21; and
- **Totex cost models**, covering the period for which historical totex costs are available.

Year-on-year cost data for each of the growth-related cost lines in scope are very lumpy (see Appendix A), which makes econometric modelling challenging. Several factors may contribute to explain such lumpiness, including:

- Costs to address demand growth take time to materialise and a time lag is likely to exist between driver and expenditure. Today's growth in demand will likely drive

[7] Ofwat, 'Assessing base costs at PR24', December 2021, p. 14.

expenditure that will materialise over more than one year because a time lag exists between identification, project design and project completion.

- Existing capacity in the system can be used to accommodate growth in demand, so that today's growth does not necessarily trigger expenditure today. When headroom capacity in the system becomes insufficient to accommodate growth in demand, companies plan and design investment to serve immediate additional demand and to restore headroom, which in turn will accommodate some of the future demand.

This means that the association between costs and drivers is likely to be stronger when costs and drivers are accumulated over a longer time period, as opposed to year-on-year, to account for investment time lags and utilisation of capacity headroom. Also, and from a modelling perspective, cumulative costs reduce the lumpiness in the cost data and therefore makes the data more amenable to econometric modelling.

To account for these factors, the modelling approach used in this project tests the same model specifications with two types of data:

- **Year-on-year data**, using two panel data regression techniques: pooled OLS and random effects. These models take advantage of differences in costs and drivers across companies over time and benefit from a larger sample size. The downsides include lumpiness in the data and the likely weakness in the association between costs and drivers, for the reasons explained above.
- **Cumulative data**, using OLS regression techniques. In these models, costs and drivers are summed over the whole sample period. For the models using capex data, this means summing costs and drivers over the 10 years from 2011-12 to 2020-21. For the models using totex data (available for growth at WwTWs and sewer flooding), costs and drivers are summed over the four years from 2017-18 to 2020-21. The cumulative data is less lumpy and thereby are more amenable to econometric modelling than the year-on-year data. These models also take advantage of the likely stronger association between costs and drivers, for the reasons described above. The downside is the smaller sample size, which is reduced to the number of companies in the sample, i.e.,17 in water and 10 in wastewater.

The use of cumulative models is not new in enhancement costs. We note that cumulative data was the standard approach that Ofwat adopted at PR19 to develop cost benchmarking models for enhancement cost lines.

3. Water network reinforcement

This section presents recommendations on possible approaches for assessing growth-related expenditure in water network reinforcement. According to the Regulatory Accounting Guidelines (RAGs),[8] this refers to expenditure for the provision or upgrading of network assets (e.g., water mains, tanks, service reservoirs) to provide for new customers with no net deterioration of existing levels of service.

The following section starts by analysing the suitability of this cost line for assessment separately from base costs. It then develops causal narratives of the plausible cost drivers based on technical insights and tests the extent to which these causal relationships can be used to build robust cost assessment models. It concludes with recommendations on assessment options.

3.1 Suitability for separate assessment

The extent to which growth-related spending in water network reinforcement is suitable for independent assessment depends on how expenditure data performs against the following set of criteria: materiality, relevance of site and/or scheme specific drivers, complementarities/interactions with base costs and changes in reporting/allocation practices. Table 3 presents a summary assessment of these criteria.

Overall, the analysis suggests that this line is suitable for assessment separately from base costs but keeping it with base costs may be appropriate. Costs are material enough to justify separate assessment. Site and/or scheme specific factors affect the way drivers impact costs. Separate assessment facilitates the task of capturing such localised effects, provided appropriate variables and data are available.

However, keeping this cost line as part of base costs may be appropriate and could also be justified on grounds of synergies with asset replacement (base costs) and differences in cost allocation practices across companies between growth-related network reinforcement and capital maintenance. The evidence available suggests that these have a substantial impact on costs. For example, YKY and PRT reported zero expenditure in water network reinforcement consistently from 2011-12 to 2016-17, while they also reported significant growth in water delivered (3% and 7%, respectively) and a 5% population growth, over the same period.

Table 3: Suitability of water network reinforcement expenditure for separate assessment

	Criteria	Evidence	Assessment
1	**Materiality**	• Industry-level cumulative expenditure amounted to £861m (2017-18 prices) over the 10-year period ending in 2020-21. • This was equivalent to 2.5% of industry-level cumulative base costs over the same period.	**Sufficiently material** to justify separate assessment.

[8] 'RAG 4.09, RAG – Guideline for the table definitions in the annual performance report', February 2021, p.65.

	Criteria	Evidence	Assessment
		• At company level, materiality over the 10-year period ending in 2020-21 was above 5% of base costs for two companies (ANH, 6.8% and SEW, 8.6%). Materiality was less than 1% for seven companies (NES, SRN, WSH, YKY, PRT, SSC, SWB/SWT).	
2	**Relevance of site/scheme specific drivers**	• The local capacity of the network and related assets (i.e., capacity headroom) is very site-specific, meaning that the same company may have capacity headroom in parts of the network but not where growth is taking place. • The same volume of growth may trigger different spending levels depending on whether it is concentrated in a small part of the network or spread across a larger area.	**Site and/or scheme specific factors** affect the way drivers impact costs. Separate assessment facilitates the task of capturing such localised effects, provided appropriate variables are available.
3	**Complementarities with base costs**	• Growth-related water network reinforcement costs are hardly substitutable with more intensive operation and/or maintenance of existing assets. • There are some synergies with replacement of existing assets. When network assets reach the end of their useful life, companies can replace them with either like-for-like assets or assets that deliver greater capacity with only a fraction of additional cost. • Opex related to network reinforcement started to be collected only from 2020-21 onwards. Previously, it was reported as part of base costs. However, based on 2020-21 data, this is likely to create an immaterial distortion as opex for this cost line accounted for less than 1% of industry-level capex in 2020-21.	**Synergies with asset replacement (base costs)** suggest assessment with base costs may be justifiable.
4	**Change in reporting/allocation practices**	• No substantial changes made to the RAGs throughout the sample period from 2011-12 to 2020-21. • RAGs allow companies to apply a level of discretion when apportioning costs between growth related network reinforcement and capital maintenance. • Three companies (YKY, PRT and NES) reported zero expenditure against this line from 2011-12 to 2016-17. This is likely indicative of differences in allocation practices across companies, as the volume of water delivered by these companies changed by 3% (YKY) and 7% (PRT) over the 10-year period ending in 2020-21. NES showed a reduction in the volume of water delivered (-5%), which is compatible with no expenditure in water network reinforcement.	**Coexistence of zero expenditure with a substantial increase in volume of water delivered** over a long time period indicates that cost apportioning issues between network reinforcement and capital maintenance may be substantial for some companies. This suggests combining assessment with base costs may be justifiable.

Source: Arup analysis.

Notes: Appendix A.1 presents the detailed data analysis supporting the evidence summarised in this table. SVH represents the combined costs from SVT, DVW, SVE and HDD.

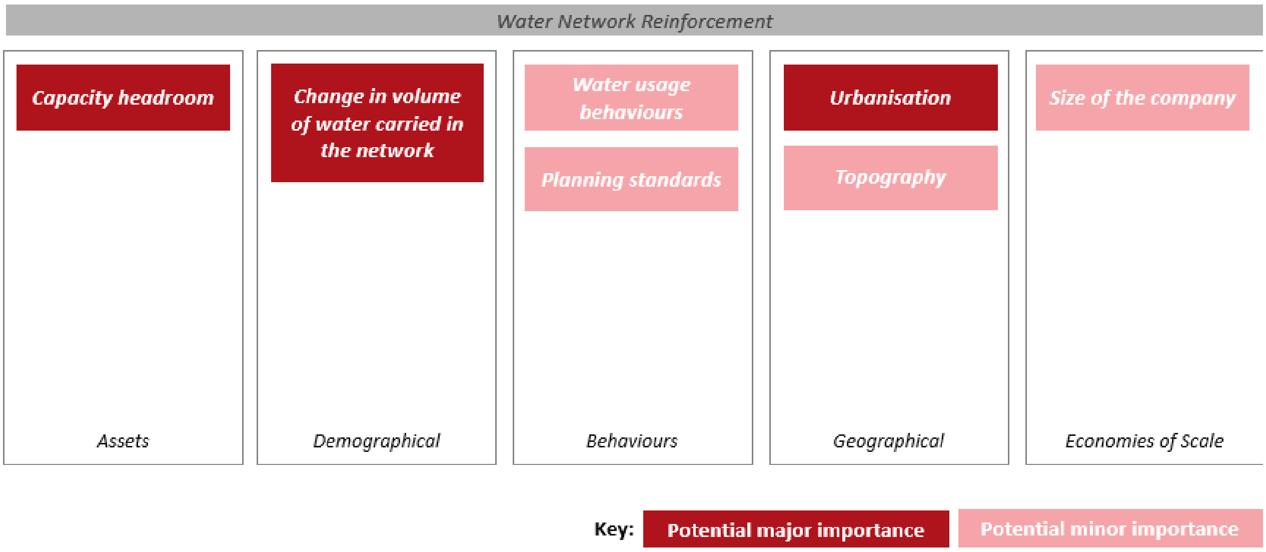
Key:	Supports separate assessment	Does not support separate assessment	Neutral

3.2 Causal narratives of plausible cost drivers

The level of expenditure in reinforcing the water network to accommodate more customers without deterioration of service is a function of multiple drivers. Figure 4 lists the potential drivers identified through an analysis of plausible causal narratives. This analysis has been undertaken at company level, as opposed to site level, to align with Ofwat data collection and cost assessment practices.

The causal narrative analysis has flagged a range of plausible drivers of 'potential major importance', including factors related to capacity headroom and change in volume of water delivered, to accommodate increases in household, industrial and commercial customers, and the level of urbanisation (i.e. population density of area). Other relevant drivers such as water usage behaviours, topography and scale of the company have also been identified although their potential impact on costs is expected to be less important.

Figure 4: Plausible drivers of growth-related spending in water network reinforcement according to engineering rationale



Source: Arup analysis

Table 4 explains, through causal narratives, how each of these plausible drivers typically impacts growth-related expenditure in water network reinforcement at company level (as opposed to site level) and identifies readily available variables to measure such drivers and data sources. It also discusses the extent to which the variables selected to measure the drivers are outside company control and could cause perverse incentives.

As the narratives explain, capacity headroom, one of the drivers of 'potential major importance', lacks a readily available variable and finding one is challenging, if at all possible, given the difficulties in quantifying network capacity headroom at company level. As noted above, the local capacity of the network and related assets (i.e., capacity headroom) is very site-specific, which means that the same company may have capacity headroom in parts of the network but not where growth is taking place.

Table 4: Causal narratives for drivers of growth-related water network reinforcement costs

Driver	Causal narratives	Variables	Data sets	Key
Capacity headroom	This represents the unused volume capacity in the water network to accommodate growth. Existing headroom is used to accommodate growth in demand so that today's growth does not necessarily trigger reinforcement of the water network. When headroom becomes insufficient to accommodate growth in demand, companies plan and design network reinforcement to serve immediate additional demand and restore headroom. Headroom needs to be allowed to accommodate other uncertainties, such as climate change, and to improve resilience. This makes quantifying capacity headroom allocated to growth extremely difficult at company level, although it is easier to quantify at local/site level. Capacity headroom indicates greater ability to accommodate growth with lower costs.	None found readily available. Difficult to quantify at company level.	None found readily available.	Major
Change in volume of water carried in the network	Change in the volume of water carried through the network captures change in water needed to serve new customers, both households and non-households. It also captures offsetting effects such as changes in water usage behaviours and planning standards designed to reduce water consumption. But it fails to directly incentivise reduction of overall demand. Therefore, some risks of perverse incentives persist. We expect an increase in water volume carried through the network to be associated with higher expenditure.	Change in water delivered[9] (direct measure). Indirect measures: new properties, population growth, water delivered to non-households.	Ofwat data.	Major
Water usage behaviours	Water usage behaviour impacts the volumes of water to be supplied to customers. There is an Ofwat incentive for water companies to reduce per capita consumption (PCC), which reduces the volume of water supplied per household. This behavioural change partially offsets the investment needed to accommodate population growth. As behaviours change towards lower water consumption per capita, water network reinforcement costs due to growth are also expected to drop.	PCC (direct measure) would create perverse incentives, hence discarded. Captured through 'water delivered' (indirect measure).	None found readily available for a direct measure. Ofwat data for the indirect measure.	Minor

[9] Variable 6B.8, RAG 4.10, p.102. It excludes distribution losses, i.e., leakage. It does not exclude supply pipe leakage, which is the customer's responsibility.

Driver	Causal narratives	Variables	Data sets	Key
Planning standards	New developments are likely to include integrated water management (IWM) features to reduce water use at customers' taps through water efficient devices and greywater reuse systems. Retrofits within existing households will also have the same impact. Similar to water usage behaviours, planning standards partially offset the investment needed to accommodate population and business growth. Planning standards are expected to be associated with less expenditure in water network reinforcement due to growth.	No direct measure found readily available. Captured through 'water delivered' (indirect measure).	None found readily available for a direct measure. Ofwat data for the indirect measure.	Minor
Urbanisation	Reinforcing the water network within a densely populated area could result in higher construction costs due to the complexity of the network of existing buried services/utilities in urban areas, reinstatement requirements, traffic management during construction and higher labour costs. Sparsely populated areas could also result in higher costs through longer travelling distances. Higher costs are expected to be associated with sparsely populated areas (i.e., low population density) and also with very densely populated areas (i.e., high population density).	Population density combined with population density squared; properties per km of mains.	Ofwat data; ONS population.	Major
Topography	Topography is a potential cost driver when additional pumping is required in the water network to convey water from the water treatment works to customers. Additional pumping capacity required is expected to be associated with higher expenditure.	Pumping capacity per km of mains, booster pumping stations per length of mains.	Ofwat data.	Minor
Size of the company	Costs increase with company size but at a decreasing pace as a result of economies of scale at company level through, for example, more efficient procurement. Larger companies are expected to have proportionally lower costs.	Properties, length of mains, population served (direct measure). Captured through 'water delivered' (indirect measure).	Ofwat data.	Minor

Source: Arup analysis

Key: Potential major importance | Potential minor importance | Suitable variable not readily available

3.3 Model testing

This section examines if robust econometric model can be developed to assess water network reinforcement costs using the modelling approaches described in Section 2.3.

Table 5 presents the modelling results for the 10-year cumulative models, which are the models with greatest robustness. Appendix C.1 shows the results for the less robust year-on-year capex models and the 2020-21 totex model.

Models 1 to 4 (Table 5) reflect the model specification that best aligns with the causal narratives of plausible drivers for which we found readily available variables:

- 'Change in volume of water carried in the network'. Technical insights suggest this is the second most important driver after capacity headroom. It is directly measured through the variable 'change in volume of water delivered'. As explained in the causal narratives above, this variable captures the additional demand driven by both population growth and growth in business activity. It also accounts for offsetting effects such as changes in water usage behaviours and planning standards designed to reduce water consumption. However, it fails to directly incentivise reduction of water demand and therefore some risks of perverse incentives persist.
- 'Urbanisation' is accounted for through two variables measuring 'population density' and 'population density squared', which Ofwat developed at PR19.
- 'Topography' is accounted for through the variable 'pumping capacity per km of mains'.

Models 5 to 12 differ from models 1 to 4 by using indirect measures for 'change in volume of water carried in the network', namely, 'number of new properties connected' (models 5 to 8) and 'population growth' (models 9 to 12). These indirect measures assume a fixed additional volume of water per each new property / new person served and do not account for offsetting factors. Therefore, we would expect these models to perform worse than models 1 to 4, which account for the growth-related actual additional volume of water, including offsetting factors.

Some of the models presented here use four drivers and a constant with a sample of 17 observations. Although these result in overfitting and, therefore, unreliable predictive power, models are presented to draw findings in terms of drivers' significance.

Table 5: Water network reinforcement modelling results, 10-year cumulative (2011-12 to 2020-21)

	Direct variable for water volume				Indirect measures for water volume							
Variable Name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Volume of water change (Ml/d)	0.0205	0.0207	0.0256	0.0225								
New properties (ln)					1.036	1.060	1.081	0.989				
Population growth (%)									0.513	0.625	0.629	0.577
Population density (ln)		0.114	1.742	1.885		-0.175	0.245	0.371		-0.648	0.812	0.464
Population density squared (ln)			-0.139	-0.162			-0.0367	-0.0504			-0.109	-0.0843
Pumping capacity per km of mains (ln)				1.186				0.557				0.482
Constant	2.030	1.280	-3.197	-3.718	-1.574	-0.525	-1.698	-1.860	-0.106	3.595	-1.110	0.0644
Dependent variable	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	20	20	20	20	20	20	20	20	19	19	19	19
R^2	26%	26%	30%	38%	47%	47%	48%	49%	39%	46%	46%	47%
RESET test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
VIF score (mean)	1.0	1.0	13.1	10.2	1.0	1.0	9.9	8.0	1.0	1.3	123.3	93.9

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis.

Note: Models exclude HDD because, due to its small size, it is an outlier in all models presented. Note: WNR capex (ln) = water network reinforcement capex in logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are mis specified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

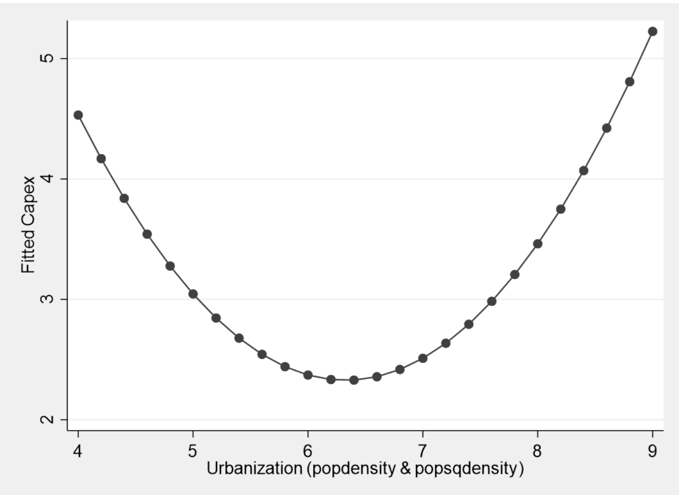
The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

3.4 Model assessment

Overall, the results show that the 10-year cumulative capex models (Table 5) are insufficiently robust to suggest that a standalone model is a feasible option for assessing growth-related water network reinforcement costs at PR24:

- **The models' predictive power is very low**, ranging from 26% to 49%, clearly below the minimum threshold of 75% to 80% as set out in Section 2;
- Of the two drivers of 'potential major significance' tested:
    - Driver **'change in volume of water carried in the network'**: the three variables tested to measure this driver show estimated coefficients **consistently significant and with the expected positive signs**. However, the indirect measures 'population growth' and 'new properties' perform better than the direct measure 'change in volume of water delivered', which is contrary to expectations.[10]
    - Driver 'urbanisation' is measured by the combined effect of two variables, 'population density' and 'population density squared'. The effect of these two variables is significant in the models with 'change in volume of water distributed'. But it is insignificant when 'volume change' is indirectly measured by population growth and new properties connected. Nevertheless, their combined effect on costs shows that **'urbanisation' has the expected 'u-shaped' effect on costs**, meaning that higher costs are associated with low-density areas and with high-density areas (see Figure 5).

Figure 5: Fitted water network reinforcement capex vs population density and population density squared



Source: Arup analysis

[10] Nevertheless, the three variables are highly significant, have the expected positive estimated coefficients and the magnitude of the coefficients is within expected ranges. A one Ml/d increase in volume of water distributed is associated with a 2% to 2.6% increase in growth-related water network reinforcement costs, everything else constant (see Models 1 to 4, Table 5). A one percent increase in new properties connected is associated with a 1% to 1.1% increase in costs.

- **‘Topography’, the driver of ‘potential minor significance’, does not improve model robustness**. When variable ‘pumping capacity per km of mains’, a measure for ‘topography’, is added to the models, the predictive power improves slightly from 30% to 38% in the models testing the direct measure for ‘water volume’ (models 3 and 4) and remains unchanged in the models testing the indirect measures ‘new properties’ (models 7 and 8) and ‘population growth (models 11 and 12). Also, the estimated coefficient for the variable ‘pumping capacity per km of mains’, is insignificant in all model specifications.

3.5 Recommendations

Based on historical data and variables currently available, it has not been possible to develop a robust standalone econometric model to assess water network reinforcement costs at PR24 within this study.

Root cause analysis suggests that this is likely the result of:

- **Localised factors affecting the way drivers identified through causal narratives impact costs** and such effects are difficult to capture through company-level variables currently available. These include:
    - The same company may have capacity headroom in part of its network but not in other parts where growth is concentrated;
    - The same volume of growth may trigger different spending levels depending on whether growth:
        - Is concentrated in a small part of the network or spread across a larger area;
        - Results from a few big developments vs several small developments, or a few large business facilities vs several small ones.
- **Substantial differences in cost allocation practices across companies** between growth-related network reinforcement and capital maintenance, based on historical data evidence. There are also some synergies between asset replacement (base costs) and network reinforcement (see Table 3).

These factors suggest the following options for assessing growth-related water network reinforcement costs at PR24:

- **Option 1, preferred option, if cost allocation issues can be mitigated: separate assessment from base costs through comparative assessment using information that better reflects localised features of growth and mitigates differences in allocation practices**. This option would need to be supported by:
    - <u>Additional data collection that reflects the localised features of growth</u>. We recommend Ofwat to work with the water industry to identify plausible

localised variables that can realistically be collected ahead of PR24. Examples of plausible variables include:

        - Local capacity of the network;
        - Length of new mains laid;
        - Diameter of new mains laid;
        - Additional pumping station capacity.

    - Improved data collection to minimise differences in cost allocation practices. One possibility could be benchmarking with the use of company business plan forecasts, if it minimises differences in cost allocation practices. However, we note that this could lead to some double counting of network reinforcement allowances, because some of these costs are included in historical base costs.

- **Option 2, preferred option if cost allocation issues cannot be mitigated: keep as part of base costs**. This option would also take advantage of the synergies with base costs through asset replacement. If kept with base costs, it is recommended that Ofwat considers:

    - Testing a driver to capture growth as part of the base cost econometric models. Network reinforcement costs share some drivers with base costs, namely urbanisation and topography. However, the base cost models used at PR19 lacked a driver to account for differences in growth across companies.

      Candidates for growth specific drivers supported by causal narratives include 'change in volume of water delivered', 'population growth' and 'new properties connected'. 'Population growth' has the advantage of being available prior to 2011-12, thereby avoiding missing any sample data points. It is also exogenous (i.e., outside of company control) while it also minimises risks of perverse incentives to companies.

    - If adding a growth driver to the base cost models proves unfeasible, Ofwat could consider applying a post-modelling growth adjustment to the base models, similar to the approach used at PR19.[11]

    - Alongside these, Ofwat could consider keeping a cost adjustment claim process similar to that used at PR19. Through this process, companies with unique growth circumstances driving higher efficient costs would have an opportunity to claim an adjustment to their modelled allowances. The assessment of cost adjustment claims would be facilitated if Ofwat requested the following evidence from companies as part of their submissions:

        - Local capacity of the network;

[11] Ofwat, 'PR19 final determinations: Securing cost efficiency appendix', December 2019, chapter 3.1.

- Magnitude of growth and its features (e.g., large vs small residential developments; industrial/commercial vs household);
- Evidence of impact on the water network, namely, laying of new mains and additional pumping capacity requirements; and
- Evidence that the higher costs claimed are efficient, e.g., through quotes from prospective bidders, quotes from bidders for comparable works carried out in the recent past and, where applicable, evidence of industry benchmarking.

4. Wastewater network reinforcement

In accordance with the RAGs,[12] growth-related wastewater network reinforcement refers to expenditure for the provision or upgrading of infrastructure network assets (e.g., sewers and pumping stations) to provide for new customers with no net deterioration of existing levels of service.

This section sets out our recommendations regarding feasible approaches for assessing this cost line at PR24. It starts by exploring the feasibility of assessing it separately from base costs and developing causal narratives underpinning plausible cost drivers. It then tests whether robust cost assessment models can be developed and concludes with recommendations for assessment options.

4.1 Suitability for separate assessment

The performance of cost data against the following four criteria determines the extent to which growth-related spending in wastewater network reinforcement is suitable for assessment separately from base costs: materiality, relevance of site and/or scheme specific drivers, complementarities/interactions with base costs, concentration of costs in a small number of companies and changes in reporting/allocation practices.

The assessment of these criteria, summarised in Table 6, is very similar to that for water network reinforcement. In short, it suggests that this line is suitable for assessment separately from base costs, although keeping it with base costs may be appropriate. Like in water network reinforcement, site and/or scheme specific factors affect the way drivers impact costs, and these effects are better captured outside the base models, provided appropriate variables and data are available.

However, similarly to water network reinforcement, keeping wastewater network reinforcement as part of base costs could also be justified on grounds of synergies with asset replacement (base costs) and differences in cost allocation practices across companies between this cost line and capital maintenance. The evidence available suggests that these are likely to have a substantial impact on costs. For example, two companies – NES and YKY – reported zero spend against this line from 2011-12 to 2016-17, while the volume of wastewater conveyed from customers' properties to WwTWs by these companies increased by 4% (NES) and 7% (YKY) and population increased by 3% (NES) and 5% (YKY) over the same period. Also, the materiality of this line (1.5% of base costs at industry level) is below the recommended 2.5% materiality threshold (see Section 2), which is another factor suggesting to keep this cost line within base costs.

[12] 'RAG 4.09 RAG – Guideline for the table definitions in the annual performance report', February 2021, p.65.

Table 6: Suitability of wastewater network reinforcement expenditure for separate assessment

	Criteria	Evidence	Assessment
1	**Materiality**	• Industry-level cumulative expenditure reached £517m (2017-18 prices) over the 10-year period ending in 2020-21. • This was equivalent to 1.5% of industry-level cumulative base costs over the same period. • At company level, materiality over the 10-year period ending in 2020-21 was above 5% of base costs only for ANH (3.1%). Materiality was less than 1% for NES, NWT, YKY.	**Materially at 1.5% is lower than that for water network reinforcement** and may be insufficient to justify separate assessment.
2	**Relevance of site/scheme specific drivers**	• The local capacity of the network and related assets (i.e., capacity headroom) is very site-specific, meaning that a company may have capacity headroom in parts of the network but not where growth is taking place. • The same volume of growth may trigger different spending levels depending on whether it is concentrated in a small part of the network or spread across a larger area.	**Site and/or scheme specific factors** affect the way drivers impact costs. Separate assessment facilitates the task of capturing such localised effects, provided appropriate variables are available.
3	**Complementarities with base costs**	• Like for water, growth-related wastewater network reinforcement costs are hardly substitutable with more intensive operation and/or maintenance of existing assets. • There are some synergies with asset replacement. When network assets reach the end of their useful life, companies can replace them with either like-for-like assets or assets that deliver greater capacity with only a fraction of additional cost. • Opex related to network reinforcement, for both water and wastewater, started to be collected only from 2020-21 onwards. Previously, opex was reported as part of base costs. However, based on 2020-21 data, this is likely to create an immaterial distortion as opex for this cost line accounted for less than 0.5% of industry-level capex in 2020-21.	**Synergies with asset replacement (base costs) suggest assessment with base costs may be justifiable**.
4	**Change in reporting/allocation practices**	• No substantial changes made to the RAGs throughout the sample period from 2011-12 to 2020-21. • RAGs allow companies to apply a level of discretion when apportioning costs between growth related network reinforcement and capital maintenance. • Two companies – NES and YKY – reported zero spend against this line from 2011-12 to 2016-17. This is likely reflective of differences in reporting/allocation practices, as the volume of wastewater conveyed from customers’	**Coexistence of zero expenditure with a substantial increase in volume of water delivered** over a long time period indicates that cost apportioning issues between network reinforcement and capital maintenance may be substantial for some companies. This suggests combining assessment with base costs may be justifiable.

	Criteria	Evidence	Assessment
		properties to WwTWs by these companies increased by 4% (NES) and 7% (YKY) over the 10-year period ending in 2020-21.	

Source: Arup analysis.

Notes: Appendix A.2 presents the detailed data analysis supporting the evidence summarised in this table. SVH represents the combined costs of SVE and HDD.

Key:	Supports separate assessment	Does not support separate assessment	Neutral

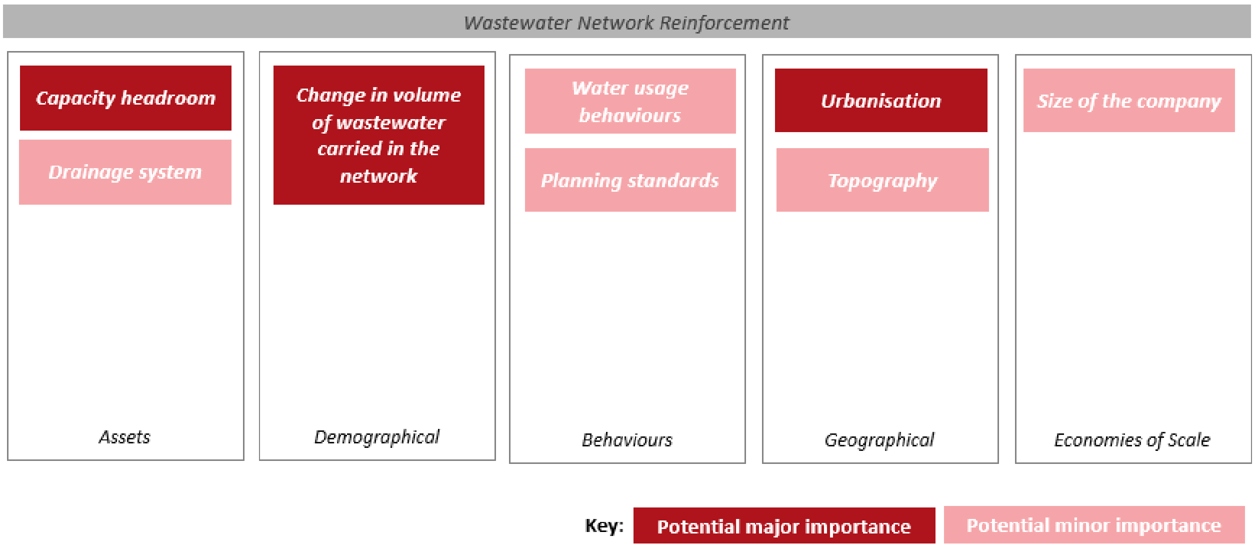
4.2 Causal narratives of plausible cost drivers

The reinforcement of the wastewater network needs to be planned and designed to accommodate additional volume of wastewater that needs to be conveyed from new customers' properties to Wastewater Treatment Works (WwTW).

In assessing the impact of growth on wastewater networks, it is assumed that in new developments surface water is managed at source, using Sustainable Drainage Systems (SuDS) and/or Nature-Based Solutions (NBS), in line with best practice. Hence, the impact of growth-related surface water on network reinforcement is not considered to be an important driver.

The analysis of causal narratives has identified multiple plausible drivers determining water companies' spending in reinforcing the wastewater network to accommodate the additional volume of wastewater. These are identified in Figure 6. Similarly to the approach followed in water network reinforcement, the causal analysis is carried out at company level, as opposed to site level, to align with Ofwat's data collection and cost assessment practices.

Figure 6: Plausible drivers of growth-related spending in wastewater network reinforcement according to engineering rationale



Source: Arup analysis

Table 7 summarises how the plausible drivers affect wastewater network reinforcement, through causal narratives, and identifies candidate variables to measure such drivers and data sources. It also discusses whether any variable is outside company control and mitigations, as well as upsides and downsides regarding potential perverse incentives.

Like in the case of water network reinforcement, the analysis was unable to identify candidate variables for measuring capacity headroom at company level, one of the drivers of ‘potential major importance’. As discussed above, capacity headroom is very site-specific, which means that the same company may have capacity headroom in parts of the network but not where growth is taking place.

Table 7: Causal narratives for drivers of growth-related wastewater network reinforcement costs

Driver	Causal narratives	Variables	Data sets	Key
Capacity headroom	This represents the volume capacity available in the wastewater network to accommodate growth. Existing headroom is used to accommodate growth in wastewater flows so that today’s growth does not necessarily trigger reinforcement of the wastewater network. When headroom becomes insufficient to accommodate growth in wastewater flows, companies plan and design network reinforcement to serve immediate additional flows and restore headroom. Headroom needs to be allowed to accommodate other uncertainties, such as climate change, and to improve resilience. This makes quantifying capacity headroom allocated to growth extremely difficult at company level, although it is easier to quantify at local/site level. More capacity headroom means greater ability to accommodate growth with lower costs.	None found or none readily available. Difficult to quantify at company level.	None found or none readily available.	Major
Drainage system	In combined systems, stormwater and foul are conveyed to WwTWs through the same pipe network. In separate systems, stormwater is dealt with through a separate system. The impact of additional growth-related flows on the wastewater network is different between combined and separate systems. The potential to accommodate additional dry weather flows within the existing network is likely to be greater in combined systems. However, utilising capacity of the combined system for growth would increase the risk of sewer flooding during storm events. Therefore, a larger proportion of combined systems can be associated with either higher or lower growth-related wastewater network reinforcement costs. This means that drainage system can be associated with	Combined sewers.	Ofwat data.	Minor

Driver	Causal narratives	Variables	Data sets	Key
	either an increase or a decrease in expenditure, as it reflects a combination of opposite effects.			
Change in volume of wastewater carried in the network	Change in the volume of wastewater conveyed through the network captures the change in wastewater entering the network from new customers, both households and non-households. It also captures offsetting effects such as usage behaviours and planning standards designed to reduce the volume of wastewater going into the network. However, it fails to directly incentivise reduction of overall wastewater conveyed through the network. Therefore, some risks of perverse incentives persist. We expect an increase in wastewater volume conveyed through the network to be associated with an increase in expenditure.	Change in wastewater treated (direct measure). Indirect measures: new properties, population growth.	Ofwat data.	Major
Water usage behaviours	Water usage behaviour impacts the volumes of wastewater discharged by customers. There is an Ofwat incentive for water companies to reduce PCC, which in turn reduces the volume of wastewater discharged. This behavioural change partially offsets the investment needed to accommodate population growth. But it fails to directly incentivise a reduction of the overall wastewater conveyed through the network. Therefore, some risks of perverse incentives persist. As behaviours change towards lower water consumption per capita, wastewater network reinforcement costs due to growth are also expected to drop.	PCC (direct measure) would create perverse incentives, hence discarded. Captured through 'volume of wastewater carried' (indirect measure)	None found readily available for a direct measure. Ofwat data for the indirect measure.	Minor
Planning standards	New developments are likely to include Integrated Water Management (IWM) features to reduce water use at customers' taps and, thereby, the volume of wastewater to be conveyed through the network. This is achieved through the deployment of water efficient devices and greywater reuse systems. Retrofits within existing households will also have the same impact. Similar to PCC, planning standards partially offset the expenditure needed to accommodate population and business growth.	No direct measure found readily available. Captured through 'volume of wastewater carried' (indirect measure)	None found readily available for a direct measure. Ofwat data for the	Minor

Driver	Causal narratives	Variables	Data sets	Key
	Planning standards are expected to be associated with less spending in wastewater network reinforcement.		indirect measure.	
Urbanisation	Reinforcing the wastewater network within a densely populated area leads to higher construction costs and, thereby, higher expenditure due to a combination of factors. These include complexity of the network of existing buried services/utilities in urban areas, reinstatement requirements, traffic management during construction and higher labour costs. Sparsely populated areas could also result in higher costs through longer travelling distances. Higher costs are expected to be associated with sparsely populated areas (i.e., low population density) and also with very densely populated areas (i.e., high population density).	Population density combined with population density squared; properties per km of sewer.	Ofwat data; ONS populatio n.	Major
Topography	Topography can be a cost driver when additional pumping is required in the wastewater network to convey wastewater from customer properties to the WwTW. Additional pumping is expected to be associated with greater expenditure.	Pumping capacity per km of sewer.	Ofwat data.	Minor
Size of the company	Costs increase with company size but at a decreasing pace as a result of economies of scale at company level through, for example, more efficient procurement. Therefore, larger companies are expected to have proportionally lower costs.	Properties, sewer length, population served (direct measures). Captured through 'wastewater treated (indirect measures).	Ofwat data.	Minor

Source: Arup analysis

Key: Potential major importance | Potential minor importance | Suitable variable not readily available

4.3 Model testing

Using the modelling approach described in Section 2.3, this section examines whether robust econometric models can be developed to assess wastewater network reinforcement costs separately from base costs.

Table 8 presents the results for the models with greatest robustness, i.e., the 10-year cumulative capex models. The results of the less robust year-on-year capex models and the 2020-21 totex model are in Appendix C.2.

The specification of models 1 to 5 (Table 8) aligns with the causal narratives of plausible drivers for which we found variables readily available:

- Driver ‘change in volume of wastewater carried in the network’, which engineering rationale suggests is the second most important driver after capacity headroom, is directly measured by the variable ‘change in volume of wastewater conveyed to WwTWs’. These models have the potential to capture the actual additional volume of wastewater conveyed as a result of greater demand from both households and non-households, while also accounting for offsetting effects such as changes in ‘water usage behaviours’ and ‘planning permits’. But this direct measure fails to directly incentivise reduction of overall wastewater conveyed through the network and, therefore, some risks of perverse incentives persist.
- Type of ‘drainage system’, measured by the ‘percentage of combined sewers’;
- ‘Urbanisation’ through the ‘population density’ variables developed by Ofwat at PR19; and
- ‘Topography’ measured by ‘pumping capacity per km of sewer’.

Models 6 to 15 differ from models 1 to 5 by using indirect measures for ‘change in volume of wastewater carried in the network’. These are the ‘number of new properties connected’ and ‘population growth’. These indirect measures assume a fixed additional volume of wastewater per new property / new person served and do not account for offsetting factors. Therefore, we would expect these models to perform worse than models 1 to 5, which account for the actual growth-related additional volume of wastewater and for offsetting factors.

Some of the models discussed in this section use five drivers and the constant with a sample of 10 observations. Although this results in overfitting and, therefore, unreliable predictive power, these are presented to draw findings in terms of drivers’ significance.

Table 8: Wastewater network reinforcement modelling results, 10-year cumulative (2011-12 to 2020-21)

	Direct variable for wastewater volume					Indirect measures for wastewater volume									
Variable name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Volume WW change (Ml/yr)	0.00000459	0.00000629	0.00000613	0.00000552	0.00000582										
New properties (ln)						0.841	1.658	1.572	1.059	1.542					
Population growth (%)											0.410	0.432	0.409	0.0726	0.0792
Population density (ln)		-0.499	-8.225	-4.284	-4.344		-1.031	-7.810	-4.974	-5.617		-0.189	-1.647	-3.210	-3.129
Population density squared (ln)			0.575	0.248	0.258			0.508	0.296	0.347			0.110	0.209	0.197
Combined sewers (%)				-0.0626	-0.0586				-0.0464	-0.0251				-0.0588	-0.0610
Pumping capacity/ km sewer (ln)					0.339					1.038					-0.276
Constant	2.907	5.924	30.79	23.60	23.10	-0.574	2.143	24.21	20.56	18.29	1.209	2.318	7.093	18.48	18.72
Dependent variable	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
R^2	27%	33%	49%	84%	84%	27%	47%	58%	73%	78%	48%	49%	49%	59%	60%
RESET test	Fail	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
VIF score (mean)	1.0	1.6	115.9	97.8	78.9	1.0	2.3	116.7	99.5	82.3	1.0	1.1	153.4	121.8	98.3

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis.

Notes: WwNR capex (ln) = wastewater network reinforcement capex in logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are mis specified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

4.4 Model assessment

Overall, the 10-year cumulative models testing the causal narratives for growth-related wastewater network reinforcement are insufficiently robust to suggest that a standalone econometric model is an option for assessing this cost line at PR24. The year-on-year models (see Appendix A.2) show even poorer robustness. Indeed, the results of the 10-year cumulative models show:

- **The model specifications aligned with the drivers of 'potential major significance' have very low predictive power and only the driver 'volume change' is significant**. Models 1 to 3, 6 to 8 and 11 to 13 test the two drivers of 'potential major significance' for which variables are readily available – 'wastewater conveyed through the network' and 'urbanisation'. As explained above, they differ in the variable tested as a measure of 'water conveyed through the network'. These models show:
    - <u>Low predictive power.</u> The predictive power of these models ranges from 27% to 58%, substantially below the minimum threshold of 75% to 80%, as set out in Section 2.
    - <u>The indirect measures of 'wastewater conveyed through the network' perform better than the direct measures</u>, which is contrary to expectations. The estimated coefficients for the two indirect measures 'new properties' and 'population growth' are significant, have the expected positive sign and are of a plausible magnitude (models 6 to 8 and 11 to 13).[13] Contrary to expectations, the estimated coefficient for the direct measure 'volume of water delivered' is insignificant in some model specifications.[14]
    - <u>The driver 'urbanisation' is insignificant, but it has the expected 'u-shaped' effect on costs</u>. The effect of driver 'urbanisation' on costs is measured by the combined effect of two variables 'population density' and 'population density squared'. Both are statistically insignificant across the model specifications tested. However, the combined effect of these two variables on costs shows that urbanisation has the expected 'U-shaped' effect on costs, meaning that higher costs are associated with low-density areas and with high-density areas (see Figure 7).

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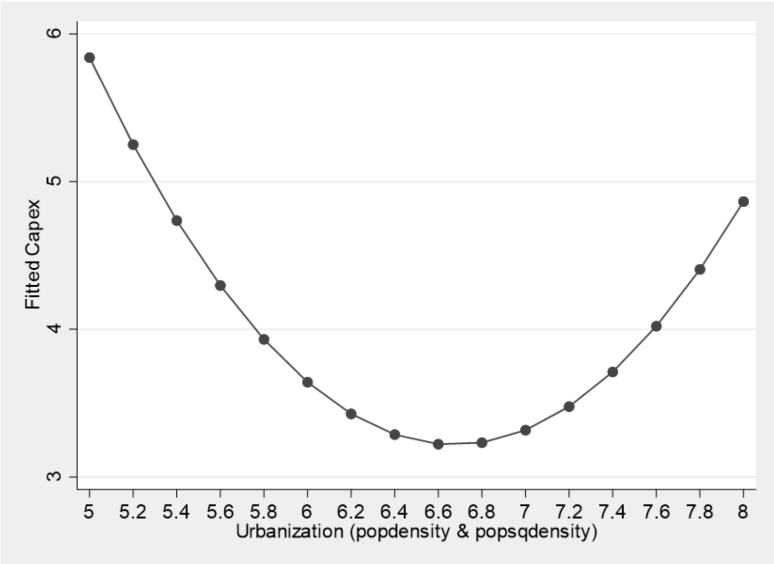
[13] A one percent increase in new properties connected is associated with a 0.9% to 1.7% increase in wastewater network reinforcement costs, everything else constant (see models 6 to 8, Table 8). A one percentage point increase in population growth is associated with a 0.4%, everything else unchanged (see models 11 to 13, Table 8).

[14] A one Ml/yr increase in volume of wastewater conveyed to WwTWs is associated with a 0.0006% increase in costs, everything else constant (see models 3, Table 8).

Figure 7: Fitted wastewater network reinforcement capex vs population density and population density squared



Source: Arup analysis

- **Adding the two drivers of 'potential minor importance', 'drainage system' and 'topography' results in model overfitting** (four variables and a constant with just 10 observations) and, therefore, unreliable high predictive power. Nevertheless, the findings in terms of drivers' significance are:
  - The variable 'combined sewers' (measure for driver 'drainage system') has a negative effect on costs consistently across all model specifications, although it is only significant in the model specification using 'change in water delivered' (models 3 and 4). As explained in the causal narratives, the drainage system can be associated with either an increase or a decrease in expenditure, as it reflects a combination of opposite effects in dry and wet weather conditions. We note that adding a variable 'combined sewers' to the models increases the models' predictive power.[15]
  - The variable 'pumping capacity', measure for 'topography', is insignificant, albeit with the expected positive sign.

[15] This is particularly the case in the model specification that also includes the variable 'change in volume of water delivered' where adding this variable increases the model's predictive power from 49% to 85% (models 3 and 4). Our sensitivity analysis shows that a model with only two variables 'change in volume of water delivered' and 'combined sewers' is not robust either. It has a predictive power at around 50%, similar to that achieved with the two drivers of 'potential major importance'. Also, the coefficient for 'change in volume of water delivered' is insignificant, which is contrary to expectations.

4.5 Recommendations

Similarly to water network reinforcement, based on historical data and variables currently available, it is not possible to develop a robust standalone econometric model to assess growth-related wastewater network reinforcement costs at PR24 within this study.

Our root cause analysis identifies this is likely a reflection of the same factors identified for water network reinforcement (detailed in section 3.5), which in short are:

- **Localised factors** affecting the way drivers impact costs, and such effects are difficult to capture through company-level variables. The main examples include localised headroom capacity and the features of growth (few large vs many small developments and concentration of growth in a small part of the network vs spread across a larger area).
- Historical evidence of substantial **differences in cost allocation practices** across companies between growth-related network reinforcement and capital maintenance. There are also some synergies between asset replacement (base costs) and network reinforcement (see Table 6).

Therefore, our recommended options for assessing this cost line mirror those recommended for water network reinforcement, which we repeat here for ease of reference:

- **Option 1, preferred option, if cost allocation issues can be mitigated: separate assessment from base costs through comparative assessment using information that better reflects localised features of growth and mitigates differences in allocation practices**. This option would need to be supported by:
  - <u>Additional data collection that reflects the localised features of growth</u>. We recommend Ofwat to work with the water industry to identify plausible localised variables that can realistically be collected ahead of PR24. Examples of plausible variables include:
    - Local capacity of the network;
    - Length of new sewers laid;
    - Diameter of new sewers laid;
    - Additional pumping station capacity.
  - <u>Improved data collection to minimise differences in cost allocation practices.</u> One possibility could be benchmarking with the use of company business plan forecasts, if it minimises differences in cost allocation practices. However, we note that this could lead to some double counting of network reinforcement allowances, because some of these costs are included in historical base costs.
- **Option 2, preferred option if cost allocation issues cannot be mitigated: keep as part of base costs**. This option would also take advantage of the synergies with

base costs through asset replacement. If kept with base costs, it is recommended that Ofwat considers:

- Testing a driver to capture growth as part of the base cost econometric models. Network reinforcement costs share some drivers with base costs, namely urbanisation and topography. However, the base cost models used at PR19 lacked a driver to account for differences in growth across companies.

  Although the candidates for growth specific drivers supported by causal narratives include ‘change in volume of wastewater conveyed’, ‘population growth’ and ‘new properties connected’, ‘population growth’ has the advantage of being exogenous (i.e. out of company control), while also minimising risks of perverse incentives to companies.

- If adding a growth driver to the base cost models proves unfeasible, Ofwat could consider applying a post-modelling growth adjustment to the base models, similar to the approach used at PR19.[16]

- Alongside these, Ofwat could consider having a cost adjustment claim process similar to that used at PR19. Through this process, companies with unique growth circumstances driving higher efficient costs would have an opportunity to claim an adjustment to their modelled allowances. The assessment of cost adjustment claims would be facilitated if Ofwat requested the following evidence from companies as part of their submissions:

  - Local capacity of the network;
  - Magnitude of growth and its features (e.g., large vs small residential developments; industrial/commercial vs household);
  - Evidence of impact on the wastewater network, namely, laying of new sewers and additional pumping capacity requirements; and
  - Evidence that the higher costs claimed are efficient, e.g., through quotes from prospective bidders, quotes from bidders for comparable works carried out in the recent past and, where applicable, evidence of industry benchmarking.

[16] Ofwat, ‘PR19 final determinations: Securing cost efficiency appendix’, December 2019, chapter 3.1.

5. Growth at wastewater treatment works

Growth at WwTWs costs refer to expenditure to meet or offset changes in demand from new and existing customers at wastewater treatment works.

This section offers recommendations on options for assessing this cost line at PR24. Like for water and wastewater network reinforcement, it discusses the extent to which this cost line is suitable for assessment separate from base costs, presents plausible cost drivers underpinned by technical rationale and causal narratives and tests the extent to which a robust econometric model exists that reflects the causal narratives. It concludes with recommendations on appropriate assessment options for PR24.

5.1 Suitability for separate assessment

Table 9 summarises the analysis of growth at WwTW costs against the criteria for assessment separately from base costs.

In sum, growth at WwTWs costs are suitable for assessment independently from base costs. This cost line is sufficiently material to justify separate assessment and materiality is fairly comparable across companies. Site-specific drivers are of limited relevance, suggesting that a separate robust benchmarking assessment may be feasible. Also, technical insights suggest that synergies with base costs are likely to be limited, making this cost line amenable to assessment separately from base costs.

Table 9: Suitability of growth at WwTWs expenditure for separate assessment

	Criteria	Evidence	Assessment
1	**Materiality**	• Industry-level cumulative expenditure reached £861m (2017-18 prices) over the 10-year period ending in 2020-21. • This was equivalent to 2.5% of industry-level cumulative base costs over the same period. • At company level, materiality over the 10-year period was above 5% of base costs for WSX (5.3%) followed by ANH (3.7%) and TMS (3.5%). Materiality was between 2% and 5% for 7 of the 10 companies. It was less than 1% only for YKY.	**Sufficiently material** to justify separate assessment. **Materiality is fairly comparable** across companies.
2	**Relevance of site/scheme specific drivers**	• Site or scheme specific factors are less significant cost drivers, as it is considered that companies have more operational flexibility to centrally manage growth at WwTWs.	**Limited relevance of site-specific factors** suggests development of standalone robust efficiency benchmark may be feasible.
3	**Complementarities with base costs**	• Opportunities to expand treatment capacity through more intensive operation and/or maintenance of existing WwTW assets are relatively limited. • Opex related to growth at sewage treatment works has been collected since 2017-18. Previously, it was reported as part of base costs. However, this is likely to create an immaterial distortion as opex has accounted for only 1% of industry-level total capex since 2017-18.	**Limited synergies with base costs** suggest separate assessment is suitable.

	Criteria	Evidence	Assessment
4	Change in reporting/allocation practices	• No substantial changes made to the RAGs throughout the sample period from 2011-12 to 2020-21.	Separate assessment not affected by substantial reporting/allocation changes.

Source: Arup analysis.

Notes: Appendix A.3 presents the detailed data analysis supporting the evidence summarised in this table. SWH represents the combined spend of SWT BWH and SWB.

Key:	Supports separate assessment	Does not support separate	Neutral

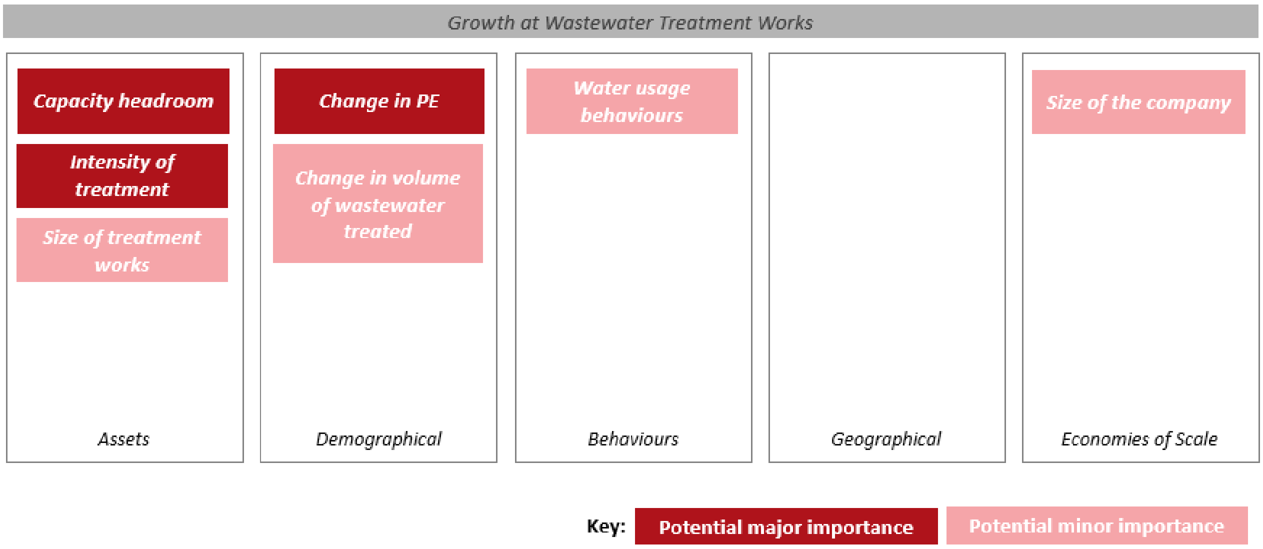
5.2 Causal narratives of plausible cost drivers

Changes in wastewater flow and load from new and existing customers, both households and non-households, are conveyed to WwTWs where additional capacity may be required to treat additional flow and load.

In assessing the impact of growth at WwTWs, it is assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-related surface water on the flow conveyed to WwTWs is not considered to be an important driver.

Causal analysis of plausible cost drivers has identified multiple drivers determining water companies' growth-related expenditure at WwTWs. These are listed in Figure 8. The analysis has been undertaken at company level, as opposed to site level, to align with Ofwat's data collection and cost assessment practices. All drivers identified are, to a large extent, outside company control and minimise risks of perverse incentives to companies.

Figure 8: Plausible drivers of growth-related spending at WwTWs according to engineering rationale



Source: Arup analysis

Table 10 summarises how the plausible drivers are expected to affect growth-related spending at WwTWs through a series of causal narratives and proposes variables to measure such drivers, as well as sources of readily available data.

Table 10: Causal narratives for drivers of growth-related spending at WwTWs

Driver	Causal narratives	Variables	Data sets	Key
Capacity headroom	This represents the spare treatment capacity within WwTWs to accommodate growth. Existing headroom is used to accommodate growth so that today's growth does not necessarily trigger expenditure for expansions and upgrades at WwTWs. When headroom becomes insufficient to accommodate growth in demand, companies plan and design WwTW expansions or upgrades to treat additional flows and loads and restore headroom. Headroom needs to be allowed to accommodate other uncertainties, such as climate change, and to improve resilience. This makes quantifying capacity headroom allocated to growth extremely difficult at company level, although it is easier to quantify at site level. Capacity headroom indicates greater ability to accommodate growth with lower costs.	None found or none readily available.	None found or none readily available for direct measure.	Major
Intensity of treatment	Tertiary treatment is associated with higher unit costs than other forms of wastewater treatment. Assuming discharge consents remain the same, and depending on capacity headroom at WwTW, greater load and flow volumes could result in greater expenditure for water companies with more intense treatment requirements. Higher proportion of load with more intense treatment is expected to be associated with greater costs.	Load requiring tertiary treatment.	Ofwat data.	Major
Size of treatment works	The average cost of wastewater treatment declines as the size of a treatment works increases. Higher percentage of load treated at small WwTWs could result in greater expenditure for water companies.	Load treated at band sizes 1 to 3 (%); load treated at band size 6.	Ofwat data.	Minor
Change in population equivalent	Change in population equivalent (PE) captures the change in load received at WwTWs from new customers, both households and non-households, as well as the change in load patterns from existing customers. Depending on the capacity headroom of the WwTW, there may be a need for expenditure associated with expanding and/or upgrading WwTWs.	Change in PE equivalent served by WwTW.	Ofwat data.	Major

Driver	Causal narratives	Variables	Data sets	Key
	Change in PE will also have an impact on operational costs of wastewater treatment.			
Change in volume of wastewater treated	Change in volume of wastewater treated captures the change in flows received at WwTWs from new customers, both households and non-households, as well as the change in flow patterns from existing customers (e.g., behavioural changes). Depending on the capacity headroom of the WwTW, there may be a need for expenditure associated with expanding and/or upgrading WwTWs. Change in wastewater flows is also likely to have an impact on operational costs of wastewater treatment. A positive change in volume of wastewater treated at WwTW is expected to be associated with greater costs.	Change in wastewater treated, new properties, population growth. We note that this variable may reduce the incentive on companies to reduce the amount of rainfall that enters the sewer.	Ofwat data.	Minor
Water usage behaviours	Water usage behaviour can impact the wastewater volumes to be treated at WwTW. There is an incentive from Ofwat for water companies to reduce the per capita consumption (PCC), therefore reducing the volume of wastewater treated at the WwTWs. This behavioural change could partially offset the increase in volume of service required, driven by population and business growth. Reduced per capita water consumption is likely to reduce expenditure in water network reinforcement due to growth.	PCC (direct measure) would create perverse incentives, hence discarded. Captured through change in PE (indirect measure).	None found readily available for a direct measure. Ofwat data for the indirect measure.	Minor
Size of the company	Costs increase with company size but at a decreasing pace as a result of economies of scale at company level through, for example, more efficient procurement. Larger companies are expected to have proportionally lower costs.	Properties, load, population served (direct measures). Captured through change in PE (indirect measure).	Ofwat data.	Minor

Source: Arup analysis

Key: Potential major importance | Potential minor importance | Suitable variable not readily available

5.3 Model testing

In this section, we test whether the causal narratives give raise to an econometric model sufficiently robust for assessing growth at WwTW costs at PR24. We use the modelling approach described in Section 2.3.

Table 11 shows the modelling results for the cumulative models, which present greater robustness than the year-on-year models. Models 1 to 4 are the 10-year cumulative capex models and models 5 to 8 are the 4-year cumulative totex models. The results for the year-on-year models are less robust and can be found in Appendix C.3.

Table 11: Growth at Wastewater Treatment Works modelling results

	10-year capex cumulative (2011-12 to 2020-21)				4-year totex cumulative (2017-18 to 2020-21)			
Variable name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
PE change served by WwTWs (000s)	0.00150	0.00162	0.00143	0.00144	0.00290	0.00289	0.00287	0.00278
Load receiving tertiary treatment (%)		0.0183	0.0162	0.0150		0.00112	-0.00202	-0.000307
Volume WW change (Ml/yr)			0.00000153	0.00000187			0.00000231	0.00000182
Load treated in WwTW size bands 1-3 (%)				0.0315				-0.0355
Constant	3.623	2.525	2.484	2.373	2.961	2.896	2.880	2.965
Dependent variable	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW totex (ln)	GWwTW totex (ln)	GWwTW totex (ln)	GWwTW totex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	10	10	10	10	10	10	10	10
R^2	66%	77%	80%	81%	76 %	76 %	80 %	81 %
RESET test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
VIF score (mean)	1.0	1.0	1.3	1.4	1.0	1.0	1.1	1.2

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis.

Notes: GWwTW capex (ln) = Growth at Wastewater Treatment Works capex, logarithmic scale. Note: GWwTW totex, (ln) = Growth at Wastewater Treatment Works totex, logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

5.4 Model assessment

The results show that an econometric model explaining cumulative costs as a function of cumulative change in PE and intensity of treatment is a very strong candidate to assess growth at WwTWs costs at PR24.

Specifically, the preferred model specification, model 2 (capex) / model 6 (totex), shows the following:

- **Estimated coefficients are aligned with causal narratives**. PE and intensity of treatment, both drivers of 'potential major importance' according to technical rationale, are significant, have the expected signs and the estimated coefficients are of a plausible magnitude.[17] Appendix E shows how these drivers and their relationship with costs vary across companies.
- **Predictive power is consistent with a sufficient level of robustness**. The predictive power, measured by the R^2, is 77% in the 10-year cumulative capex model and 76% in the 4-year cumulative totex model. These meet the minimum threshold of 75% to 80% consistent with sufficient level of robustness.
- **Parsimonious and sensible**. The preferred model specification includes only two explanatory variables – 'change PE' and 'percentage of load receiving tertiary treatment'. Including these two key variables ensures a sensible, simple model specification, while avoiding the risk of the model being over-specified.
- **Statistically valid**. In addition to a sufficiently robust R^2 at 77% (capex model) and 76% (totex model), the model also passes the Reset test of linear specification, meaning that its specification is appropriate for explaining costs. The significance of the estimated coefficients is robust against multicollinearity, as the mean VIF statistic is around 1, which is below the acceptable level of 10.
- **Additional drivers reduce model validity.** Two additional plausible drivers of 'minor importance' suggested by engineering narratives, 'change in volume of flow treated' and 'size of WwTWs', add little predictive power to the model (R^2 goes up from 77% to 81%). Also, these drivers are both statistically insignificant (albeit with the expected positive signs).
- **Estimated model results are stable**. The model robustness remains unchanged when capex and drivers are summed over the 4 years ending in 2020-21, as opposed to 10 years. Given that PR24 assessment will be on a totex basis, this is an encouraging result. It suggests that this model specification will likely be equally robust when costs are on a totex basis and summed over more than the 4 years currently available.

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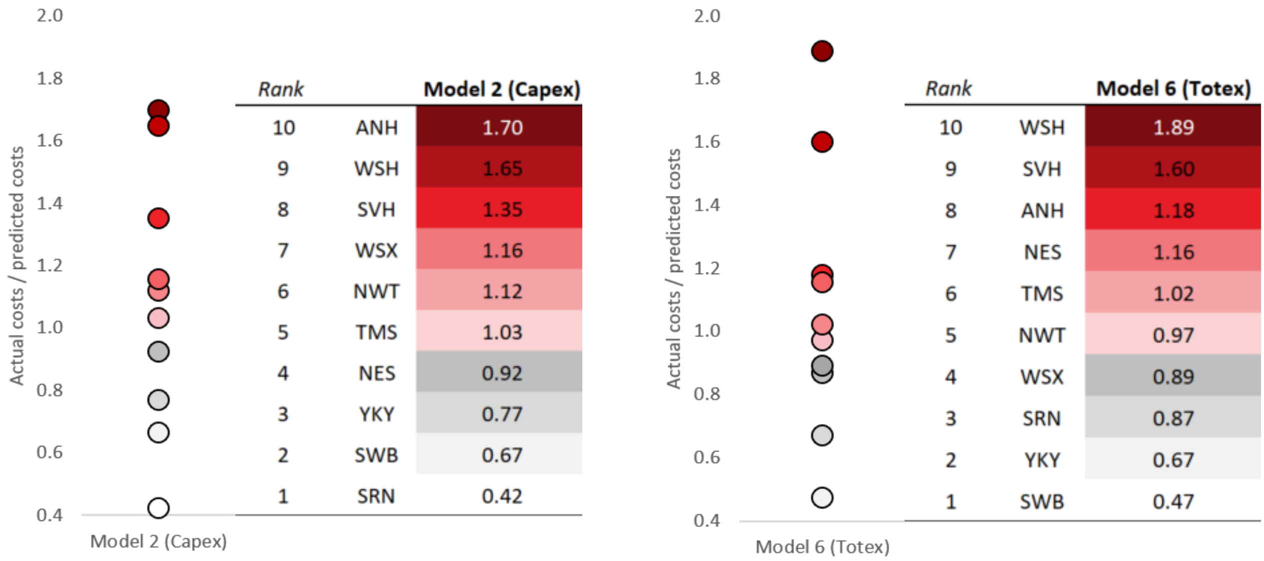
[17] A one thousand change in PE served by WwTWs is associated with a 0.16% (capex model 2) and 0.29% (totex model 6) increase in costs, everything else constant. A one percentage point increase in the proportion of load receiving tertiary treatment is associated with a 0.18% (capex model 2) and 0.11% (totex model 6) increase in costs, everything else unchanged.

- **Ratio between actual and predicted costs**. The actual vs. predicted costs ratios are important because if they showed too large a spread, this would indicate the model did not capture companies' costs well enough. In the preferred model specification for growth at WwTWs costs, the ratio between actual costs and predicted costs ranges between 0.4 to 1.7 in the 10-year capex model (model 2) and between 0.5 and 1.9 in the 4-year totex model (model 6). Companies' ranking remains fairly stable in both capex and totex models. Figure 9 plots these results.

  For comparison, at PR19 the corresponding ratios for the Phosphorus removal model ranged from 0.5 and 1.4. This suggests that the proposed models for growth at WwTWs may result in an appropriate range of actual vs. predicted costs ratios. Nevertheless, Ofwat may consider supplementing the econometric modelling with a cost adjustment claim process similar to that used at PR19. Through this process, companies that consider their unique circumstances to drive higher efficient costs can claim an adjustment on their allowances.

Figure 9: Ratio between actual and predicted costs for the growth at WwTWs model



Rank		Model 2 (Capex)
10	ANH	1.70
9	WSH	1.65
8	SVH	1.35
7	WSX	1.16
6	NWT	1.12
5	TMS	1.03
4	NES	0.92
3	YKY	0.77
2	SWB	0.67
1	SRN	0.42

Rank		Model 6 (Totex)
10	WSH	1.89
9	SVH	1.60
8	ANH	1.18
7	NES	1.16
6	TMS	1.02
5	NWT	0.97
4	WSX	0.89
3	SRN	0.87
2	YKY	0.67
1	SWB	0.47

Source: Arup analysis

5.5 Recommendations

Growth at WwTWs costs lend themselves to assessment separate from base costs through econometric models. Costs are fairly distributed across companies; they are sufficiently material and site-specific drivers are considered to be of less relevance.

The modelling results suggest that **an econometric model is a viable option for assessing growth at WwTWs cost at PR24**. The recommended econometric model should have the following characteristics:

- **Cumulative over a long time period**. By accumulating costs and drivers over a long time period, the model mitigates the lumpiness of costs data, making data more amenable to modelling.
- **'Change in PE served by WwTWs' and 'percentage of load receiving tertiary treatment' are key drivers**. Causal narratives identify 'change in PE' and 'treatment intensity' as two drivers of 'potential major importance', in addition to capacity headroom. Historical data Ofwat collects for 'PE' and for 'percentage of load receiving tertiary treatment' (variable measuring 'treatment intensity') performs well in explaining costs. Both drivers are readily available, outside company control and do not create perverse incentives to companies.
- **Additional drivers need to be balanced against the small sample size**. In a cumulative model, the number of observations is equal to the number of companies providing wastewater treatment services, currently 10. This limits the number of explanatory variables the model can accommodate while remaining statistically valid. Any additional drivers Ofwat may consider adding to this model should balance causal narratives against model validity and model simplicity. As discussed above, none of the drivers of 'potential minor importance' identified through causal narratives (i.e., 'size of treatment works' and 'change in volume of flow treated') proved capable of improving model robustness and their inclusion in the model would compromise the model's statistical validity.

Depending on the spread of the ratio between actual and predicted costs, Ofwat may want to consider **supplementing the econometric model with a cost adjustment claim process similar to that used at PR19.** Through this process, companies for which unique circumstances drive higher efficient costs can claim an adjustment to their modelled allowed costs. Evidence that Ofwat may consider requiring as part of the cost adjustment claim submission includes:

- Demonstration of the need for the upgrade, how it relates to any existing capacity headroom and assumed time horizon;
- Identification of the expected impacts of additional load in terms of type of treatment required (primary, secondary or tertiary);
- Description of the upgrade needed, including the assets and/or technological solutions chosen;
- Description of site-specific constraints that impact on upgrading costs, e.g. ground conditions; and
- Evidence that the higher costs claimed are efficient, e.g., through quotes from prospective bidders and, where applicable, evidence of industry benchmarking.

6. Sewer flooding

Costs to reduce the risk of sewer flooding to properties are expenditure for the purpose of enhancing the public sewerage system to reduce the risk to properties and external areas of flooding from sewers. It excludes expenditure with maintenance of asset capability. At PR19, this cost line was assessed with base costs. It was also considered part of a wide definition of growth-related costs.

In line with the approach followed for the previous cost lines, this section analyses whether sewer flooding is suitable for assessment separately from base costs, identifies plausible cost drivers based on causal narratives and tests whether robust econometric cost models can be found that reflect the causal narratives. It concludes by recommending assessment options for PR24.

6.1 Suitability for separate assessment

Table 12 summarises the performance of this cost line against the criteria for assessment separately from base costs set out in Section 2.2.

In sum, the suitability assessment suggests that keeping expenditure to reduce risks of sewer flooding as part of base may be appropriate, given the substantial interdependencies with capital maintenance and asset replacement (both part of base costs). Indeed, although the regulatory accounting guidelines explicitly state that expenditure with maintenance of asset capability should be excluded from this cost line, in practice (and from a technical point of view) expenditure on solving/preventing blockages improve overall asset capability, while also reducing the risks of sewer flooding, and there is a fine line separating the two.

However, separate assessment could be justified given the materiality of this cost line for most companies. Such high materiality can be an indication of hydraulic incapacity of the network to deal with legacy properties, as well as increased risks of sewer flooding to newer properties as a result of climate change. We elaborate more on this point and on the feasibility of separate assessment in the following sections.

Table 12: Suitability of risk of sewer flooding expenditure for separate assessment

	Criteria	Evidence	Assessment
1	**Materiality**	• Industry-level cumulative expenditure reached £1,515m (2017-18 prices) over the 10-year period ending in 2020-21. • This was equivalent to 4% of industry-level cumulative base costs over the same period. Sewer flooding is the most material line in scope for this work. • At company level, materiality over the 10-year period ending in 2020-21 was at or above 5% of base costs for half of the companies: NES (11%) and SVH (6%), NWT (5%), TMS (5%) and WSX (5%). Materiality is less than 2% only for ANH.	**Sufficiently material** to justify separate assessment. **Materiality is significant for most companies**, representing at least 5% of base costs for half of the companies.

	Criteria	Evidence	Assessment
2	**Relevance of site/scheme specific drivers**	• The most important site-specific factor is the location of properties and local weather patterns, which impact the extent to which properties are at risk. However, these factors should be possible to measure at company level, provided information is available.	**Localised factors (rainfall and properties at risk) should be measurable at company level** and usable for separate assessment as well as for combined assessment, provided data are available.
3	**Complementarities with base costs**	• Build-up of waste in the network, both flushable and 'non flushable', contributes to sewer flooding risks. This is largely addressable through maintenance and prevention interventions (base costs). • Synergies also exist with asset replacement (base costs) as older assets and assets in poorer conditions are likely to be more prone to blockages. • Up to 2016-17, opex related to risk of sewer flooding was reported as part of base costs. However, this is likely to create an immaterial distortion as opex has accounted for only 1% of industry-level capex since 2017-18, when opex data was available.	**Substantial synergies with maintenance and asset replacement** suggest combining assessment with base costs may be justifiable.
4	**Change in reporting/allocation practices**	• No substantial changes made to the RAGs throughout the sample period from 2011-12 to 2020-21. • RAGs explicitly exclude maintenance of asset capability from this cost line.	**Separate assessment not compromised** by substantial changes**.**

Source: Arup analysis.

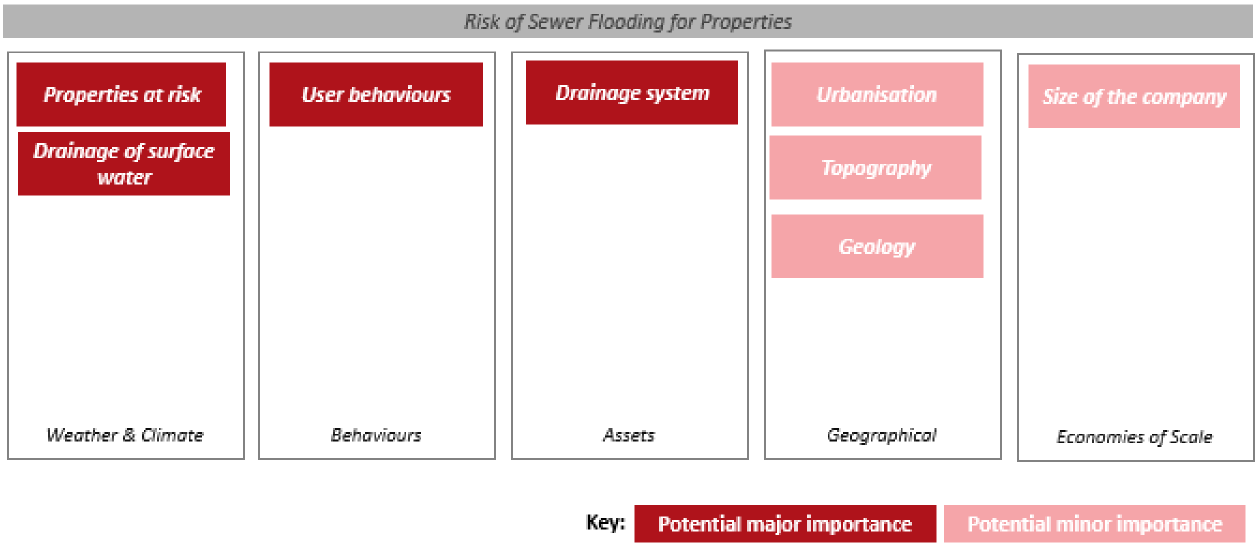
Notes: Appendix A.4 presents the detailed data analysis supporting the evidence summarised in this table. SVH represents the combined spend of SVE and HDD.

Key:	Supports separate assessment	Does not support separate assessment	Neutral

6.2 Causal narratives of potential cost drivers

An analysis of causal narratives has identified multiple plausible drivers determining water companies' expenditure to reduce the risk of sewer flooding to properties. These are identified in Figure 10. Similarly to the approach followed in previous lines, all drivers identified are, to a large extent, outside companies' control and minimise risks of perverse incentives to companies. The causal analysis is at company level, as opposed to site level, to align with Ofwat data collection and cost assessment practices.

Figure 10: Plausible drivers of expenditure to reduce the risk of sewer flooding to properties according to engineering rationale



Source: Arup analysis

Table 13 sets out how each plausible driver affects expenditure to reduce the risk of sewer flooding to properties through causal narratives. It also lists the variables to measure such drivers and sources of readily available data.

Table 13: Causal narratives for drivers of spending in reducing risk of sewer flooding to properties

Driver	Causal narratives	Variables	Data sets	Key
Properties at risk	Water companies with high number of properties at risk of internal sewer flooding issues will require greater expenditure in improving the hydraulic adequacy of their infrastructure to reduce such risk. Properties at risk of sewer flooding include legacy properties, i.e., properties built in locations with greater risk of sewer flooding but also newer properties that, while built in accordance with new and more stringent planning permits, may become at risk of sewer flooding as a result of climate change. A larger number of properties at risk is expected to be associated with greater costs.	None found readily available as a direct measure. Total number of connected properties (indirect measure).	None found readily available for a direct measure. Ofwat data for the indirect measure.	Major
Drainage of surface water	Urban areas with significant surface water run off face a higher risk of experiencing flooding incidents due to greater pressure placed upon the sewerage system.	Urban rainfall run off.	Arup-Vivid Economics variable.[18]	Major

[18] Arup-Vivid Economics, 'Use of econometric models for cost assessment at PR19', 2018. United Utilities kindly provided the data updated as of 2020-21 which we used in this work. We reviewed the data and conducted independent quality checks to ensure consistency with the methodology set out in the Arup-Vivid Economics report in 2018.

Driver	Causal narratives	Variables	Data sets	Key
User behaviours	Sewer blockages can occur when there is a build-up of waste (e.g, foreign objects, tree leaves), both flushable and 'non flushable', entering the sewers. Fats, oils and grease released in sewers from households and Food Service Establishments (FSEs) could aggregate and solidify within the wastewater network. Customer behaviour education, regular maintenance and inspection of the wastewater network could prevent blockages, hence there are significant synergies with base costs. We note that it is illegal to discharge fats, oil and grease to the sewer. Companies can investigate cases where sewer misuse has been identified and run awareness campaigns to educate customers, hence this driver is under company management control, to some extent.	None found readily available as a direct measure. Number of food and service establishments per km of sewer (indirect measure). Population density (indirect measure).	None found readily available for a direct measure. Public Health England (FSEs; indirect measure). Ofwat data (population density; direct measure.)	Major
Drainage system	Combined sewers are more susceptible to flooding than separate systems, particularly for internal flooding, as both the storm and foul flows are carried in the same pipe. We expect a greater proportion of combined sewers in the network to be associated with greater spending to reduce risk of sewer flooding.	Combined sewers.	Ofwat data.	Major
Urbanisation	Reducing the risk of flooding within a densely populated area leads to higher construction costs and, thereby, higher expenditure due to a combination of factors. These include complexity of the network of existing buried services/utilities in urban areas, reinstatement requirements, traffic management during construction and higher labour costs. Sparsely populated areas could also result in higher costs through longer travelling distances. Higher costs are expected to be associated with sparsely populated areas (i.e., low population density) and also with very densely populated areas (i.e., high population density).	Population density combined with population density squared; properties per km of sewer.	Ofwat data; ONS population.	Minor
Topography	Areas with limited potential for surface water to drain to watercourses by gravity could increase the risk of flooding to properties. Runoff from higher ground can exacerbate these problems.	Pumping capacity per km of sewer.	Ofwat data.	Minor

Driver	Causal narratives	Variables	Data sets	Key
	Additional pumping is expected to be associated with greater costs.			
Geology	Sewers are vulnerable to groundwater ingress forced through cracks in the access chambers or the pipes themselves. Geology and groundwater levels could reduce the capacity of below ground wastewater systems and result in additional expenditure to mitigate the risk of sewer flooding to properties.	None found readily available.	None found readily available.	Minor
Size of the company	Costs increase with company size but at a decreasing pace as a result of economies of scale at company level through, for example, more efficient procurement. Therefore, larger companies are expected to have proportionally lower costs.	Indirectly accounted for through total number of properties connected.	Ofwat data	Minor

Source: Arup analysis

Key: Potential major importance | Potential minor importance | Suitable variable not readily available

6.3 Model testing

We tested whether a robust econometric model which reflects the causal narratives linking sewer flooding costs with plausible drivers exists through the modelling approach described in Section 2.3.

Table 14 shows the results for the model suites with greater robustness: the 10-year cumulative capex models (models 1 to 5) and the 4-year cumulative totex models (models 6 to 10). The results for the less robust year-on-year models are in Appendix C.4.

In the absence of a variable measuring the number of properties at risk, the models tested 'total number of properties connected' as an indirect measure of properties at risk. Admittedly, this is a poor measure as it implicitly assumes that the proportion of existing properties that are at risk of sewer flooding is the same for all companies, which is a very strong assumption. We elaborate on the implications and possible mitigations for this as part of the recommendations.

'User behaviours', of both households and businesses, can lead to the build-up of other flushable and non-flushable objects in the network (e.g, foreign objects, tree leaves, fats, oils and grease), which increase the risk of blockages and, thereby, the risk of sewer flooding to properties. A direct measure of user behaviours that is exogenous, i.e., outside management control, was not found to be readily available.[19] We tested the readily available indirect measure 'number of food service establishments per km of sewer'

[19] A direct measure of user behaviours would be the number of sewer blockages, but this was discarded because it would drive perverse incentives and it is, to some extent, under company control through maintenance and preventive inspection.

instead. Admittedly, this is an imperfect measure as it captures only one type of user behaviour, businesses, while it fails to capture household behaviours.

Some of the models discussed here use four drivers and the constant with a sample of 10 observations. This results in overfitting and, therefore, unreliable predictive power. Nevertheless, these models are presented to draw findings in terms of drivers' significance.

Table 14: Risk of sewer flooding modelling results

	10-year capex cumulative (2011-12 to 2020-21)				4-year totex cumulative (2017-18 to 2020-21)			
Variable name	1	2	3	4	5	6	7	8
Connected properties (ln)	0.867	0.686	0.885	0.905	0.836	0.771	1.409	1.372
Food service establishments per km of sewer		11.72	7.627	7.657		4.185	-8.883	-6.534
Combined sewers (%)			0.0136	0.00895			0.0435	0.0212
Urban rainfall per km (million m^3 / km)				43.09				165.0
Constant	-1.832	-1.502	-3.493	-4.094	-2.771	-2.655	-9.047	-10.42
Dependent variable	RSF capex (ln)	RSF capex (ln)	RSF capex (ln)	RSF capex (ln)	RSF totex (ln)	RSF totex (ln)	RSF totex (ln)	RSF totex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	10	10	10	10	10	10	10	10
R^2	56%	67%	69%	70%	34%	35%	49%	63%
RESET test	Pass	Pass	Pass	Pass	Fail	Fail	Pass	Pass
VIF score (mean)	1.0	1.2	2.3	2.2	1.0	1.2	2.3	2.3

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis.

Note: RSF capex (ln) = Risk of sewer flooding capex, logarithmic scale. Note: RSF totex (ln) = Risk of sewer flooding totex, logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

6.4 Model assessment

The modelling results for the 10-year cumulative capex and 4-year cumulative totex are insufficiently robust to suggest that a separate econometric model is an option to assess sewer flooding expenditure at PR24.[20] This is largely a result of two factors:

- **The model specification aligned with the drivers of 'potential major importance' has unreliable predictive power and the estimated coefficients are insignificant for all but one driver**. Model 4 (10-year cumulative capex) and model 8 (4-year cumulative totex) test a combination of variables that measure each of the drivers of 'potential major importance' identified through causal narratives: 'properties at risk' (measured by 'total connected properties'), 'user behaviours' (measured by 'number of FSEs per km of sewer'), 'drainage system' (measured by the 'percentage of combined sewers') and 'drainage of surface water' (measured by 'volume of urban rainfall per km of sewer').[21] These models show:
    - Overfitting, which makes these models statistically unreliable. Model 4 (10-year cumulative capex) and model 8 (4-year cumulative totex) include four drivers and a constant with a sample size of only 10 observations. Although this results in overfitting and, therefore, unreliable predictive power, these are presented to draw findings in terms of drivers' significance.
    - Unreliable predictive power. Although the R^2 is relatively high at 70% (10-year cumulative capex) and 63% (4-year cumulative totex), this predictive power is unreliable as it is largely a reflection of model overspecification.
    - The estimated coefficient for total number of connected properties (indirect measure of properties at risk) is statistically significant, of the expected positive sign and has a plausible magnitude.[22]
    - Estimated coefficients for the remaining drivers of 'potential major importance' are statistically insignificant, although they all have the expected positive sign, at least in the 10-year cumulative capex model.
- **Unit cost econometric model is a promising approach, provided a suitable variable measuring the number of properties at risk is found**. A suitable variable would be one that measures the number of properties at risk of sewer flooding as a result of hydraulic inadequacy of the network to account for:
    - Volume and risk of rainfall, including impacts of climate change; and
    - Location of properties, both legacy properties at risk and new properties that may become at risk as a result of more intense storms caused by climate

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[20] The results using year-on-year data, presented in Appendix C.4, show even poorer model robustness.

[21] In addition to testing the drivers of 'major significance' our modelling also tested the two drivers of 'minor significance' for which variables are readily available: population density, as a measure for urbanisation, and pumping capacity, as a measure of topography. The results did not improve model robustness.

[22] A one percent increase in the total number of properties connected is associated with between 0.9% (10-years cumulative capex) and 1.3% (4-year cumulative totex) increase in expenditure in reducing sewer flooding risk for properties.

change.

To the best of our knowledge, such a variable is currently not readily available and it is outside the scope of this study to develop one. The number of total connected properties is admittedly a poor indirect measure of properties at risk as a result of hydraulic inadequacy of the network for two reasons. Firstly, because it implicitly assumes the same proportion of properties at risk across all companies. Secondly, because the 'total number of properties connected' account for factors other than properties at risk, namely scale of the company and, to some extent, population growth.

Nevertheless, the modelling results, using 'total connected properties' as an indirect measure of properties at risk, suggest that a standalone unit cost econometric model with a suitable variable for properties at risk is a promising approach. Indeed, the modelling results in Table 14 show that a unit cost econometric model (model 1) has a promising predictive power, with an R^2 of 56% in the 10-year cumulative model.

6.5 Recommendations

Expenditure in reducing the risk of sewer flooding to properties is the most material line in scope for this work. In the 10 years ending in 2020-21, it was equivalent to 4% of the industry level base costs. Half of the companies reported expenditure against this line equivalent to at least 5% of their base costs in the 10 years ending in 2020-21. On materiality grounds, there is a case for considering assessing this cost line separately from base costs at PR24.

However, standalone econometric models based on data available are insufficiently robust. This is likely a reflection of the combination of factors affecting costs with sewer flooding. Indeed, the causal narratives indicate that costs to reduce risk of sewer flooding to properties are driven by a combination of the following factors:

1. **Synergies with base costs.** Customer behaviour and education, regular inspection and maintenance of the network prevent blockages and, thereby, reduce the risk of sewer flooding. These factors have substantial synergies with regular capital maintenance, which is part of base costs. Synergies with base costs also exist through asset replacement, as older assets and assets in poorer condition are more prone to blockages.

2. **Number of properties that are at risk of sewer flooding, as a result of hydraulic inadequacy of the network** to account for volume and severity of rainfall and location of properties (more on these below).

   A proper assessment of the efficient level of expenditure required for reducing the risk of sewer flooding to properties would require knowing how many properties are at risk and the severity of such risk. To the best of our knowledge, such information is not readily available.

The synergies between costs to reduce risk of sewer flooding to properties and base costs combined with the absence of a suitable variable measuring the number of properties at risk suggest the following options for assessing this cost line at PR24:

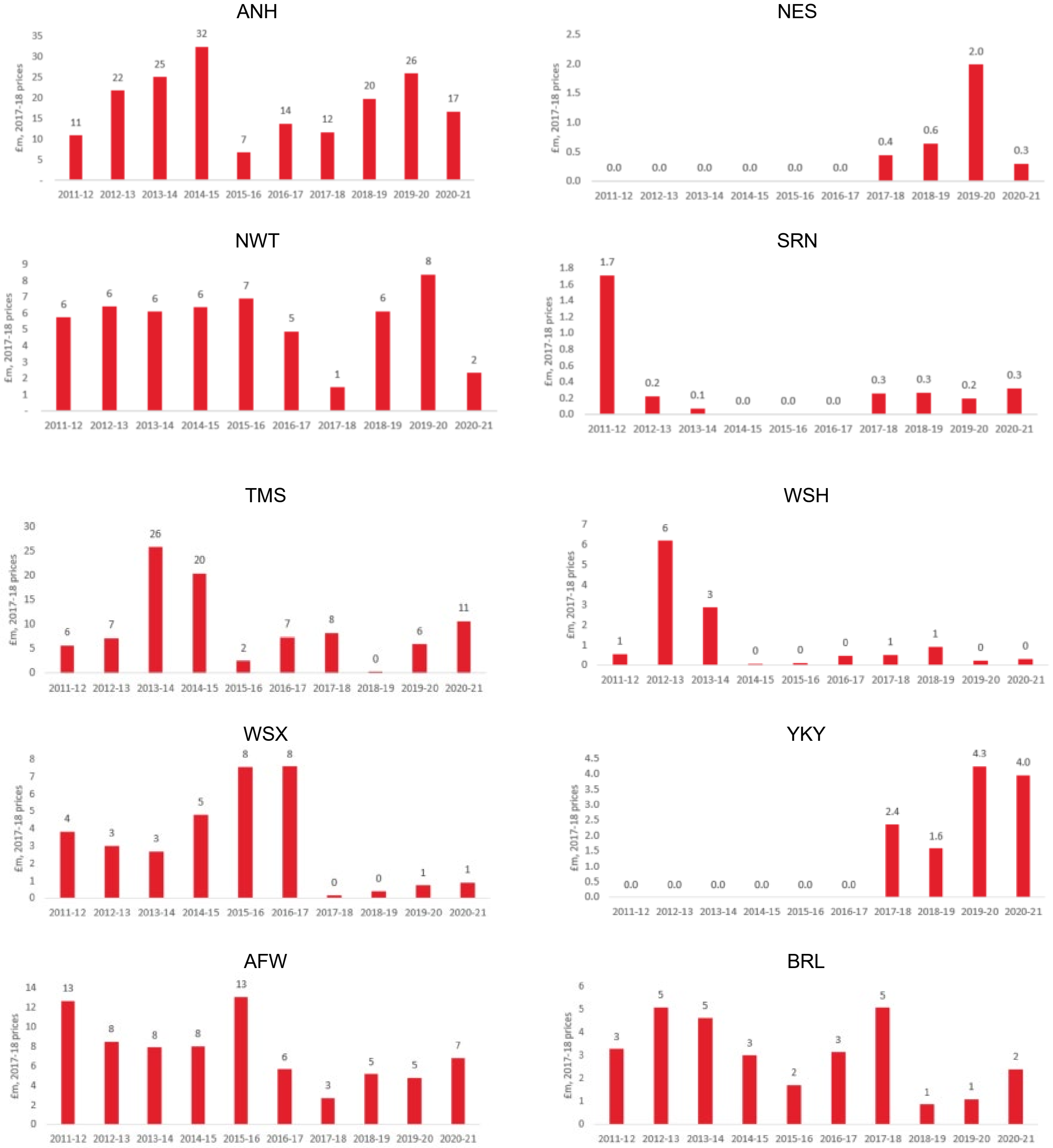
- **Option 1: keep sewer flooding costs with base costs and consider testing a drainage driver as part of the base cost models**. This may be appropriate considering the substantial synergies with base costs. Base costs already account for a number of drivers of sewer flooding as identified through causal narratives, including:
  - ‘Total number of properties connected’, which causal narrative and modelling results suggest being an important, albeit imperfect, indirect measure for ‘properties at risk’;
  - ‘Population density’, as a measure of ‘urbanisation’; and
  - ‘Pumping capacity per length of sewers’, which is a measure for ‘topography’.

  However, base costs lack drainage of surface water, which causal analysis has identified as a driver of ‘potential major significance’, hence the recommendation to consider testing a drainage driver as part of the base cost models. Surface water runoff is arguably also a driver for greater maintenance and inspection of the network and, thereby, a driver that captures many of the synergies between reducing risk of sewer flooding to properties and base costs.
- **Option 2, appropriate if a suitable variable for quantifying the number of properties at risk is found:**
  - Work with the industry (e.g., through DWMPs) to develop a suitable variable for quantifying properties at risk of sewer flooding as a result of hydraulic inadequacy of the network. Such variable should account for the following factors, all of which are outside management control:
    - Volume and severity of rainfall, including impacts of more intense storms caused by climate change; and
    - Location of properties. This needs to consider legacy properties at risk of sewer flooding because they were built under less stringent planning standards. It also needs to include newer properties which, whilst built in accordance with new and more stringent planning permits, may become at risk of sewer flooding as a result of more intense storms caused by climate change.
  - Separate assessment of sewer flooding costs, based on a unit cost model with properties at risk as a driver.
  - Consider testing drainage driver as part of base cost models to account for synergies with base costs.

Appendix A - Cost data

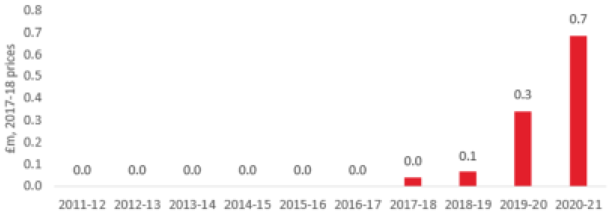
A.1 – Water network reinforcement

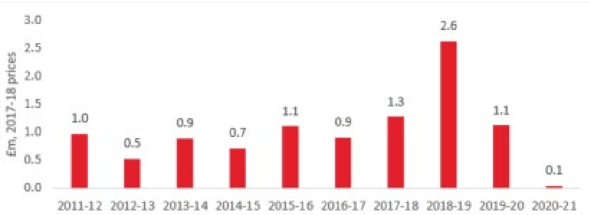
Figure 11: Water network reinforcement - Capex by company, 2011-12 to 2020-21



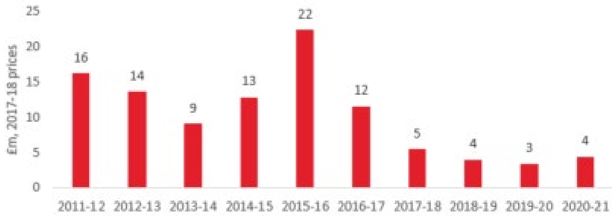
PRT

SES

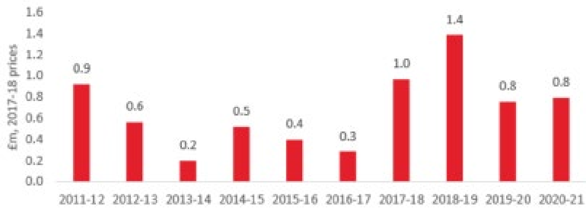




SEW

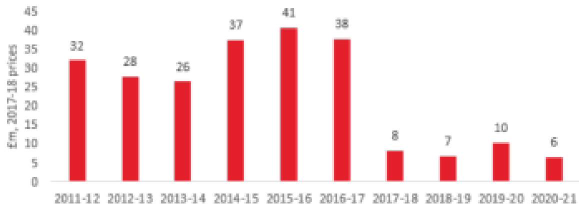


SSC



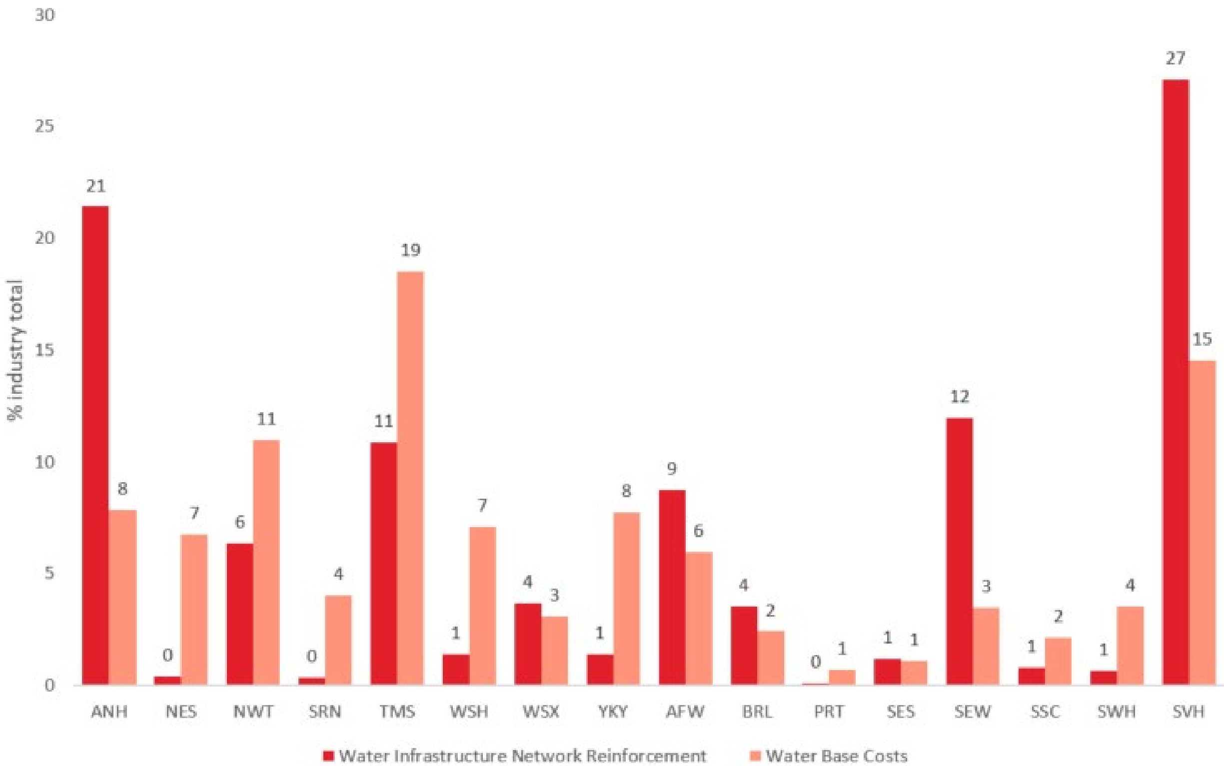
SWH = SWT+BWH+SWB

SVH = SVT+DVW+SVE+HDD



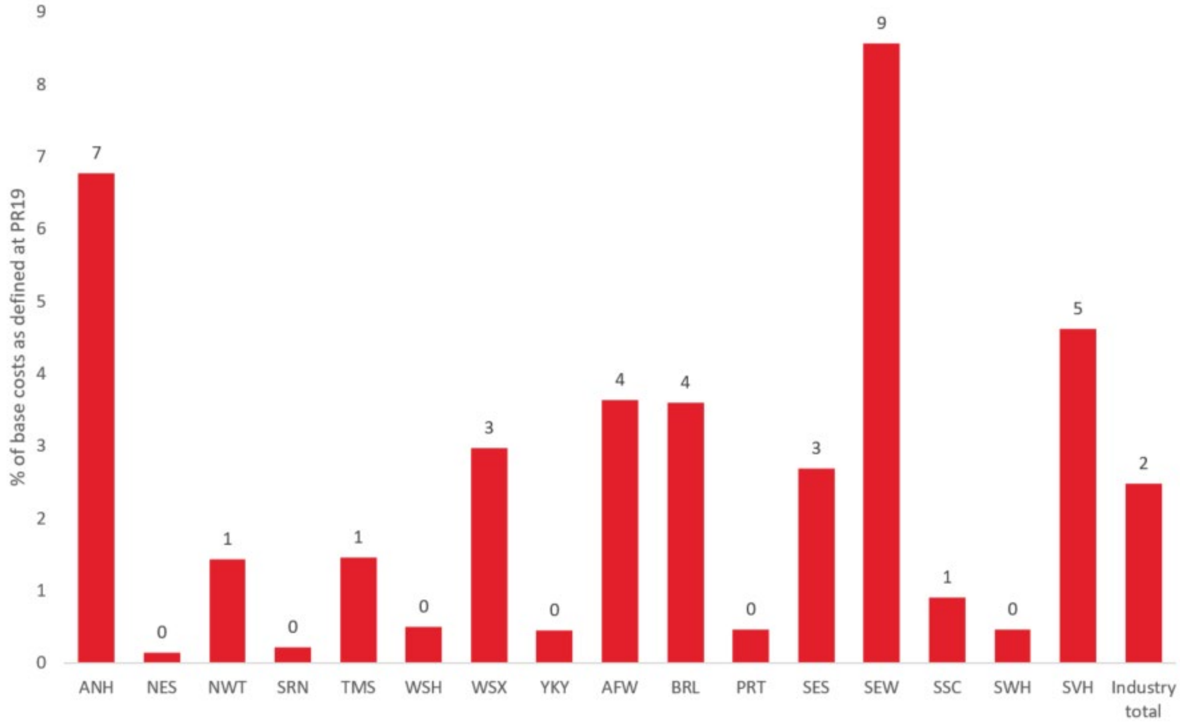
Source: Arup analysis of data provided by Ofwat
Notes: SWH = SWT+BWH+SWB for all years. SVH = SVT+DVW+SVE+HDD up to and including 2017-18. For 2018-19, 2019-20 and 2020-21 SVH = SVE+HDD (to avoid double counting).

Figure 12: Water network reinforcement – Capex share of industry total by company, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

Figure 13: Water network reinforcement – Capex as a percentage of companies' base costs, 2011-12 to 2020-21

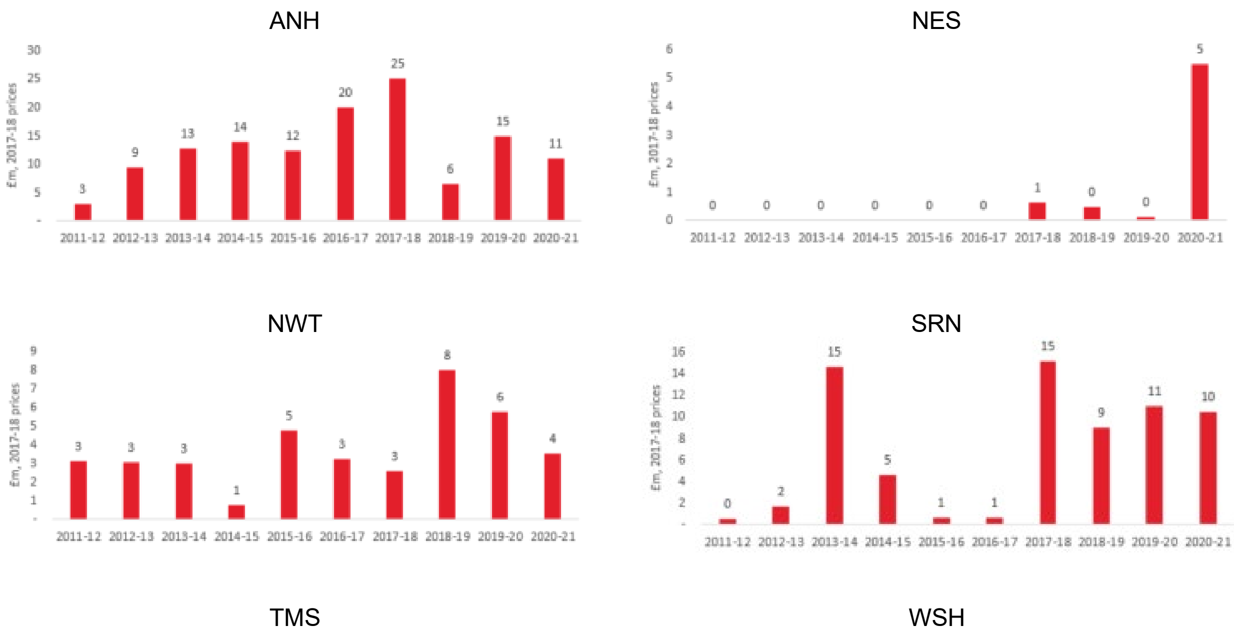


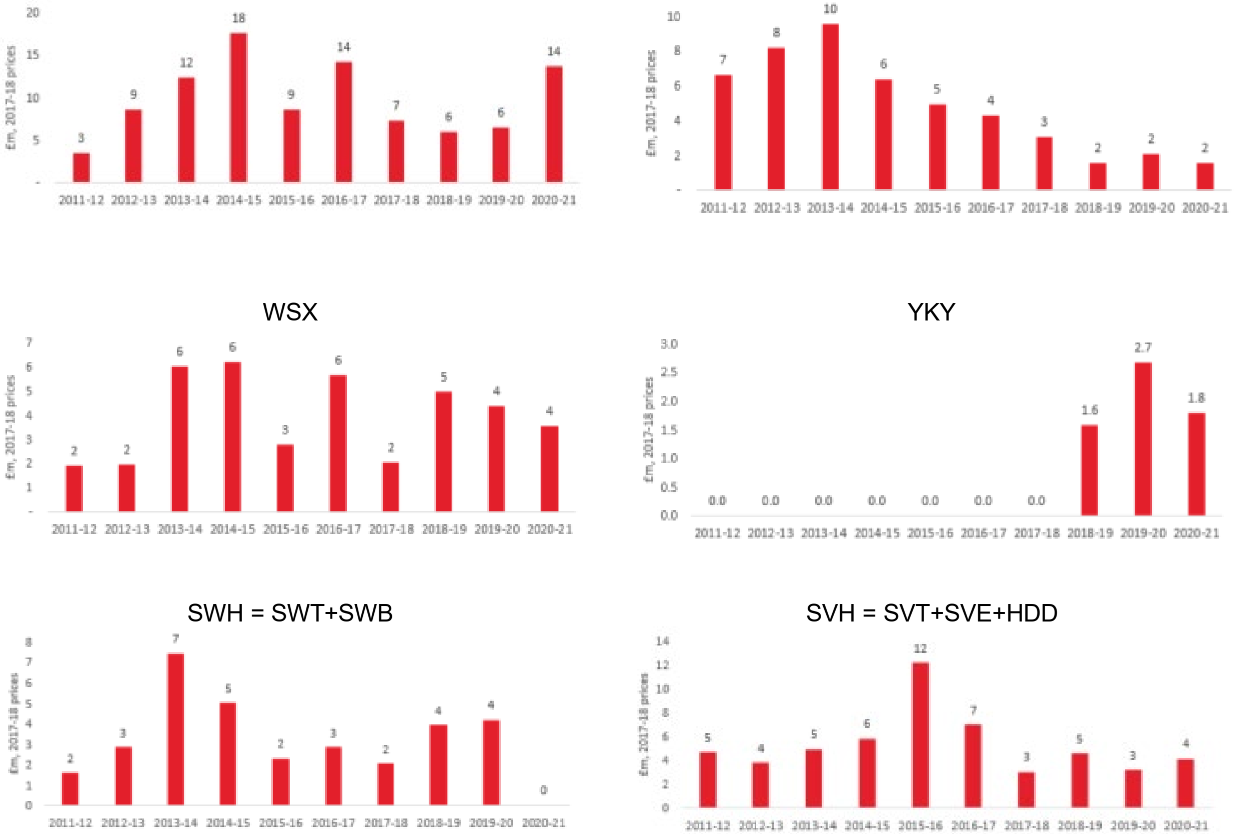
Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.

Source: Arup analysis of data provided by Ofwat

A.2 – Wastewater network reinforcement

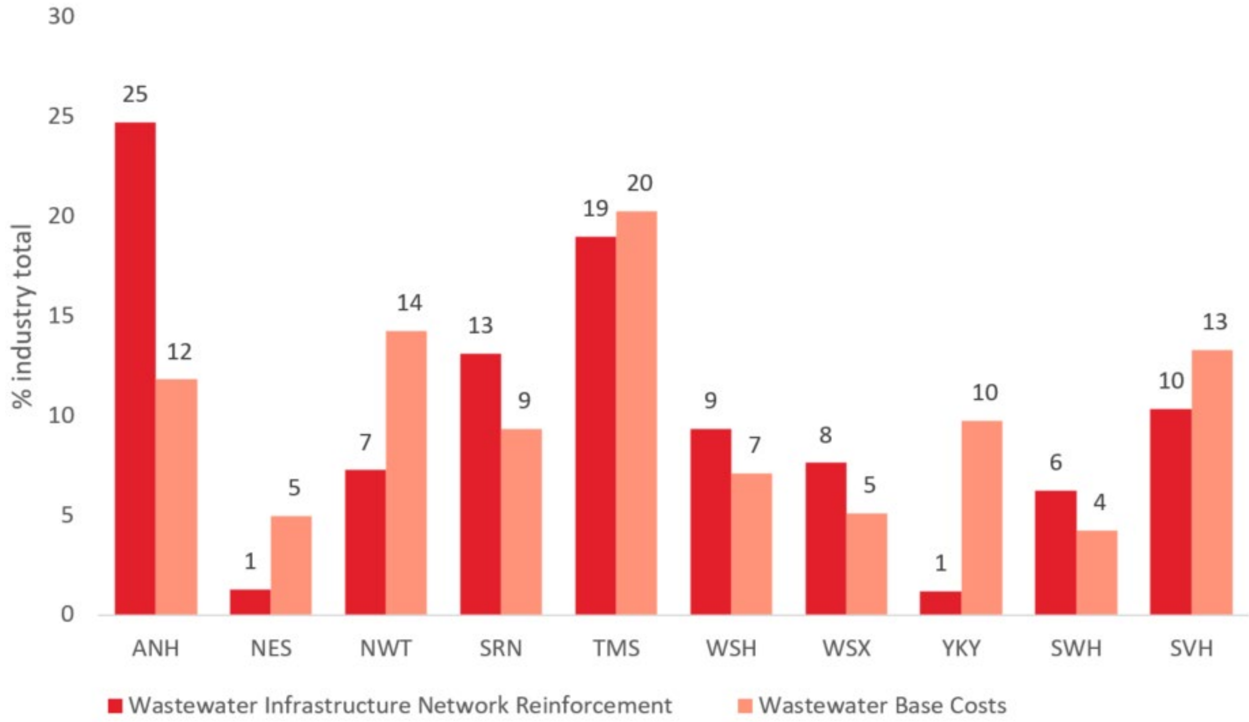
Figure 14: Wastewater network reinforcement – Capex by company, 2011-12 to 2020-21





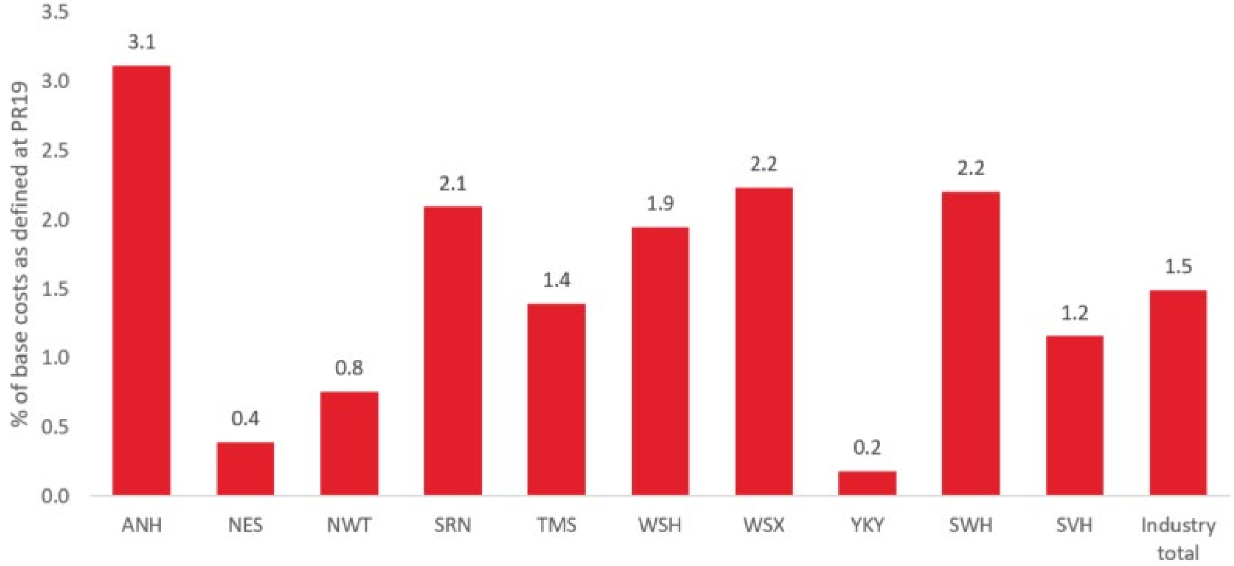
Source: Arup analysis of data provided by Ofwat
Note: SWH = SWT+SWB for all years; and SVH = SVT+SVE+HDD up to and including 2017-18. For 2018-19, 2019-20 and 2020-21 growth capex is SVH = SVE+HDD (to avoid double counting).

Figure 15: Wastewater network reinforcement – Capex share of industry total by company, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

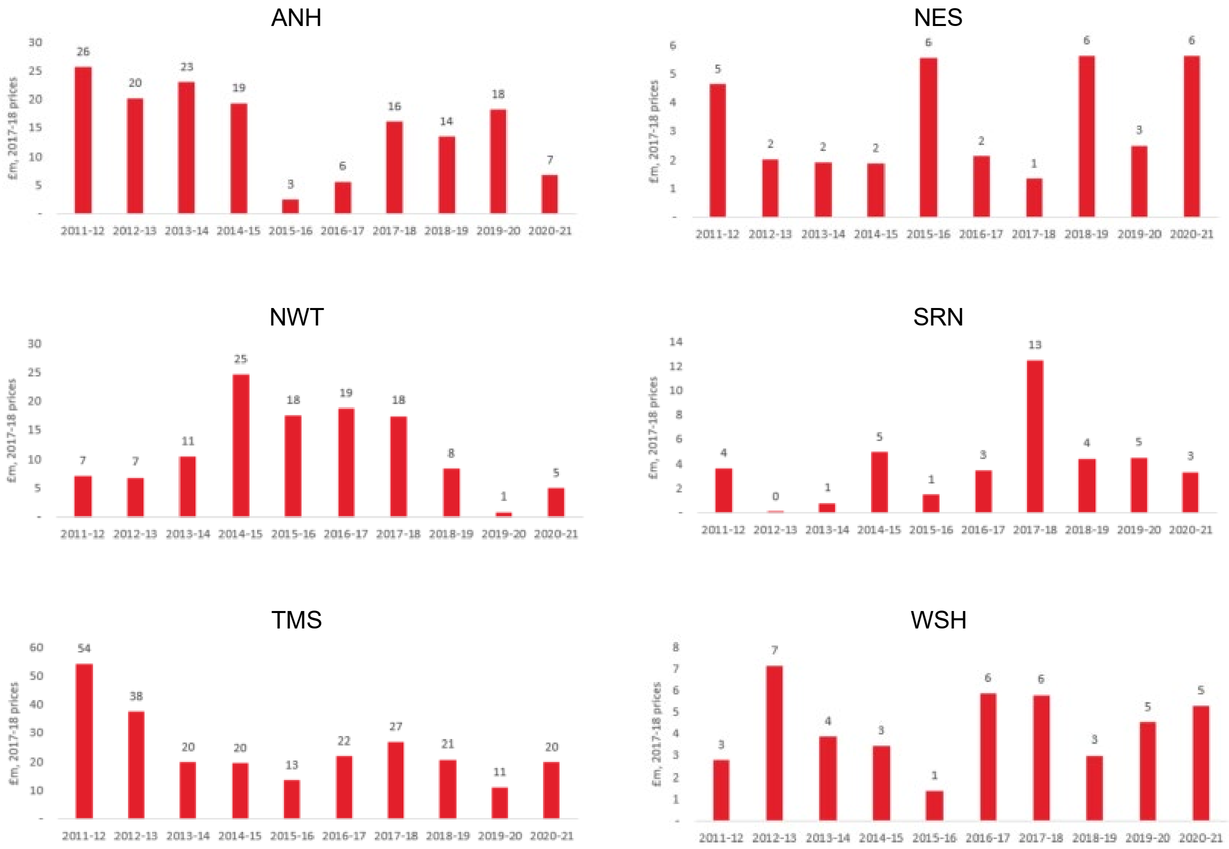
Figure 16: Wastewater network reinforcement – Capex as a percentage companies' base costs, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

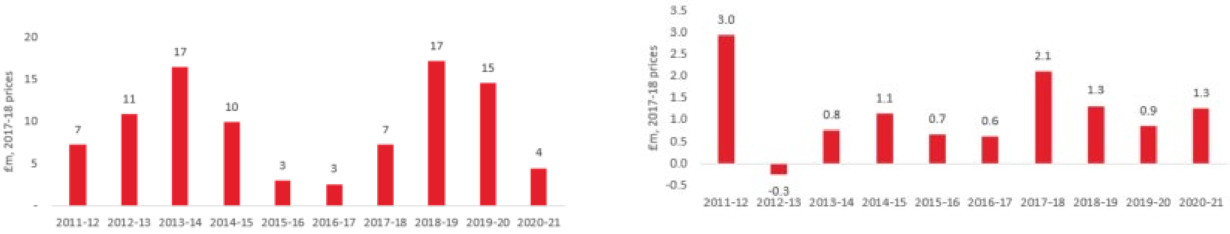
A.3 – Growth at wastewater treatment works

Figure 17: Growth at wastewater treatment works – Capex by company, 2011-12 to 2020-21



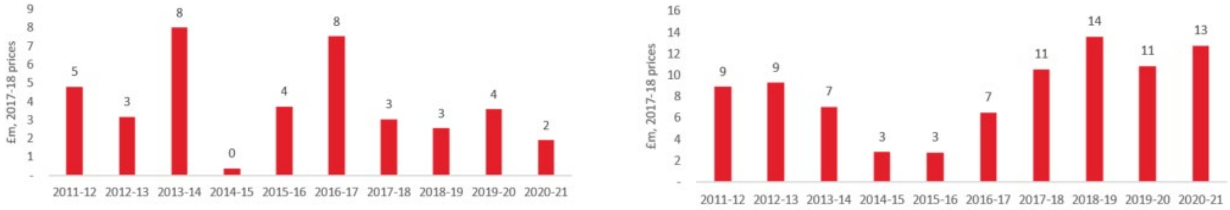
WSX

YKY



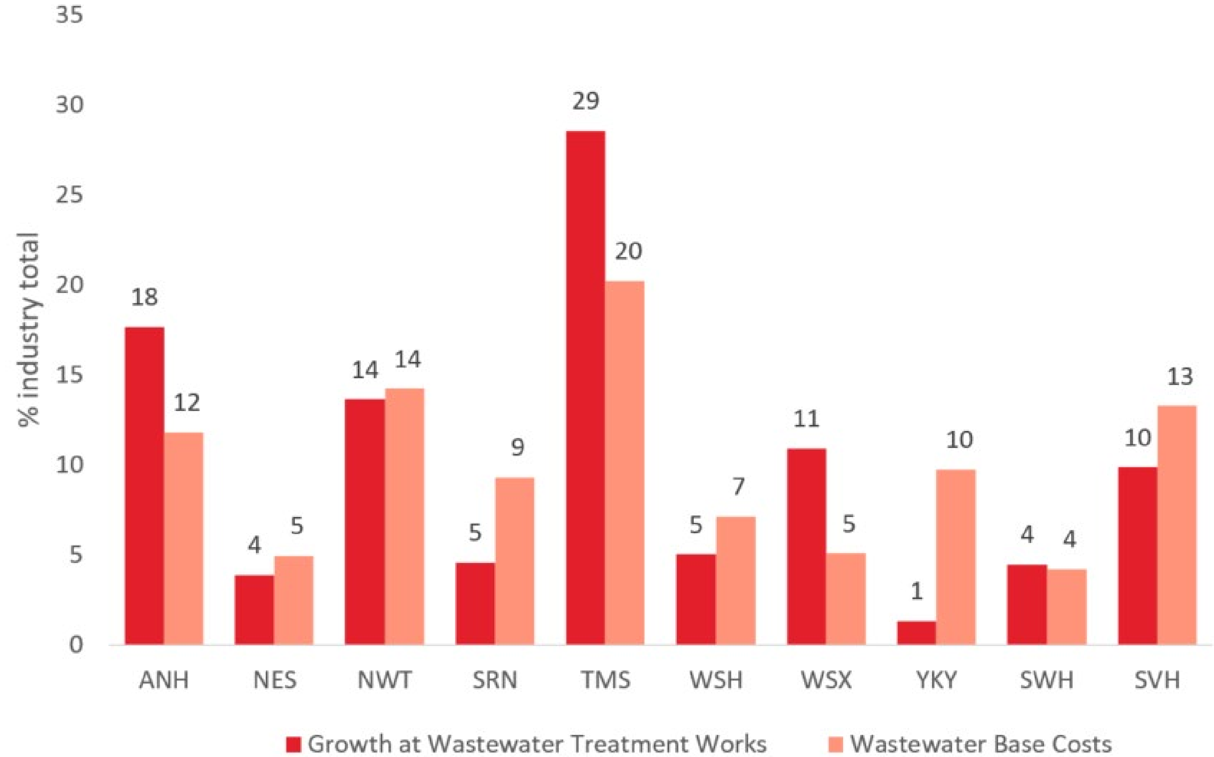
SWH = SWT+SWB

SVH=SVT+SVE+HDD



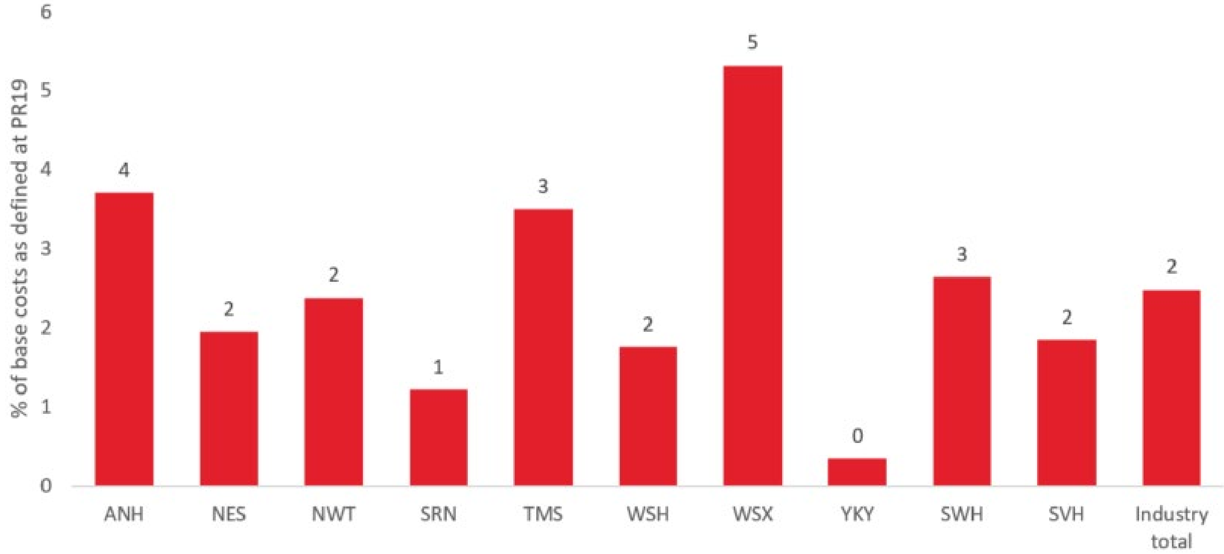
Note: SWH = SWT+SWB for all years; and SVH = SVT+SVE+HDD up to and including 2016-17. For 2017-18, 2018-19, 2019-20 and 2020-21 growth capex is SVH = SVE+HDD (to avoid double counting).
Source: Arup analysis of data provided by Ofwat

Figure 18: Growth at wastewater treatment works – Capex share of industry total by company, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

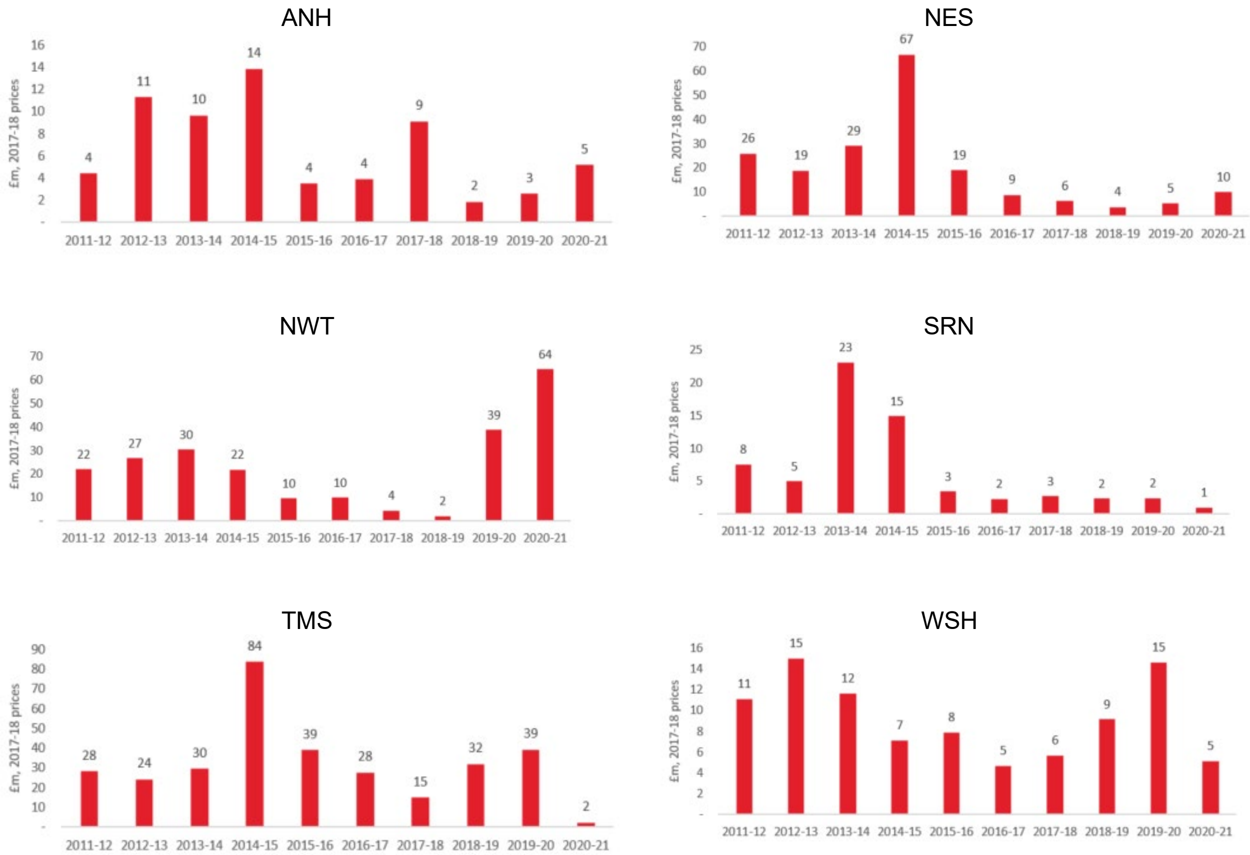
Figure 19: Growth at wastewater treatment works – Capex as a percentage companies' base costs, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

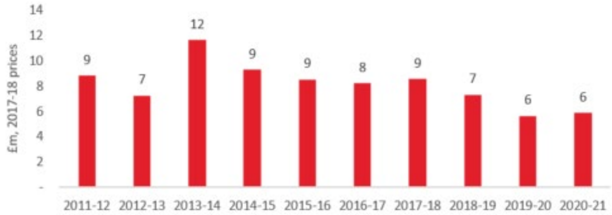
A.4 – Reducing risk of sewer flooding to properties

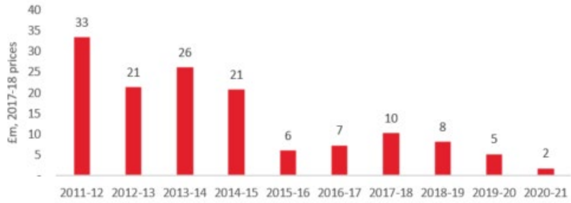
Figure 20: Reducing risk of sewer flooding – Capex by company, 2011-12 to 2020-21



WSX

YKY



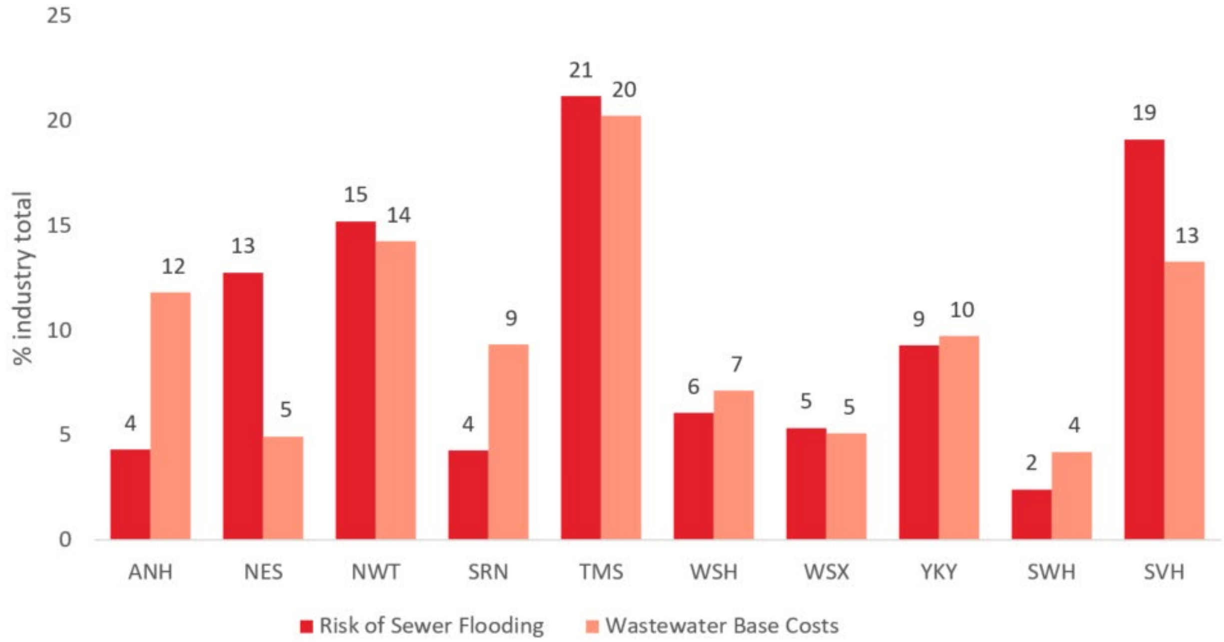


SWH = SWT+SWB

SVH = SVT+SVE+HDD

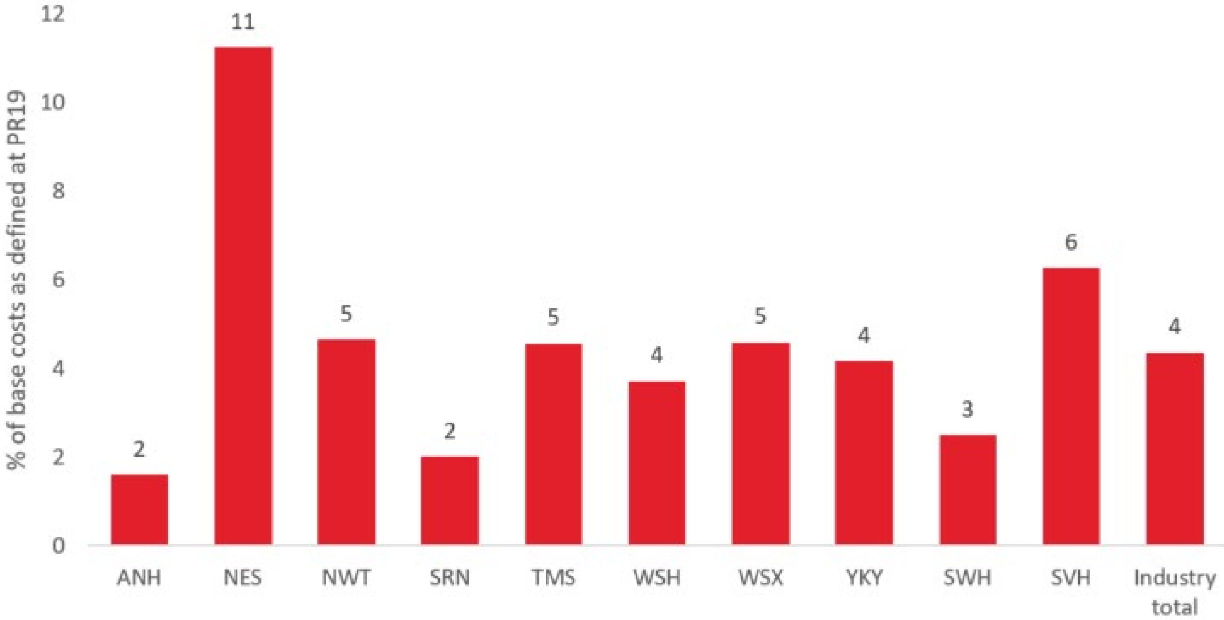
Note: SWH = SWT+SWB for all years; and SVH = SVT+SVE+HDD up to and including 2016-17. For 2017-18, 2018-19, 2019-20 and 2020-21 growth capex is SVH = SVE+HDD (to avoid double counting).
Source: Arup analysis of data provided by Ofwat

Figure 21: Reducing risk of sewer flooding – Capex share of industry total by company, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

Figure 22: Risk of sewer flooding – Capex as a percentage of companies' base costs, 2011-12 to 2020-21



Note: SWH = SWT+BWH+SWB for all years; and SVH = SVT+DVW+SVE+HDD.
Source: Arup analysis of data provided by Ofwat

Appendix B – Additional drivers considered

Table 15: Growth-related water network reinforcement costs: additional drivers considered

Driver	Causal narratives	Variables	Why not taken forward
New industrial and commercial sites	Increase in business demand and activity (e.g. industrial and commercial developments), beyond what can be accommodated within the system headroom, requires reinforcement of the water network assets and, therefore, is associated with an increase in spending. The change in business demand pattern of existing customers is expected to follow the economic cycle with capacity headroom expanding in an economic downturn and decreasing an economic upturn.	New non-household properties connected, measured business water demand.	This driver is now captured under 'change in volume of water carried in the network'.

Table 16: Growth-related wastewater network reinforcement costs: additional drivers considered

Driver	Causal narratives	Variables	Why not taken forward
New industrial and commercial sites	Increase in business demand and activity (e.g. industrial and commercial developments), beyond what can be accommodated within the system headroom, requires reinforcement of the wastewater network assets and, therefore, is associated with increase in spending. The change in business demand pattern of existing customers is expected to follow the economic cycle with capacity headroom expanding in an economic downturn and decreasing an economic upturn.	New non-household properties connected, measured business water demand.	This driver is now captured under 'change in volume of wastewater conveyed through the network'.
Land use	Land use impacts on the run-off coefficient, which is linked to the surface water volumes entering combined systems of the wastewater network.	None found readily available for a direct proxy	In assessing the impact of growth on wastewater networks, we assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-related surface water on network reinforcement is not considered to be an important driver.
Drainage of surface water	Urban areas with higher rainfall are likely to result in greater surface water volumes that need to be conveyed through the combined systems of wastewater networks.	Urban run-off	In assessing the impact of growth on wastewater networks, we assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-

Driver	Causal narratives	Variables	Why not taken forward
			related surface water on network reinforcement is not considered to be an important driver.

Table 17: Growth at WwTWs: additional drivers considered

Driver	Causal narratives	Variables	Why not taken forward?
Planning standards	New developments are likely to include Integrated water management (IWM) features to reduce water use at customers' taps and, thereby, the volume of wastewater to be conveyed through the network. This is achieved through the deployment of water efficient devices and greywater reuse systems. Retrofits within existing households will also have the same impact. Similar to PCC, planning standards partially offset the expenditure needed to accommodate population and business growth. Planning standards are expected to be associated with less spending in wastewater network reinforcement.	None found readily available for a direct proxy	In assessing the impact of growth on wastewater treatment works, we assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-related surface water on wastewater treatment is not considered to be an important driver.
Land use	Land use impacts on the run-off coefficient, which is linked to the surface water volumes entering combined systems of the wastewater network.	None found readily available for a direct proxy	In assessing the impact of growth on wastewater treatment works, we assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-related surface water on wastewater treatment is not considered to be an important driver.
Drainage of surface water	Urban areas with higher rainfall are likely to result in greater surface water volumes that need to be treated at WwTWs.	Urban run-off	In assessing the impact of growth on wastewater treatment works, we assumed that in new developments surface water is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of growth-related surface water on wastewater treatment is not considered to be an important driver.

Table 18: Risk of sewer flooding for properties: additional drivers considered

Driver	Causal narratives	Variables	Why not taken forward?
Land use	Land use impacts on the run-off coefficient, which increases the risk of sewer flooding due to greater volumes of surface water entering combined systems of the wastewater system.	None found readily available for a direct proxy	In assessing the impact of land use on the risk of sewer flooding for properties, we assumed that changes in land use and surface water run-off is managed at source, using SuDS/NBS, in line with best practice. Hence, the impact of land use on the risk of sewer flooding for properties is not considered to be an important driver.

Appendix C – Modelling results

C.1 – Water network reinforcement

Table 19: Water network reinforcement modelling results, year-on-year, 2011-12 to 2020-21

Variable Name	13	14	15	16	17	18	19	20	21	22	23	24
Volume of water change (Ml/d)									0.00453	0.00290	0.00309	0.00238
New properties (ln)	0.921	0.934	1.071	1.094								
Population growth (%)					2.693	2.754	2.918	2.861				
Population density (ln)		-0.0793	7.034	7.254		-0.0858	3.719	3.595		0.147	2.038	1.694
Population density squared (ln)			-0.529	-0.543			-0.282	-0.276			-0.140	-0.124
Pumping capacity per km mains (ln)				-0.164				0.174				0.538
Constant	-1.178	-0.675	-23.85	-24.63	-1.131	-0.597	-12.99	-12.54	0.612	-0.370	-6.494	-5.275
Dependent variable	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)	WNR capex (ln)
Estimation method	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS
N	146	145	145	145	128	128	128	128	132	131	131	131
R^2	28%	28%	33%	33%	17%	17%	19%	19%	0%	1%	1%	3%
RESET test	Fail	Fail	Fail	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Fail	Fail
VIF score (mean)	1.0	1.0	143.4	110.5	1.0	1.1	135.6	102.6	1.0	1.0	130.2	98.4

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis

Notes: Models exclude HDD because, due to its small size, it is an outlier in all models presented. Note: WNR capex (ln) = Water network reinforcement capex in logarithmic scale.

Pooled OLS results are presented here. Sensitivity analysis using Random Effects produced similar results.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

Table 20: Water network reinforcement modelling results, 2020-21

Variable name	25	26	27	28	29	30	31	32	33	34	35	36
Volume of water change (Ml/d)									0.0350	0.0358	0.0399	0.0355
New properties (ln)	0.922	0.937	0.956	0.687								
Population growth (%)					1.982	3.553	3.803	-3.645				
Population density (ln)		0.390	3.526	3.457		0.542	2.645	0.133		0.383	-3.867	-2.554
Population density squared (ln)			-0.232	-0.231			-0.154	-0.0129			0.315	0.212
Pumping capacity per km mains (ln)				1.079				2.247				1.618
Constant	-1.630	-4.300	-14.52	-14.33	-0.737	-5.143	-12.15	-0.00635	-0.424	-3.031	10.65	5.523
Dependent variable	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)	WNR totex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	16	16	16	16	15	15	15	15	16	16	16	16
R^2	33%	37%	38%	46%	2%	8%	8%	35%	22%	25%	27%	52%
RESET test	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
VIF score (mean)	1.0	1.0	123.8	93.3	1.0	1.3	131.7	101.9	1.0	1.0	141.4	107.2

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis

Note: Models exclude HDD because, due to its small size, it is an outlier in all models presented. Note: WNR totex (ln) = Water network reinforcement totex in logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

C.2 – Wastewater network reinforcement

Table 21: Wastewater network reinforcement modelling results, year-on-year, 2011-12 to 2020-21

Variable name	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Volume WW change (Ml/yr)											-0.000000617	-0.000000867	-0.000000823	-0.000000727	-0.000000828
New properties (ln)	0.759	1.262	1.258	1.049	1.058										
Population growth (%)						1.002	0.852	0.780	-0.538	-0.519					
Population density (ln)		-0.635	-2.820	-1.695	-1.712		0.215	-0.909	-0.378	-0.221		0.295	-1.894	0.123	0.273
Population density squared (ln)			0.162	0.0734	0.0749			0.0838	0.0162	-0.00946			0.162	-0.0195	-0.0450
Combined sewers (%)				-0.0264	-0.0260				-0.0580	-0.0647				-0.0514	-0.0585
Pumping capacity/ km sewer (ln)					0.0256					-0.622					-0.639
Constant	-0.669	2.138	9.171	7.956	7.938	0.765	-0.550	3.099	7.041	7.842	1.437	-0.495	6.559	4.619	5.506
Dependent variable	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)	WwNR capex (ln)
Estimation method	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS
N	87	87	87	87	87	79	79	79	79	79	79	79	79	79	79
R^2	19 %	26 %	27 %	31 %	31 %	4 %	6 %	6 %	23 %	25 %	0 %	3 %	4 %	22 %	24 %
RESET test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Fail	Pass	Fail
VIF score (mean)	1.0	2.3	135.7	108.3	88.9	1.0	1.1	146.0	110.7	89.3	1.0	1.0	133.7	105.7	85.3

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis

Notes: WwNR capex (ln) = Wastewater network reinforcement capex in logarithmic scale.

Pooled OLS results are presented here. Sensitivity analysis using Random Effects produced similar results.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

Table 22: Wastewater network reinforcement modelling results, 2020-21

Variable name	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Volume WW change (Ml/yr)											0.0000119	0.00000722	0.00000395	0.00000425	0.00000692
New properties (ln)	1.834	1.605	1.602	0.789	0.541										
Population growth (%)						-11.99	-9.747	-9.033	-11.65	-18.69					
Population density (ln)		0.302	15.31	19.74	21.16		0.771	2.578	3.773	-3.774		1.410	15.68	20.28	21.19
Population density squared (ln)			-1.107	-1.435	-1.547			-0.129	-0.297	0.152			-1.048	-1.446	-1.547
Combined sewers (%)				-0.0733	-0.0881				-0.101	-0.139				-0.0904	-0.106
Pumping capacity/ km sewer (ln)					-1.041					-3.329					-1.653
Constant	-3.928	-5.301	-53.98	-61.64	-63.78	6.917	0.730	-5.676	1.650	38.32	0.920	-8.340	-54.82	-61.53	-61.20
Dependent variable	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)	WwNR totex (ln)
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
R^2	42%	42%	58%	69%	71%	48%	53%	53%	80%	97%	10%	32%	46%	68%	73%
RESET test	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Fail
VIF score (mean)	1.0	2.4	116.4	98.9	85.2	1.0	1.3	298.0	224.6	194.1	1.0	1.1	121.8	98.7	80.7

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis

Notes: WwNR totex (ln) = Wastewater network reinforcement totex in logarithmic scale.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

C.3 – Growth at wastewater treatment works

Table 23: Growth at wastewater treatment works modelling results, year-on-year

	10-year capex Y-o-Y (2011-12 to 2020-21)				4-year totex Y-o-Y (2017-18 to 2020-21)			
Variable name	9	10	11	12	13	14	15	16
PE change served by WwTWs (000s)	0.00121	0.00141	0.00117	0.000996	0.00190	0.00185	0.00228	0.00216
Load receiving tertiary treatment (%)		0.0108	0.0107	0.0123		0.00720	0.00844	0.0107
Volume WW change (Ml/yr)			0.00000135	0.00000129			-0.00000373	-0.00000410
Load treated in WwTW size bands 1-3 (%)				-0.0705				-0.0901
Constant	1.571	0.930	0.929	1.117	1.738	1.309	1.306	1.524
Dependent variable	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW capex (ln)	GWwTW totex (ln)	GWwTW totex (ln)	GWwTW totex (ln)	GWwTW totex (ln)
Estimation method	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS
N	89	89	89	89	40	40	40	40
R^2	2 %	4 %	5 %	8 %	9 %	11 %	15 %	22 %
RESET test	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
VIF score (mean)	1.0	1.0	1.1	1.1	1.0	1.0	1.1	1.1

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis

Notes: GWwTW capex (ln) = Growth at wastewater treatment works capex, logarithmic scale. Note: GWwTW totex, (ln) = Growth at wastewater treatment works totex, logarithmic scale.

Pooled OLS results are presented here. Sensitivity analysis using random effects produced similar results.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

C.4 – Reducing risk of sewer flooding to properties

Table 24: Risk of sewer flooding modelling results, year-on-year

	10-year capex Y-o-Y (2011-12 to 2020-21)				4-year totex Y-o-Y (2017-18 to 2020-21)			
Variable name	9	10	11	12	13	14	15	16
Connected properties (ln)	0.857	0.767	1.051	1.056	0.707	0.697	1.136	1.095
Food service establishments per km of sewer		5.955	0.269	0.491		0.666	-8.140	-6.232
Combined sewers (%)			0.0199	0.0170			0.0307	0.0181
Urban rainfall per km (million m^3 / km)				0.239				0.854
Constant	-4.296	-4.153	-7.033	-7.321	-3.364	-3.348	-7.815	-8.351
Dependent variable	RSF capex (ln)	RSF capex (ln)	RSF capex (ln)	RSF capex (ln)	RSF totex (ln)	RSF totex (ln)	RSF totex (ln)	RSF totex (ln)
Estimation method	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS
N	100	100	100	100	40	40	40	40
R^2	25%	27%	29%	29%	16 %	16 %	20 %	26 %
RESET test	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
VIF score (mean)	1.0	1.2	2.3	2.0	1.0	1.2	2.3	2.1

= Significant at 1% = Significant at 5% = Significant at 10%

Source: Arup analysis.

Note: RSW capex (ln) = Risk of sewer flooding capex, logarithmic scale. Note: RSW totex (ln) = Risk of sewer flooding totex, logarithmic scale.

Pooled OLS results are presented here. Sensitivity analysis using Random Effects produced similar results.

The Ramsey RESET test outcome is based on F test using a 5% significance level. Models that pass the RESET are well specified with a linear model (with a 5% confidence level). Models that fail the RESET test are misspecified in the sense that a polynomial or other non-linear functional form would be a better fit (with a 5% confidence level).

The VIF score measures the amount of correlation among the cost drivers. As a rule of thumb, a mean VIF score above 4 indicates medium risk and VIF above 10 indicates harmful collinearity. Harmful multicollinearity means that the result of the significance test for the estimated coefficients may be misleading, i.e., the result may say that the coefficient is insignificant when in reality it is not, and vice-versa.

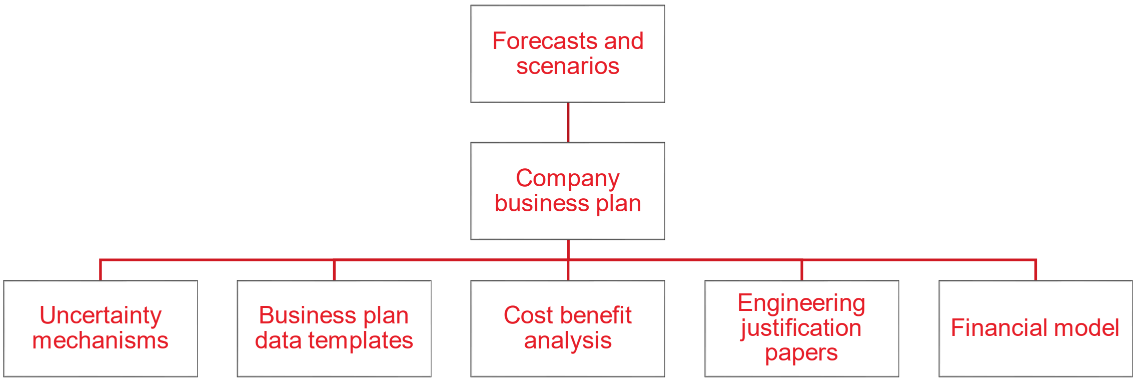
Appendix D – Ofgem approach to network reinforcement cost assessment

At RIIO-ED2, Ofgem utilised a number of assessment tools to assess future network reinforcement costs. They also expected network companies to submit specific analysis as part of their business plan submissions to demonstrate that the network reinforcement costs were efficient and justified. Together, the analysis submitted and the tools used demonstrated that sufficient optioneering took place, the costs were efficient and there was flexibility in the business plans for any future uncertainty.

The need for reinforcement of the electricity network is expected to be of a bigger magnitude than that for water and wastewater network reinforcement. Like in water/wastewater, electricity network reinforcement needs to accommodate additional demand driven by population growth and greater business activity. But in addition to this, it also needs to accommodate demand driven by electrification of heating and electrification of transport. Despite the difference in magnitudes, the assessment tools Ofgem used at RIIO-ED2 to assess network reinforcement costs offer a good reference for the water sector.

A high-level summary of Ofgem's assessment process is described below, as well as a diagram which shows the document hierarchy that was used when business plans were submitted, and when Ofgem assessed those business plans for network reinforcement needs.

Figure 23: Document hierarchy supporting Ofgem assessment of network reinforcement costs at RIIO-ED2



D.1 – Forecasts and scenarios

Network reinforcement plans were expected to be based, as far as practicable, on well informed and justified forecasts of demand (and generation) growth. Ofgem expected the forecasts to be informed by assumptions found in published Net Zero compliant energy pathways. For electricity, Ofgem used the Electricity System Operators Future Energy Scenarios and the Climate Change Committee's Carbon Budget, as both of these are consistent with the Government's plans for decarbonisation.

Each Distribution Network Operator (DNO) had to translate these national pathways into scenarios applicable for their licenced areas, and supplement this with engagement with local stakeholders to better justify/understand the local context. The DNO's forecasts were expected to allow for clear comparative analysis of forecast expenditure between the different networks, as well as being robust across the different Net Zero complaint pathways/scenarios.

Ofgem used the analysis provided by the networks on the various scenarios to determine how much funding to allocate to 'baseline funding', and how much to be provided through 'uncertainty mechanisms'. Uncertainty mechanisms can be triggered by the DNOs and by Ofgem if it is found that there is greater uncertainty of a certain scenario playing out.

D.2 – Cost information

Once the forecasts described above have been established, the networks submitted a Business Plan, which contained cost information and justification for the proposed future spend. The Business Plan sets out clearly:

- the cost drivers;
- a consideration of the options;
- justification of costs, including the profiling of costs; and
- how efficiency and innovation were used to reduce costs.

Companies submitted Business Plan Data Templates (BPDTs) alongside their written Business Plan which, when combined, provided full justification of future costs, highlighted the growth in expected demand, as well as communicated the condition of current network assets and their utilisation.

The business plans also had to establish the cost of 'doing nothing' versus the projected business plan and explained why the chosen options were best for the network and consumers. This was supported with Cost Benefit Analysis (CBA). Justification for the chosen pathway and network reinforcement were evidenced through Engineering Justification Papers (EJPs).

D.3 – Cost Benefit Analysis

CBA is an important decision support tool that is used by the companies and Ofgem to justify the investment requirements in future price control periods. At RIIO-ED2, Ofgem expected the companies to include CBA when there were multiple options on how to manage intervention on the networks, especially when there was a step change between price control periods.

CBAs could also be used where there was a capex/opex trade off, where a move between capex/opex was likely to deliver long-term benefits, but where this benefit could extend outside of the immediate price control period. For example, CBA could be used to assess asset replacement decisions (replacement versus refurbishment), understand deferred replacement, reinforcement of parts of the network or large schemes. CBA could also be used to assess innovative techniques such as new digital tools or schemes that increased network resilience.

D.4 – Engineering Justification Papers

EJPs were used to provide clear justification for load related and non-load related investments. They acted as a decision support tool which was open to scrutiny and challenge, and they were submitted alongside other evidence which justified the investment requirements (such as the Business Plan and CBA). An EJP clearly sets out:

- the need for the investment including evidence to support this;
- the structured process that was taken when optioneering solutions; and
- proposed scope, costs, risks and benefits.

EJPs were required for all high-value load related and non-load related investment programmes where the cost of the solution exceeded £2m. EJPs were also required for load or non-load related investment programmes where the asset replacement volume proposals had increased by more than 33% when compared to the previous price control and the forecast cost exceeded £500k. Ofgem also stated that EJPs could be considered by the DNOs for projects under £2m for greater transparency. However, this was not a requirement, and projects under £2m were generally subject to 'light touch' scrutiny. EJPs could be used for single projects or aggregated investment programmes that aimed to reinforce the network, improve asset health or network performance. EJPs must, however, be aligned clearly with the costs, volumes and data in the Business Plans that were submitted, as well as with the BPDTs.

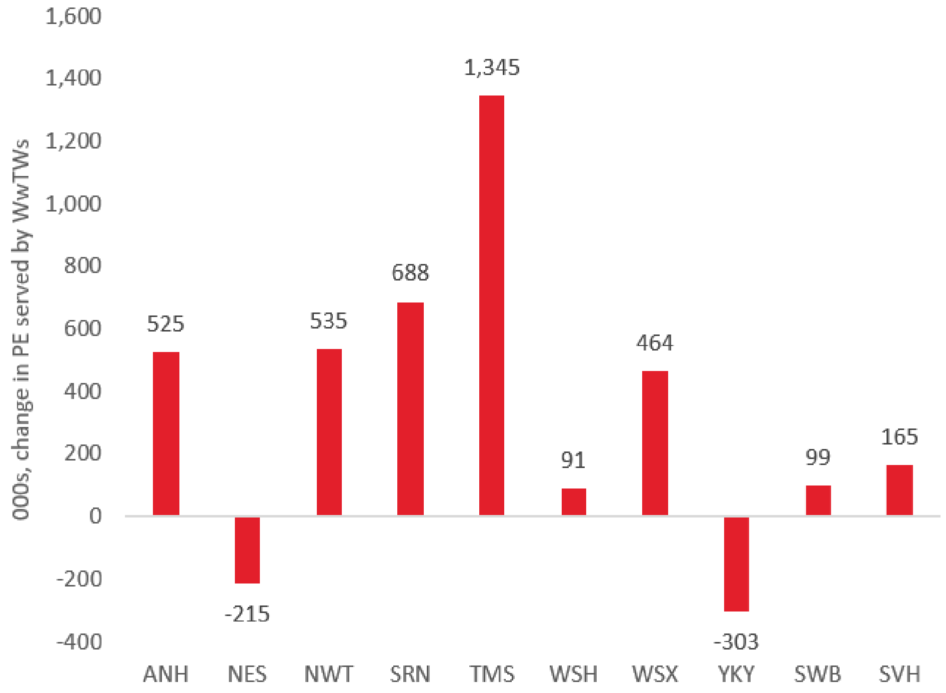
D.5 – Uncertainty mechanisms

At RIIO-ED2, Ofgem utilised uncertainty mechanisms where there was uncertainty over the expected level of investment at a local level or where there could be a large range in future demand forecasts.

Ofgem allowed changes to the networks allowed revenues to be made, in light of what was happening during the price control period. For instance, an uncertainty mechanism utilised for the electricity networks was the Capacity Volume Driver, which allowed for additional funding to be allocated where high electricity demand created capacity constraints at the substation assets on the network. In this mechanism, reinforcement was triggered either by Ofgem or by the DNO once utilisation moved between set 'utilisation bands', with a fixed unit cost (£/MVA) being used to release capacity at the substations or through increased build out of low voltage and high voltage circuits (£/km). In this sense, Ofgem and the DNOs could build any future uncertainty into their business plans, whilst maintaining sight on the potential cost.

Appendix E –Analysis of drivers used in the growth at WwTW model

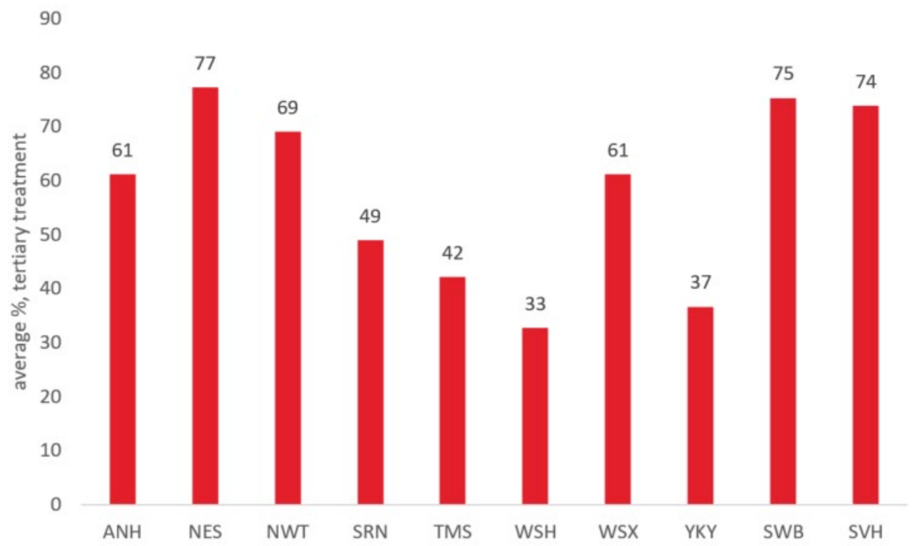
Figure 24: Change in PE by company, 10-year cumulative, 2011-12 to 2020-21



Source: Arup analysis.

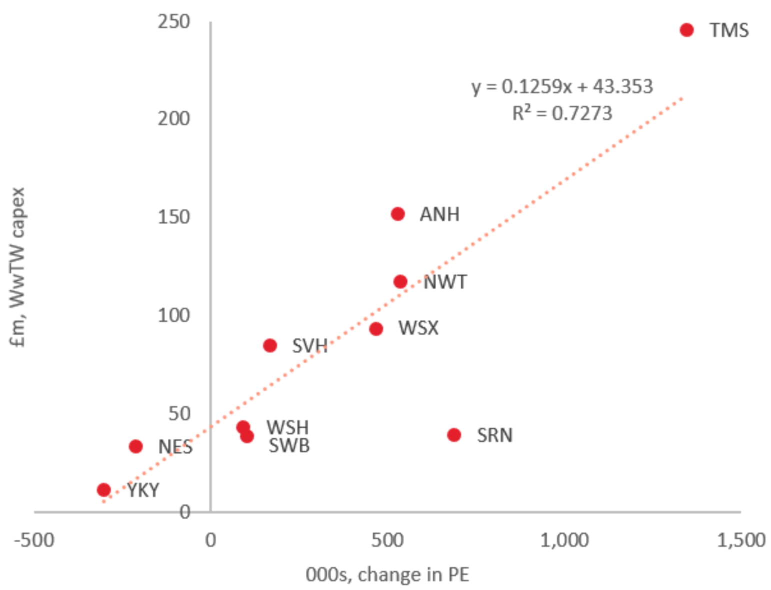
Note: PE = Population Equivalent. WwTWs = Wastewater Treatment Works.

Figure 25: Proportion of load receiving tertiary treatment by company, 10-year average, 2011-12 to 2020-21



Source: Arup analysis.

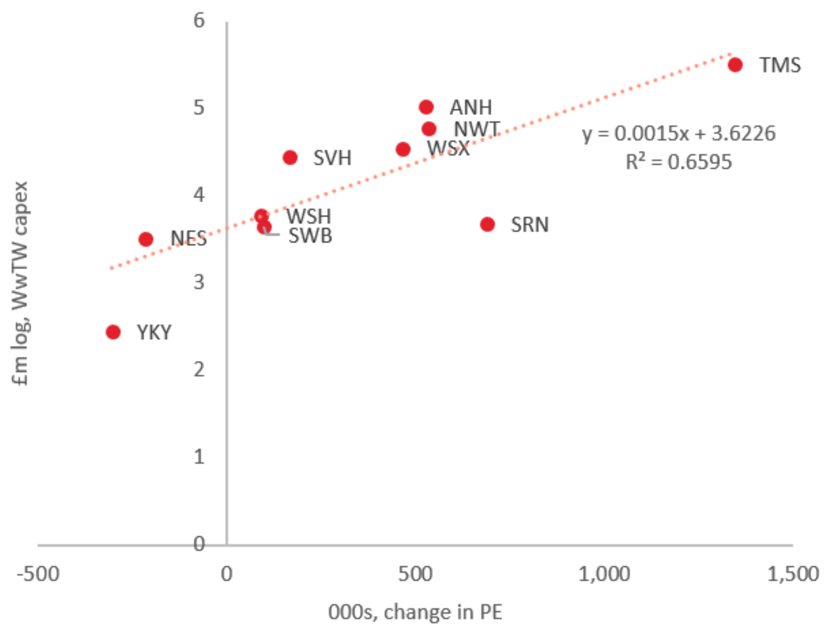
Figure 26: 10-year growth at WwTW capex vs change in PE, 2011-12 to 2020-21, linear model



Source: Arup analysis.

Note: PE = Population Equivalent. WwTW = Wastewater treatment works.

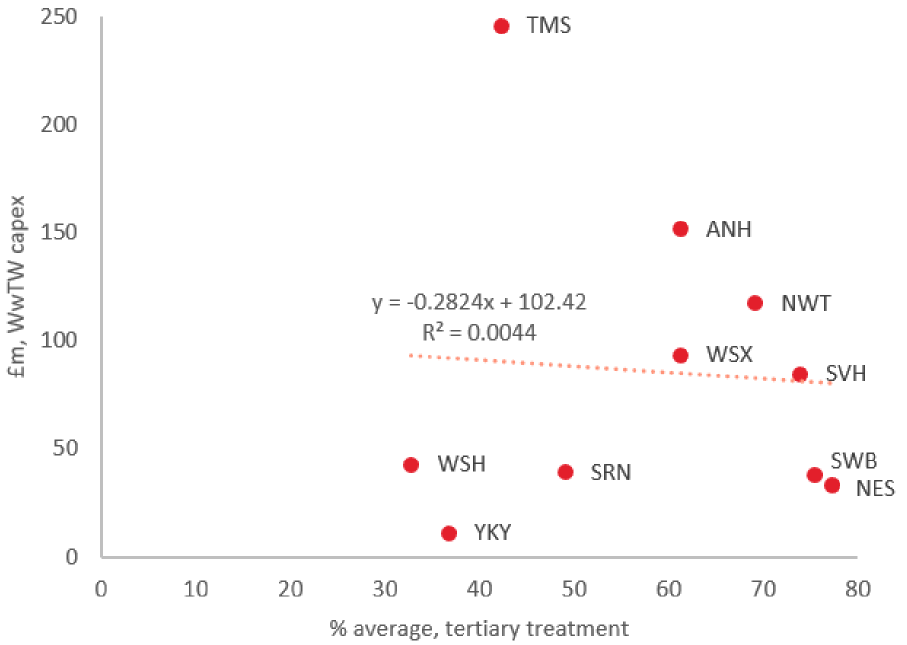
Figure 27: 10-year WwTW capex vs change in PE, 2011-12 to 2020-21, log-linear model



Source: Arup analysis.

Note: PE = Population Equivalent. WwTW = Wastewater Treatment Works.

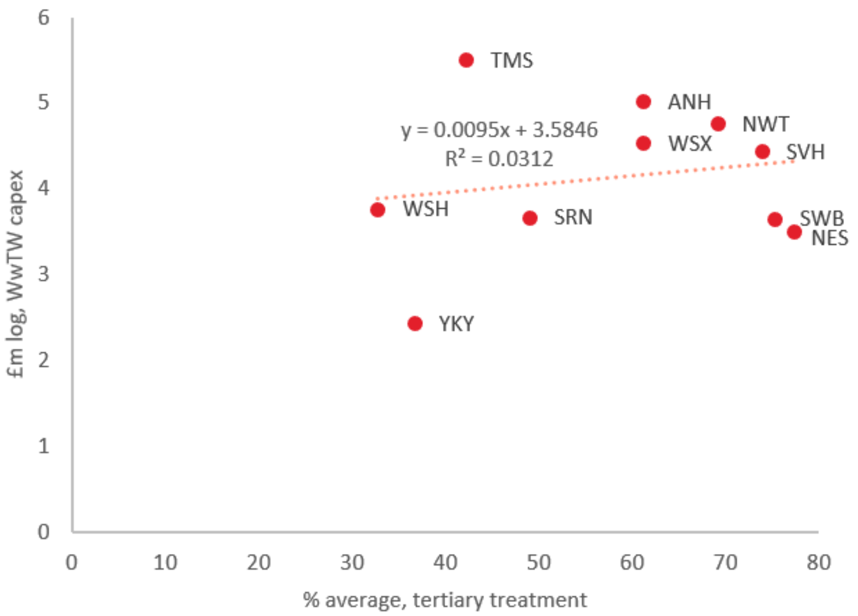
Figure 28: 10-year WwTW capex vs % of load receiving tertiary treatment, 2011-12 to 2020-21, linear model



Source: Arup analysis.

Note: WwTW = Wastewater Treatment Works.

Figure 29: 10-year WwTW capex vs % of load receiving tertiary treatment, 2011-12 to 2020-21, log-linear model



Source: Arup analysis.

Note: WwTW = Wastewater Treatment Works.

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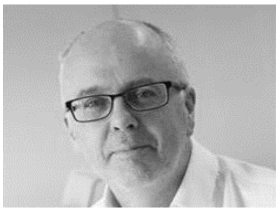

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