Anglian Water

10A. WATER INDUSTRY COST MODELLING: ANGLIAN WATER'S APPROACH AND INITIAL RESULTS. SEPTEMBER 2017

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WATER INDUSTRY COST MODELLING

ANGLIAN WATER'S APPROACH AND INITIAL RESULTS

September 2017

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Executive Summary

This report provides details of the cost models Anglian Water has developed over the last year. Our intention in developing these models has been to determine whether it is possible to model costs for the water industry using econometrics and, if so, how such work can contribute to measurements of historical relative efficiency and forecasts of future expenditure requirements. The results have been broadly positive and have strengthened our view that econometrics can be used effectively to estimate base totex[1] – that is, totex excluding enhancement capex. (We refer to base totex throughout this report as botex).

This report can be seen as a continuation of the Marketplace for Ideas report we published in June 2015, which set out what we considered to be an appropriate approach to water industry cost modelling.

The work on which we are reporting here is very much work in progress. We have used the 2016 data collection exercises in August (for Water) and October (for Water Recycling). Our intention is to now make use of the longer and more homogenous data set collected earlier this year in a thorough-going revision of the work to date. In doing this, we will take advantage of comments from third parties, including our independent academic assessors. We aim to publish a revised report early in 2018 to take account of the revisions, additional tests and improvements to the models.

We are alive to the need for a robust and effective means to estimate enhancement cost efficiency and expenditure requirements. This analysis explicitly excludes these costs.

We hope that by publishing our interim findings, we can help inform the continuing debate regarding both efficiency benchmarking and PR19 cost modelling.

Terminology

The service of collecting and treating used water is variously termed Waste Water or Sewerage but we prefer the term Water Recycling and use that in this report. To avoid a surfeit of Ws, we have coded Water Recycling models with the letter S.

We have used the term Bioresources to refer to the whole service of recycling the solid components of used water but retain the term 'sludge' for the untreated material and biosolids for the treated material. We have also used the word sludge in the Business Unit names, following Ofwat, (as in: Sludge Transport, Sludge Treatment and Sludge Disposal) although we would prefer the name Biosolids Recycling to Sludge Disposal as we feel this reflects more accurately the nature of the activity undertaken within that Business Unit.

Practitioners vary in their definition of the term 'model'. Take the example that we propose that our dependent variable, costs, is a function of labour and capital. We might test this using 'number of workers' or 'number of hours worked' as the labour variable. Some would regard these two options as separate specifications of the same model but we have regarded them as separate models.

References to 'the industry' mean the water companies of England and Wales which are regulated by Ofwat. At the time of writing, they comprised ten water and sewerage companies (WASCs) and six water-only companies (WOCs). However, the 2016 data set which we have used included both Bournemouth Water and Dee Valley Water which have subsequently been acquired.

[1] *Totex, or total expenditure, is the sum of operating expenditure and capital expenditure.*

1. Introduction

This report covers work we have undertaken in response to two challenges that we face as a water company and which are shared challenges for the sector as a whole. Firstly, we need to be able to make accurate forecasts of the expenditure we'll need to make over the next regulatory period (2020-2025) to deliver the outcomes our customers expect. Secondly, we want to be able to assess whether our costs are efficient relative to the best companies in our sector. The first is a one-off challenge, which comes to a head when we submit our business plan for 2020-2025 in September 2018. The second is an on-going, permanent challenge. But both challenges are important for our customers and meeting them successfully is essential for ensuring that our customers' bills are no higher than they need to be.

We think that econometric modelling can play a significant role in helping us meet these twin challenges. The objective of econometric modelling is to derive robust relationships between companies' costs and the factors which cause them to spend money (in this report we will call these factors cost drivers). Applying statistical techniques to datasets of historical costs and cost drivers allows us to establish these relationships. In conjunction with estimates of future cost drivers, we can use the modelled relationships to forecast future cost levels, meeting our first challenge. Comparison between the costs calculated by the models and those which were actually incurred can help to give a view of companies' relative efficiency, meeting our second challenge.

Econometric modelling is far from easy. The biggest challenge is obtaining datasets which are sufficiently large for statistical purposes and where a sufficient degree of consistency has been applied to the numbers by the companies which produced them. There are numerous decisions to be made about the form of modelling to adopt and limitations on the power of statistical techniques. We recognise that no model can take into account all the factors which drive the costs incurred by all companies and that it may not even be possible to produce models which are good enough to meet our needs. We also recognise that the outputs of models – even good ones - should be combined with other sources of evidence to produce conclusions. We therefore approach this work in a spirit of skepticism that the results may be unsatisfactory; but also one of hope, in the knowledge of the significant contribution which modelling success can bring to meeting our challenges.

2. Purpose of this report

We have been building cost models since the start of 2017 and the purpose of this report is to share the results of our work to date. Others in the sector are undertaking, or will be planning to undertake, similar work. Our aim in publishing is to offer our thoughts (which will continue to develop) in a spirit of openness. We hope that through this report we can share our learning for the benefit of others, just as we would like to benefit from the learning shared by others. We hope that industry stakeholders might approach consensus on cost modelling by combining the collective findings of all those engaged on the task. This is our contribution to that effort.

Specifically in the report we describe the following:

- The approach we have taken to modelling (the data and statistical techniques we have used and our criteria for model acceptability)
- The findings we have made
- The observations of our academic peer reviewer
- Our overall conclusions so far and expectations for what happens next.

We view this report as work in progress. We intend to publish an updated report early in 2018. The intention is that the updated report should:

- Make use of the recently collected 2017 data collection exercise (the Information Request);
- Take account of Ofwat's statements in the Draft Methodology documents which were published in mid July 2017, shortly before the completion of our cost models;
- Reflect the external assessment which we have commissioned for this interim report; and
- Contain tests and commentary on the stability of the models.

3. Our approach to modelling

The purpose of this section is to describe the approach we have taken to building our cost models.

3.1 Modelled costs – botex rather than totex

Expenditure by water companies falls into three main categories:

- Operational expenditure - opex – day-to-day expenditure on recurrent items, such as power and salaries, to deliver the ongoing services of the business;
- Capital maintenance – investment in existing assets to compensate for natural deterioration and ensure they remain serviceable; and
- Capital enhancement – investment in assets necessary to deliver enhanced service levels. Examples are new lengths of water mains to satisfy the needs of new customers and additional treatment technology at water treatment works to meet higher drinking water quality standards.

Historically, costs in each of these categories were treated in isolation for regulatory purposes. In recent years, a view emerged that this approach introduced asymmetric incentives which distorted the behaviour of companies to deliver potentially uneconomic outcomes. The consequence of this was a decision to ignore the boundaries between the categories for regulatory purposes and regard expenditure 'in the round'.

We fully support this development. We have seen how regulation of total expenditure (or 'totex') rather than the separate components of expenditure has removed constraints that existed hitherto and encouraged companies to make better investment choices.

The move to regulate totex suggests to some that cost modelling should be performed on a totex basis rather than on the cost categories in isolation. However, we have always been skeptical about the ability to create acceptable full totex cost models. Levels of capital enhancement vary significantly between companies and between years because the drivers for it vary also in time and geographically. We think it highly unlikely that any model could adequately include a sufficient number of the drivers to account for differing levels of capital enhancement expenditure, even more so if that same model were also expected to deal with the two other categories of expenditure.

We think there is substantial support for our position in the evidence from stakeholders' attempts to build viable totex cost models at PR14. Most telling, perhaps, was the observation that Ofwat itself did not use any totex models for its assessment of companies' wastewater costs at PR14.

Aside from capital enhancement expenditure, the two other categories of expenditure have collectively been termed base expenditure, or 'botex'. As the name implies, they represent the expenditure necessary to deliver the base services of the companies. In the same way that demand for these essential services is broadly constant and predictable, we observe that for any individual company botex levels are also broadly constant, varying relatively little between years. Given this, and the comparable nature of services provided by companies, we think it should be feasible to find drivers for these costs which apply across time and between companies. Consequently, all our cost modelling has been done using historical base expenditure and all our conclusions apply to botex only.

We consider the forecasting of future enhancement expenditure and the assessment of enhancement efficiency must be done on a separate basis. We do not tackle that subject in this report.

We set out our views on this subject in much greater detail in a paper we published in 2015. This paper is still available from the WaterUK website .

Finally, we note that the Competition and Markets Authority (CMA) reached the same conclusion when making its determination of Bristol Water's price controls in 2015; all of the CMA's cost modelling was performed on a botex basis.

In its July 2017 Methodology Consultation documents, Ofwat acknowledges the difficulty of incorporating enhancement cost drivers into cost models. It suggests a hybrid approach wherein some elements of enhancement capex, such as growth, may be capable of being modelled and may be incorporated into botex models. This "botex plus" suggestion is interesting and we will explore it during the next phase of our work.

3.2 Aggregated versus granular models

We said earlier that no single model gives the correct answer and that conclusions about future expenditure requirements or historical efficiency levels should be based on the evidence from a range of sources, of which modelling may be only one. Within the evidence sourced from econometric modelling, it follows that reliance should not be placed on the outputs of a single model. A better approach is to create a range of models and draw overall conclusions on the basis of their collective conclusions. This process of making an overall decision having viewed the same question from a variety of different angles is sometimes termed triangulation.

One way in which we have varied the frame of the cost modelling challenge is by changing the scope of the service under consideration. We have built models that seek to encompass the entire scope of the water and wastewater services. We call these aggregate, or whole service, models. But we have also broken these services into smaller sub-services and built separate models for these. We call these granular models.

The creation of both whole service and granular models provides us with a richer evidence base, enabling us to triangulate the results and increasing the probability of drawing accurate conclusions from our modelling work. It is also consistent with Ofwat's proposals for how it will regulate the industry in the period 2020-2025. Cost assessments will be required for each area of service subject to a separate price control, not only at an aggregate service level.

Modelling at a granular level introduces the risk of error as a consequence of differences between companies in cost allocation practices. In other words, despite all efforts to ensure consistency through guidance, two identical companies could allocate the same cost to different sides of a sub-service boundary, with consequences for Modelling outcomes. Our Modelling results even provide evidence for where this might be happening. We do not think this provides an argument against granular Modelling altogether but it does require us to be alive to the risk when comparing the results from models at different levels of disaggregation.

The diagrams below show the models we have built and how we have disaggregated the water, wastewater and retail services into granular parts. We refer to each block in each table as a service area. We have assigned a reference code to each service area and use these codes in the remainder of the report. We also show the proportion of industry botex attributable to each service area. These are calculated from cumulative industry data over the period 2013-14 to 2015-16 for water and 2011-12 to 2015-16 for water recycling.

[1] http://www.anglianwater.co.uk/_assets/media/Totex_cost_assessment_at_PR19_-_Final.pdf

Water service W1 100%	**Water resources** W2 12%	
	Network Plus W3 88%	**Raw water distribution** W4 3%
		Water treatment W5 30%
		Treated water distribution W6 55%

Water recycling service S1 100%	**Network Plus** S2 82%	**Water Recycling collection** S4 34%
		Water Recycling treatment S5 48%
	Bioresources S3 18%	**Sludge transport** S6 3%
		Sludge treatment S7 12%
		Sludge disposal S8 3%

Household retail R1 100%	**Bad debt** R2 51%
	Meter reading R3 4%
	Customer services R4 19%
	Other R5 25%

3.3 Data sources

The development of cost models is dependent on the availability of data which meet the following criteria:

- Provide sufficient observations to enable statistically significant relationships to be observed
- Reflect all the likely dynamics of the service under examination
- Have been reported in a consistent manner by all companies to ensure that they are comparable measurements of the same thing.

The sources of the data for all our wholesale cost modelling are the data returns requested of companies by Ofwat during 2016. The August Submission covered the water service and the October Submission covered the water recycling service. The scope of these submissions was developed by Ofwat in conjunction with companies, who proposed the factors they considered to be significant drivers of costs. Reporting requirements were provided for each line of the submissions in an attempt to ensure consistency of reporting between companies. Data were required for a number of years as the submissions sought to fill the gaps created by a period of several years during which data have not been collected.

Data for the retail models were sourced by Ofwat from the PR14 data submissions and from the subsequent annual regulatory accounts submissions made to Ofwat.

It follows from the above that our modelling work is constrained by the availability of data and the specification of business units in Ofwat's data reporting frameworks.

3.4 Ofwat views on acceptable models

At a meeting of the industry Cost Assessment Working Group in March 2016, Ofwat presented its views on cost modelling under the heading 'what good looks like'. In this presentation, Ofwat acknowledged the barriers to model accuracy and that models do not deliver the perfect answer. Given this, it acknowledged that rather than find the "right" model, we need to be able to differentiate between acceptable and unacceptable models and understand how to make appropriate use of model outputs.

Ofwat presented the following criteria it might apply to assess the quality of models:

Specification

- Theoretical correctness – cost drivers that make sense operationally / consistent with knowledge
- Simple and transparent
- Incentivising - no perverse incentive / incentive for companies to operate efficiently / no capex bias
- Regulatory burden

Results

- Coefficient estimates (or elasticities) with an "appropriate" sign and magnitude
- Statistically robust (statistical tests, AIC, BIC, Adjusted R^2 etc.)
- Stable coefficient estimates and stable forecasts
- Robust to past outliers and shifts

Ofwat also set out some thoughts on an appropriate overall approach to modelling:

- A suite of models – "all models are wrong" hence we want a number of models to triangulate
- Ensure outcome is achievable (no "super company")

We agree with these views presented by Ofwat in 2016 and have sought to reflect them in our work. We believe this is evident in the sections below where we present how we have specified our models, chosen our cost drivers and decided between acceptable and unacceptable models.

3.5 Methodology

The fact that there were only ten water and sewerage companies (WaSCs) and eight water only companies (WoCs) at PR14 led to the decision to use panel data (data sets comprising observations of multiple phenomena obtained over multiple time periods for the same companies). With five years' data, that gave 90 data points for water and, with seven years' data, 70 data points for water recycling. This was adequate for cost modelling. The 2016 water submission only covered three years, meaning there were a total of 54 data points. This made the choice of using panel data all the more necessary for this cost modelling exercise. It also argued for model specification to be as frugal as feasible.

All of the cost modelling was undertaken using the statistical software application STATA v.14. The regression statistics from STATA, along with the results from a set of tests, were incorporated into the analysis of the developed models.

Three tests were routinely run. These were:

1. Ovtest - this runs the Ramsey Reset test for missing higher order terms in the formulation of the cost model
2. Hettest - this runs the Brausch Pagan test for heteroskedasticity
3. VIF - this calculates the Variance Inflation Factors for all coefficients and provides evidence of multicollinearity.

Our starting point for model development has been to use a log-log approach along the lines of the Cobb Douglas form. This has been for a number of reasons:

- The CMA's use of Cobb Douglas in the PR14 Bristol Water appeal
- A desire to follow the principle of Occam's Razor and start with a (relatively) straightforward approach, moving on to a more complicated approach only if necessary
- Being mindful of the CMA's criticisms of the over-complicated and counter-intuitive nature of the PR14 econometric models, the wish to be able to have recourse to engineering logic in evaluating the relative merits of the models.

In line with the approach of making our models no more complex than they needed to be, we started by using Ordinary Least Squares (OLS).

Where a model failed the Ramsey Reset test, a version which included squared terms of scale variables was run. These could be seen as being semi-translog in form, although they are referred to within the annexes as translog. Where a model failed the Brausch Pagan test, a General Least Squares (GLS (RE)) version of the model was run to take account of the identified heteroskedasticity.

Throughout the work set out in this report, and contrary to the approach taken at PR14, we have used unsmoothed capital maintenance costs in calculating botex[2]. There are three reasons why we consider the use of unsmoothed capital maintenance to be acceptable in this cost modelling exercise:

- At PR14 Ofwat smoothed both capital maintenance and enhancement capex to try to mitigate the year-to-year variability of capital expenditure. As explained in section 3.1 above, capital maintenance is more steady and predictable than capital enhancement (the capital equipment used by companies is fairly homogeneous across companies and all requires regular maintenance). Consequently, the importance of smoothing is significantly greater for totex (as it includes enhancement capex) than for botex. Putting the same point the other way around, it is significantly less important to smooth maintenance capex than for enhancement capex. Consequently, using unsmoothed data for botex analysis may be considered acceptable.
- Given that the basis for computing regulatory accounts changed in 2015-16 from GAAP to IFRS, we cannot mine the regulatory accounts to extend the dataset back in time as is necessary for capital smoothing.
- As the available dataset of costs and independent variables only covers three years for Water and five for Water Recycling, this makes capex smoothing infeasible.

3.6 Choice of cost drivers

All of the models which we have developed have used the data collected in the 2016 August and October Submissions. As previously described, the data in these submissions were largely specified by companies, making use of the combined expertise among members of the Cost Assessment Working Group about the drivers of costs in water and sewerage.

Our choice of drivers to include in our cost models was based on this industry knowledge plus the expertise in Anglian about cost drivers derived from analysis of our own operations. As a cross-check we referred to the drivers which have been used in historical cost models.

There are three variables which we would highlight.

1. The **regional wages** variable. This is an updated version of the series developed for PR14, using ONS data relating to hourly pay excluding overtime. At PR14, Ofwat's regional wage series was based on only two categories of workers - SOC code 21 (Science, research, engineering and technology professionals) and SOC code 53 (Skilled construction and building trades), assigned 40% and 60% weights respectively. At PR14, the Regional Wage variable did not perform at all well in cost models. For PR19, Ofwat has extended the approach to take account of all 25 SOC level 2 categories, using industry employment data to set the weights. Our experience using the new PR19 Regional Wage variable has been little better than the PR14 experience, as can be seen in the modelling results.

2. The **sparsity** and **density** variables were developed after Ofwat collected data on the population density within the Lower Super Output Areas (LSOAs) for all companies. The variables were defined as the proportion of a company's customers living with LSOAs whose population density exceeded (for density) or fell below (for sparsity) threshold levels. The variables are designed at that granular LSOA level to provide a much more precise measure than previously used measures such as average passing distance. We have noticed that the precise floor and ceiling used to define density and sparsity makes a big difference in the cost modelling. If one uses a very high threshold for density, the density measure, for many companies, is zero for each year. This explains why the density measure often performed less well than the sparsity measure. Given this, we will be using a lower threshold for density in any subsequent cost modelling work.

3. Unlike the approach taken by CEPA at PR14, we have used a **time trend** instead of time dummies in our cost modelling. The main reason for this choice was for the sake of a more frugal model specification, given the small size of the panel.

[2] That is, each year's capital maintenance expenditure is used as an individual, discrete observation. The alternative is to calculate each year's observation as the average capital maintenance expenditure over a number of preceding years – say, five. The argument for doing this is that it smoothes the natural peaks and troughs of expenditure between years.

3.7 Criteria for acceptable models

During this project, we have developed a wide variety of cost models at different levels of aggregation, as set out in section 3.2 above. Within each of the twelve cost modelling annexes to this report, there were multiple variants tested. Many were rejected while those which appeared promising were taken forward. Having identified this set of promising models for each of the service areas set out in section 3.2, the question was how to identify those models which we would go on to use.

We wanted to develop a set of objective criteria which could be used to pick the models which we would use to address the twin challenges set out at the start of the report.

The approach we took was to set four tests for each model variant:

1. Was the Adjusted R^2 above 0.7? The adjusted R^2 measures the proportion of the dependent variable that is predictable from the independent variables
2. Was the Akaike Information Criterion (AIC) for the model variant in the top 75 percent[3]? The AIC measures the relative quality of statistical models for a given data set
3. Are more than two thirds of the coefficients statistically significant[4]?
4. Do the statistically significant coefficients make sense from both an economic and engineering perspective?

While accepting that the specific criteria are essentially arbitrary, we believe that they address several key elements identified by Ofwat of how to recognize a satisfactory model and set out in section 3.4 above. We also felt it important to apply these criteria mechanistically so as to avoid any accusations of bias in selecting model variants.

3.8 Combination of acceptable models

As we described in section 3.7, for all the service areas we have tackled, we have built several models. Typically, a significant number of these models failed to meet our acceptability criteria and were discarded. However, in most areas we found more than one acceptable model, leaving us with the task of deciding how to make use of these multiple, potentially acceptable models.

One approach would be to pick a single "best" model for each service. From an academic standpoint this approach would be viewed as quite unexceptional and there are standard ways of doing so, such as the likelihood ratio test. Given Ofwat's stated view that it wants to use a number of (concatenated) models for each service, we have decided not to follow this approach. Instead, we have gone down the route of triangulation.

At PR14 Ofwat, through CEPA, developed a set of models for Water and for Water Recycling. Like us, it then went on to rule out a number of these models. The outputs of the remaining models were then concatenated by taking their arithmetic average, a process Ofwat referred to as triangulation.

This approach assumed that the outputs of the various models were of equal merit and thus assigned the same weight to each. However, it was evident from the published data concerning the CEPA models that they were not of equal merit.

In our Marketplace for Ideas report of 2015, we suggested that models of differing quality should be accorded different weighting in the triangulation process such that better models made a greater contribution to the results. Putting this into practice, we have developed a composite measure of model quality based on the coefficient of determination (R^2) and the Akaike Information Criterion (AIC). We have described this approach as quality-adjusted triangulation.

In all of the areas we have modelled we have calculated the results from using both arithmetic and quality-adjusted triangulations. As triangulation comes after the imposition of our acceptability criteria, which winnowed out weaker models, the results of the quality-adjusted triangulation in terms of rankings was almost always the same as that from arithmetic triangulation. In the annexes we have only reported the results from the quality-adjusted triangulation.

We went on to add into the composite measure the proportion of coefficients in each model with a significance level greater than 80%. This affected the computed triangulation or each company by at most 0.1%. Once again, the rankings remained identical.

Despite the observation that, to date, the results of our modelling are indiferent to the way in which the individual models have been combined, we retain our belief in the superiorty of the quality-adjusted approach to triangulation.

[3] As the better the model, the lower the AIC, strictly speaking this is the bottom 75%

[4] It has been pointed out at a late stage in the development of this project that this criterion should be modified so as to exclude the constant term. It should also fail this criterion if all scale variables are insignificant. This modification will be incorporated into subsequent work.

3.9 Use of the work of others

Most of the work presented in this report is our own. However, in some areas we have become aware of comparable work performed by others which met our acceptability criteria and achieved our objective of providing a good foundation for the service areas in question on which stakeholders could build. Given the availability of finite resources and the need for us to focus in areas where there were no models, we did no further work in these areas. We present their results in the same style as our own. Below we identify the areas in question and acknowledge their sources:

Water service (W1) – when the CMA made its determination of Bristol Water's price controls in 2015 it set aside the models Ofwat had used in favour of a new set of botex models which it built specifically for the purpose. The results we present for the water service use these models, which we have successfully recreated.

Retail (R1-R5) – In February 2017 Ofwat presented a suite of models it had developed for Household Retail (R1), Bad Debt and Debt Management (R2) and Meter Reading (R3). We have used these models and supplemented them with our own for Customer Services (R4) and Other Retail costs (R5).

4. Independent review of our work

Except where stated above, the work presented in this report has been carried out in-house by Anglian Water employees. We recognised the value that could be obtained from appointing an independent, academic econometrician to assess what we have produced so far and provide direction to its future development. Following competitive tender, we appointed a team led by Professor David Saal to this role.

Professor Saal is Co-Director of the Centre for Productivity and Performance at Loughborough University where he was previously Head of the Economics department. He has twenty years of experience in the academic and regulatory application of cost modelling to the water industry and has published a significant number of widely cited academic papers employing cost and other performance measurement techniques to English and Welsh data. The other members of the team are Dr Alessandra Ferrari and Dr Maria Nieswand, who are both also members of CPP.

The terms of reference for Professor Saal's team were to -

- Provide an opinion on the validity of the approach followed and to whether the conclusions of the AWS report are supported by the models
- Suggest areas in which the approach followed could be strengthened.

We will incorporate the challenges and suggestions made by Professor Saal and his team in the next phase of our work.

5. Summary of results

We publish a summary of the results of all our modelling work in a common format in the tables which follow section 7. The detailed description of our work in each area is set out in Annexes 1 – 12.

Lines in each table show the range of variances between actual and modelled expenditure for all modelled companies. The way we calculated these variances is by 'hindcasting' the level of expenditure predicted by the model for each company for the modelled years. That is, we use the relationship described by the model on the basis of the data for the whole industry to tell us how much an individual company 'ought' to have spent. The hindcast figure represents the expected expenditure of a company from the model.

We then compare this modelled hindcast with the company's actual expenditure for the same period. Companies whose expenditure is lower than the modelled hindcast show a positive variance while those spending more show a negative variance. In the Annexes we include charts which show the range of variances.

Mathematically, the equation for this calculation is:

(modelled expenditure minus actual expenditure) / modelled expenditure x 100

The result is expressed as a percentage.

Positive variances can be attributable to model error (the model does not predict well the expected level of expenditure), efficiency or a combination of the two. Likewise, negative variances can be attributable to model error, inefficiency or a combination of the two. We make no comment in this report about companies' relative efficiencies and neither do we attribute variances to named companies.

In the tables we also include an assessment of the robustness of the models for each service area. These are our subjective assessments, based on the statistical tests for the models and our confidence in their engineering logic. We have included them because we think it is helpful for guiding those areas where more modelling work may be required or more attention should be paid to data quality.

It is also consistent with our view that the dependence on a model's results should be informed by its quality. While we may be confident about using the results from good models for decision-making, we should be prepared to supplement, or entirely replace, the evidence from poor models with evidence from other sources.

6. Conclusions and next steps

The purpose of our modelling work has been to evaluate whether an econometric approach can provide robust and valuable evidence to support conclusions about historical relative efficiency and future expenditure needs. On the basis of the work we have done so far, the results of which we have presented in this report, we conclude that the answer to that question is positive. The quality of our models is variable but we rate the majority of them to be adequate or better. The service areas covered by models which we rate to be less than adequate account for, at most, 5% of the botex for the price control areas of which they form a part.

Despite this promising start to our work, we remain vigilant to the prospect that cost models on their own may not provide the answers to the challenges we face. In most cases, evidence from them will need to be supplemented – or at least cross-tested – using evidence from other sources. Once cost models are finalised, *ex post* adjustments may be necessary to cater for factors which were not suitable for modelling. These might include cost drivers which are specific to an individual company and adjustments to reflect differing levels of service. Our cost models assume uniform service quality between the companies but better performing companies deserve allowances for the investments they may have made to achieve their higher service levels.

On the basis of our positive conclusion about modelling, we intend to continue with model development. We now have access to a substantial set of new financial and non-financial data which all water companies reported in July 2017. We will test our preferred models against these new datasets to examine how they continue to perform. We will also test other ideas that occurred to us during the project to date. Finally, we will act on the advice and recommendations of our academic peer reviewer about how our modelling could be improved.

We invite the opinions of other stakeholders on our work to date. Within the water companies, economic regulator, academe and consultants sits a substantial body of expertise on the subjects covered by this report and we welcome the thoughts and feedback from all. Our mailbox, Regulation@anglianwater.co.uk, can be used for this purpose.

We plan that the next phase of our modelling will continue from now until the end of 2017. We intend to publish an update to our work in spring of 2018.

7. A final thought

It is a truism that the quality of econometric models is constrained by the quality of the data which they incorporate. Our modelling work has provided evidence to support that view that further improvements in data quality are required. For example, we found that large variances between companies in the results of the individual Raw Water Distribution and Water Resources models were significantly reduced when the results were combined, suggesting differences between companies in the way they allocate costs across that boundary. We saw similar differences across the granular retail models which were substantially reduced on consolidation.

These observations remind us of the need of relevant stakeholders to continue focusing on data consistency. The key responsibility lies with companies and their assurance providers but Ofwat also has a role to play in mediating discussions about differences, maintaining sufficiently detailed reporting requirements and incentivising compliance. This is particularly important as we move towards a regulatory framework that puts more financial weight on relative performance.

Service area	W1 Water service
Number of models passing acceptability criteria	7
Modelled cost	Botex for the water service, excluding rates, pension deficit repair costs and third party costs, smoothed over 5 years to 2012-13 and unsmoothed over 7 years to 2012-13
Cost drivers used in acceptable models	• Water delivered • Regional wages • Number of connected properties • Length of potable water mains • % of distribution input from rivers • % of distribution input from reservoirs • Average pumping head • % of water consumed by metered non-households • % of distribution input treated to W3 or W4 standards • Time dummy variables
Other cost drivers tested	• None – discarded models varied in their statistical form rather than their choice of cost drivers
Largest positive variance (where actual expenditure is most below modelled expenditure)	+15.7%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-27.2%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	5
Comments	These models were built by the Competition and Markets Authority for determining Bristol Water's price controls in 2015 and our work has been confined to recreating them. Unlike our approach in other areas, these models were triangulated arithmetically, as was the case at PR14 (and, as far as we can tell, by the CMA) The CMA favoured unit cost models which have lower R^2 values than aggregate models (given the additional variability from the denominator). For this reason, the adjusted R^2 element of our acceptability criteria was omitted.
Detailed description	Annex 1

Service area	W2 Water Resources
Number of models passing acceptability criteria	4
Modelled cost	Botex for Water Resources, excluding rates, abstraction licence fees and exceptional items; three years to 2015-16 unsmoothed
Cost drivers used in acceptable models	• Abstracted volume • Licensed abstraction volume • Average pumping head for water resources • Distribution input • Water Scarcity Index • Density • % distribution input from different source types (river, groundwater, etc.) • Number of sources • Aggregate reservoir capacity • Power used in water resources
Other cost drivers tested	• Average volume per source type • Regional wages • Licensed area served by the company
Largest positive variance (where actual expenditure is most below modelled expenditure)	+26.3%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-97.9%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	We note that the variability of results reduces when W2 Water Resources and W4 Raw Water Distribution are combined, suggesting that there may be a mis-allocation of costs (probably power) between these two business units.
Detailed description	Annex 2

Service area	W3 Water Network Plus
Number of models passing acceptability criteria	5
Modelled cost	Botex for Network Plus activities, excluding rates, third party costs and exceptional items, unsmoothed costs for three years to 2015-16
Cost drivers used in acceptable models	• Length of potable water mains • % of potable mains laid before 1940 • % of potable mains laid after 2000 • Distribution input • Length of non-potable water mains • % of distribution input from surface water • % of distribution input from ground water • Number of water treatment works • Sparsity • Density • Average passing distance • Regional wages • Time trend • Volume of leakage • Volume of non-potable water supplied • Length of raw water mains • Length of potable mains repaired or replaced
Other cost drivers tested	• Average size of water treatment works • Percentage of properties metered • Volume of leakage below the sustainable economic level, as a % of distribution input
Largest positive variance (where actual expenditure is most below modelled expenditure)	+16.7%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-20.3%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 3

Service area	W4 Raw Water Distribution
Number of models passing acceptability criteria	5
Modelled cost	Botex for raw water distribution, excluding rates, third party costs and exceptional items, unsmoothed costs for three years to 2015-16
Cost drivers used in acceptable models	• Volume of raw water transported • Length of raw water mains • Licensed area served by the company • Sparsity • Time trend • % distribution input from rivers • % distribution input from boreholes • Volume of water abstracted as a % of licensed volume
Other cost drivers tested	• Water stress index • Density • Regional wages
Largest positive variance (where actual expenditure is most below modelled expenditure)	+72.0%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-244.6%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	2
Comments	This is the smallest business unit of the water service, representing only 3% of botex. There are very few variables which are specific to it and data on those to date are sparse or absent. These factors account for the low quality of the models. We note that the variability of results reduces when W2 Water Resources and W4 Raw Water Distribution are combined, suggesting that there may be a mis-allocation of costs (probably power) between these two business units.
Detailed description	Annex 4

Service area	W5 Water Treatment
Number of models passing acceptability criteria	3
Modelled cost	Botex for water treatment, excluding rates, third party costs and exceptional items, unsmoothed costs for three years to 2015-16
Cost drivers used in acceptable models	• Regional population • Average pumping head for water treatment • Volume of water abstracted • Number of surface water WTWs • Number of ground water WTWs • Sparsity • Regional wages
Other cost drivers tested	• Surface water volume index • Ground water volume index • Density • Average volume supplied from surface water WTWs • Average volume supplied from ground water WTWs • Time series • % of population receiving water treated with orthophosphate • Licensed area served by the company
Largest positive variance (where actual expenditure is most below modelled expenditure)	+34.7%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-58.1%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	
Detailed description	Annex 5

Service area	W6 Treated Water Distribution
Number of models passing acceptability criteria	5
Modelled cost	Botex for treated water distribution, excluding rates, third party costs and exceptional items, unsmoothed costs for three years to 2015-16
Cost drivers used in acceptable models	• Length of potable mains • Average passing distance • Sparsity • Density • Time trend • Licensed area served by the company • Average pumping head for treated water distribution • Distribution input • Leakage volume • Length of mains replaced and renewed • Age of mains
Other cost drivers tested	• Number of households served • Volume of non-potable water delivered • Volume of leakage below the sustainable economic level, as a % of distribution input • Regional wages
Largest positive variance (where actual expenditure is most below modelled expenditure)	+6.7%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-15.4%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 6

Service area	S1 Water Recycling service
Number of models passing acceptability criteria	4
Modelled cost	Botex for all wholesale water recycling services, excluding rates, third party costs and exceptional items, unsmoothed costs for five years to 2015-16
Cost drivers used in acceptable models	• Total length of sewers including lengths transferred under s.105A of the Water Industry Act in 2011 • Sludge produced, in tonnes of dry solids • Load treated by WRCs, measured in population equivalent, p.e. • Number of properties connected to the sewerage system (household and non-household) • % of total waste water load treated at WRCs in bands 1-3 (serving up to 2,000 p.e.) • Work done in transporting sludge • Sparsity • % of sludge which has to be transported from WRC to STC • % of load treated at WRCs with a consent standard for phosphorus of 1mg/l or less • % of load treated at WRCs with a consent standard for BOD of 10mg/l or less • Average WRC size • Length of sewers repaired or renewed • Length of sewers by age cohort
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+3.5%
Largest negative variance (where actual expenditure is most above modelled expenditure)	- 4.9%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 7

Service area	S2 Water Recycling Network Plus
Number of models passing acceptability criteria	4
Modelled cost	Botex for all wholesale water recycling services less bioresources, excluding rates, third party costs and exceptional items, unsmoothed for five years to 2015-16
Cost drivers used in acceptable models	• Load treated by WRCs, measured in population equivalent, p.e. • % of total waste water load treated at WRCs in bands 1-3 (serving up to 2,000 p.e.) • Total length of sewers including lengths transferred under s.105A of the Water Industry Act in 2011 • Sparsity • Density • Time trend • Total volume of wastewater treated
Other cost drivers tested	• Total volume of trade effluent treated
Largest positive variance (where actual expenditure is most below modelled expenditure)	+20.3%
Largest negative variance (where actual expenditure is most above modelled expenditure)	- 28.1%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	
Detailed description	Annex 8

Service area	S3 Bioresources
Number of models passing acceptability criteria	3
Modelled cost	Botex for bioresource management, excluding rates, third party costs and exceptional items, unsmoothed for five years to 2015-16. Revenues from sale of power generated from biogas and revenues from treated digestate netted off as negative costs.
Cost drivers used in acceptable models	• Sludge produced, in tonnes of dry solids • Sparsity • Density • Licensed area served by the company for water recycling • Work done in transporting biosolids from STCs to recycling destination • % of sludge which has to be transported from WRC to STC
Other cost drivers tested	• Work done in transporting sludge from WRCs to STCs • % of sludge treated by advanced anaerobic digestion • Regional wages • Time trend
Largest positive variance (where actual expenditure is most below modelled expenditure)	+11.6%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-24.2%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	Data quality of the amount of sludge produced was still questionable in the October Submission, though it may have ben addressed in the 2017 Information Request following work by the industry on a common basis of measurement
Detailed description	Annex 9

Service area	S4 Water Recycling Collection
Number of models passing acceptability criteria	5
Modelled cost	Botex for wholesale waste water collection services, excluding rates, third party costs and exceptional items, unsmoothed costs for five years to 2015-16
Cost drivers used in acceptable models	• % of total waste water load treated at WRCs in bands 1-3 (i.e. serving up to 2,000 p.e.) • Length of sewers by age cohort • Sparsity • Time trend • Licensed area served by the company for water recycling • Volume of waste water collected • Total length of sewers including lengths transferred under s.105A of the Water Industry Act in 2011 • Total pumping station capacity • Length of sewers in oldest two (pre-1900) and youngest two (post-1980) cohorts, as % of total sewer length • Length of sewers in oldest two (pre-1900) cohorts, as % of total sewer length • Average passing distance
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+0.3%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-1.7%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	Pumping station capacity is recognized as endogenous. Used as a proxy control variable to take account of WaSC geography.
Detailed description	Annex 10

Service area	S5 Water Recycling Treatment
Number of models passing acceptability criteria	4
Modelled cost	Botex for wholesale waste water treatment, excluding rates, third party costs and exceptional items, unsmoothed costs for five years to 2015-16
Cost drivers used in acceptable models	• Total load served by WRCs measured by population equivalent, p.e. • Average WRC size • Tightness of consent standards for BOD, phosphorus and ammonia • Sparsity of the population served • Density of the population served • Licensed area served by the company for water recycling • Proportion of total load treated at Band 6 WRCs (serving catchments with p.e.>25,000) • Proportion of total load treated at WRCs with tertiary treatment
Other cost drivers tested	• Proportion of total load treated at Band 1-3 WRCs (serving catchments with p.e.<2,000)
Largest positive variance (where actual expenditure is most below modelled expenditure)	+3.1%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-8.7%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 11

Service area	S6 Sludge Transport
Number of models passing acceptability criteria	7
Modelled cost	Botex for sludge transport, excluding rates, third party costs and exceptional items, unsmoothed for five years to 2015-16
Cost drivers used in acceptable models	• Sparsity of the population served • Density of the population served • Licensed area served by the company for water recycling • Time trend • Work done in transporting sludge from WRCs to STCs • % of sludge which has to be transported from WRC to STC
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+15.8%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-19.6%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 9

Service area	S7 Sludge Treatment
Number of models passing acceptability criteria	4
Modelled cost	Botex for sludge treatment, excluding rates, third party costs and exceptional items, unsmoothed for five years to 2015-16. Revenues related to power generation from biogas are netted off.
Cost drivers used in acceptable models	• Licensed area served by the company for water recycling • Sludge produced, in tonnes of dry solids • % sludge treated by process (untreated, liming, conventional AD, advanced AD, incineration, phyto-conditioning/ composting) • Energy used on sludge treatment • Sparsity • Density • Regional wages • Time trend
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	-0.3%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-25.3%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	
Detailed description	Annex 9

Service area	S8 Sludge Disposal
Number of models passing acceptability criteria	5
Modelled cost	Botex for transport and recycling of treated biosolids, excluding rates, third party costs and exceptional items, unsmoothed for five years to 2015-16. Revenues from sales of biosolids are netted off.
Cost drivers used in acceptable models	• Total biosolids recycled, measured as tonnes of dry solids • Licensed area served by the company for water recycling • Sparsity • Density • Time trend
Other cost drivers tested	• Proportion of biosolids by recycling destination (land reclamation, farmland, other) • Work done in transporting biosolids from STCs to recycling destination • Regional wages
Largest positive variance (where actual expenditure is most below modelled expenditure)	+23.8%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-116.7%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	
Detailed description	Annex 9

Service area	R1 Household Retail service
Number of models passing acceptability criteria	2
Modelled cost	All base expenditure on household retail activities, over four years to 2015-16. Unlike the rest of our models, the modelled costs were in price of the day rather than 12-13 prices.
Cost drivers used in acceptable models	• Average household bill • Humber of households
Other cost drivers tested	• None – the rejected model differed in form rather than its choice of drivers
Largest positive variance (where actual expenditure is most below modelled expenditure)	+26.4%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-29.9%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	These models were created by Ofwat. Given the small number of models used, we aggregated their results by simple averaging rather than the quality-weighted technique we used in wholesale models.
Detailed description	Annex 12

Service area	R2 Doubtful Debt and Debt Management
Number of models passing acceptability criteria	2
Modelled cost	The charges for doubtful debts plus all costs relating to the management of debt recovery for appointees' household customers, over four years to 2015-16. Unlike the rest of our models, the modelled costs were in price of the day rather than 12-13 prices.
Cost drivers used in acceptable models	• Total revenue • Index of Multiple Deprivation
Other cost drivers tested	• Regional unemployment rate choice of drivers
Largest positive variance (where actual expenditure is most below modelled expenditure)	+38.9%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-51.3%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	These models were created by Ofwat. Given the small number of models used, we aggregated their results by simple averaging rather than the quality-weighted technique we used in wholesale models.
Detailed description	Annex 12

Service area	R3 Meter Reading
Number of models passing acceptability criteria	2
Modelled cost	All costs associated with meter reading for appointees' household customers, over four years to 2015-16. Unlike the rest of our models, the modelled costs were in price of the day rather than 12-13 prices.
Cost drivers used in acceptable models	• Number of metered household customers • Sparsity • Density
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+84.6%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-56.2%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	2
Comments	These models were created by Ofwat. Given the small number of models used, we aggregated their results by simple averaging rather than the quality-weighted technique we used in wholesale models.
Detailed description	Annex 12

Service area	R4 Customer Services
Number of models passing acceptability criteria	2
Modelled cost	The costs associated with providing the following services for the appointee's household customers: billing, payment handling, remittance and cash handling, charitable trust donations, vulnerable customer schemes, customer enquiries and complaints. Total base costs over four years to 2015-16. Unlike the rest of our models, the modelled costs were in price of the day rather than 12-13 prices.
Cost drivers used in acceptable models	• Number of household customers
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+31.6%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-63.6%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	Given the small number of models used, we aggregated their results by simple averaging rather than the quality-weighted technique we used in wholesale models.
Detailed description	Annex 12

Service area	R5 Other Retail
Number of models passing acceptability criteria	2
Modelled cost	All other retail costs not modelled in R2-R4, over four years to 2015-16. Unlike the rest of our models, the modelled costs were in price of the day rather than 12-13 prices. Costs include provision of offices, insurance premiums, net retail expenditure on demand-side water efficiency initiatives and customer side leaks, other direct costs, general and support expenditure, local authority rates and other business activities. This category also includes depreciation.
Cost drivers used in acceptable models	• Number of household customers
Other cost drivers tested	• None
Largest positive variance (where actual expenditure is most below modelled expenditure)	+38.3%
Largest negative variance (where actual expenditure is most above modelled expenditure)	-59.6%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	Given the small number of models used, we aggregated their results by simple averaging rather than the quality-weighted technique we used in wholesale models.
Detailed description	Annex 12

Glossary

AD	Anaerobic digestion, a process widely used for treating sludge
R^2	Coefficient of determination: the proportion dependent variable that is predictable from the independent variables.
AIC	Akaike Information Criterion measures the relative quality of statistical models for a given data set. A lower figure represents a better model
Average passing distance	Length of pipe (water main or sewer) per connected property, a well established measure of network intensity
BIC	Bayesian Information Criterion, similar in form to the AIC. Less well viewed from a theoretical perspective
BOD	Biological Oxygen Demand, a measure of the polluting potential of water
Cobb Douglas (CD)	Cost function of the form $Y=x_1^{\beta 1}\ x2^{\beta 2} \ldots xn^{\beta n}$ or $\ln(Y) = \beta_1\ln(x_1) + \beta_2\ln(x_2) + \ldots + \beta_n\ln(x_n)$
Cost Assessment Working Group	Ofwat Working Group of industry representatives, set up early 2016
GAAP	Generally Accepted Accounting Practice
Heteroskedasticity	A problem in regression analysis where error terms are correlated with an independent variable.
Hindcast	The sum of expected values produced by model for the historical years which have been modeled. It can be regarded as the sum of money which the model says an averagely efficient company would have spent for the years in question.
IFRS	International Financial Reporting Standards
LSOA	Lower Super Output Area – a very small geographical sub-division, typically comprising around 600 properties
Multicollinearity	In regression analysis, where two or more independent variables are highly correlated.
OLS	Ordinary Least Squares, the entry-level form of regression analysis
ONS	Office of National Statistics
Panel data	Data sets comprising observations of multiple phenomena obtained over multiple time periods for the same firms or individuals.
PR14, PR19	Quinquennial Price Reviews carried out by Ofwat culminating in 2014 and 2019
SOC	Standard Occupational Category
STC	Sludge treatment centre
WASC	Water and Sewerage Company – one of the ten companies providing both water and sewerage services
WOC	Water Only Company – one of the eight companies providing water services only
WRC	Water recycling centre, known elsewhere as a sewage treatment works (STW) or a waste water treatment works
WTW	Water treatment works
Model performance (for annexes)	
1	>99% confidence limit on coefficient
5	>95%-99% confidence limit on coefficient
10	90%-95% confidence limit on coefficient
20	80%-90% confidence limit on coefficient
⊠	<80% confidence limit on coefficient
+	Positive coefficient
-	Negative coefficient

Appendix 1: Cost Modelling Report Context

1. Background

The purpose of this Appendix is to put the analysis of the individual wholesale Business Units plus Household Retail costs into an overall context. It highlights the scale of the different Business Units and the relative importance of the different elements of botex and totex.

The analysis is based on analysis of the August 2016 and October 2016 data submissions to Ofwat for Water and Water Recycling respectively. These data covered the following periods: for three years to 2016 for wholesale Water; for five years to 2016 for wholesale Water Recycling; and for four years to 2016 for Household Retail. They were collated and made available to WaSCs and WoCs by Ofwat through its Share-point drive. The data are taken from the most recent files made available, that is to say Master data – 20161207.xls for water; Master waste HC 20161221.xls for wastewater; and Ofwat HH Retail dataset 20170313.xls for Household Retail. The Water data entries for Affinity Water were corrected (using Affinity's data submission file made available by Ofwat) in the Master data file where they had become corrupted.

2. Definitions

During 2016, Ofwat worked together with appointed water industry companies to develop an agreed approach to cost modelling at PR19. This was done within the Cost Assessment Working Group (CAWG).

At PR14, the econometric models excluded a number of costs which were deemed beyond the control of the industry. We have followed the same approach.

The PR14 econometric models took the following approach to totex costs:

- Operational expenditure *excluding*
    - o Third Party Opex
    - o Local Authority Rates

+

- Capital Maintenance

+

- Capital Enhancement net of
    - o Third Party Capex
    - o Grants & Contributions

PR14 also introduced the concept of base totex. Within this report, we refer to base totex as botex. Botex excludes capital enhancement from totex. So the costs we have modelled include:

- Operational expenditure *excluding*
    - o Third Party Opex
    - o Local Authority Rates

+

- Capital Maintenance

In all of the tables and graphs for wholesale water and water recycling, all costs quoted are in 2012-13 cost base, in line with the approach taken by Ofwat in the run-up to PR19.

3. Water

Within its Regulatory Accounting Guidelines (RAGs), Ofwat has defined four water Business Units. These are Water Resources (WR), Raw Water Distribution (RWD), Water Treatment (WT) and Treated Water Distribution (TWD). The precise definitions and boundaries for the Business Units are set out in RAG 4.

Table A1 sets out the various elements of cost included in botex and totex for the four water Business Units. Botex covers six of the first seven columns of costs, highlighted in gold. The final two categories of cost on the right of the table, highlighted in orange, make up capital enhancement. These, along with botex, make up totex.

Table A1: Components of Water Botex and Totex

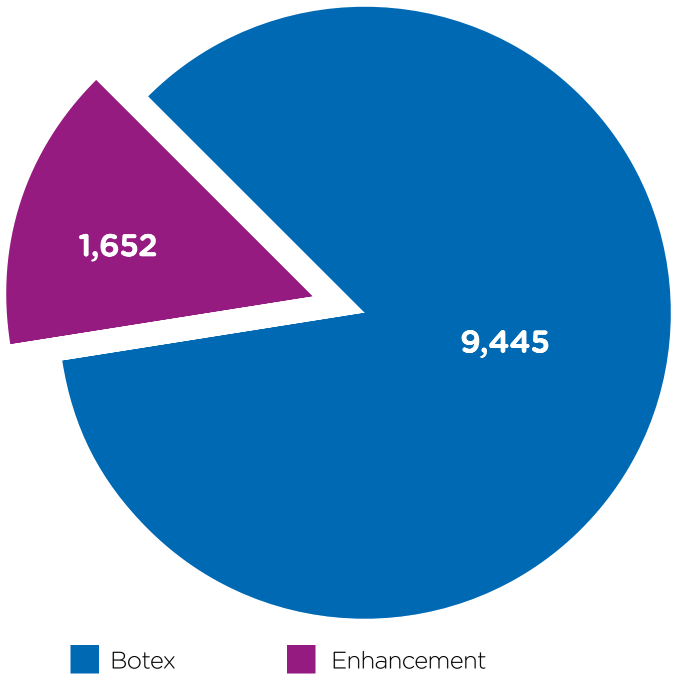
£m	Power	Service charges/ discharge consents	Bulk supply/ Bulk discharge	Other opex	Local authority rates	Capital maintenance - infra	Capital maintenance - non-infra	Other capex - infra	Other capex - non-infra
WR	161	295	47	284	104	70	138	42	126
RWD	83	1	0	86	65	60	28	35	14
WT	369	5	45	1,029	169	-2	1,179	1	481
TWD	276	1	5	1,738	721	1,554	933	475	478
Total	888	302	98	3,137	1,059	1,682	2,278	552	1,100

Source: Ofwat 2016 data submission, Anglian Water analysis

Figures A1 – A7 show the aggregate costs for all WaSCs and WoCs incurred within Wholesale Water over the three year period to 31 March 2016. All costs shown in the Figures are in 2012-13 cost base and are shown in millions of pounds.

Figure A1 shows the split between botex and enhancement expenditure. Enhancement expenditure represents only 15% of totex. Botex, which we have modeled in all the work discussed in this report, represents 85% of industry expenditure for the water service. Henceforth we put enhancement expenditure and totex aside and the remainder of this section refers to botex only.

Figure A1: Industry-wide split between botex and enhancement capex for water



Source: Ofwat 2016 data submission, Anglian Water analysis

Appendix 1: Cost Modelling Report Context

Table A2 shows the botex totals for the four Water Business Units. It is a helpful starting point for putting water costs into context. Figure A2 displays the data in Table A2 in graphical form. In these and all of the subsequent Figures, the numbers on the pie charts represent the aggregate sums for the industry for each cost category in millions of pounds over the three years to 2015-16, all in 2012-13 cost base.

For the purpose of subsequent work developing cost models, we will be using the data collected from the industry in July 2017. This data set covers the six years from 2011-12 to 2016-17. All data are now in IFRS, whereas the current data are in a mix of UK GAAP and IFRS.

Table A2: Water Botex by Business Unit

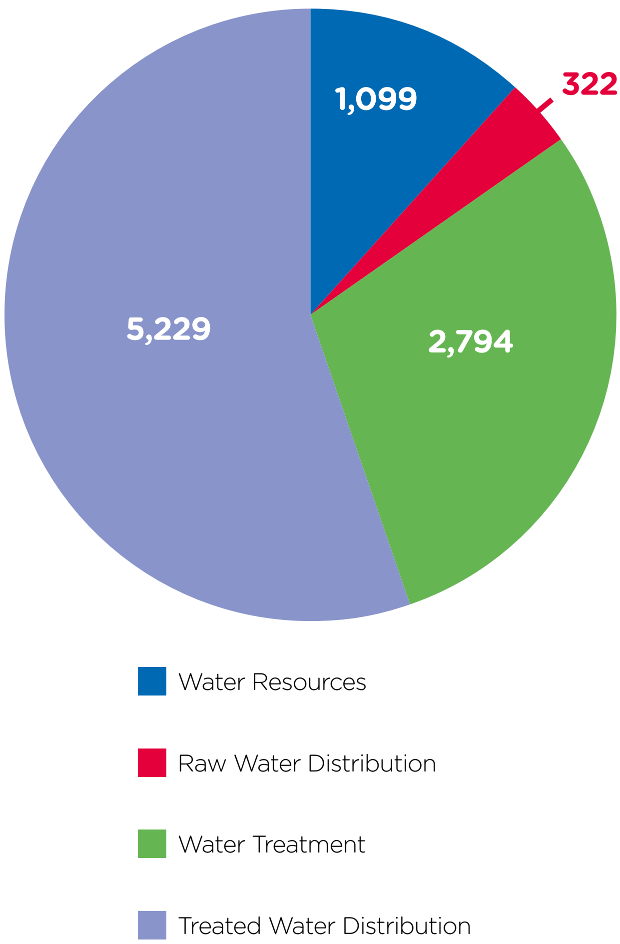
£m	Water Resources	Raw Water Distribution	Water Treatment	Treated Water Distribution
Botex	1,099	322	2,794	5,229

Source: Ofwat 2016 data submission, Anglian Water analysis

What is immediately apparent from looking at Table A2 and Figure A2 is that TWD accounts for more than half of the total Water costs. WT accounts for 30%, with WR and RWD together making up around 15% of botex.

At this moment, it is worth remembering that at PR19, there will be a separate cost assessment for WR (as there also will be for Bioresources on the Water Recycling side). The remaining three water Business Units are grouped together as Water Network Plus. From this it can be seen that the Water Network Plus cost assessment will account for over 85% of total Water botex.

Figure A2: Industry-wide Water Botex by Business Unit



Source: Ofwat 2016 data submission, Anglian Water analysis

Figures A3 to A7 set out the split of botex cost elements across all of the Water Business Units.

If the two elements of Capital Maintenance are taken together, they make up the largest individual cost element within botex. Together they account for 42% of botex. Costs within Capital Maintenance are predominantly staff costs (direct and HCS) and equipment repair or replacement costs.

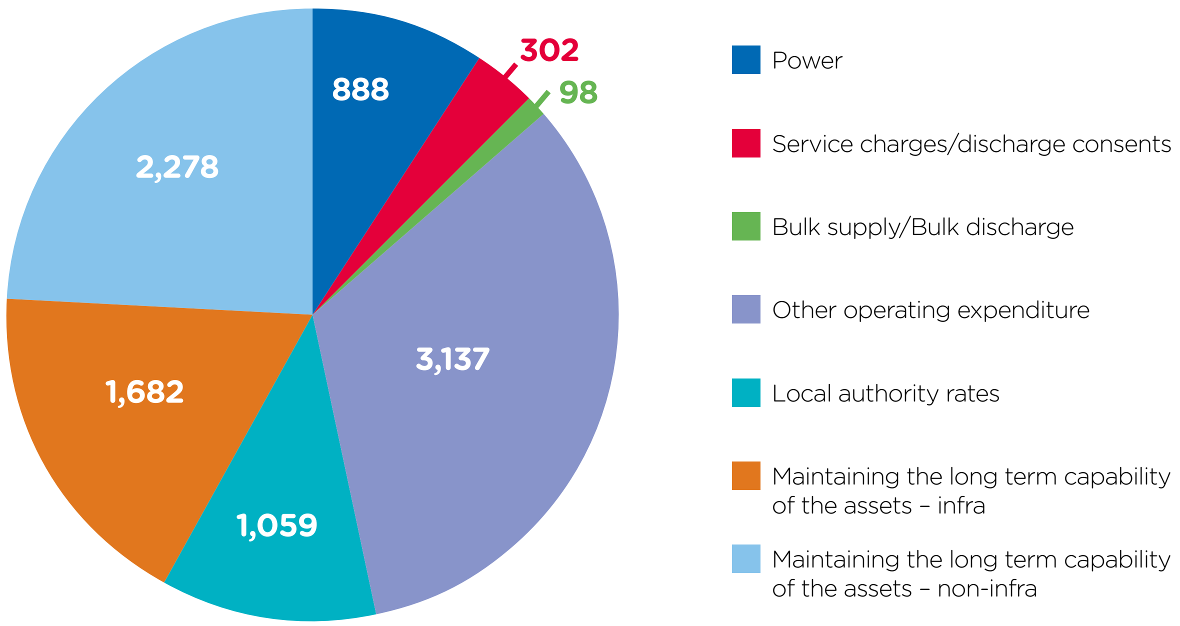
Local Authority Rates were excluded from the cost base at PR14 on the grounds that they could not be controlled by management. As can be seen, they represent 11% of botex.

The next largest cost included within botex is the other operating expenditure. This category includes direct and contract staff costs, transport costs, chemicals and equipment replacement as well as company overheads. This represents 33% of botex.

The final large cost element is for power. This represents just short of 10% of botex.

Service charges for water are the abstraction licence fees paid by companies to the Environment Agency. At 3%, they represent a small proportion of total water botex but they are more significant in the context of waster resources.

Figure A3: Industry-wide Water total Botex by cost category



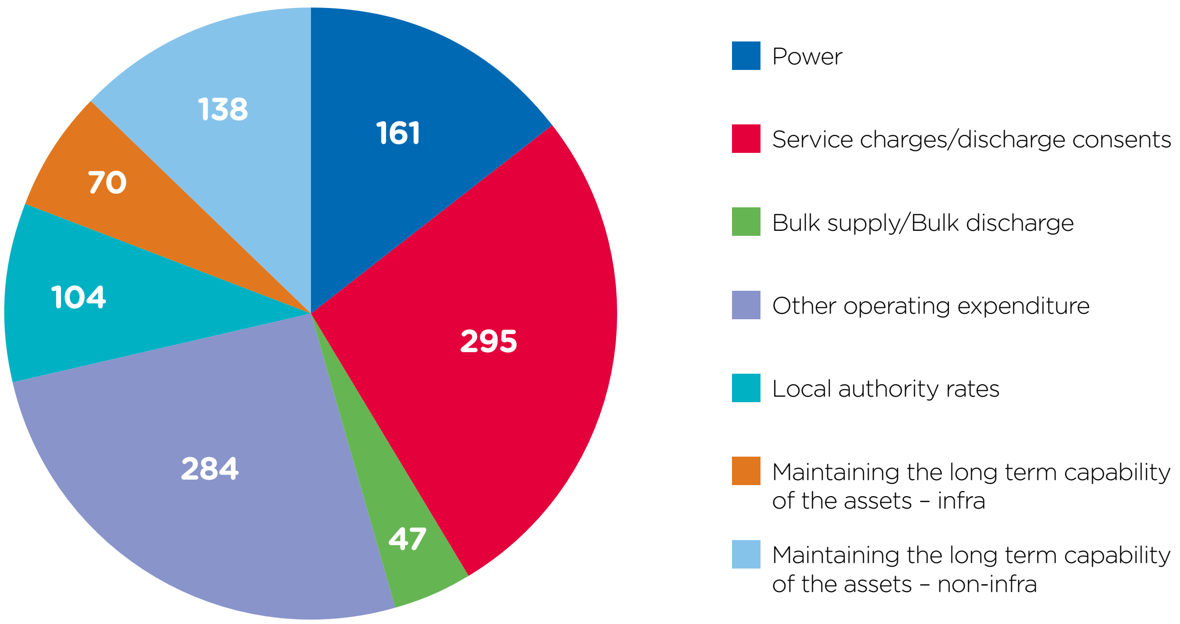
Source: Ofwat 2016 data submission, Anglian Water analysis

3.1. Water Resources

Figure A4 sets out the distribution of cost elements for Water Resources (WR). From Table A2, WR can be seen to represent 12% of water botex. Looking at the figure overleaf, the points to note are as follows:

- Capital Maintenance represents 19% of Water Resources botex
- For Water Resources, Local Authority rates (which were excluded at PR14 and also in our cost models) represent around 10% of botex
- It can be seen that the largest single element of botex for Water Resources is represented by Service Charges and Consents which represent 27% of botex. These are costs levied by the Environment Agency and do not relate directly to actual volume extracted. It has been argued that given that these costs are outside the control of management they too should be excluded from the cost base. Ofwat appeared to accept the logic of this case but has not given a definitive statement regarding their inclusion or exclusion. We consider that the case to exclude in the same way (and for the same reason) as Local Authority Rates is a strong one. In the cost modelling of Water Resources, we have excluded Service Charges from the cost base. Adding in local authority rates, it can be seen that we are excluding 36% of botex from our Water Resources cost models
- The next largest cost category is Other Operating Costs, accounting for 26% of botex
- Power is a higher proportion of Water Resources botex than for Water as a whole, representing 15%. Power is used principally for pumping water out of rivers and boreholes and into reservoirs.

Figure A4: Water Resources Industry-wide Botex



Source: Ofwat 2016 data submission, Anglian Water analysis

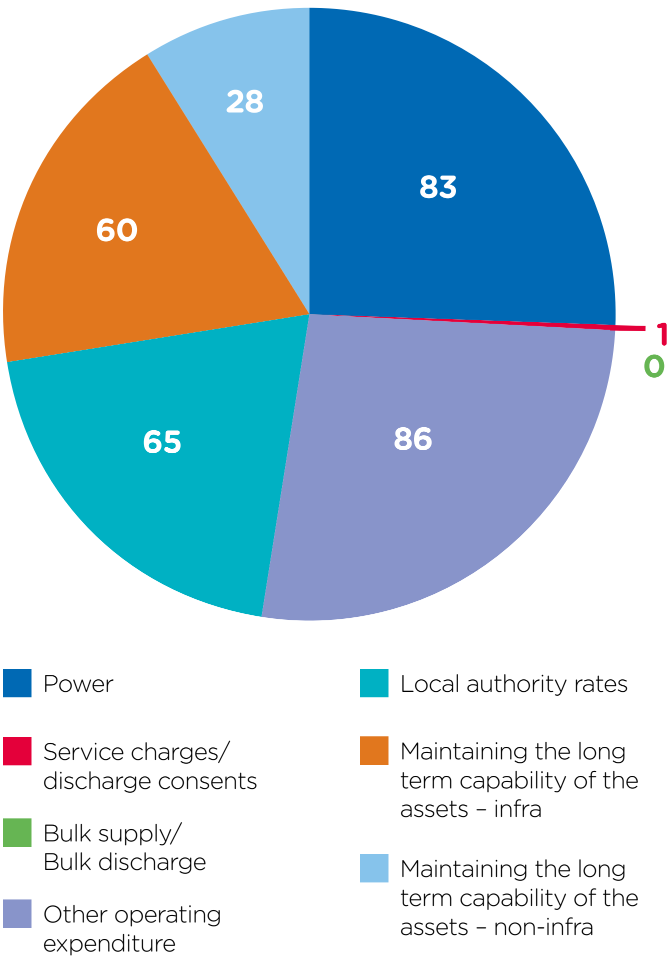
3.2. Raw Water Distribution

As can be seen from Table A2, Raw Water Distribution (RWD) is by far the smallest of the four Water Business Units, representing only 3% of total Water botex. Figure A5 sets out the split of RWD botex by cost categories. The key points to note are:

- Local Authority Rates represent 20% of botex
- Capital Maintenance is the largest individual cost category, with 28% of botex
- This is closely followed by Other Operating Costs (27%) and by Power (26%).

For us, and we believe for most other appointed companies, it is common for the power provided to WR and RWD (and in some cases Water Treatment as well) to be supplied through a single meter without any subsequent sub-metering. Power costs are then allocated between the different Business Units. The basis on which these costs are allocated is set out in RAG 4. However, the accuracy of such estimated disaggregation is open to question. The cost modelling we have carried out of WR and RWD strongly suggests that the overall quality of the split of costs in particular between WR and RWD is questionable.

Figure A5: Raw Water Distribution Industry-wide Botex



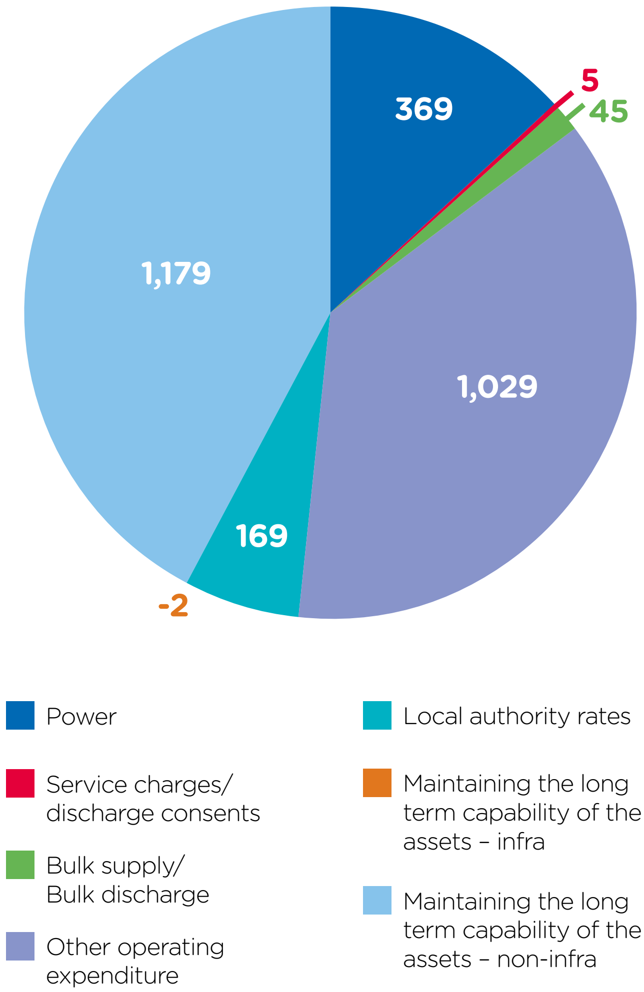
Source: Ofwat 2016 data submission, Anglian Water analysis

3.3. Water Treatment

From Table A2, Water Treatment can be seen to represent 30% of total Water botex. Figure A6 sets out the split of botex by cost categories. The key points to note are:

- Local Authority Rates represent 6% of botex for Water Treatment
- Capital Maintenance represents 42% of botex
- Other Operating Costs account for 37% of botex
- Power represents 13% of botex.

Figure A6: Water Treatment Industry-wide Botex



Source: Ofwat 2016 data submission, Anglian Water analysis

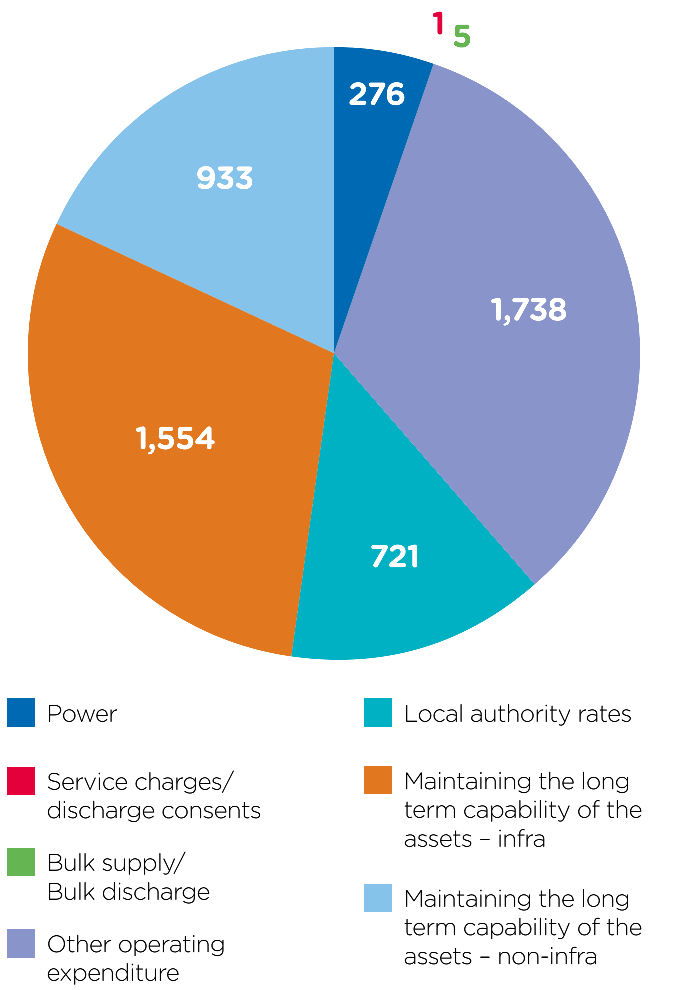
3.4. Treated Water Distribution

From Table A2, Treated Water Distribution (TWD) can be seen to be the largest single Water Business Unit. Representing around 55% of Water botex, it is in fact larger than the other three Water Business Units put together.

Figure A7 sets out the split of botex by cost categories. The key points to note are:

- Local Authority Rates represents 14% of botex
- TWD Capital Maintenance represents 48% of botex
- Industry-wide, TWD Power costs are well below the average for Water Business Units overall, at 5% of botex
- Other Operating Costs for TWD, including staff costs and transport represent 33% of botex for the Business Unit.

Figure A7: Treated Water Distribution Industry-wide Botex



Source: Ofwat 2016 data submission, Anglian Water analysis

4. Water Recycling

In line with our preferred terminology, in this report Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

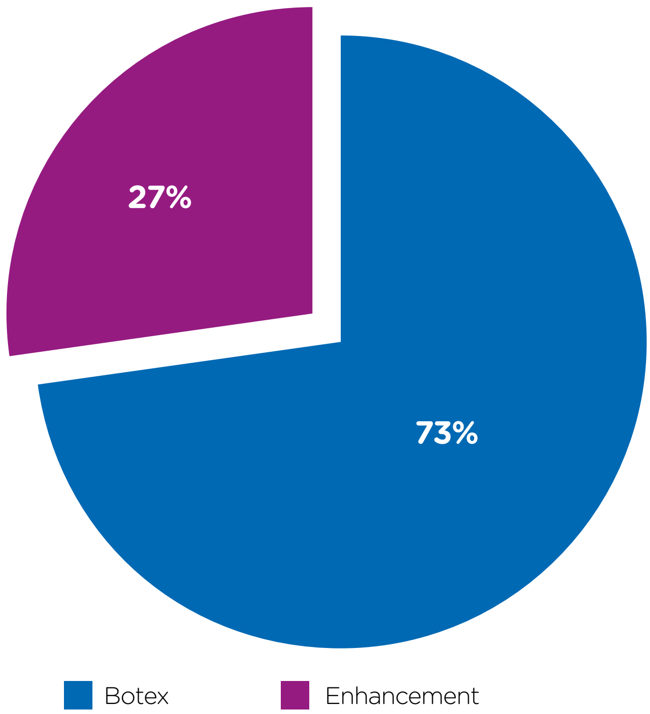
Within its Regulatory Accounting Guidelines (RAGs), Ofwat has defined five Wastewater Business Units. These are Water Recycling Collection, Water Recycling Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal. The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures A8-A16 show the aggregate botex costs incurred within Water Recycling over the five year period to 31 March 2016. All costs shown in the Figures are in 2012-13 cost base and are shown in millions of pounds.

Table A3 sets out the various elements of cost included in botex and totex for the five Water Recycling Business Units. Botex covers six of the first seven columns of costs, highlighted in gold. The final two categories of cost on the right of the table, highlighted in orange, make up capital enhancement. These, along with botex, make up totex.

Figure A8 shows the split between botex and enhancement expenditure. Enhancement expenditure represents 27% of totex. Botex, which we have modeled in all the work discussed in this report, represents 73% of industry expenditure for the water recycling service. Henceforth we put enhancement expenditure and totex aside and the remainder of this section refers to botex only.

Figure A8: Industry-wide split between botex and enhancement for Water Recycling



Source: Ofwat 2016 data submission, Anglian Water analysis

Table A3: Components of Water Recycling Botex and Totex

£m	Power	Service charges/ discharge consents	Bulk supply/ Bulk discharge	Other opex	Local authority rates	Maintenance capex - infra	Maintenance capex - non-infra	Other capex - infra	Other capex - non-infra
Water Recycling Collection	304	67	0	1,672	39	1,984	938	1,930	432
Water Recycling Treatment	912	171	2	1,994	700	22	3,162	40	2,312
Bio-resources total	-95	3	0	1,649	154	4	919	0	607
Sludge Transport	0	0	0	361	9	3	7	0	0
Sludge Treatment	-84	2	0	864	138	1	884	0	587
Sludge Disposal	-11	1	0	425	7	0	28	0	19
Total	1,120	240	2	5,315	892	2,009	5,019	1,970	3,350

Source: Ofwat 2016 data submission, Anglian Water analysis

Table A4 shows the botex totals for the five Water Recycling Business Units. It is a helpful starting point for putting water recycling costs into context. Figure A9 displays the data in Table A4 in graphical form. In these and all of the subsequent Figures, the numbers on the pie charts represent the aggregate sums for the industry for each cost category in millions of pounds over the five years to 2015-16, shown in 2012-13 cost base.

Table A4: Water Recycling Botex by Business Unit

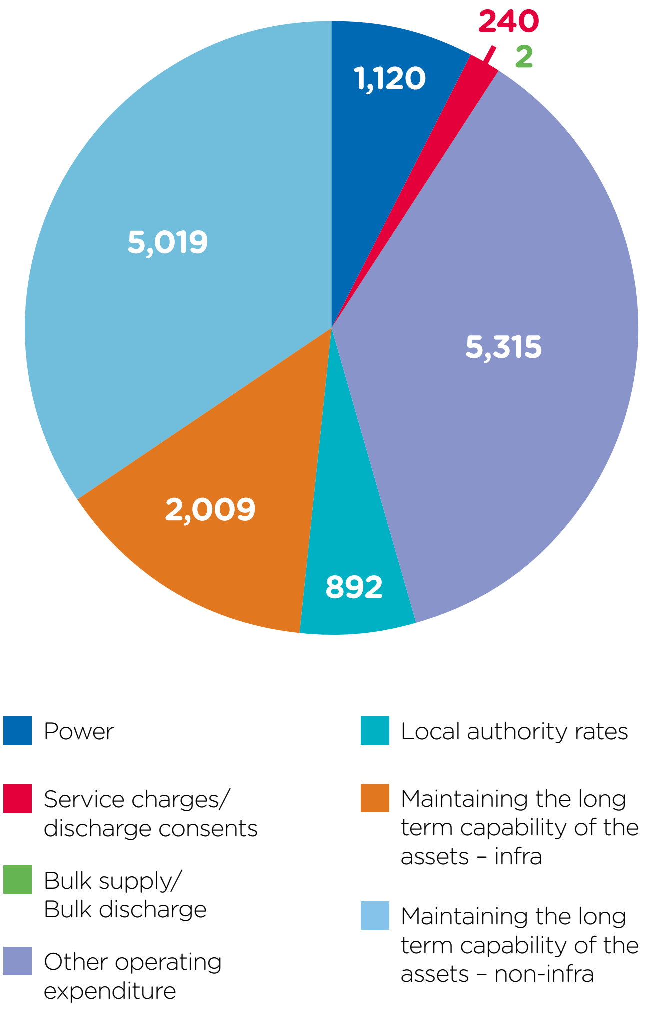
£m	Water Recycling Collection	Water Recycling Treatment	Bio-resources	Sludge Transport	Sludge Treatment	Sludge Disposal
Botex	5,003	6,961	2,635	380	1,805	449

Source: Ofwat 2016 data submission, Anglian Water analysis

The key points to note from Figure A9 are:

- At an industry level, Local Authority Rates represent 6% of botex. This is lower than for Water
- Capital Maintenance represents 48% of botex.
- The largest Water Recycling opex cost category is Other Operating Costs, covering principally staff costs, HCS, chemicals and transport. At 36% of botex, these are similar to the proportions for Water
- Power appears to represent a lower proportion of Water Recycling botex at 8%. It needs to be remembered that the Water Recycling Power number is attenuated by the generation of power by Bioresources, a revenue which is shown as a negative (power) cost. However, even after taking that into account, Water Recycling's share of botex represented by power is lower than for Water.

Figure A9: Industry-wide Water Recycling Total Botex by cost category



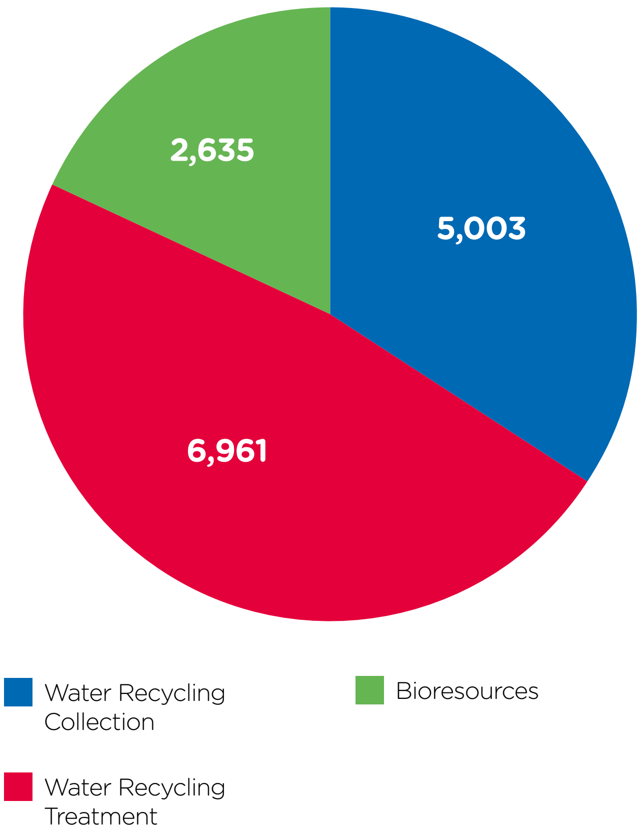
Source: Ofwat 2016 data submission, Anglian Water analysis

There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment – form Water Recycling's Network Plus price control. The other three – Sludge Transport, Treatment and Disposal – forms the Bioresources price control. In the following four Figures, we describe the relative size of the two cost controls and the shares of costs within each.

Looking at Figure A10, it can be seen that Water Recycling Network Plus accounts for 82% of botex for Water Recycling. Compared to Water, where Network Plus is dominated by TWD, the sizes of Water Recycling's Network Plus Business Units are relatively uniform.

The three business units making up the Bioresources price control account for 18% of Water Recycling botex. Of these, Sludge Treatment accounts for around 70%. Sludge Transport and Sludge Disposal are similar in size, each representing around 15% of sludge botex and 3% of overall Water Recycling botex.

Figure A10: Industry-wide Water Recycling Botex by Business Unit



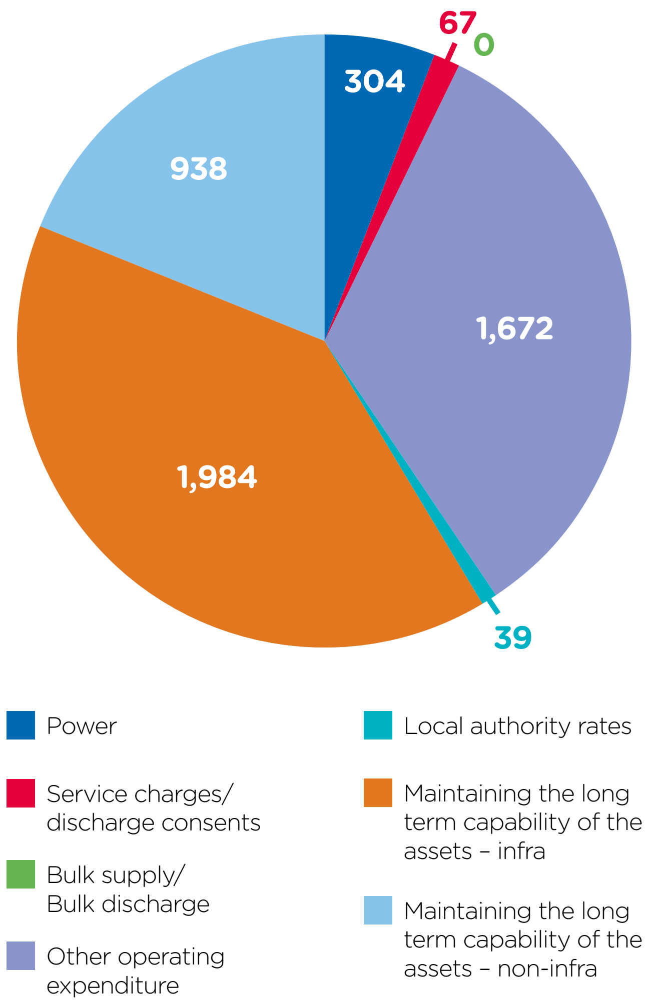
Source: Ofwat 2016 data submission, Anglian Water analysis

4.1. Water Recycling Collection

Figure A11 shows the split of Water Recycling Collection botex by cost categories. Key points to note are:

- Local Authority Rates account for only 1% of botex
- For Water Recycling Collection, Capital Maintenance accounts for 59% of botex
- The largest single opex cost category for Water Recycling Collection is Other Operating Expenditure at 33% of botex
- The only other significant cost component is power at 6% of botex, reflecting the pumping requirements of sewerage.

Figure A11: Water Recycling Collection Industry-wide Botex by cost category



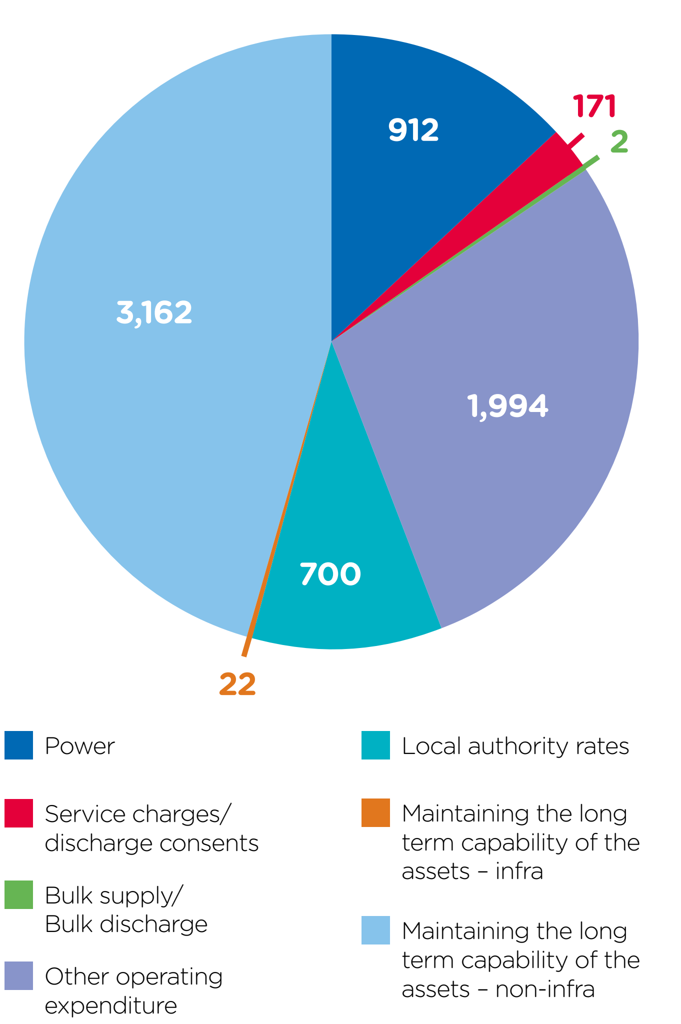
Source: Ofwat 2016 data submission, Anglian Water analysis

4.2. Water Recycling Treatment

Figure A12 shows the split of Water Recycling Treatment botex by cost categories. Key points to note are:

- Local Authority Rates account for 10% of botex for Water Recycling Treatment
- Capital Maintenance represents 45% of botex for Water Recycling Treatment
- Again, the largest opex cost category is Other Operating Cost at 29% of botex of Water Recycling Treatment
- Power is a significant element of Water Recycling Treatment costs at 13% of botex.

Figure A12: Water Recycling Treatment Industry-wide Botex by cost category



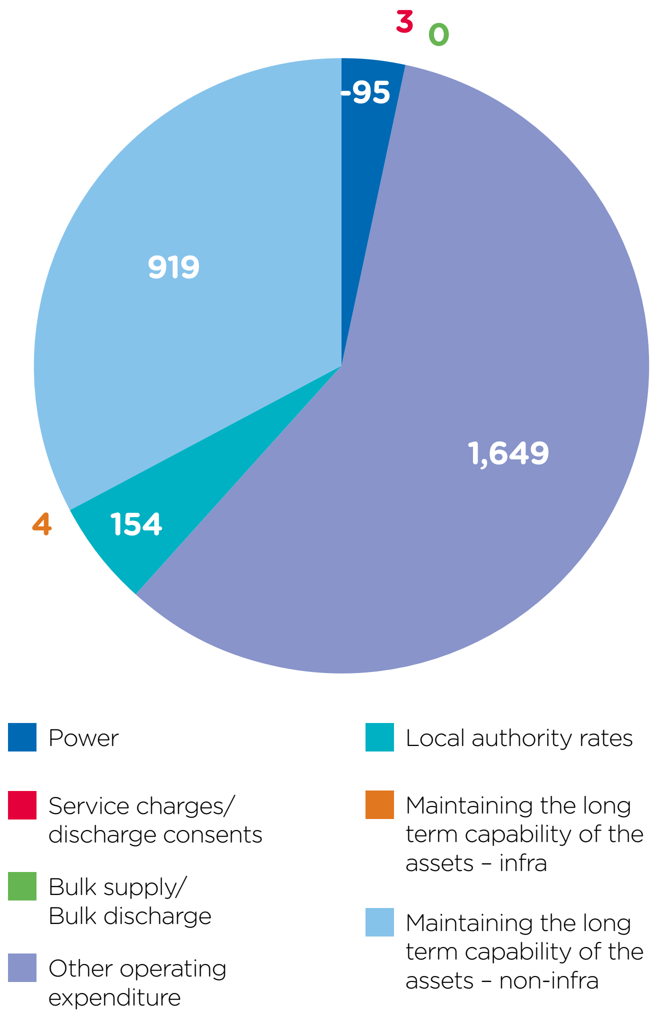
Source: Ofwat 2016 data submission, Anglian Water analysis

5. Bioresources

Figure A13 shows the split of total Bioresources botex by cost categories. Key points to note are:

- Local Authority Rates account for 5% of total Bioresources botex
- Capital Maintenance represents 33% of botex for the three Bioresources Business Units
- Other Operating Expenses represent 58% of botex for Bioresources overall
- Net power costs are -3% of botex.

Figure A13: Bioresources Industry-wide Botex by cost category

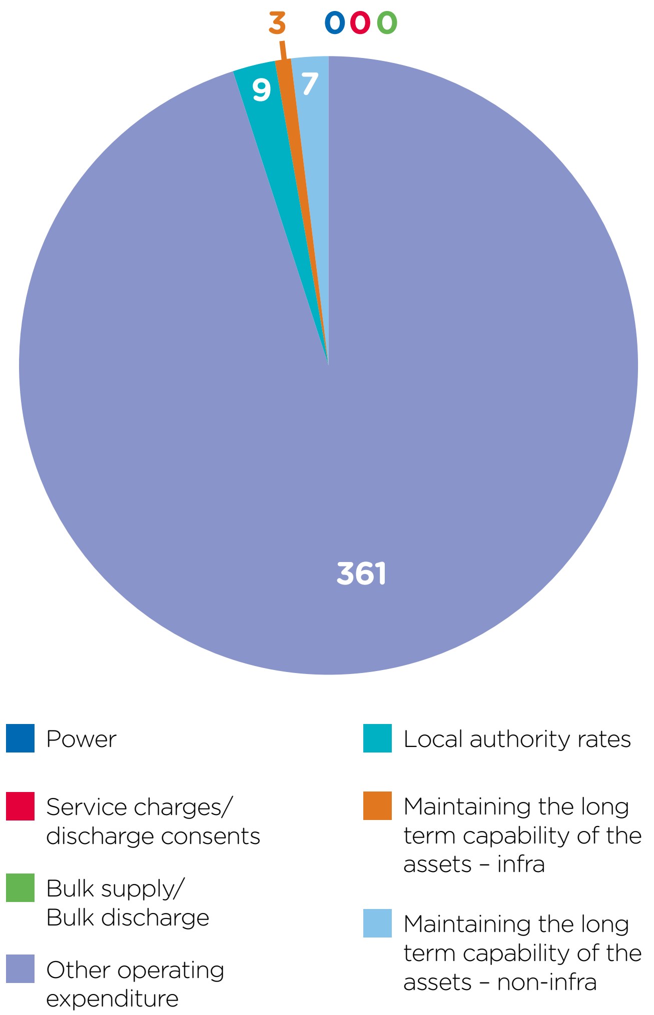


Source: Ofwat 2016 data submission, Anglian Water analysis

5.1. Sludge Transport

Figure A14 shows the split of Sludge Transport botex by cost categories. The key point to note is that Other Operating Cost (which includes transport costs and bought-in services) represents 95% of botex.

Figure A14: Sludge Transport Industry-wide Botex by cost category

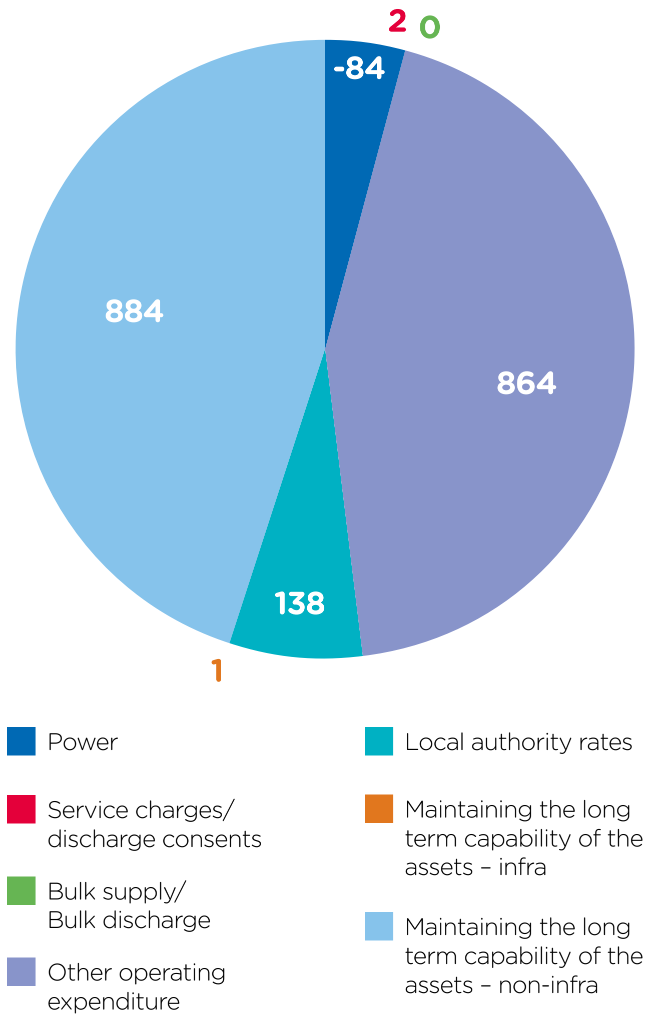


5.2. Sludge Treatment

Figure A15 shows the split of Sludge Treatment botex by cost categories. Key points to note are:

- Local Authority Rates account for 7% of botex
- Capital Maintenance accounts for 45% of botex
- The bulk of opex is represented by Other Operating Costs. This accounts for 44% of botex
- Power is a negative cost, reflecting the importance of power generation for WaSCs which have taken the AD approach to Sludge Treatment.

Figure A15: Sludge Treatment Industry-wide Botex by cost category



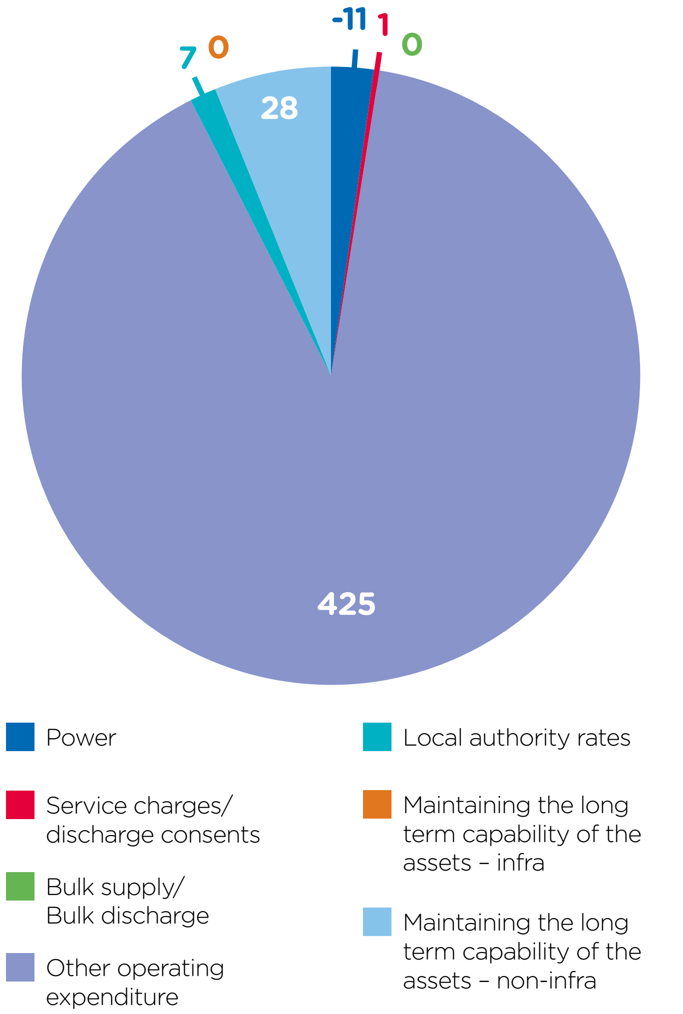
Source: Ofwat 2016 data submission, Anglian Water analysis

5.3. Sludge Disposal

Figure A16 shows the split of Sludge Disposal botex by cost categories. Key points to note are:

- Local Authority Rates represents 2% of botex
- Capital Maintenance represents 6% of botex. Compared to Sludge Transport, maintenance capex is higher for Sludge Disposal, indicating that WaSCs overall have kept more of Disposal in-house. Indeed, only one company has completely outsourced Sludge Disposal
- As Sludge is mainly (though not universally) disposed to land, transport costs are a large part of costs. This explains Other Operating Costs representing 90% of botex.

Figure A16: Sludge Disposal Industry-wide Botex by cost category



Source: Ofwat 2016 data submission, Anglian Water analysis

6. Household Retail

Within its Regulatory Accounting Guidelines (RAGs), Ofwat has defined four cost categories for retail. Retail is further subdivided between household and non household retail. The precise definitions and boundaries for these different categories are set out in RAG 4. Since April 2017, the non household market has been open to competition. For this reason, non household retail has been excluded from the price control regime at PR19. Consequently, all of the analysis, and all of our retail cost modelling, focuses purely upon household retail costs.

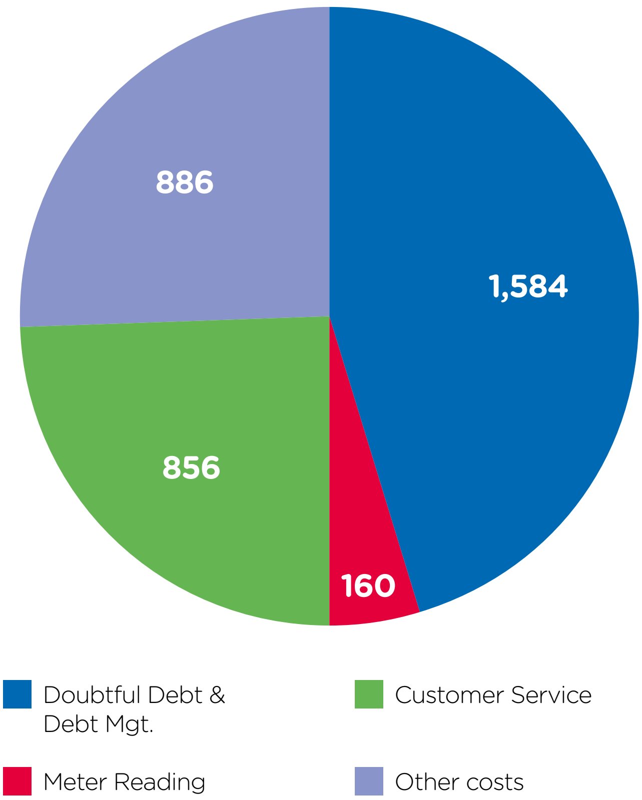
For the sake of simplicity, at PR14 Ofwat made the assumption that Retail (at that time, both household and non household) had no significant capital expenditure and thus required no allocation of RCV. It was recognized that there was existing capital and thus there would be depreciation. Within Table A5 and Figure A17, this depreciation is shown as part of Other costs. This simplifying assumption has been extended to PR19.

Table A5 sets out the various elements of cost included in the four Retail cost categories. The figures represent four years' costs; from 2012-13 to 2015-16. The data are limited to just four years as it was in the 2012-13 regulatory accounts that the current level of cost disaggregation was first introduced. Unlike the data for wholesale, all Retail cost data are in costs of the day and have not been restated into a single cost base. This is in line with Ofwat's contention that there are no inflationary pressures impinging on Retail costs.

Since Ofwat collected these data and began its programme of analysis of household retail, the 2016-17 regulatory account data have been published. Further work on Retail will incorporate the 2016-17 data, giving a five year data base.

Figure A17 sets out Table A5 in graphical form. Nearly half of botex is made up of doubtful debt and debt management. Customer Service and Other Expenditure both account for a quarter of botex each. Meter reading is by far the smallest category of cost.

Figure A17: Household Retail botex by cost categories



Source: Regulatory Accounts, Anglian Water analysis

Table A5: Household Retail Botex by cost category.

£m	Doubtful Debt & Debt Mgt.	Meter Reading	Customer Service	Other costs	Total botex
Total	1,583.7	160.0	856.2	885.9	3,485.9

Source: Regulatory Accounts, Anglian Water analysis

Loughborough University

Centre for Productivity and Performance
School of Business and Economics

Independent Review of Anglian Water's Preliminary Regulatory Cost Modelling for PR2019

September 2017

Review led By Professor David Saal and co-authored by Dr. Alessandra Ferrari and Dr. Maria Nieswand

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This appendix sets out the opinions of the Independent Assessor of Anglian Water's initial cost modelling work which is contained in the Main Report and in Annexes 1-12.

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Appendix 2: Independent assessment of the water industry models

Introduction and Terms of Reference

Anglian Water has independently produced a series of service-specific cost assessment models with the aim of analysing the most relevant cost drivers of various water sector business units, as defined by Ofwat. It thereby aims to contribute to the development of appropriate methodologies for Ofwat's 2019 Price Review (PR -19). We emphasize that the Centre for Productivity and Performance (CPP) has played no role in the development of these models or their estimation. Our role has instead been to provide a review of the models developed by Anglian Water, taking into account both our academic expertise in the economics of performance measurement, while keeping in mind the regulatory context of PR19.

In all, Anglian estimated a total of 19 different models in its cost assessment. Three of these models provide cost assessments respectively for integrated water, sewerage, and retail activities. The remaining 16 models aim to provide disaggregated cost assessment within these 3 integrated services. We understand that this approach is consistent with Ofwat's determination to proceed with disaggregated regulatory price settings at PR19, as separate price caps will be set for Network Plus Water, Network Plus Sewage, Water Resources, Sludge Activities, and Household Retail Activities. However, further disaggregation beyond this level has been pursued by Anglian, and appears to be largely based on arguments that augmenting top down assessments with the aggregation of bottom-up assessment will provide a set of alternative cost assessments that should also be taken into account in regulatory price setting.

Given this description of Anglian's approach and the regulatory context, our report proceeds as follows. The next section briefly discusses issues that became apparent as we reconciled our own approach to cost assessment to the approach followed by Anglian Water given the regulatory context of PR19 within which it operates. This section raises three caveats with regard to the modelling approach that the regulatory context has resulted in, and which to varying degrees are outside of Anglian Water's control. The subsequent section provides comments on the general approach to modelling adopted by Anglian Water and hence covers issues that were common to all or most of its cost assessment reports. The remainder of the report provides a separate section for water, sewerage, and retail cost modelling. These sections provide first a brief commentary on the overall modelling, and then a detailed review for each of the 19 disaggregated service areas where Anglian Water carried out modelling.

Issues Raised When Reconciling our Academic Approach to Cost Assessment With Anglian Water's PR19 Determined Approach

CPP's researchers are experts in the theory of economics and operations research based approaches to performance measurement. As such, we generally work within a methodological framework based on the economic theory of costs and production economics, which informs the underlying specification of the models that we subsequently estimate by applying appropriate standard econometric, stochastic frontier analysis, and/or data envelopment analysis. However, because we are also applied performance measurement experts, we also do not generally blindly apply economic and measurement theory. Instead, we aim to provide well specified models that are consistent with economic theory but also appropriately reflect the practical real world context of the firms whose costs we model. Thus, our preferred approach to modelling is one where models that are consistent with economic theory are specified, but are also chosen and modified so as to properly account for the economic, regulatory, engineering, and environmental characteristics of a firm and the context within which it operates.

While a discussion of the implications of this academically informed but practical approach to water industry cost modelling is beyond the scope of this report, we refer the interested reader to the academic appendix of Cambridge Economic Policy Associates (CEPA) initial 2011 report on cost assessment modelling for Ofwat during PR14, which was written by Professor Saal. Nevertheless, before proceeding, we would like to underline that we understand and accept that Anglian has produced its analysis working within constraints that are determined by the regulatory context. In particular, these constraints include Ofwat's regulatory decision to pursue sector disaggregation and sub firm level price caps and its decision to abandon what we believe was an economically consistent approach to defining economic costs in favour of a new definition of "regulated costs" – namely the requirement to aggregate capital expenditure with OPEX.

This section will therefore caveat our review, by briefly discussing these issues and their implications. It will then further discuss the implications of what we perceive as a shift towards increasing reliance on cost driver based cost assessment in the water sector. This will allow us to then move forward to review Anglian's models, while accepting that its approach to cost assessment has understandably been heavily informed and motivated by the regulatory context of PR19, which of course follows on from that of PR14.

BOTEX Modelling

Our first caveat relates to the use of BOTEX as the "cost" that is assessed. A brief synopsis of the impact of PR14 is that Ofwat moved away from its previous approach of separate OPEX and CAPEX assessment in favour of TOTEX modelling, based on arguments that this approach would better control for perceived pro capital biases in the industry. Subsequent review in the Bristol Water case led the CMA to reject the TOTEX approach, and the CMA's models relied on an alternative proxy for costs, now referred to as BOTEX by Anglian, which excludes enhancement CAPEX from TOTEX. Anglian Water also argues strongly for the use of BOTEX modelling for PR19, given the high variation in enhancement CAPEX across firms and also within firms across time, while in contrast, maintenance CAPEX and OPEX are more stable and predictable.

We concur with Anglian's decision to employ BOTEX based on its superiority to TOTEX. Moreover, in a capital intensive industry we can accept a certain logic that there are blurred lines between OPEX and maintenance CAPEX, which could be used as a justification to aggregate these expenditure categories. However, by both standard economic and accounting definitions of cost, all OPEX is a cost while CAPEX, regardless of whether it is for enhancements or maintenance, is investment which contributes to a capital stock. This capital stock then has associated depreciation and capital financing costs. Thus, at the most basic level both BOTEX and TOTEX falsely aggregate a cost (OPEX) with an investment activity (CAPEX). Moreover, Ofwat's mechanisms which allow firms to allocate part of TOTEX to their regulatory capital values, further demonstrate the tensions created by using such false "cost" aggregates in cost assessment. We therefore believe that, as with TOTEX modelling, BOTEX modelling will almost certainly lead to biased estimates of relative cost performance because of this conceptually incorrect aggregation.

However, while we would strongly recommend application in PR19 and beyond of relatively easily estimable approaches to controlling for capital biases while modelling consistently defined costs, Ofwat appears to remain committed to some form of TOTEX-like "cost" assessment for PR19. Thus, absent an unexpected change in that regulatory commitment, we accept and support Anglian's conclusion that BOTEX modelling is superior to TOTEX modelling, but only because it is the least worst of the apparent options on the regulatory menu for PR19. Thus, rather than standing on the ivory tower and criticizing Anglian Water for not employing appropriately defined regulatory cost definitions that are beyond its control to change, we instead choose to support its efforts to build from the CMA decision and to employ BOTEX modelling as a movement in the right direction for water industry cost assessment.

Disaggregated Cost Assessment and Cost Interactions

Our second caveat relates to the need for better consideration of the role of cost interactions when defining and modelling disaggregated units for cost assessment. As discussed heavily in both the main text and the academic appendix of CEPA (2011) the presence of significant cost interactions between disaggregated units of assessment can result in considerable biases if not controlled for

[1] *CEPA (2011), "Cost assessment-use of panel and sub-company data Ofwat" Report commissioned from Cambridge Economic Policy Associates and and Published by Ofwat.*

properly. Moreover, as there is considerable evidence that such cost interactions may exist in the water industry, cost assessment and regulatory price determination at inappropriate levels of disaggregation may result in perverse incentives.

Given this, we first comment on issues that are outside of Anglian Water's control, e.g. the level of cost assessment where Ofwat has announced it will set price controls. We also will simply highlight this issue with an example. While the logic of setting a separate price cap for Water Resources may or may not be appropriate to facilitate stronger market mechanisms in water abstraction, we strongly support Anglian Water's assertion that separating this activity from Raw Water Abstraction is problematic from a cost assessment perspective. This is because the past location decisions of water abstraction, raw water transportation, and even water treatment facilities have been made by cost minimizing firms that seek to minimize costs across these activities, after taking into account complex cost interactions related to type of water abstracted and settlement patterns. As a result, it is extremely unlikely that this level of separation will provide appropriate cost assessment, unless extremely careful controls for these cost interactions are employed. We therefore note that, while the mandated regulatory boundary definition is outside of Anglian's control, it can nonetheless test its concerns and their implications in future work by conducting cost assessments at alternative aggregations to those imposed by Ofwat. Moreover, we strongly believe this approach would be consistent with providing appropriate results to test the cost implications of further unbundling.

The second aspect of this issue is within Anglian's control and relates to improving the underlying modelling that it employs when it estimates disaggregated models that it plans to then aggregate up to provide alternative assessments to those made at more aggregated levels. Our considerable experience in modelling and controlling for cost complementarity and testing for the implications of imposing separation of such activities suggests that a much more careful consideration of the conceptual interrelationships and consistency of aggregated and disaggregated models is necessary. We believe that such an approach will not only help provide evidence that will improve the arguments made by Anglian and others in the industry with regard to whether assessment at a given level of disaggregation is appropriate, but will also help in better evaluating the relative quality of aggregate and disaggregated cost assessment modelling.

Cost Driver Based Cost Assessment Modelling

We finally choose to highlight what we perceive as a growing and possibly excessive reliance on what is interpreted as a simpler focus on identifying variables that are believed to be cost drivers, and an accompanying movement away from specifications influenced by economic cost modelling, let alone a general to specific approach to model selection. Thus, the CMA effectively argued for an alternative modelling approach in which less complex and more understandable models should be specified. As a result, the CMA' s decision relied on cost assessment models which were relatively more informed by a cost driver approach, when compared to the CEPA(2014) approach implemented by Ofwat in PR14 which paid moderate attention to academic considerations within regard to econometric modelling, if not the economic or accounting definition of cost (see above).

In our opinion, subsequent guidance from Ofwat and the resulting direction of travel of collaborative work between firms carried out by the Cost Assessment Working Group in preparation for PR19, has reinforced the adoption of this cost driver approach, in which practical knowledge of appropriate factors that drive input requirements forms the primary modelling technique. However, our feel is that there is an increasing potential and tendency to effectively apply a data mining approach in model development, rather than an approach built on careful consideration of appropriate model specifications and the interactions of variables within them.

Given this, we accept that Anglian Water has chosen to apply a cost driver approach. Moreover, we further accept that if properly applied it can lead to the development of models that can robustly account for the economic, regulatory, engineering, and environmental characteristics of a firm and the context within which it operates. However, applying such an approach still requires careful consideration of how variables interact within a model, and controls for factors such as outputs, prices, and operating characteristics. Thus, we believe that developing strong cost driver based cost assessment is ultimately quite similar to economic theory based approaches, and requires development of appropriately considered models, which are only subsequently statistically tested and then further refined.

Our report will therefore proceed by identifying significant issues in Anglian's cost driver based models and make suggestions with regard to how Anglian can improve its overall modelling approach, through both better preliminary specification of models and subsequent statistical testing to allow the identification of the strongest empirical specifications of those models.

Review of Anglian Water's Modelling Approach

The previous section has focussed on several significant conceptual issues that we believe influence the potential quality and underlying nature of the overall regulatory approach to cost assessment modelling. In contrast, this section provides a review of Anglian's approach to modelling, which broadly accepts the modelled cost definitions, and the level of aggregation chosen by Anglian Water. Our overall view is that while there is certainly room for improvement for what is currently work in progress we do acknowledge the valuable effort made by Anglian in what is an extremely complex task, because of the activities analysed, the econometric issues encountered and the regulatory constraints behind some of the choices made.

Our review of Anglian's modelling approach proceeds as follows. We firstly detail some issues about terminology that we think should be addressed. We then discuss the criteria that should inform the selection of variables and their measurement, with various examples. This is followed by a discussion focused more specifically on the econometric estimation techniques and the model selection process adopted; finally we comment on Anglian's approach to "triangulation".

Terminology

Speaking from an academic standpoint, we note a general need for the use of more precise and consistent terminology. The wording of the reports produced by Anglian suggests that "model" refers indiscriminately to the underlying economic specification, the estimation technique, the variable selection process, and the different resulting specifications at the same time. We would advise more precision in order to prevent confusion. Similarly, as we discuss more in detail later on, the use of terms such as Cobb Douglas or Translog should be avoided since the models estimated (cost-drivers analyses) do not correspond to the above named functions. The same is true of the use of the term efficiency.

This has important implications as for example an approach that carefully develops alternative models, specifications of which are then tested and refined, and further tested for robustness with alternative econometric estimation methods will not only lend clarity to the description of the models, but will also improve the quality of the overall cost assessments provided in the process.

Clarification of the production structure and selection of relevant variables

Clarification of the production process under analysis

Most of the models we reviewed were at a very disaggregated, service-specific level (or Business Unit level, BU). In several cases we felt that variables were selected that did not pertain to the production process being modelled and were in a sense only indirectly (and therefore imprecisely) correlated to the specific task analysed. We therefore recommend an initial clear description of the relevant production/cost processes, and how the various BUs might be linked. Clarifying the production process means that the associated inputs and outputs must be identified, along with any other factors that are relevant to the production process (control variables). This is a delicate part of the modelling process, and particularly in a cost driver process given the absence of an economic theory based specification that provides clear guidance with regard to the relationship between outputs, prices and costs.

Furthermore, a well-specified description of the links and cost interactions between the various Business Units informs the development of more aggregated, composite models such as "Network Plus". There is indeed, in our opinion, an issue of excess disaggregation with many of the BUs, only some of which is required by the regulator. The separate analysis of parts of the production process that are heavily interlinked (for example water abstraction, raw water distribution and treatment) could potentially overlook important complementarities in input use and economies of scale and scope, leading to inaccurate conclusions.

The distinction between inputs, outputs and control variables also determines how these variables should enter the production/cost model, how they ideally should be measured, and how they can be econometrically treated. Insufficient consideration of these distinctions is made in Anglian's modelling approach.

A notable missing variable in virtually all the models we reviewed was a measure of the relative price of labour inputs, despite Anglian's attempts to use the Ofwat derived regional wage variable. We are aware that these models are not proper cost functions, in the economic sense, but cost-drivers analyses (see both above and below comments); nonetheless the BOTEX measure used as a dependent variable does include labour expenses, and staff levels are certainly an important input to the production process. This creates the risk of specification bias, whereby the effect on BOTEX of the labour input is captured by other included cost-drivers. There is also potential that the over-complex definition of Ofwat's regional wage variable, as well as possible differences in the deflation approach employed for BOTEX and this wage variable may result in its insignificance.

Most significantly, water and sewerage are network industries and a vast economic literature highlights that in such industries costs are driven by complex interactions between volume, connection and transport characteristics of supply, which must be controlled for while also controlling for the possibility that the collinear relationship between such variables requires delicate and carefully developed model specifications. Given this, we find the guidance provided by Ofwat within the Cost Assessment Working Group to be highly inappropriate, as it suggests that separate variables can be identified for output characteristics and those associated with returns to scale. This is simply not the case, as it is well established that economies of scale are determined by this complex interaction between the volume of output produced, the number of customers served, and the distance and characteristics of the transportation required to serve them. Anglian Water and the industry will be well served by developing models that do not seek to artificially capture output and scale effects with different variables, but instead should develop models that aim to provide understandable and tractable models that properly capture the complex determinants of water industry costs.

Economic production/cost models versus cost-driver analysis

To model its services in water, sewerage and retail, Anglian takes the approach of explaining BOTEX by a number of selected cost-drivers and develops a final set of 6 water models, 8 water recycling (sewerage) models, and 5 retail models. For each of the cost-driver models, several variants were estimated that differed, for example, in the selection of variables and measures, and sometimes in the estimation technique.

We acknowledge the informative character of cost-driver models. It is, however, worth emphasising again that the developed models in their current shape do not represent production or cost functions as derived by economic principles. So, as we said before, any reference to functional forms such as the Cobb Douglas or the Translog should be avoided.

The estimation results must be evaluated within this specific cost driver context, and as per our immediately preceding subsection, more careful selection and consideration of interactions between cost drivers is likely to provide stronger cost driver modelling.

Variable measurement issues

We are well aware that the selection and treatment of variables is not only determined by the identified production process but also by the availability and quality of data. Data limitations are beyond the control of the modeller and lead to the use of adaptations and proxies. It is important that such adaptions should be reasonable, justified, comprehensible and communicated in a transparent way. Whether the adjustments are reasonable is always context-specific and should be carefully explained. The adjustment might relate to the selection, measurement, and/or econometric treatment of the variables.

For example, although not used in the final models, the variable Regional Wages was considered as a measure of staff costs. This variable proved to be a very poor performer as it probably does not properly reflect staff costs and staff levels in individual companies, and it has been criticised by other in the past . Viable alternatives could be company-specific measures calculated as the ratio of staff costs to FTEs; the (rather radical) exclusion of any labour input including its value from BOTEX; or finally the exclusion of any staff costs measure as an independent variable (as chosen by Anglian). Each of these alternatives has different pros and cons which should be carefully explored to justify a final choice. For example, ignoring staff costs in the equation will create specification bias, unless labour expenses were only a negligible figure and the resulting bias therefore acceptable from a practitioner's point of view.

A further example highlights the issue of variables measurement.

The variable "Density" used in the reports to measure population density is a threshold-based index created by Ofwat. How this index has been constructed is not sufficiently well explained, making the interpretation of the results difficult to understand.

As indicated for example in Table 4 of the "Water Resources" report, the variable "Density" is only defined when the population is larger than 2000 per squared kilometre. This implies that the density index is forced to take zero values when the measure is below that threshold, and implies that population density does not have an impact on costs when the threshold is not exceeded. Furthermore the actual variable does indeed result in a very large number of zero values making it of limited use. Similar considerations are true for the variable "Sparsity".

It is really not clear to us why a threshold rather than a continuous variable should be used to capture the impact of population density on costs, and our experience suggests that a continuous variable and inclusion of quadratic terms will allow for a well-known nonlinear impact of population density on costs in network industries. To the best of our knowledge, data exist that allow for creating a simple measure of population density, i.e. number of inhabitants per squared kilometre, which has a straightforward meaning and interpretation. Its use especially in non-linear form would be much more informative. Alternative approaches, such as a weighted average density measure for local authorities served are also likely be more appropriate than a threshold based measure. Moreover, as many important cost drivers such as mains length and area served implicitly also capture the impact of population density on costs, it is important to consider how their inclusion relates to density and sparsity before including density controls to a model.

We also note the incorrect use of natural logs, which are undefined when variables are equal to zero. In that case natural logs should not be used at all, and the zeros should not be replaced by very small numbers. It is well known that this approach results in biases which can potentially be very large as recently demonstrated for example for the case of the electricity industry (Triebs, et al. 2016).

Dealing with collinearity

A related issue to variables measurement is the handling of collinearity. We note the following points:

a. While it is normal that many variables will be correlated with one another, the problem will be reduced by careful selection of only those that strictly pertain to the service sector analysed. Put otherwise, often the problem in Anglian models arose from the introduction of inappropriate, excessive, and duplicative cost drivers.
b. If a problem of collinearity exists and the variables do belong to the model the researcher should acknowledge this problem and the resulting larger variance in the estimators. It is not a good solution to remove potentially relevant variables from the model as this introduces specification bias which has more

a. serious implications. Individual tests of significance are of limited value in the presence of collinearity, and joint ones should be preferred if there are doubts as of the relevance of cost drivers.
b. As an example, we noticed a problem with the handling of the variables DI_ir, DI_pr, DI_r, and DI_b, which represent the proportion of distribution input coming from different water sources. Not only their sum was at times larger than 1 (i.e. larger than 100%); one of the categories contained only values of 0 but for 2 observations. This category was used as a base for the estimations in W2 (i.e. removed from the list of regressors) leaving almost perfect collinearity among the others. Careful analysis of the data and presentation of descriptive statistics would go a long way to prevent this type of problem. As we note later in the W2 report, this had further consequences as the resulting collinearity issue further impacted the model selection process carried out by Anglian Water.
c. Similar concerns have been raised in the individual reports with regard to the use of excessively disaggregated mains length data by age of main category, which produce models with high R-Squared, but coefficients on these variables which are difficult to interpret, because of the resulting intermingling of the effect of the length of mains and the age of the network on modelled costs.
d. We also again note the frequent inclusion of multiple variables such as density, mains length, area, sparsity, and even variables such as average plant sizes, which are all closely related to population settlement patterns and therefore likely to be highly correlated. This suggests that specifying and then testing models with different controls for a given aspect of costs, will not only improve model specifications but reduce collinearity issues.

Measurement errors

We fear that measurement errors might be an issue and should be checked for carefully before estimation. Sticking to the example discussed in point c) above, we found that for some observations the sum of the proportions was larger than one and the deviations could not be explained by rounding. In other cases, the sum was negative. For these cases, the data showed the existence of two more sources of delivered input (artificial recharge water supply schemes and aquifer storage and recovery water supply schemes) that were not included among the sources available. We recommend a careful reconsideration of the definition and measurement of this variable, and a general through check for measurement errors in the dataset.

Estimation approach

Average vs optimal performance

The preferred estimation technique used in the reports is Ordinary Least Squares (OLS), or occasionally, GLS with a Random Effects specification. If the aim of the analysis is to compare the relative efficiency of different companies then the approach should not be OLS, which by definition assumes that all deviation from predicted values results from white noise. It should instead be a (possibly stochastic) frontier estimation method. Frontier techniques measure explicitly the distance of observations from an ideal benchmark (the frontier) and therefore justify the use of the term and the notion of efficiency. OLS and GLS on the other hand estimate the average relation between dependent and independent variables, and deviations from that average are due to noise. This approach is valid if the aim of the analysis is to describe and estimate the average influence that cost-drivers have on BOTEX, but then any reference to inefficiency should be removed.

We are nonetheless aware that, due to several considerations including what we believe are misplaced concerns with regard to the reliability of frontier estimation methods (discussion of which is beyond the scope of this report), Ofwat is likely to apply an upper quartile approach, as defined by the ranking of the deviation of predicted costs from actual costs, but using econometric approaches that only allow for statistical noise. While this approach is not consistent with the increasingly widespread practice of regulators, including those in German and Scandinavian electricity, who confidently apply frontier techniques, Anglian Water must adapt its modelling approach to that which will be taken by Ofwat. However, in doing so it should be sure to properly describe the results of the models as what they are: i.e. measurements of deviations from predicted costs, and not measured inefficiency.

Also, while we would certainly support the use of panel data estimation techniques, the reports appear to use the GLS-RE specification only in case of heteroskedastic errors in the OLS model. This is not the right answer to a heteroskedasticity problem, as we detail below; panel data techniques could be considered for future reference, after appropriate testing and selection of different models (fixed vs random effects for instance).

Model selection

It is our opinion that the model selection process adopted by Anglian to choose and select between various model specifications should be statistically more structured and robust, and better explained. The process used appears to start from restricted, generally log-linear models; these are then augmented and modified on the grounds of Ramsey RESET tests and individual tests of significance. This selection procedure is not statistically robust and in fact leads to the estimation of too many models. This methodology and its application to final selection among them to arrive at the final "triangulation" is also questionable.

We therefore strongly advise to (i) adopt a general-to-specific approach where the starting point is the most unrestricted version of any model(s), both in terms of what variables should enter the equation and the form in which they should enter it (choice of functional form); (ii) to make the initial choice on the grounds of a clear and explicit understanding of the specific production process analysed, as we discussed earlier; and (iii) to carry out a more structured series of specification tests, reporting their statistics and adopting appropriate solutions (see for example the comments on multicollinearity and those hereinafter about heteroskedasticity). There seems to be excessive reliance on individual tests of significance which are affected by various issues (for example by heteroskedasticity and collinearity), no use of joint tests, and no apparent order in which such tests seem to be carried out, or conclusions drawn from them.

As a result, the number of models selected by Anglian is often too large and some of them are nested in one another and could therefore be eliminated. We do appreciate the complexity of the task undergone by Anglian and find some of the final models presented relatively convincing, so that it is perfectly possible that a different selection procedure might lead in some cases to the same final selection. It is important however that the process to arrive there is clear and statistically robust.

Handling of heteroskedaticity

Ample use is made of the Breusch-Pagan test for heteroskedasticity and the solution offered to the problem is to estimate the model as GLS-RE. This is not the right econometric approach. If heteroskedasticity is found (and we would advise to use other tests too, such as White's general test for instance) then its possible reasons should be explored and resolved (it could result for instance from omitted relevant variables, or scale related factors). If a cause cannot be successfully identified and solved then robust standard errors should be used, which are not equivalent to GLS-RE estimation. This is particularly important given the emphasis put in the reports on the tests of significance.

We strongly suspect that the adoption of proper model selection criteria in the first place, in terms of variables and functional forms, will reduce the existence of this problem quite remarkably. For example, very little use is made of quadratic effects on many of the variables (what Anglian refers to as Translog modelling), and when quadratic terms are introduced (on the basis of Ramsey tests) they are limited generally to one variable only. This is a strong unnecessary restriction in many instances: it is in fact perfectly possible that different returns to scale exist at different output levels, and that non-linearities characterise the effect of other cost drivers (for example density of population).

Triangulation

Anglian Water has adopted a Triangulation approach in interpreting the results of its modelling, which is meant to provide a balanced approach that accounts for errors and differences in modelling by using an average deviation of OLS predicted values rather than relying on a single model's predicted values.

We do not have an objection to this approach in principle, as it is feasible for well specified alternative models to result in different cost assessment outcomes. Moreover, we point to the example of German electricity distribution regulation where it is legally required for cost assessment to be done with two different definitions of capital cost and two different estimation techniques (SFA and DEA) and differences in models are allowed for by using whichever model is most favourable for a firm to set its prices.

However, in practice we have two issues with the triangulation approach employed by Anglian.

Firstly, to some extent triangulation is being employed as an alternative to good modelling, under an implicit assumption that all models will have errors and averaging will average away those errors. As a result, the models that are being triangulated are of lower quality than could be, and too many are being triangulated. We therefore strongly believe that an approach which carefully develops alternative conceptual cost driver models and then refines empirical specifications of these specifications through application of general to specific testing, will result in a stronger but smaller set of chosen models that could then be "triangulated".

Our second concern relates to Anglian's weighted average triangulation approach. We acknowledge that in principle greater weight should be given to stronger models, but firstly believe that the model development procedure we have just suggested will significantly reduce the prevalence of low quality models, and thereby reduce the need for variable weighting. However, our more significant concern is that if a statistically based weighting system is to be applied, it must be statistically robust, and we are not confident that the approach currently being suggested by Anglian meets this standard.

Summary

We were required to provide feedback on the estimations carried out with an aim of providing suggestions that could result in the improvement of the quality of future cost assessment work to be carried out by Anglian Water and the industry. We are nonetheless very aware of the complexity of the task undertaken by Anglian, because of the nature of the activities analysed, of the sometimes questionable quality of the available data and, last but not least, of the difficulties inherent in econometric analysis. We are also aware that some of the definitions used (for example the identification of the service areas to be modelled) are often beyond Anglian's control and that some requirements on what costs should be analysed (BOTEX versus OPEX for instance) were also based on regulatory requirements. Given all the above we believe that the work carried out, while open to considerable improvement, already provides a very valuable contribution to the analysis of the sector and can be built upon in future modelling. This should definitely be acknowledged. Our following detailed assessment of Anglian's models has therefore sought to provide suggestions for improvements that can be made in future rounds of modelling.

Summary of the Water Model Assessments

The below table summarizes our numerical assessment of the models developed by Anglian Water for each of the six areas of assessment it has estimated for water activities; the following reports provide our detailed commentary with regard to each of their analyses.

Focussing first on W1 Total Integrated Water Activities, and despite Anglian's reproduction of models developed by the CMA, we have been able to easily demonstrate that these models impose unrealistic assumptions on the relationship between outputs and costs. Nevertheless, we also strongly believe that future modelling taking on board lessons from a considerable economic cost modelling literature, can result in more robust models for integrated water services. Similar arguments also apply with regard to the potential for developing robust models for W3 Network Plus which, despite the exclusion of W2 Water Resources, has very similar required model characteristics to W1 Total Integrated Water Activities.

With regard to W2 Water Resources, we strongly support Anglian Water's assertion that separating this activity from W3 Raw Water Abstraction is problematic from a cost assessment perspective. This is because the past location decisions of water abstraction, raw water transportation, and even water treatment facilities have been made by firms that have sought to minimize costs across these activities, after taking into account complex cost interactions related to type of water abstracted and settlement patterns. Moreover, Raw Water Abstraction and Raw Water Distribution respectively account for 12 and 3 percent of BOTEX, which are both relatively very small shares of cost to be subject to regulatory assessment.

However, we go further than Anglian and raise a question with regard to the regulatory boundaries defined by Ofwat. Thus we suggest that the regulatory boundary between Raw Water Resources and Network Plus defined by Ofwat are inappropriate on cost assessment grounds alone, and note that in at least two countries (Germany and Japan), where both fully integrated and vertically separated companies have developed organically, the boundary is between downstream water distribution and upstream operations including water abstraction, raw water distribution, and treatment (Treatment Plus). We therefore believe that there is merit in testing the appropriateness of separate assessment of a combined W2/W3 abstraction and raw water treatment model, and an additional Treatment Plus model, which could be assessed in combination with W5 Water Treatment, so as to test the appropriateness of separating these activities.

The W6 Treated Water Distribution Model only received a numerical assessment of one. However, this assessment was driven by the necessity to signal that the approach of using a full set of disaggregated mains length data by every available age category has almost certainly resulted in a model with high R-Squared but little conceptual validity. However, our review of the data and our knowledge of a vast literature on distribution activities gives us confidence that robust W6 models can be developed for PR19.

We finally reiterate the need for more careful consideration of the conceptual interrelationships and consistency of aggregated and disaggregated models. We believe that this will not only help provide evidence that will improve the arguments made by Anglian and others in the industry about the appropriate level of disaggregation, but will also improve the overall modelling and help in better evaluating the relative quality of aggregate and disaggregated based cost assessment modelling.

Water Models –Summary of Numerical Assessment Scores	
W1 Total Integrated Water Activities	**3**
Disaggregated Models	
W2 Water resources	**2**
W3 Water network plus	**3**
W4 Raw water distribution	**2**
W5 Water Treatment	**3**
W6 Treated Water Distribution	**1**

Key	
Approach Needs Substantial Conceptual and/or Empirical Adjustment	**1**
Variables and Specifications have potential but require substantial improvement	**2**
Specifications that we believe could be improved and/or alternative approaches may provide stronger models	**3**
Satisfactory	**4**
Excellent	**5**

W1 Total Integrated Water Activities

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

Anglian has reproduced a significant number of the CMA's models. We have focused on the 3 models chosen by Anglian for its triangulation process. These are a logged unit cost model with a set of independent variables labeled EV2, and two linear unit cost models with alternative independent variable definitions labelled EV2 and EV3. We emphasize that our commentary relates directly to Anglian Water's replication of the CMA models, and we that we do not directly consider the CMA Bristol Water report.

Our numerical Assessment (1-5) 3

Anglian Water models reviewed

Anglian has chosen to reproduce the modelling approach adopted by the CMA in its Bristol Water Review on the grounds that the CMA models are the most recent regulatory benchmarking assessment models applied in the UK water sector. In addition, Anglian states that it concurs with the CMA's conclusions with regard to the superiority of Botex modelling over Totex modelling. As per our general review of Anglian's modelling we accept that they have carried out Botex modelling and agree that it is superior to Totex modelling. Moreover, we do not offer further comment with regard to the deviation of both of these expenditure aggregates from the economic definition of costs that we believe would be most appropriate for regulatory benchmarking.

Anglian's report firstly demonstrates that it has accurately reproduced the actual models produced by the CMA, with datasets aiming to match the data used by the CMA, and applied its arithmetic average triangulation over several of these models. It then rolls these models forward to later 5 and 7 year panels and concludes that these rolled forward models demonstrate that the models have remained stable in the later sample periods. We are not surprised by this result given that the underlying characteristics of integrated water operations has not changed significantly over the modelled time periods.

The CMA models reproduced by Anglian have merit, as for example demonstrated by their effective inclusion of controls for both regional wages and time variables, and their consistent inclusion of variables of connected property, water delivered, and mains length variables, which capture what we believe are the key volumetric, connections, and transportation outputs of any network industry.

Nonetheless, we have also identified several significant issues that warrant further modelling to improve the robustness of models to be applied during PR19. We note that our following commentary is not exhaustive, but serves to illustrate what we believe are untenable assumptions with regard to the relationship between modelled Botex and outputs in the water industry.

We focus first on the logged unit cost model. Simple algebraic manipulation of the model specification reveals that given that the logged dependent variable Botex per property is modelled on the logged values of water delivered per property and mains length per property, constant returns to scale has been imposed on this model. However, multiple studies have found evidence of variable returns to scale in the UK water industry, including, for example, the Stone and Webster report commissioned by Ofwat in 2004. We therefore believe that the appropriateness of this restriction should be tested, and our experience suggests that it will need to be relaxed, as the model is highly likely to be providing biased results because of the inappropriate imposition of constant returns to scale.

Focusing on the Linear Unit Cost Models, we firstly note that our experience in modelling various infrastructure industries mitigates strongly against an assumption of constant average cost effects for all explanatory variables, as implied by entering variables in a pure linear specification. We do not believe that such a rigid assumption with regard to cost impacts is consistent with water industry cost relationships, nor likely to be robust to statistical testing if it were to be relaxed.

Secondly, we note that with these models the implied total Botex relationship can be obtained by simply multiplying through the estimated model by connected properties. Doing so, we find the underlying total Botex specification employed to be peculiar:

A. Marginal Botex effects are assumed to be constant for mains length, which is untenable given the considerable attention normally given to density in water industry modelling, and which has in particular characterized Anglian's disaggregated modelling.

B. Focusing on water delivered, although not directly apparent from the provided model specification, simple algebraic manipulation demonstrates that the model effectively estimates a separate and constant marginal cost for each of water derived from boreholes, reservoirs and rivers, and a related relationship that suggests a separate increasing impact on the marginal cost of total water delivered as average pumping head increases. We firstly find this specification of constant marginal costs regardless of output scale for the water delivered variables untenable. Secondly, we note that consideration of the underlying statistical significance of these coefficients (not reported by Anglian but reviewed by us) reveals that the variable "total potable water delivered per property" is always statistically insignificant, while the additional variables which measure potable water per property from river and reservoir sources (EV2), and potable water per property treated at w3/w4 levels (EV3) are always statistically significant. Simple algebraic manipulation of the specification reveals that these results imply that the marginal cost of supplying water from boreholes is not statistically significantly different from zero in EV2, and water which is treated at levels less than w3/w4 is similarly modelled to have statistically insignificant marginal costs in EV3. This is a peculiar result, and while we can accept the related implication that the marginal cost of river water and reservoir based supply is statistically significantly higher than boreholes in EV2 (and that higher treatment levels have higher marginal costs in EV3), it is hardly tenable that these marginal costs along with those for added mains length are constant for all companies and at all levels of production.

C. The marginal Botex cost of serving a property is a complex linear function of the constant, the time dummies, the regional wage coefficient times the regional wage variable, and the coefficient of the %water consumed by metered NHH times that variable. We do not provide detailed comment on the characteristics of this estimated marginal cost, but note, for example, that it seems inappropriate to assume that regional wages impact the marginal cost of serving a property but not the marginal cost of providing mains or water delivery.

Anglian's report notes that a prime objective of the CMA modelling approach was to make the results interpretable from an engineering perspective, and that the CMA developed its models in response to concerns with Ofwat's PR14 model including difficulties in interpreting the models, arguments against using translog functional forms, and concerns it had with assumed relationships between expenditures and some cost drivers. However, we strongly believe that because the resulting specifications can be easily demonstrated to also have very strong and untenable assumptions with regard to the relationship between outputs and Botex, these models are subject to precisely the same criticisms.

In sum, we believe and accept that appropriate regulatory benchmarking should account for the regulatory, engineering, and economic factors that influence input requirements. However, if we wish benchmarking models to meaningfully and accurately capture the true underlying relationships that determine input requirements in the water industry, much more careful attention must be given to the cost relationships implied by a given specification. That would be best accomplished, by considering and adopting a modelling approach where careful consideration of economic cost theory more significantly influenced model selection and interpretation. Moreover, we point to a vast academic and practical literature which could be readily applied in this effort. Thus, while we believe these models were judged adequate by the CMA and Anglian, there is a clear case that they should be improved for PR19.

W2 Water resources

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

We have focused on reviewing the 4 models chosen by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our Numerical Assessment (1-5) 2

Verbal Assessment

While the set of variables considered by Anglian is broadly appropriate, our assessment of the resulting models is that they require improvement. This assessment rests primarily on our conclusions that each of the 4 chosen models includes at least one variable that we believe is transformed in ways that will potentially lead to inconsistent results. This includes, for example, logging of variables after replacement of zero values.

While the model properly identifies the main output for the service area, we also believe that the method of inclusion of key cost drivers related to abstraction type could and should be substantially improved. In addition, Model WR3 is a restricted version of model WR4 without econometric justification (since Ab/Lic is significant in WR4) and so should not be included among the options.

Settlement patterns, topography and geography will strongly influence abstraction location and type. While these complex relationships will not be fully captured by measures such as Density and Sparsity, we support Anglian's efforts to use these variables in its modelling. However, we find the threshold-based approach developed by Ofwat to be highly inappropriate. We therefore strongly suggest that Anglian and the industry should develop alternative measures using a weighted average of local authority density and scarcity measures in further modelling.

Our overall conclusion on the raw water abstraction model is that there is strong potential to develop a satisfactory model building from Anglian's efforts. We suggest firstly to consider carefully the implications of how data is handled in the models, and secondly to build on this understanding to develop a limited number of specifications that should in principle capture the engineering, economics, and regulatory drivers of water resource Botex. Subsequent econometric estimation, testing and adjustment of these specifications should potentially provide the robust models required for regulatory Botex assessment.

We finally note that "water abstraction" is potentially a clearly defined activity, but that water systems result from past decisions in which the choice of available water sources, location of water treatment capacity, and decisions about raw water transportation, are all interlinked, and also create considerable differences in input requirements. These issues suggest that efficient operation of a water supply system, as well as appropriate Botex modelling may require a more aggregated analysis to properly allow for cost interactions and complementarities. Our experience in the water industry therefore suggests that further robustness tests might include models that aggregate raw water abstraction, transportation, and treatment activities to properly allow for such cost interactions and complementarities.

W3 Water Network Plus

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

We have focused on the 5 final models chosen for triangulation. We have however looked at the whole modelling procedure.

Our numerical assessment (1-5) 3

Verbal assessment

Water Network Plus is meant to provide an integrated evaluation of Raw Water Distribution, Water Treatment, and Treated Water Distribution, while excluding Water Resources (Abstraction). We note that Water Resources includes a relatively small share of Botex, but as per our other service level assessment reports, is likely to have considerable cost interactions between the excluded water resources and the included Raw Water Distribution and Water Treatment activities. However, as Water Resources accounts for a relatively small portion of overall water operations, a good model should bear similarities to one that is appropriate for a fully integrated company, while also attempting to control for the exclusion of raw water resource activities and input requirements.

Given this discussion, the Water Network Plus model should be consistent with one for an integrated company that seeks to minimize the total input usage (net of raw water abstraction costs) required to deliver water to its customers. Thus, at a conceptual level we would expect a model with water delivered as the key volumetric output, controls for the number of connections served and transport distances, and further control variables for issues such as the type of water source, leakage, treatment characteristics, etc., as well as outcome attributes valued by customers. By definition a hypothetical Network Plus firm would of course be further assumed to have appropriately internalized cost interactions between different parts of its vertical supply chain so as to minimize its costs.

We therefore firstly note with interest Anglian's conclusions that length of mains is a better output variable than the volumetric measure Distribution input. We suggest that using water delivered as the base output in their models, would alter these conclusions as it is the key output delivered to customers. It is also more consistent with consumer focused regulation.

Despite this important issue, we would suggest that the modelling provided by Anglian is adequate but is in need of improvement. In particular we believe that development of models WNP3 and WNP5 to create more parsimonious specifications has high potential, and we have provided Anglian more details with our advice with regard to how to proceed. We prefer these models as they include both a volumetric output measure and mains length, thereby capturing the key volume and transportation characteristics required to deliver water, as well as key engineering based characteristics such as controls for age of mains and water source and customer type, which significantly influence maintenance and treatment costs. We do have concerns with regard to some of the controls employed, as for example the simultaneous use of sparsity and density, in model WNP3 does not seem appropriate. However, we do believe that careful development of the underlying specifications will allow a strong and parsimonious model for Network Plus activities.

In sum, we believe that the key drivers for Network Plus, should firstly be the volume of delivered water (net of distribution losses); the length of both raw and final mains; the source and treatment level for water (which account for both treatment and RWD); connection density; and measures of capital quality and intensity, as well as the relative regional cost of staff. All of these have been considered by Anglian in their modeling; however, we would suggest the inclusion of attributes valued by customers such as pressure or supply interruptions. We are not always confident with regard to the logic behind Anglian's inclusion or exclusion of variables. Nevertheless, careful further developments that build from a basic output specification will provide stronger models, in Anglian's next round.

W4 Raw water distribution

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

We have focused on reviewing the 5 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 2

Verbal Assessment

We accept the fact that Anglian has chosen to separately model this activity, and Ofwat's decision to set prices separately for water resources. However, we note that our experience suggests that system design with regard to water resourcing involves a joint decision between abstracting and transporting raw water, to a cost-effective location for treatment within the overall water system. That is, we are not particularly confident that this activity should be subject to separate cost assessment, and that the boundaries between firm activities in Ofwat's regulatory accounting guidelines have been drawn appropriately to allow appropriate cost assessment. The issues raised here relate to those raised by Professor Saal in the academic appendix to CEPA (2011) as strong cost complementarities between these activities suggest the need for a more aggregated analysis, and the potential for inaccurate results and conclusions arising from excessive disaggregation.

Moreover, we also note substantial heterogeneity across firms and abstraction types with regards to the potential ability to meaningfully separate costs for this activity from both water resources and water treatment. Thus, we strongly support Anglian's insinuation that the separation of this service activity from water resources may be tricky.

Additionally, as five of the variables employed (V,LS,S,AB/LIC, and A) have identical values for the 3 years modelled, we further support Anglian's concerns about the severe limitations of the database employed. This also suggests that a preliminary model based on that single year's data would be most appropriate.

The reported results also provide a clear example that general to specific modelling could be employed to more effectively choose between models. In particular, the GLS version of model RWD1 is nested in the GLS version of model RWD2, and the added variable is statistically insignificant, indicating that RWD1 should be rejected statistically in preference to RWD2. Similarly, the OLS version of model RWD1 is nested in the OLS version of model RWD2, which is in turn nested in model RWD3, suggesting that appropriate use of joint significance tests and analysis of multicollinearity could lead to a clearer, statistically more robust final specification

Our consideration of the variables selected by Anglian is influenced by the general issue of meaningfully separating this activity. A "raw water distribution" function suggests that modelling should be concerned only with the phase that goes from abstraction to treatment points. The key aspect of this idealized activity is presumably how much water is transported and how far, and how many abstraction and treatment points exist in the area. Thus, it is notable that the remaining variables employed by Anglian do not directly relate to the raw water distribution function but to other parts of the water services network. This is perhaps evidence of data constraints, as well as the difficulty of modelling this activity without cost drivers that relate to cost interactions with other activities.

Given that the prevalence of raw water transportation is heavily influenced by settlement patterns and the type of water source employed, we seriously doubt whether "raw water distribution?" is potentially a clearly defined activity. Moreover, we believe that the current system results from past system design decisions involving interlinked decision making with regards to water abstraction, transportation and treatment. This therefore suggests that further robustness tests should include models that aggregate raw water abstraction, transportation, and treatment activities.

We finally note that given water scarcity and improved management of water resources is a primary justification for the reforms and vertical separation approach being developed by Ofwat, controlling for leakage within the raw water distribution system would be desirable. I.e. if water is to be valued properly, controls for water losses within water networks are required, otherwise firms will have limited incentives to engage in costly efforts to reduce losses, and will in fact be penalized for carrying out such activities in cost assessments.

W5 Water Treatment

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water Models reviewed

We have focused on the 3 final models chosen for triangulation. We have however looked at the whole modelling procedure.

Our numerical Assessment (1-5) 3

Verbal assessment

We believe that the most appropriate output measure for this service area is distribution input, as identified in Ofwat's regulatory accounting guidelines, while Anglian's models have used population and water abstraction volumes instead. While we suggest that Anglian adopts Distribution Input or other volumetric treatment data in its future models, the close correlation between these aggregate company level output measures suggests that final results might not be influenced too significantly by this change.

On balance we believe the modelling is adequate but could also be improved. Thus, all the variables (pumping activity, sparsity, regional wages, and the number of ground and surface water plants) are appropriate and the transformations included in the models chosen by Anglian for triangulation are acceptable. However, a better explanation and justification for their inclusion in the report should be given. For example, no explanation is provided as to why the statistically significant signs of the number of ground water and surface water plants should differ.

With regards to suggested improvements, we first note that the number of ground and surface water plants is included in almost all of the reported models as a proxy/control for differences in treatment type and scale. However, as the number of treatment plants also increases with overall treatment volumes these variables are over 0.70 correlated with both the population and abstraction based output proxies. Thus, the statistical insignificance of both the quadratic output variables, as well as alternative variables on treatment complexity and heterogeneity tested by Anglian may be influenced by this.

We therefore suggest that future refinement of these models should further explore how heterogeneity in treatment can be modelled; and that careful consideration of how variable inclusion impacts the overall quality of the specified model will result in stronger models. Thus, for example, we believe that the approach of including disaggregated volumes of water by source or treatment type, which was experimented with by Anglian but rejected, is in fact promising. However, as these variables are a disaggregation of the appropriate output variable, their inclusion requires the removal of the aggregate output variable, and appropriate statistical testing of whether this disaggregation improves the model. Given the lack of controls for the type of chemical treatment that water undergoes, as well as the scale of water treatment plants, we believe a similar approach of replacing aggregate output volumes with disaggregated volumetric data for a limited number of appropriate source, treatment type, and/or scale of treatment works categories would be worth pursuing. Such an approach might also impact the need for a company level sparsity variable, as it would directly capture how resulting differences in treatment methods influence water treatment Botex.

We finally note our belief that water system design and input requirements have been influenced by complex factors suggesting the strong potential for cost interactions and complementarities between water abstraction, raw water abstraction transportation, and treatment activities. We therefore suggest further robustness tests that include models that aggregate raw water abstraction, transportation, and treatment activities.

W6 Treated Water Distribution

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

We have focused on reviewing the 5 models chosen by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 1

Verbal Assessment

A clearer identification of the relevant drivers and controls for this stage and of a stricter, more logical selection process between models would be beneficial. Thus, we do not feel that the model is focused on the key output to consumers which is delivered water (none of Anglian's selected models include a volumetric output measure), and how variations in the number of connections and transportation distance required influence input requirements. Moreover, it is also particularly important to consider how variables are included given that many of the potential variables are highly collinear and capture similar effects.

Thus, our concerns with regard to this model relate primarily to its use of mains length data. However, we first emphasize that in principle mains length is an effective variable, which is often used to proxy for the distance of transportation output characteristic, but also captures the extent of the network that must be maintained. Nevertheless, every model reported by Anglian includes a full set of 8 variables representing logged values of mains length broken out by their age, suggesting that these variables formed the base model from which further extended models were built. We strongly believe that the resulting disaggregation of the network based on age has been divided into too many categories, and the resulting coefficients for these categories and differences between them are difficult to meaningfully interpret. Stated differently, it is likely that due to this excessive disaggregation, the model cannot effectively disentangle the effect of the length of main from that of age of main. Moreover, if we focus on an example that only two companies have any significant mains length laid before 1880, these variables may really be capturing other effects such as the extent of urban population served.

This choice may reflect an excessive focus on an engineering perspective in which mains characteristics influence required costs, as opposed to an outcomes based approach in which outputs delivered and operating characteristics influencing consumer outcomes would be relatively more important. Moreover, we can understand the statistical logic of including these mains length variables, as our own analysis reveals that as a group they explain 0.974 of the variance in water distribution Botex.

However, following the intuition of Ofwat's regulatory accounting guidelines which suggest delivered water is the primary output of this activity, a regression including the single variable potable water delivered explains 0.958 of the variance in modelled Botex. E.g there is little meaningful difference in the statistical variance explained by a regression including only the primary output of this sector, and Anglian's effective base model including 8 variables. However, we suggest that a base model focusing on the relationship between the key output and Botex is clearly a stronger base from which to build a more robust model controlling for other Botex drivers.

Given this substantial concern with regard to the underlying model approach employed by Anglian, and what appears to be a relatively ad hoc model selection process aimed at adding variables to their chosen disaggregated mains length model, our overall conclusion is that these models do not perform well in providing good specifications that account for the economic, regulatory, and engineering factors that influence treated water distribution Botex. Moreover, as the selection process is not straightforward between models it is difficult to evaluate the final choices.

We also note the issue of potential complementarities and cost interactions between activities, which suggest that disaggregated models have the potential for biases that would be captured by an aggregate model. However, leaving aside issues such as the close integration of borehole abstraction and treatment systems into distribution systems, we are reasonably confident that well specified models for a distribution only model are feasible.

We also wish to express support for Anglian's efforts to control for leakage in the model, given that Ofwat's reforms are partially designed to improve incentives and respond to water resource scarcity. However, the reported signs are not consistent with our expectations with regard to the relationship between input requirements and leakage. E.g the model suggests that increased leakage is associated with higher input requirements, when it is commonly believed that distribution companies may have incentives to shirk leakage reduction efforts so as to reduce costs.

We finally note that a vast academic and practical literature exists in which distribution activities are modelled. Review of it would be useful before developing further models, as it uggests many alternatives to reconciling controlling for multiple outputs and operating characteristics while also dealing with the high correlation between such potential variables. In this light, we note that Ofwat's regulatory accounting guidelines also identify many relevant factors that might be controlled for in a distribution model.

Summary of the Water Recycling Model Assessments

The table below summarizes our numerical assessment of the models developed by Anglian Water for each of the eight areas of assessment it has estimated for water recycling activities. The following reports provide our detailed commentary on Anglian's models for each service area. On balance we find strengths to build from in Anglian's models, but have also been able to identify clear suggestions for improvement. Moreover, unlike the arguments we have made with regard to the Water Modelling we can broadly accept both the regulatory logic of separating Sludge assessment from Network Plus assessment, as well as the further disaggregation of these models. Thus, we understand that Anglian Water is particularly interested in accounting for what it argues are the high sludge transport and treatment costs given its population settlement patterns. This does not however mitigate against the need for stronger models, and particularly the need for models that both control for the likely presence of cost interactions and provide for a more consistent approach between disaggregated and aggregate models. Thus, for example, Ofwat's intention to assess Sludge and Network Plus activities separately requires consideration of cost interactions, as a considerable amount of sludge is co-treated at sewage treatment plants. Cost complementarities are also suggested by the post-privatisation trend for companies to close smaller sewage treatment plants, where feasible, and transport sewage further, to better exploit plant size economies in sewage treatment. Similarly, the primary reason why we give the S3 Integrated Bioresources Model a numerical assessment of one is that while relatively strong output proxies for Sludge Treatment, Sludge Transport, and Sludge Disposal are identified in the disaggregated models, these characteristics are not adequately controlled for in the Integrated Sludge Models. Thus, if it is desired to pursue both aggregated and disaggregated modelling for sludge activities, we would suggest that the four models be developed in a more consistent way.

Thus, in addition to the specific comment we have made for each of the Water Recycling models, we would reiterate that Anglian's overall approach would benefit substantially from improving the conceptual consistency of each model, as well as the consistency between aggregated and disaggregated models. Subsequent estimation of such models and application of a general to specific approach would ultimately generate relatively fewer but stronger specifications for application in cost assessment, and improve their reliability.

Water Recycling Models – Summary of Numerical Assessment Scores	
S1 Total Integrated Water Recycling Activities	3
Disaggregated Models	
S2 Network Plus Water Recycling	2
S4 Sewage collection	2
S5 Sewage Treatment	3
S3 Integrated Bioresources Model	1
S6 Sludge Transport	2
S7 Sludge Treatment	2
S8 Biosolids Recycling (Sludge Disposal)	3

Key	
Approach Needs Substantial Conceptual and/or Empirical Adjustment	1
Variables and Specifications have potential but require substantial improvement	2
Specifications that we believe could be improved and/or alternative approaches may provide stronger models	3
Satisfactory	4
Excellent	5

S1 Total Integrated Water Recycling

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

We have reviewed the 4 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 3

Verbal Assessment

The Integrated Water Recycling Model should be consistent with one for an integrated company that seeks to minimize the total input usage for collecting sewage from its customers, treating that sewage, and further treating and/or disposing of sludge. At the conceptual level we would therefore expect a model with treatment volumes as the key volumetric output, controls for the number of connections served and transport distances. Further controls are also required for characteristics such as the type of treatment employed and treatment levels, as well as the age profile of the capital stocks. The model should also account for significant differences between firms such as the required amount of sludge transport, and the size of treatment plants required as determined by population settlement patterns. By definition, such a vertically integrated firm would of course be further assumed to have appropriately internalized cost interactions between different parts of its vertical supply chain so as to minimize its costs.

Before proceeding, we note that sewage treatment, sewage collection, and total sludge costs respectively account for 48, 34, and 18 percent of modelled Botex. This indicates that while collection is an important factor that must be controlled for, sewage and sludge treatment are the primary driver of Botex. This suggests that output measures that capture the volume of treatment required should be relatively more important in determining Botex.

However, it also highlights the potential biases in the Botex approach as sewage networks have considerably higher capital stocks. Neither Botex nor Totex modelling accounts for the financial cost required to service capital: thus, by ignoring financial costs of capital, Botex and Totex modelling may both result in well specified models that nevertheless do not accurately capture the full drivers of total regulated costs. E.g the modelling approach may reward firms that minimize their operating costs and current capital spend, but this is not the same as minimizing the total cost that will need to be paid by consumers of the service.

When taken together, the variables chosen by Anglian provide the foundations required. Data on mains length, the number of connected properties, properties connected, population equivalent treatment loads, tons of dry sludge produced, all provide strong output proxies for the volumetric, connections, and transport characteristics that must be modelled. Similarly, operating characteristics such as the share of treatment carried out in small works, the share of sludge that is transported for further treatment, estimates of the sludge transport output, average treatment plant size, the age profile of mains, and the share of treatment load subject to tight numerical constraints are appropriate. While further consideration could improve these controls (differences between solid and liquid sludge discussed in the sludge modelling reports provide an example) overall they provide a fairly comprehensive dataset.

Unfortunately, none of Anglian's selected models fully strike the appropriate balance between controlling significantly for the complex activities being modelled, and the likely collinearity between explanatory factors. Thus, WRI1 controls for length of mains, sludge volumes the proportion of treatment done in small works, and a sludge transport work output variable, but does not control for connections, sewage treatment levels or sewage treatment outputs. WRI2 is nested in WRI3, with the latter model being statistically preferred. WRI3 does control for treatment quality and volumes and the average size of treatment works, but includes no controls for sludge output or transportation, nor mains length controls. WRI 4 includes no control for sewage or sludge volumes and treatment levels while controlling for connections, and is the only model that controls for the age profile of the collection network: however, it employs a variant of the excessive disaggregation of mains length data that we have commented on in other reports. Given this, we believe that none of the integrated water recycling models fully capture all of the relevant aspects that would be required to model at this level.

Overall, while we are confident that strong models can be developed from the variables that Anglian has identified for consideration, substantially stronger specifications can be developed. We suggest this can be fostered via better consideration of the underlying relationships between chosen variables, and how they interact. Moreover, reference to the substantial literature on network industry modelling should provide useful insights with regard to modelling the multiple factors that influence input requirements, while also allowing the close correlation and interrelationship between these factors.

Disaggregated Models

S2 Network Plus Water Recycling

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 4 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 2

Verbal Assessment

The models for Network Plus water recycling aim to incorporate sewage collection and sewage treatment as an integrated entity. However, in contrast to our conclusions with regard to the Water Network Plus modelling which provided a strong foundation from which to develop improved models, the Sewage Network Plus modelling will require substantially more development.

This assessment stems from the facts that variables are missing that have been shown to be important cost drivers for the component sewage collection or sewage treatment activities. For example, variables controlling for differences in the level of treatment significantly influenced treatment Botex but were not considered in the Network Plus water recycling models. Similarly, while the age of mains was treated as an important cost driver in the sewage collection models it is not controlled for here. The reverse is also true, as sewage volumes did not appear in the constituent models but was included in two of the Network Plus models chosen by Anglian.

A related concern is substantial and unexplained differences between data used in the constituent models (sewage treatment and collection) as opposed to the network plus models. Thus, for example, the Network Plus models incorporate density (here again including zero values) and sparsity values that do not coincide with those used in the individual reports. Other variables such as length of sewers are identical, which is expected.

In sum, while we would expect some variance in model choice between the disaggregated specifications and the aggregated ones, we would also expect a greater degree of consistency in the variable choices as ultimately the same underlying production relationships are being modelled. The most obvious difference that should exist from a conceptual level, relate to differences in modelling that relate from the need to control for cost interactions and the potential for excessive correlation of variables in the integrated models. However, this does not seem to be the reason for the differences in Anglian's modelling.

In some sense, our concern with this model is the opposite of those for many of the other models we have reviewed. E.g. while, for example several of the sewage collection models may over egg the pudding by including too many mains length age variables, the models for Network Plus, may be too parsimonious. As a result, crucial determinants of the production processes of sewage treatment and collection seem to be neglected in the network plus modelling. Perhaps WRNP1 is best illustrative of this, as it relies on only sparsity, population equivalent, and the share of load treated in small works to explain Network Plus Botex.

Given this discussion, we believe the Water Recycling Network Plus model should be consistent with one for an integrated company that seeks to minimize the total input usage required to collect and treat sewage from its customers (net of sludge treatment and disposal). Thus, at a conceptual level we would expect a model with treatment volumes as the key volumetric output (population equivalent is suitable for this but trade effluent needs to be controlled for), controls for the number of connections served, transport distances, and further control variables for issues such as the level of treatment provided, differences in scale of treatment facilities, network characteristics such as age and settlement patterns etc. Moreover, carefully developing the integrated and constituent models in tandem, will lead to stronger specifications that are nonetheless also parsimonious.

S4 Sewage collection

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 5 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 2

Verbal Assessment

The underlying data and developing models on sewage collection are promising. They seem to include the vast majority of relevant variables influencing the costs of this service. Additional alternative variables are available by which the existing models could be extended or which could be used for alternative measures of the same cost driver. The data is of reasonable quality and do not involve challenges such as, for example, zero values.

The models show that Botex is influenced by the provided service measured either as length of sewers, areas served or volume of sewerage. It has been further indicated that variables capturing the characteristic of the supplied area, such as sparsity, rurality and network intensity, significantly drive costs.

However, each of the chosen models include at least 2 alternative measures which capture the impact of density and settlement patterns on input requirements (disaggregated or total mains length, Area, Sparsity, and Average Passing Distance). This over-specification might explain some of the signs that we feel go against our prior expectations, such as the estimated negative impact of sparsity on Botex. In contrast, the role of serving connections is only explored in the one model chosen by Anglian that includes Average Passing Distance.

A positive feature of the models on sewage is the inclusion of variables which account for the age characteristics of the respective network. The results indicate that age influences Botex and needs to be accounted for, and we would expect that opex and capital maintenance costs are related to the age and condition of the network. The treatment of age variables, however, requires considerable revision. Thus, 3 of the models chosen by Anglian include a complete set of 8 length of main by age variables: As discussed in our report for W6 Water Treated distribution, we do not believe this specification is appropriate because it will not be able to disentangle the age of assets effect from a length of mains effect. Moreover, difficulty in providing interpretation for the signs and magnitudes of these coefficients supports our concerns.

However, two of the sewage collection models chosen by Anglian do take the alternative approach of using a total length of main variable and a sub set of share of mains length by age category, which we believe is an appropriate way to employ this data. However, as it is still difficult to understand the negative sign on the pre 1980 share variable, we suggest that these specifications be tweaked so as to employ a smaller set of share variables. The example already set by Anglian in their Water Network Plus model is illustrative here: In that model they used shares for pre-1940 mains length, which appeared to provide a robust and parsimonious specification with appropriate signs.

The models could be improved, and particularly regarding their functional form, to allow for non-linear effects and for completeness to test the inclusion other potentially relevant cost-drivers.

In sum, the models should be more carefully refined so that they capture the key output, volume, and transport output characteristics of a network, while carefully accounting for the high correlations between potential variables. We therefore finally note that a vast academic and practical literature exists in which distribution activities are modelled, and reference to this literature would be useful before developing further models. This literature suggests many alternatives to reconciling controlling for multiple outputs, as well as further control variables, while also dealing with the high correlation between such potential variables.

S5 Sewage Treatment

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 4 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 3

Verbal Assessment

We find the modeling developed by Anglian on sewage treatment particularly promising, as they seem to have considered a strong set of relevant variables influencing the costs of this service. The population equivalent variable and characteristics of the service area (e.g., density, sparsity, size bands for the plants in which sewage is treated) appear to be relevant cost drivers. Additionally, controls for the level of sewage treatment required based on numerical consent compliance data and tertiary treatment data are both considered. We are therefore extremely confident that further refinement of these models is very likely to result in a strong and robust model.

Since the data provide many alternatives for characterizing the service produced, the rationale underlying the chosen measures needs to be defined more precisely. Furthermore, potential relations between them must be better understood to avoid misinterpretation of the results. Also, non-linear relations between Botex and the explanatory variables should be explored in more detail.

In general, the chosen models show highly significant coefficients for most of the cost-drivers. As a result, it seems that in many cases not justified that variables should be excluded from some models despite having significant coefficients in others. We therefore suggest moving forward with models where the primary output is captured by equivalent population and its square, the impact of plant size economies is controlled for with the size banding approach, and models which include the numerical consent and/or tertiary treatment quality data.

However, our initial review of the models also suggests strong interactions between the nature of treatment, size of plant, and variables such as sparsity, density, and Area. We therefore also suggest that these models could be improved through careful testing of these interactions. The resulting model selection process is likely to even more effectively capture the relevant engineering attributes, and improve their statistical robustness.

S3 Integrated Bioresources Model

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 3 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 1

Verbal Assessment

The Integrated Bioresources (Sludge) Model should be consistent with one for an integrated operation that seeks to minimize the total input usage for transporting, treating and disposing of sludge. At the conceptual level, we would therefore expect a model with sludge treatment volumes as the key volumetric output with further explanatory variables accounting for differences in types of sludge treatment, controls for the amount of sludge transport required, and further controls for factors that may influence the disposal costs for sludge.

The three models selected by Anglian are particularly frugal, and for example do not use the detailed data on treatment types that was employed in the sludge treatment model. In contrast all three specifications include the sludge transported variable tds(1-I), and the disposal work done variable WD, thereby suggesting an excessive focus on transportation related sludge activities. In fact, as specification B1 only adds Area and Sparsity, while specification B2 further adds Density, these models include no variables at all that are explicitly designed to capture the impact of treatment costs. We find this difficult to understand given that sludge treatment costs dominate Botex while sludge transport and disposal account for only a quarter of it. Moreover, as Model B1 is nested in Model B2, the latter is preferred on statistical grounds. However, we again note that the individual statistical significance of the Area, Sparsity and Density variables is less important to us than the conceptual difficulty of explaining the negative signs of both the threshold based settlement pattern variables developed by Ofwat data. Stated differently, controls for settlement patterns are also over-specified in this model.

The final model B3 removes the Area variable and adds tds(I). Removing Area is consistent with allowing sparsity and density to capture the impact of settlement patterns, but the resulting model still yields unexplained negative coefficients for both of these variables. Inclusion of tds(I) is potentially justifiable as it effectively captures a difference in the input requirements of sludge that is treated at waste water works and that which is transported before treatment. The flavour of Anglian's arguments and our expectations suggest that sludge which is moved should have stronger Botex effects. However, the estimated Botex elasticity for moved sludge is substantially lower than that for sludge that is not moved before treatment. The difficulty of explaining this result suggests that further modelling is required to produce a more robust specification.

In sum, Anglian Water's Integrated Sludge modelling has identified some interesting potential output proxies and explanatory factors. However, the report ultimately suggests the need for more careful consideration of the interrelationship between models at both the conceptual and statistical level.

S6 Sludge Transport

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 7 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 2

Verbal Assessment

Several of the models chosen by Anglian for inclusion in their final model specification are nested in other models, and can be eliminated based on statistical arguments alone. Thus, STrans3 is nested in STrans2 and is preferred as it eliminates the statistically insignificant time trend variable. Similar arguments support the elimination of STrans5 model in preference for STrans6.

Focusing on the remaining 5 models, we firstly consider STrans1 and STrans3 together. These models both include the tds(1-I) variable which we believe captures the key sludge transportation output. They differ only in their specification of how settlement patterns influence Botex. Thus, STrans3, which has a noticeably higher R-Squared, only further includes Area. In contrast, STrans 1 includes both the Ofwat definition of Sparsity and Density. Including all three variables in a single model and testing the joint significance of the Sparsity and Density variables relative to STrans 3, would potentially lead to a single model being judged to be appropriate. i.e. it is feasible to statistically test which of these alternative specifications is appropriate. Conceptual considerations also support STrans3, as the positive and significant Area coefficient is consistent with prior expectations that, other things being equal, firms that serve larger areas will have higher sludge transport costs. In contrast, we find it difficult to interpret the negative signs on both the density and sparsity variables in STrans 1. This result may occur because of the inclusion of two closely related measures and/or what we believe is the inappropriate threshold definition of these variables suggested by Ofwat.

We next turn to STrans4 and note that STrans3 is nested within it, as it further includes Sparsity, WL, and I, which are all significant at least at the 10 percent level. However, inclusion of these variables leads to the output proxy tds(1-I) becoming statistically insignificant. Despite the high R-Squared of this model, we are wary of it as we have difficulty understanding its conceptual basis. We see no logic for the inclusion of I, which captures the share of sludge that is not transported, as the output variable already takes into account which sludge needs to be transported. However, the inclusion of WL, may have merit as it captures the share of sludge transport output that is liquid, and hence higher cost.

STrans6 is identical to STrans 4, except for the replacement of the total sludge moved variable with WT, which measures transport work as sludge ton kilometres: this appears to be a viable alternative output proxy. However, we do not feel that the potential merit of this alternative output proxy can be gauged given the same concerns raised for STrans4, which may explain the statistically insignificant coefficient for WT.

Finally, despite the high reported R-Squared for STrans7, we are also not confident in this specification, which does not include any output proxy for the key output which is Sludge Transport. Thus, we do not believe this model can be considered conceptually appropriate.

In sum, Anglian's Sludge Transport modelling has identified some interesting potential output proxies, and explanatory factors. However, the report ultimately suggests the need for more careful consideration of the interrelationship between models at both the conceptual and statistical level.

S7 Sludge Treatment

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 4 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 2

Verbal Assessment

Anglian appears to have faced data limitations, as our review of the underlying spreadsheet detailing the model suggest that while Botex varies across the 5 years modelled, the models include 2016 values for all of the explanatory variables with the exception of tons of sludge treated. These models must therefore be considered as extremely preliminary. However, we do note that given the low number of observations it would be difficult to develop modelling with a single year's data.

All of the final model specifications chosen by Anglian include an appropriate measure of output which is the total volume of dry solids treated; and a detailed separation of the type of treatment required.

However, all of the models chosen by Anglian also include a full set of 6 logged share variables by type of sludge treatment, and these variables sum to one. Moreover, this includes at least 3 categories where the majority of firms have what appear to have been zero values that have been replaced with very small values to allow logging. Furthermore for these 3 variables, the few remaining firms only employ very low proportions of this type of treatment. Thus, while logging of these share variables (which we do not recommend) has prevented perfect multicollinearity in the specification, this over specification nonetheless suggests why many of the reported coefficients for these variables are not particularly significant.

Nevertheless, the underlying principle of Anglian's approach is appropriate and we strongly support future modelling that employs it. However, such modeling should be pursued with either the inclusion of a set of appropriate sludge treatment outputs by type, or the continued use of total sludge treatment, but with a more limited set of treatment type share variables, that do not need to be logged.

In general, the report does not make it clear why further variables have been chosen for inclusion, nor what criteria or model specification process was employed, particularly given that sludge treatment is a reasonably well defined activity. Thus, for example, the inclusion of Area is unclear in its expected effect, if treatment and transport are to be seen as two separate services. Moreover, the inclusion of only area squared in one of the chosen models appears arbitrary, does not meet any particular intuition and is in fact not significant, making that specification redundant relative to another of the chosen models that is nested within it. Similarly, the inclusion and interpretation of sparsity and density should be better explained at this level of service as it is not really clear what the expected effect on sludge treatment would be. Moreover, as other models emphasize a difference associated with whether sludge is transported from sewage treatment plants, it is unclear why this does not influence this model.

In sum, we believe that the underlying modeling approach of controlling for total sludge treatment and type of treatment is appropriate. However, the specification provided needs to be improved, and a proper panel data set needs to be employed. Given these changes, we are reasonably confident that further modelling will provide more robust specifications.

S8 Biosolids Recycling (Sludge Disposal)

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Sewage models reviewed

We have focused on reviewing the 5 models chosen for triangulation by Anglian Water. We have nonetheless considered the overall modelling procedure.

Our numerical Assessment (1-5) 3

Verbal Assessment

Two of the models chosen by Anglian for inclusion in its final model specification are nested in other models, and can be eliminated based on statistical arguments alone. Thus, the first model is nested in the second, but the second can be rejected based on the statistically insignificant time trend. Similarly, Model SD5 is preferred to Model SD4, which differs only by the inclusion of the statistically insignificant Sparsity variable. We therefore only further consider models SD1, SD3 and SD5 as reported by Anglian.

The three remaining models are in turn related to each other with both Model SD1 and Model SD5 being nested in Model SD3. Thus, all of them include a volumetric measure of the tons of sludge disposed, which has a positive and significant sign, and is an appropriate output variable to build the model around. Model SD3 further includes both Area and Density, with Area being statistically significant but Density very insignificant. Thus, despite Density being significant in Model SD5, Model SD1 is the only model which survives application of this very simple example of general to specific modelling. I.e. there is no need for triangulation of these 5 models as only one of them survives the application of standard hypothesis testing.

Given this conclusion, Model SD1 provides what appears to be a sparse but appropriate specification, as modelled Botex increases with an appropriate output, and decreases with the Area served by the company. We believe the latter result is appropriate as we would expect disposal costs to be lower for firms that have easier access to rural/agricultural disposal sites.

In sum, this single model provides an adequate basic specification, and while we do not speculate further with regard to how it could be improved, further careful elaboration of the model with appropriate controls, type of disposal indicators, and other explanatory variables should be explored. Most importantly, consideration of this report demonstrates strongly the need for more careful consideration of the interrelationship between models at both the conceptual and statistical level.

Summary of the Retail Model Assessment

The table below summarizes our numerical assessment of the models developed by Anglian Water for each of the five areas of assessment for retail activities. The following reports provide our detailed commentary on Anglian's models for each service area.

As with our previous summary of the water and water recycling models, our assessment finds some strengths to build from in these models, but also suggests the need and potential benefit from more rigorously applying a cost assessment approach that should firstly develop carefully considered models, and then use general to specific refinement and estimation of these models to generate relatively fewer but stronger candidate models to be employed in cost assessment.

With regard to the retail models, we must however emphasize that our overall assessment is that we are not sanguine with regard to the prospect of developing robust cost assessment with the disaggregated models, and we therefore strongly suggest that future modelling should focus on assessing costs for total retail integrated activities (R1). This conclusion is firstly based on our rejection of the appropriateness of cost assessment for other retails costs (R5) as this relatively large cost disaggregate is by definition a miscellaneous grab bag for costs that are not easily categorized, and also has no clearly defined output associated with it. In contrast, debt management, meter reading, and customer services all have clearly defined outputs that can be associated with these cost disaggregates. However, our R2 assessment challenges the definition of costs and outputs employed for debt management, and notes the potential for significant cost interactions between debt management and customer services. We similarly note the potential for cost interactions between meter reading and customer services. We finally note that as retail services account for a very small share of overall regulated costs, disaggregated modelling could be viewed as excessive, and as evidence of excessive regulatory interference in the operation of water and sewerage companies.

We therefore suggest that Anglian Water should further develop its retail cost assessment modelling by focussing on an integrated approach, which is also specified so as to allow it to capture the impact of managers who seek to minimize the total integrated costs of providing meter readings, customer service, and debt management services to retail customers. If such a model were developed but then also applied by Ofwat in setting retail prices, we believe that it would not only provide the best feasible approach to assessing retail costs, but also give appropriate incentives for firms to minimize the overall cost of providing retail functions to their customers.

Retail Models –Summary of Numerical Assessment Scores	
R1 Total Integrated Retail Activities	3
Disaggregated Models	
R2 Doubtful debt & debt management	2
R3 Meter reading	2
R4 Customer services	3
R5 Other Retail Costs	1

Key	
Approach Needs Substantial Conceptual and/or Empirical Adjustment	1
Variables and Specifications have potential but require substantial improvement	2
Specifications that we believe could be improved and/or alternative approaches may provide stronger models	3
Satisfactory	4
Excellent	5

R1 Total Integrated Retail Activities

Overall Assessment of the Models Chosen by Anglian

Anglian Water models reviewed

Given their small number we have looked at all 3 models even though only 2 were finally selected by Anglian.

Our numerical Assessment (1-5) 3

Anglian Water models reviewed

Anglian's model choice followed that of Ofwat and tested a linear specification of total retail costs as a function of the total number of households served and average bill paid, but chose log linear specifications of the same models with OLS and GLS random effects for inclusion in their triangulation procedure.

As such, the model identifies a clear relationship between an appropriate output proxy (total number of households connected) and the modelled expenditure. Moreover, we can see the potential validity of the average bill size variable: it may in practice capture some of the increased retail activity of a WaSC relative to a WoC, which we have discussed in our disaggregated retail modelling reports.

However, given the conclusions of our disaggregated retail reports and that managing doubtful debts, meter reading, and customer service activities have all been identified as distinct retail activities, we also believe that the frugal modelling approach here will need to be extended. Otherwise, firms will be unfairly penalized for legitimately higher levels of retail activities.

Thus, at a minimum, controlling for the number of water and sewerage connections as well as the number of metered connections is necessary to capture legitimate differences in metering activity as well as customer service activity. Moreover, allowing for squared output variables is also necessary to allow for potential scale effects in retail activities. Our limited preliminary analysis of Anglian's underlying data supports these conclusions.

Regional variance in staff costs might be included, and given that the data is in nominal terms a time variable should also be considered.

Debt management is clearly a further important retail activity. As discussed in our report on Anglian's disaggregated model for this service area, we do support the inclusion of debt management expenditure in retail costs. However, we do not believe that doubtful debt should be included in retail costs, because it is in fact a potential loss in revenue, not a cost. Moreover, the very purpose of debt management activities is to reduce doubtful debt and revenue losses. We do not have an immediate solution to this issue, but suggest excluding doubtful debt from retail costs, and considering how an output can be specified which captures the benefit of debt management activities.

We finally offer our comments with regard to the suitability of aggregated retail modelling as opposed to disaggregated modelling. We firstly note Anglian's confidence in the similarity between its aggregated and disaggregated cost modelling for total retail costs. Our response is to state an admittedly untested belief that when future aggregated and disaggregated models better control for legitimate differences in output characteristics, greater divergence will exist.

In our opinion, there are at least two strong conceptual arguments that support our recommendation that aggregated retail modelling should be employed for regulatory purposes.

Disaggregated Models

R2 Doubtful debt & debt management

Overall Assessment of the Botex Models Chosen by Anglian

Anglian Water models reviewed

Given their small number we have looked at all 3 models although only models 2 and 3 were finally selected by Anglian.

Our numerical Assessment (1-5) 2

Verbal Assessment

These are models that Ofwat developed and Anglian reproduced. The specification is not very elaborate nor is there a clear explanation of what the characteristics of the service being modelled are and what the key output is. If the aim is to explain the determinants of the total of bad debts and debt management, it is unclear what the logic behind the use of total revenue is, besides the obvious: i.e. that the size of bad debts and debt management will be positively correlated with a company's revenues.

Non linearities here could be explored, as there are likely to be scale effects in retail. Similarly, unemployment has been excluded by Anglian but might be reconsidered unless its effect is already included in the IMD variable.

The average bill will be higher for a WaSC than for a WoC, because they provide two services to a substantial number of their customers. It would therefore seem necessary to explore the potential that this larger bill size may impact the likelihood of customers not paying their bills and hence the need for more debt management by WaSCS.

Furthermore regional variance in staff costs might be included, and given that the data is in nominal terms a time variable should also be considered.

Overall the models are able to account for a substantial share of the variance in the cost aggregate they model, but we are less clear that explaining a variable that aggregates bad debts and debt management costs is meaningful. Thus one might argue that the purpose of increased debt management is itself to reduce bad debts: i.e., that reducing bad debt is the output and debt management is the input. This issue has deeper ramifications which suggest the treatment of bad debt as what it is, which is a revenue loss, and debt management as a cost designed to reduce this revenue loss, and therefore not including bad debts in overall retail costs.

R3 Meter reading

Overall Assessment of Models Chosen by Anglian

Anglian Sewage models reviewed

All 3 models were analyzed although only models 8 and 9 were chosen by Anglian.

Our numerical Assessment (1-5) 2

Verbal Assessment

For meter reading, the chosen models do have a clear relationship between an appropriate output (metered households) and the modelled expenditure. Moreover, as the sparsity variable is entered in levels it does not suffer with the issue of replacing zero values in order to take logs that we have raised in other reports.

While we accept and support controls for settlement patterns we question the threshold definition of both density and sparsity used in retail modelling, as density effects are likely to have a continuous rather than threshold impact on metering costs, and we would expect these to be nonlinear. These concerns are highlighted by the negative (positive) signs on the sparsity (density) variables in Model 8 (9). This goes against our prior expectation that increased density would have a first order decreasing effect on metering costs, while a second order effect might show that costs will start increasing at higher levels of density.

It is also unclear why levels and not logs of metered households are used, as our simple replication of model 7 with a log-log specification instead of the linear specification adopted by Ofwat increases the R-Squared from 0.725 to 0.914. While these R-Squared variables are not directly comparable because these models are not nested, this comparison does suggest that allowing for non-linearity in the estimated relationship between metering and botex may be beneficial. Moreover, it suggests the further need to account for second order output effects so as to capture potential variable returns to scale effects in metering activities.

Regional variance in staff costs might be included, and given that the data is in nominal terms a time variable should also be considered.

Similarly, while regulatory goals may or may not be consistent with considering further factors, we would expect that the share of metered households and factors such as the adoption of smart metering and/or electronic/internet enabled metering technologies would have impacts on the cost of metering. E.g., firms with lower metering uptake would have more distance between each metered household, other things being equal.

Our overall conclusion is that metering is modelled with an appropriate output matching its cost but that substantial improvements can be made on the model.

However, we finally note that as meter reading makes up 5 percent of total retail costs, it might be more appropriate for these costs to be included in an overall total retail model, so as to both reduce regulatory burden and allow company discretion in how they manage overall retail costs. Nevertheless, this does not preclude the potential value to companies, in benchmarking their metering operations, of a well-developed metering model.

R4 Customer services

Overall Assessment of the Models Chosen by Anglian

Anglian Sewage models reviewed

We looked at the 2 finally chosen models (20 and 21) but considered the whole modelling procedure.

Our numerical Assessment (1-5) 3

Verbal Assessment

For customer services, the chosen models do have a clear relationship between an appropriate output (total number of households) and the modelled expenditure. However, while parsimony in specification is a virtue the single variable regression is excessively frugal. We note several issues that could be controlled for:

Leaving aside the cost of physical meter reading, we would expect customer service activity to differ between metered customers, whom we presume would be more likely to question their bills, and non-metered customers. We also note a potential cost interaction not captured in disaggregated modelling as a company with low cost, poor quality meter reading services would face higher costs of customer service via more billing contacts.

Similarly, for the same sized companies we would expect WaSCs to have more customer contacts as they manage both water and sewerage services. They therefore have more billing contacts let alone customer service contacts related to service related inquires such as interruptions and other quality issues. Our simple inclusion of a WaSC dummy variable to the logged OLS model (Model 20) yields a statistically significant positive coefficient, demonstrating this.

While perhaps it should be tested, the lack of controls for population settlement patterns is probably reasonable, as customer service is largely a phone and internet based service.

Testing for nonlinearities via squared terms is also necessary given the likely presence of scale economies in retail services. We note the peculiarity that this is done in some retail models but not others.

Regional variance in staff costs might be included, and given that the data is in nominal terms a time variable should also be considered.

In sum, the specified models capture the key relationship between the modelled expenditure and a key output driver; however legitimate differences in customer characteristics need to be controlled for so that companies are not penalized for their associated legitimate higher customer service activities.

R5 Other Retail Costs

Overall Assessment of the Models Chosen by Anglian

Anglian Sewage models reviewed

We looked at the 2 finally chosen models (14 and 15) but considered the whole modelling procedure

Our numerical Assessment (1-5) 1

Verbal Assessment

With regard to other retail costs, Anglian's report provides no clear explanation with regard to how this activity is distinct from other retail activities. Moreover, we would assume that by definition this cost category captures miscellaneous costs that are not easily categorized against specific retail functions. Thus, we do not think that a distinct output related to other retail costs can ever be identified, and are drawn to conclude that cost assessment at this level of disaggregation is inappropriate because any resulting benchmarking would be meaningless.
As we cannot identify a distinct activity related to this miscellaneous cost disaggregate, we are unsure about what it is benchmarked to. We therefore believe normal practice would be to aggregate such miscellaneous costs within meaningfully defined retail outputs categories.

The number of households is clearly a key variable, and Anglian's modelling approach includes appropriate testing between linear, log linear, and log linear quadratic models. However, as we do not understand how other retail costs are distinct from the other disaggregated modelling activities, we think there is a strong potential that all of the disaggregated retail modelled results may be heavily influenced by cost allocation issues.

Our concerns with regard to this retail cost disaggregate are strong enough that we suggest that Anglian should not pursue this model in future rounds of modelling. Moreover, this forms a key factor in our overall conclusion with regard to the retail modelling. Various cost interaction and cost allocation issues strongly suggest that aggregate retail cost assessment is most appropriate for regulatory cost determination purposes.

Summary

This annex sets out our cost modelling for Integrated Water (Service Area W1).

We have recreated the models used by the Competition and Markets Authority (CMA) in its 2015 Bristol referral. These models appear to be robust and consistent over time.

1. Water service: business unit process identification

Water service describes the entire range of assets and activities to supply treated water to customers from environmental water resources. It includes the abstraction of raw water from surface and underground water bodies; the transport of raw water to water treatment works, possibly via intermediate raw water storage bodies; the conversion of raw water to potable water via water treatment processes; and the distribution of treated water to customers. Key assets include reservoirs, pipes, water treatment process units, storage structures and pumps. Key activities are the pumping and treatment of water and the maintenance of assets.

Key variables are volumes of water supplied, the nature of treatment provided, pumping head and the diameter and length of pipeline assets. Exogenous botex drivers of these variables are the nature and quality of raw water sources, the age and characteristics of treatment and transport assets (many of which have asset lives of decades or even centuries) and the topology and demography of the area served.

2. Approach taken

Rather than developing from scratch a set of top down botex Water cost models, we have replicated the models developed for the CMA in 2015 for the Bristol Water determination. The reasons for taking this approach were:

1. The CMA models are the most recent set of cost models developed for the UK water market
2. They post-date the Ofwat PR14 models and have addressed many of the short-comings of those models
3. Their style matches the general approach which we have taken in developing our own suite of models
4. Recreating these models provides a basis on which comparative efficiency of water operations can be compared over time, by recreating the models annually using additional data as it becomes available.

As such, this annex differs from the other detailed cost modelling annexes which we have produced, both in terms of the content - the models are not our original work - and the format.

This annex sets out:

- The approach taken by the CMA
- The approach we have taken in recreating the models
- The level of accuracy of those recreations
- The reasons for inaccuracies, and
- The results of the recreations.

3. The approach taken by the CMA

The CMA took an approach to cost modelling that could be described as robust. The idea of developing totex econometric models was rejected. Instead, the CMA felt it sensible to restrict the application of econometrics to operating expenditure plus maintenance capex – what we have referred to as botex (base totex).

A prime objective of the CMA's modelling approach was to make the resulting models interpretable from an engineering perspective. The cost relationships were Cobb Douglas and the estimation approach was Pooled Ordinary Least Squares (OLS).

The CMA put forward three model forms. These are called EV1, EV2 and EV3. The CMA used a number of alternative options and combinations for the group of explanatory variables included in each model. These are set out below in Table 1.

For each of these three forms, the CMA used three different variants for each of its botex models:

1. A logarithmic unit cost model in which the dependent variable is the natural log of the measure of botex divided by the number of connected properties
2. A linear unit cost model in which the dependent variable is a measure of botex divided by the number of connected properties, and
3. A logarithmic aggregate cost model in which the dependent variable is a measure of aggregate botex.

Table 1: Independent variables used

Model name	Logarithmic unit cost models	Linear unit cost models	Logarithmic aggregate cost models
EV1	Constant term	Constant term	Constant term
	Time dummy variables for all years except 12-13	Time dummy variables for all years except 12-13	Time dummy variables for all years except 12-13
	Ln(water delivered/property)	Water delivered/property	Ln(water delivered/property)
	Ln(Regional wage measure)	Regional wage measure	Ln(Regional wage measure)
	Ln(mains length/property)	Mains length/property	Ln(total mains length)
	% of DI from rivers	% of DI from rivers x water delivered /property	Ln(total connected properties/total mains length)
	% of DI from reservoirs	% of DI from reservoirs x water delivered /property	% of DI from rivers
	Ln(Avg. Pumping Head)	Avg. Pumping Head x water delivered /property	% of DI from reservoirs
			Ln(Avg. Pumping Head)
EV2	As per EV1 plus	As per EV1 plus	As per EV1 plus
	% water consumed by metered NHH	% water consumed by metered NHH	% water consumed by metered NHH
EV3	As per EV2 but with rivers & reservoirs variables removed & replaced with	As per EV2 but with rivers & reservoirs variables removed & replaced with	As per EV2 but with rivers & reservoirs variables removed & replaced with
	% of DI subject to W3 or W4 treatment	% of DI subject to W3 or W4 treatment Head x water delivered /property	% of DI subject to W3 or W4 treatment

Source: CMA

The CMA then went on to use two different approaches to concatenating maintenance capex and operating expenditure:

1. Botex smoothed over five years. Botex is defined as being the sum of operating expenditure in that year plus the five year moving average of maintenance capex. This smoothed botex uses the five year data sample used and published by Ofwat

2. Unsmoothed botex. This uses a seven year data set, going back two further years (2006-07 and 2007-08). Botex is here defined as being the operating expenditure in that year plus the maintenance capex in that year.

The CMA made a number of points which supported some fundamental aspects of the PR14 approach:
- Totex helps mitigate capex bias
- Benchmarking contributes to a price control framework that incentivises operating and investing efficiently
- Benchmarking reduces risk of relying on company forecasts that are over-stated, risk-averse or do not take enough account of cost saving opportunities via innovation
- It also helps mitigate risks relating to investment deferral.

The CMA report then went on to make critical observations of the Ofwat PR14 models:
- The CMA agreed that capex smoothing is useful, but had no reason to think that five year smoothing was sufficient given industry asset lives are much longer
- Modelling enhancement capex in econometric models is inherently flawed
- The PR14 models are insufficiently granular, they should look at treatment and distribution separately
- As in Ofgem's RIIO approach, detailed bottom up modelling should complement the top down approach. In the case of RIIO, the two approaches are given equal weight
- The CMA found that there are considerable difficulties in interpreting the models:

  "We found it difficult to understand the intuition for Ofwat's model specifications and were concerned that aspects of Ofwat's models did not seem to make sense from an economic and engineering perspective"

- The CMA found the arguments in favour of using of the translog functional form unpersuasive
- The CMA took issue with assumed relationships between expenditure and some cost drivers:

"..we found that in some cases the models impose assumptions on the relationship between expenditure and cost drivers that did not seem to make sense"

- The CMA criticized the inclusion of inputs in the explanatory variable where companies have some control:

  - Length of mains
  - Proportion of water extracted from rivers or reservoirs
  - Percentage of properties that are metered
  - Length of new mains laid in year divided by total length of mains
  - Length of mains relined and renewed divided by total length of mains
  - Leakage as percentage of DI

- The CMA highlighted a number of possible missing cost drivers:
  - Number of connected properties
  - Peak demand, or measures of variance between peak and average demand
  - A measure of the complexity of treatment processes

- The number of explanatory variables relative to sample size and variation was criticised:

  "it is ambitious to take a data set spanning 18 companies over five years and attempt to use an econometric model to produce estimates that quantify the relationship between expenditure and up to 27 different explanatory variables"

4. The approach we took in recreating the CMA models

So in total the CMA developed three model forms, each with three variants (log unit cost, linear unit cost and log aggregate). These were shown on the basis of both five year smoothed and seven year unsmoothed. Hence, in total, the CMA developed 18 separate models (three forms, each with three variants, each with two cost bases). Of these 18 models, the CMA went on to discard eleven on the grounds that they could not be interpreted from an engineering perspective in a rational manner. The models discarded included all six of the aggregate cost models.

The CMA refused to publish its models but published their coefficients. We have replicated the seven models which the CMA went on to use in the Bristol determination. We were able to replicate some of the CMA's models precisely. Others are close, but not exact. The CMA coefficients and the coefficients of the recreations are set out in Tables 2 and 3 overleaf. Tables 4 and 5 then set out the extent to which our recreations of the models match the originals.

Table 2: The goodness of fit of the logarithmic unit cost models

	CMA			Recomputation		
	EV2 5 yr smoothed	EV3	EV2 7 yr uns	EV2 5 yr smoothed	EV3	EV2 7 yr uns
ln (water delivered/property)	0.4086	0.5592	0.5536	0.4112	0.5588	0.4515
ln (regional wage)	0.6130	0.0540	0.4549	0.6090	0.0456	0.6519
ln (mains length/property)	0.3996	0.4293	0.3849	0.3991	0.4260	0.3949
ln (avg pumping head)	0.2487	0.1377	0.2466	0.2486	0.1396	0.2376
% Consumption by metered NHH	-0.9979	-0.8242	-1.3926	-1.0004	-0.8241	-1.2049
% DI subject to w3/w4		0.4409			0.4406	
% DI from rivers	0.3333		0.3504	0.3332		0.3570
% DI from reservoirs	0.2720		0.2887	0.2720		0.2870
Time dummy 2006-07			-0.0554			-0.0459
Time dummy 2007-08			-0.0537			-0.0497
Time dummy 2008-09	-0.0226	-0.0149	-0.0823	-0.0225	-0.0144	-0.0880
Time dummy 2009-10	-0.0079	0.0075	-0.1308	-0.0078	0.0080	-0.1370
Time dummy 2010-11	-0.0180	-0.0058	-0.1230	-0.0179	-0.0054	-0.1270
Time dummy 2011-12	-0.0138	-0.0195	-0.0328	-0.0139	-0.0195	-0.0287
Constant	-5.7924	-3.9092	-5.0302	-5.7772	-3.8865	-5.6861
R^2	0.5021	0.4669	0.3829	0.5016	0.4684	0.3893
Adj R^2	0.4318	0.3994	0.3113	0.4313	0.4011	0.3184
# Observations	90	90	126	90	90	126

Source: CMA, Anglian Water

Table 3: The goodness of fit of the linear unit cost models

	CMA				Recomputation			
	EV2	EV3	EV2	EV3	EV2	EV3	EV2	EV3
	5 yr smoothed		7 yr unsmoothed		5 yr smoothed		7 yr unsmoothed	
Potable water delivered/property	0.0114	0.0164	0.0345	0.0396	0.0124	0.0165	0.0469	0.0195
Regional wage measure	0.0031	0.0010	0.0027	0.0003	0.0031	0.0009	0.0039	0.0016
Mains length/property	0.0036	0.0039	0.0037	0.0040	0.0036	0.0039	0.0035	0.0040
% of DI from rivers x avg potable water delivered/property	0.0686		0.0742		0.0686		0.0390	
% of DI from reservoirs x avg potable water delivered/property	0.0472		0.0513		0.0470		0.0487	
APH x avg potable water delivered/property	0.0004	0.0002	0.0003	0.0001	0.0004	0.0001	0.0003	0.0001
% Consumption by metered non households	-0.1341	-0.1034	-0.1784	-0.1444	-0.1348	-0.1036	-0.1362	-0.1194
% DI at w3/w4 x avg potable water/property		0.0956		0.1000		0.0953		0.0980
Time dummy 2006-07			-0.0052	-0.0040			-0.0051	-0.0039
Time dummy 2007-08			-0.0042	-0.0037			-0.0048	-0.0037
Time dummy 2008-09	-0.0013	-0.0016	-0.0092	-0.0094	-0.0013	-0.0016	-0.0103	-0.0101
Time dummy 2009-10	0.0004	0.0009	-0.0144	-0.0139	0.0004	0.0009	-0.0155	-0.0145
Time dummy 2010-11	-0.0011	-0.0007	-0.0138	-0.0133	-0.0011	-0.0007	-0.0147	-0.0138
Time dummy 2011-12	-0.0014	-0.0017	-0.0030	-0.0034	-0.0014	-0.0017	-0.0031	-0.0030
Constant	0.0003	0.0098	0.0171	0.0290	0.0004	0.0108	-0.0192	0.0130
R^2	0.5001	0.4852	0.3466	0.3287	0.4999	0.4863	0.3642	0.3268
Adj R^2	0.4296	0.4201	0.2708	0.2574	0.4294	0.4213	0.2904	0.2553
# Observations	90	90	126	126	90	90	126	126

Source: CMA, Anglian Water

Table 4: Accuracy of logarithmic recomputations (recomputation/CMA)

	EV2	EV3	EV2
	5 yr smoothed		7 yr uns
ln (water delivered/property)	101%	100%	82%
ln (regional wage)	99%	84%	143%
ln (mains length/property)	100%	99%	103%
ln (avg pumping head)	100%	101%	96%
% Consumption by metered NHH	100%	100%	87%
% DI subject to w3 & w4		100%	
% DI from rivers	100%		102%
% DI from reservoirs	100%		99%
Time dummy 2006-07			83%
Time dummy 2007-08			93%
Time dummy 2008-09	100%	97%	107%
Time dummy 2009-10	99%	107%	105%
Time dummy 2010-11	100%	93%	103%
Time dummy 2011-12	101%	100%	88%
Constant	100%	99%	113%
R^2	100%	100%	102%
Adj R^2	100%	100%	102%

Source: Anglian Water

Table 5: Accuracy of linear recomputations (recomputation/CMA)

	EV2	EV3	EV2	EV3
	5 yr smoothed		7 yr unsmoothed	
Potable water delivered/property	109%	101%	136%	49%
Regional wage measure	99%	95%	148%	538%
Mains length/property	100%	100%	95%	100%
% of DI from rivers x avg potable water delivered/property	100%		53%	
% of DI from reservoirs x avg potable water delivered/property	100%		95%	
Avg pumping head x avg potable water delivered/property	101%	100%	107%	91%
% Consumption by metered NHH	100%	100%	76%	83%
% DI with w3 & w4 treatment x avg potable water/property		100%		98%
Time dummy 2006-07			100%	98%
Time dummy 2007-08			116%	99%
Time dummy 2008-09	100%	97%	112%	107%
Time dummy 2009-10	100%	105%	107%	105%
Time dummy 2010-11	100%	95%	107%	103%
Time dummy 2011-12	101%	101%	101%	88%
Constant	145%	110%	-113%	45%
R^2	100%	100%	105%	99%
Adj R^2	100%	100%	107%	99%

Source: Anglian Water

For its analysis, the CMA used data published by Ofwat (that is, data running up to 2012-13, matching CEPA's input data period). We have used the same dataset in our recreations of the CMA models.

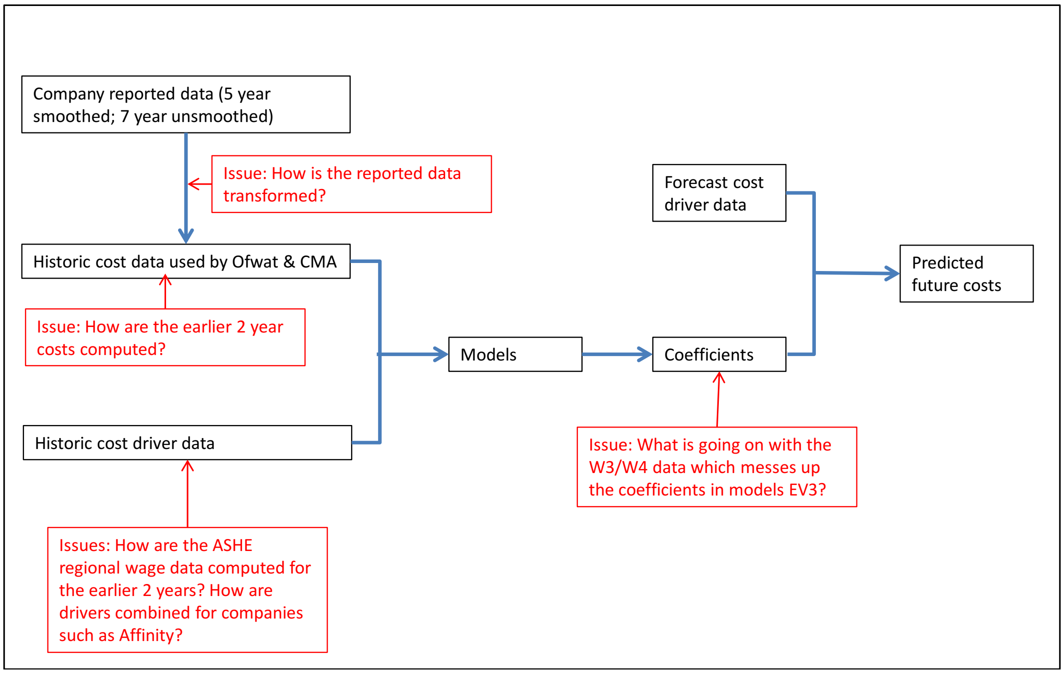
As CEPA and Ofwat had used only a five year series to compute its models, we had to generate the earliest two years of the seven year series of data inputs. This involved conflating the results from:

a. the three constituent parts of Affinity
b. South Staffs and Cambridge, and
c. South East Water and Mid Kent.

Assumptions are needed as to how that conflation should be achieved. The CMA's refusal to share its models meant we have had to infer its approach to conflating companies' numbers. The fact that some of our models produce exactly the same result as reported by the CMA and others are close but not exact suggests that our inferences are not all perfect.

Figure 1 below sets out the various areas where problems were faced in replicating the CMA models. Our inability to answer precisely the individual outstanding issues may explain why the coefficients of all models failed to match to published figures.

Figure 1: CMA model replication approach



Source: Anglian Water

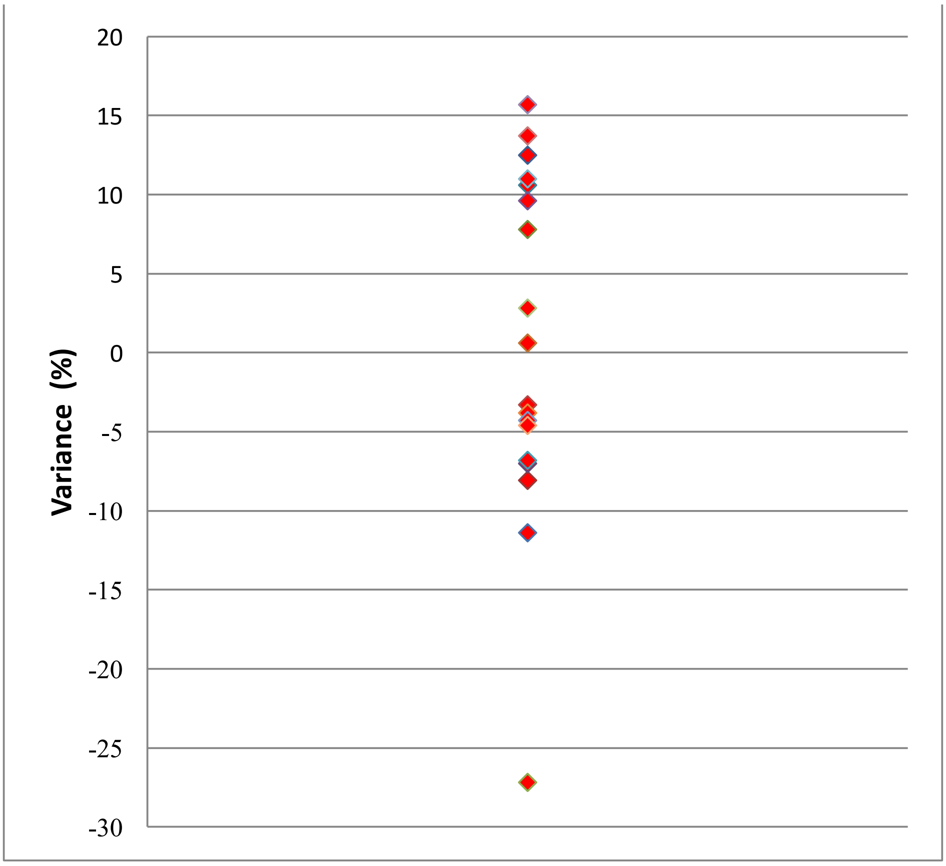
5. The results of the model recreations

We have calculated the expected value produced by each model for the eighteen companies. The models were concatenated (by the CMA and by ourselves in the recreation) using the Ofwat approach of triangulation-that is to say, arithmetic averaging. In order to maintain the same approach as used by Ofwat (and by us for its other cost models), all of the seven models have been evaluated over the same five year period, from 2008-09 to 2012-13. As the CMA unsmoothed models run over seven years and not five, this involves excluding the first two years for each of the three unsmoothed models.

Figure 2 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range of variances is from +16% to –27%. However, excluding one outlier, it shrinks to +16% to -11%. This appears to be credible and supports our view that the models are fit for purpose.

We have rolled the cost models forward for the subsequent three years, to 2013-14, 2014-15 and 2015-16. In each case, the earliest year's data was dropped and the later year was added. The results of this rolling forward are shown in Tables 6 – 12.

Figure 2: Percentage variance between modelled and actual expenditure: Integrated Water



Source: Anglian Water

Table 6: Log unit costs EV2, 5 year smoothed

5 years to	2012-13	2013-14	2014-15	2015-16
ln (water delivered/property)	0.4112	0.3438	0.3114	0.3160
ln (regional wage)	0.6090	0.7805	0.9005	0.5806
ln (mains length/property)	0.3991	0.3859	0.3722	0.3131
ln (avg pumping head)	0.2486	0.2486	0.2573	0.2713
% Consumption by metered non households	-1.0004	-0.8729	-0.7275	-0.2424
% DI subject to w3 & w4				
% DI from rivers	0.3332	0.3045	0.2983	0.1682
% DI from reservoirs	0.2720	0.3353	0.3817	0.4225
Time dummy year n-6				
Time dummy year n-5				
Time dummy year n-4	-0.0225	-0.0628	-0.0478	-0.1562
Time dummy year n-3	-0.0078	-0.0711	-0.0304	-0.1469
Time dummy year n-2	-0.0179	-0.0595	-0.0214	-0.1037
Time dummy year n-1	-0.0139	-0.0490	0.0267	-0.1123
Constant	-5.7772	-6.2548	-6.6904	-5.6920
R^2	0.5016	0.5229	0.5164	0.5969
Adj R^2	0.4313	0.4556	0.4482	0.5401

Source: Anglian Water

Table 7: Log unit costs EV3, 5 year smoothed

5 years to	2012-13	2013-14	2014-15	2015-16
ln (water delivered/property)	0.5588	0.5278	0.5482	0.5059
ln (regional wage)	0.0456	0.0291	-0.0340	-0.2683
ln (mains length/property)	0.4260	0.4271	0.4030	0.2967
ln (avg pumping head)	0.1396	0.1398	0.1578	0.2155
% Consumption by metered non households	-0.8241	-0.8664	-0.8493	-0.6431
% DI subject to w3 & w4	0.4406	0.4111	0.3802	0.3340
% DI from rivers				
% DI from reservoirs				
Time dummy year n-6				
Time dummy year n-5				
Time dummy year n-4	-0.0144	-0.0343	-0.0111	-0.1686
Time dummy year n-3	0.0080	-0.0477	-0.0296	-0.1492
Time dummy year n-2	-0.0054	-0.0635	-0.0102	-0.1043
Time dummy year n-1	-0.0195	-0.0453	0.0313	-0.1104
Constant	-3.8865	-3.7871	-3.6346	-2.8973
R^2	0.4684	0.4708	0.4344	0.4620
Adj R^2	0.4011	0.4038	0.3628	0.3939

Source: Anglian Water

Table 8: Log unit costs EV2, 7 year unsmoothed

7 years to	2012-13	2013-14	2014-15	2015-16
ln (water delivered/property)	0.4515	0.5159	0.4448	0.4914
ln (regional wage)	0.6519	0.4945	0.6977	0.2686
ln (mains length/property)	0.3949	0.4000	0.3417	0.3007
ln (avg pumping head)	0.2376	0.2366	0.2833	0.2397
% Consumption by metered non households	-1.2049	-1.1743	-0.9095	-0.7152
% DI subject to w3 & w4				
% DI from rivers	0.3570	0.3433	0.3498	0.2016
% DI from reservoirs	0.2870	0.2977	0.4224	0.4615
Time dummy year n-6	-0.0459	-0.0535	0.0128	-0.0167
Time dummy year n-5	-0.0497	-0.0915	-0.0346	-0.0550
Time dummy year n-4	-0.0880	-0.1389	-0.0233	0.0156
Time dummy year n-3	-0.1370	-0.1302	0.0774	0.0336
Time dummy year n-2	-0.1270	-0.0373	0.1059	0.0322
Time dummy year n-1	-0.0287	-0.0060	0.1115	-0.0515
Constant	-5.6861	-5.2100	-6.1110	-4.5347
R^2	0.3893	0.3704	0.3985	0.3989
Adj R^2	0.3184	0.2974	0.3287	0.3292

Source: Anglian Water

Table 9: Linear unit costs EV2, 5 year smoothed

5 years to	2012-13	2013-14	2014-15	2015-16
Potable water delivered/property	0.0124	0.0083	-0.0101	0.0539
Regional wage measure	0.0031	0.0034	0.0051	0.0032
Mains length/property	0.0036	0.0034	0.0033	0.0007
% of DI from rivers x avg potable water delivered/property	0.0686	0.0639	0.0624	0.0197
% of DI from reservoirs x avg potable water delivered/property	0.0470	0.0601	0.0783	0.0152
Avg pumping head x avg potable water delivered/property	0.0004	0.0004	0.0004	0.0001
% Consumption by metered NHH	-0.1348	-0.1276	-0.0985	0.0494
% DI subject to w3 & w4 treatment x avg potable water/property				
Time dummy year n-6				
Time dummy year n-5				
Time dummy year n-4	-0.0013	-0.0025	-0.0050	0.0049
Time dummy year n-3	0.0004	-0.0059	-0.0037	0.0048
Time dummy year n-2	-0.0011	-0.0058	-0.0027	0.0048
Time dummy year n-1	-0.0014	-0.0043	0.0027	0.0048
Constant	0.0004	0.0009	-0.0277	0.0468
R^2	0.4999	0.5082	0.4858	0.5793
Adj R^2	0.4294	0.4388	0.4132	0.5200

Source: Anglian Water

Table 10: Linear unit costs EV3, 5 year smoothed

5 years to	2012-13	2013-14	2014-15	2015-16
Potable water delivered/property	0.0165	0.0526	0.0635	0.0636
Regional wage measure	0.0009	0.0022	0.0027	0.0031
Mains length/property	0.0039	0.0007	0.0008	0.0008
% of DI from rivers x avg potable water delivered/property				
% of DI from reservoirs x avg potable water delivered/property				
Avg pumping head x avg potable water delivered/property	0.0001	0.0001	0.0001	0.0001
% Consumption by metered non households	-0.1036	0.0393	0.0470	0.0538
% DI subject to w3 & w4 treatment x avg potable water/property	0.0953	0.0212	0.0232	0.0264
Time dummy year n-6				
Time dummy year n-5				
Time dummy year n-4	-0.0016	0.0050	0.0056	0.0056
Time dummy year n-3	0.0009	0.0048	0.0052	0.0055
Time dummy year n-2	-0.0007	0.0046	0.0054	0.0055
Time dummy year n-1	-0.0017	0.0046	0.0052	0.0055
Constant	0.0108	0.0351	0.0399	0.0484
R^2	0.4863	0.4801	0.4226	0.4420
Adj R^2	0.4213	0.4142	0.3495	0.3714

Source: Anglian Water

Table 11: Linear unit costs EV2, 7 year unsmoothed

7 years to	2012-13	2013-14	2014-15	2015-16
Potable water delivered/property	0.0469	0.0267	-0.0395	0.0246
Regional wage measure	0.0039	0.0024	0.0058	0.0016
Mains length/property	0.0035	0.0037	0.0029	0.0028
% of DI from rivers x avg potable water delivered/property	0.0390	0.0744	0.0731	0.0412
% of DI from reservoirs x avg potable water delivered/property	0.0487	0.0557	0.1030	0.0947
Avg pumping head x avg potable water delivered/property	0.0003	0.0003	0.0005	0.0005
% Consumption by metered non households	-0.1362	-0.1543	-0.0743	-0.0927
% DI subject to w3 & w4 treatment x avg potable water/property				
Time dummy year n-6	-0.0051	-0.0035	-0.0018	-0.0102
Time dummy year n-5	-0.0048	-0.0095	-0.0069	-0.0073
Time dummy year n-4	-0.0103	-0.0140	-0.0058	0.0043
Time dummy year n-3	-0.0155	-0.0157	0.0072	0.0076
Time dummy year n-2	-0.0147	-0.0038	0.0095	0.0072
Time dummy year n-1	-0.0031	-0.0009	0.0118	-0.0031
Constant	-0.0192	0.0164	-0.0387	0.0143
R^2	0.3642	0.3388	0.3588	0.4209
Adj R^2	0.2904	0.2601	0.2844	0.3537

Source: Anglian Water

Table 12: Linear unit costs EV3, 7 year unsmoothed

7 years to	2012-13	2013-14	2014-15	2015-16
Potable water delivered/property	0.0195	0.0656	0.0666	0.0581
Regional wage measure	0.0016	0.0028	0.0028	-0.0025
Mains length/property	0.0040	0.0009	0.0009	0.0030
% of DI from rivers x avg potable water delivered/property				
% of DI from reservoirs x avg potable water delivered/property				
Avg pumping head x avg potable water delivered/property	0.0001	0.0001	0.0002	0.0003
% Consumption by metered NHH	-0.1194	0.0514	0.0506	-0.1145
% DI subject to w3 & w4 treatment x avg potable water/property	0.0980	0.0274	0.0271	0.0582
Time dummy year n-6	-0.0039	0.0076	0.0079	-0.0102
Time dummy year n-5	-0.0037	0.0074	0.0079	-0.0052
Time dummy year n-4	-0.0101	0.0074	0.0078	0.0036
Time dummy year n-3	-0.0145	0.0073	0.0074	0.0072
Time dummy year n-2	-0.0138	0.0071	0.0075	0.0070
Time dummy year n-1	-0.0030	0.0071	0.0074	-0.0026
Constant	0.0130	0.0455	0.0460	0.0736
R^2	0.3268	0.3012	0.2632	0.2965
Adj R^2	0.2553	0.2270	0.1850	0.2218

Source: Anglian Water

Table 13: Key to abbreviations in tabular data

APH	Average Pumping Head
DI	Distribution Input
NHH	Non Household
W3	More than one stage of complex treatment of water out of the following list: • Super chlorination • Coagulation • Flocculation • Biofiltration • pH correction • Orthophosphate dosing • Softening • Membrane filtration
W4	This category is intended to capture water treatment processes with very high operating costs: • Ozone addition • Activated carbon / pesticide removal • UV treatment • Arsenic removal • Nitrate removal
R^2	Coefficient of determination: the proportion of the variance in the dependent variable that is predictable from the independent variables.
Adj R^2	The adjusted R^2 (Adj R^2) increases only if the new term improves the model more than would be expected by chance. It decreases when a predictor improves the model by less than expected by chance.
UC	Unit Cost

Source: Anglian Water

Summary

This annex sets out our cost modelling for Water Resources (Service Area W2).

We have a set of apparently robust models for Water Resource botex which can form the basis for further development. We note that the variability of results reduces when Water Resources and Raw Water Distribution are combined, suggesting that there may be misallocation of costs (most likely power costs) between these two business units.

1. Water resources: business unit process identification

Water Resources is the first stage in the water production service and consists primarily of the abstraction of raw water from surface and underground water bodies. It precedes the remaining water services business units, Raw Water Distribution, Water Treatment and Treated Water Distribution, which Ofwat collectively treats as Network Plus. As well as water abstraction, the activities within water resources include abstraction licence negotiation, catchment management and any pre-treatment where it is upstream of raw water distribution. RAG 4.07 defines the end to the process to be where raw and pre-treated water enters the raw distribution network, a water treatment works or raw water storage facilities or is delivered to the end customer. The wide variability in configurations of assets and distribution infrastructure at this point of the value chain increases the potential for inconsistent identification of the boundary between water resources and raw water distribution between companies and therefore their treatment of assets and costs.

The key assets within water resources are those for restraining water in reservoirs and lakes and pumping water from water bodies (reservoirs, rivers and boreholes). Other assets include pipework between water resources assets (for example, from a river to pumped storage reservoir) and pre-treatment devices.

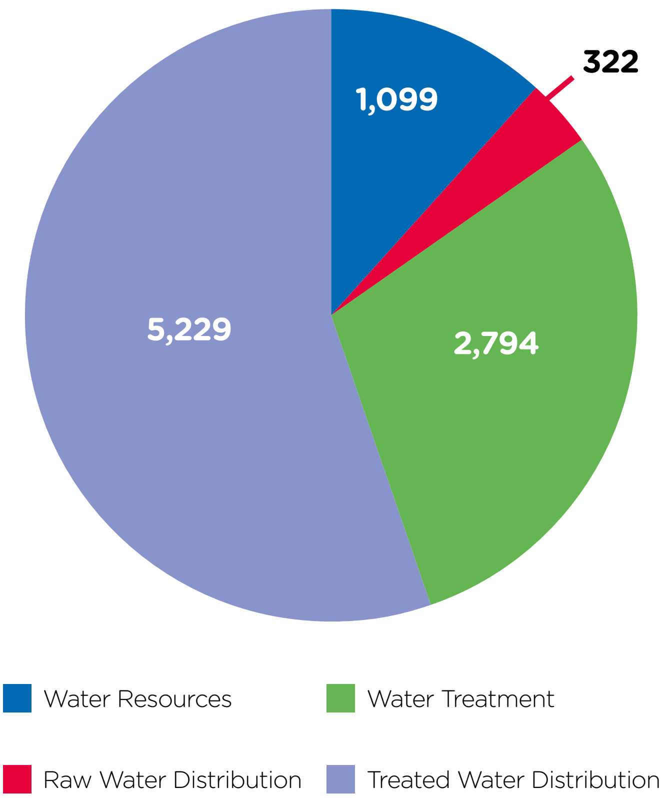
The key variables of this stage are the volume of water abstracted and the lift applied to the abstracted volume (reflecting the difference in vertical height between the point of abstraction and the point where water leaves water resources). Abstraction licence costs are set on a regional basis by the Environment Agency and are variable between companies. Botex drivers are therefore likely to include variables which capture scale and pumping head.

Figures 1 and 2 show the aggregate costs incurred within WR over the three year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

At PR19, there will be a separate cost assessment for WR. The remaining three water business units are grouped together as Water Network Plus.

Figure 1 below shows the distribution of botex across the four water business units. These represent total costs for the whole industry, in £ million, for the three modelled years. From this it can be seen that WR represents 12% of total water botex and the three business units making up Water Network Plus account for 88%.

Figure 1: Industry-wide Water Botex by Business Unit

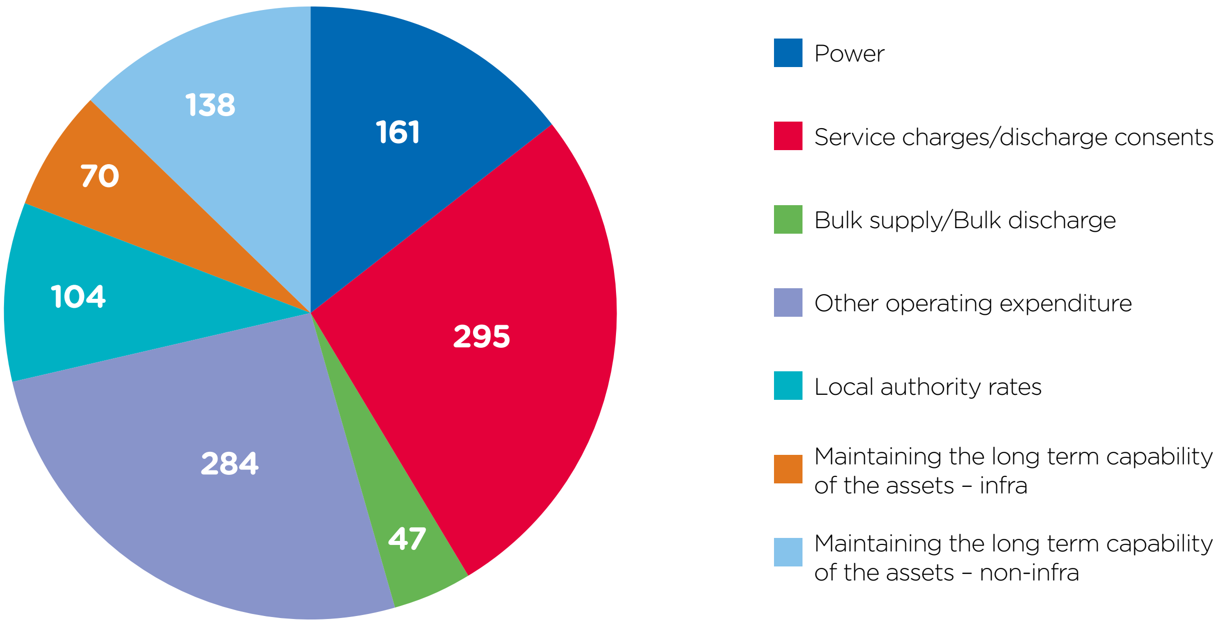


Source: 2016 August Submission, Anglian Water analysis

Figure 2 sets out the distribution of cost elements within WR. Points to note are as follows:

- Capital Maintenance represents 19% of WR botex, compared with 42% for Water overall.
- For WR, Local Authority rates (which were excluded at PR14 and also in our cost models) represent 9% of botex, compared with 11% for Water overall.
- The largest single element of botex for WR is Service Charges and Consents which represent 27% of botex. These are costs levied on companies by the Environment Agency for the right to abstract volumes of water. It has been argued that given that these costs are outside the control of management they too should be excluded from the modelled cost base. Ofwat appeared to accept the logic of this case but has not given a definitive statement regarding their inclusion or exclusion in its July 2017 PR19 methodology consultation. We consider that the case to exclude in the same way (and for the same reason) as Local Authority Rates is a strong one. In the cost modelling of WR, we have excluded Service Charges from the cost base. Together with rates, we are therefore excluding 36% of botex from our Water Resources cost models. These costs will need to be separately assessed for future cost forecasting.
- The next largest cost category is Other Operating Costs (OOC), accounting for 26% of botex. This compares to 33% for Water overall. The largest components of OOC are staff costs and Hired and Contracted Services (HCS). The next largest component of OOC is chemical costs.
- For WR, Power costs represent 15% of botex, compared with 9% for Water overall. Power in WR is used principally for pumping water out of rivers and boreholes and into reservoirs.

Figure 2: Water Resources Industry-wide botex



Source: 2016 August Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Abstraction volume (Abs): The volume of water abstracted is a natural cost driver for WR.

Density (D), Sparsity (S): Sparsity (and its inverse, density) affects the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

Proportion of DI from impounding reservoirs (DI_{ir}): Distribution Input (DI) captures aspects of economies of scale. Disaggregating DI by category of water source (boreholes, rivers, reservoirs) allows for a more granular consideration of scale economies.

Proportion of DI from pumped storage reservoirs (DI_{pr}): DI captures aspects of economies of scale. Disaggregating DI by category of water source (boreholes, rivers, reservoirs) allows for a more granular consideration of scale economies.

Proportion of DI from rivers (DI_r): The rationale for including DI_r is that river abstractions, being generally larger than borehole abstractions, will be more likely to justify RWD capacity.

Proportion of DI from boreholes (DI_b): Per contra, the rationale for including DI_b is that boreholes, being generally smaller than river abstractions, will be less likely to justify RWD capacity

Number of sources (S_{ource}): The number of water sources is a measure (albeit imperfect) of asset intensity. The expectation would be for a positive coefficient.

Aggregate reservoir capacity (R_{cap}): Reservoir capacity is an alternative measure of asset intensity to the number of sources.

Power used by Water Resources (P): As can be seen from Figure 2, power costs for Water Resources represent 15% of WR botex and 23% of modelled botex. Power used by WR is a function of the geography and geology of the appointed area. It reflects the depth from which water is abstracted from boreholes and is in turn a function of volume abstracted and Average Pumping Head. That being the case, it might be thought strange not to use APH directly. It is used as a proxy for APH because of the suspected flaws with that measure.

Average Pumping Head x Distribution Input (APH.DI): The amount of power used in moving water though the mains network is related to volume[1] and to the Average Pumping Head (APH), insofar as the APH is a well defined and computed statistic.

Volume Abstracted (Abs)/Licensed maximum abstraction volume (Lic): We hypothesize that Water Scarcity is a cost driver for Water Resources: a water scarce company will find itself having to use less attractive water sources (incurring higher cost of abstraction and treatment) As the Water Stress dummy based on the EA view of water stress[2] performed poorly, we developed an alternative variable to capture water scarcity. This was abstracted volume divided by the maximum licensed volume permitted for abstraction. The thinking was that more water stressed companies were likely to be abstracting a higher proportion of their licensed volume.

[1] Here volume is measured by Distribution Input, DI, which is a measure of the volume of potable water put into the TWD mains.
[2] The Environment Agency (EA) in 2008 developed a three level measure of water scarcity which it published, showing the categorization of each of the WOCs and WASCs. We tried using this as a dummy variable.

3. The models

The four models which passed our acceptability criteria are set out below in Figure 3. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the WR botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. In addition, for Water Resources, we followed the suggestion made in Northumbrian Water's persuasive presentation to CAWG in January 2017 and also excluded abstraction for the same reason. This is consistent with our response to the July 2017 draft PR19 methodology consultation.

WR1 –WR4 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity is low, in the range 3 to 5. A version of WR1 which omitted the Abs^2 term failed the RR test[3] which led us to try WR1.

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +26% to –98%, is large. Excluding one outlier, the range of variances shrinks substantially to a range of +26% to -33%.

This range is still large. We suspect that part of the reason for the size of the variability is due to the misallocation of costs, or alternatively due to differences in the approach to allocation of costs between Business Units by companies in the industry. In particular, historically the boundary between WR and Raw Water Distribution (RWD) was not considered business critical by WaSCs and WoCs. While one might expect that this will change, with Water Resources soon to be subject to its own price control, it is likely that the full implications of the change have yet to be assimilated by all companies.

However, in our view while these models are imperfect, we consider that they are credible and support our view that our preferred models could be used.

Figure 3: Model forms

Model	Formula
WR1	$\ln C = \alpha + \beta_1 \ln(Abs) + \beta_2 \ln(Abs^2) + \beta_3 \ln(D) + \beta_4 DI_{ir} + \beta_5 DI_{pr} + \beta_6 DI_r + \beta_7 DI_g + \beta_8 \ln(APH) + \beta_9 \ln(Abs/Lic) + u$
WR2	$\ln C = \alpha + \beta_1 \ln(Abs) + \beta_2 D + \beta_3 \ln(S_{ource}) + \beta_4 \ln(R_{cap}) + \beta_5 \ln(P) + \beta_6 \ln(Abs/Lic) + u$
WR3	$\ln C = \alpha + \beta_1 \ln(Abs) + \beta_2 \ln(S) + \beta_3 \ln(S_{ource}) + \beta_4 \ln(R_{cap}) + \beta_5 \ln(P) + u$
WR4	$\ln C = \alpha + \beta_1 \ln(Abs) + \beta_2 \ln(S) + \beta_3 \ln(S_{ource}) + \beta_4 \ln(R_{cap}) + \beta_5 \ln(P) + \beta_6 \ln(Abs/Lic) + u$

Source: Anglian Water analysis

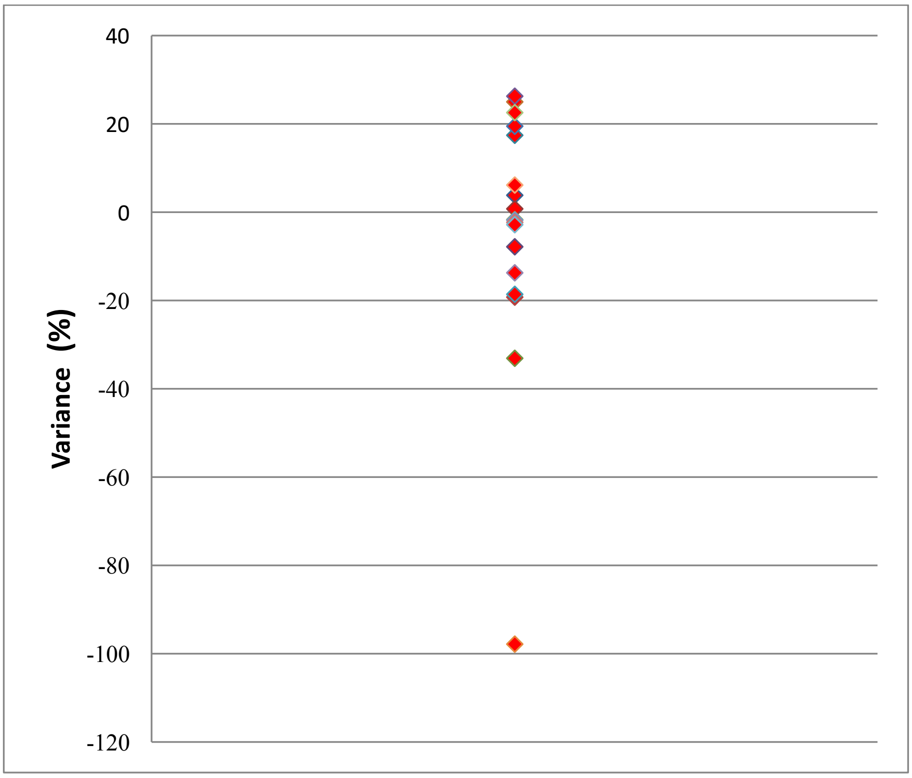
[3] *A general specification test for the linear regression model. If the result is below a threshold (generally 5%), this indicates the model is misspecified, with missing higher order terms.*

Table 1: Detailed model results (all unsmoothed)

Version	WR1	WR2	WR3	WR4
ln Abs	1 +	1 +	1 +	1 +
ln Abs^2	1 -			
D		☒ -		
ln(D)	5 -			
ln(S)			5 +	20 +
DI_{ir}	5 -			
DI_{pr}	5 -			
DI_{r}	5 -			
DI_{b}	5 -			
ln(S_{ource})		☒ +	☒ +	☒ +
ln(R_{cap})		1 +	☒ +	5 +
ln(P)		20+	1 +	20+
ln(APH.DI)	20+			
ln(Lic/Ab)	☒ +	1 +		5 +
C	1 -	1 -	1 -	1 -
Adj R^2	.910	.910	.908	.915
AIC	-114	-116	-116	-119
RR		0.10	0.45	0.24
BP		0.95	0.76	0.69
Avg VIH		3.9	4.9	4.6

Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Water Resources

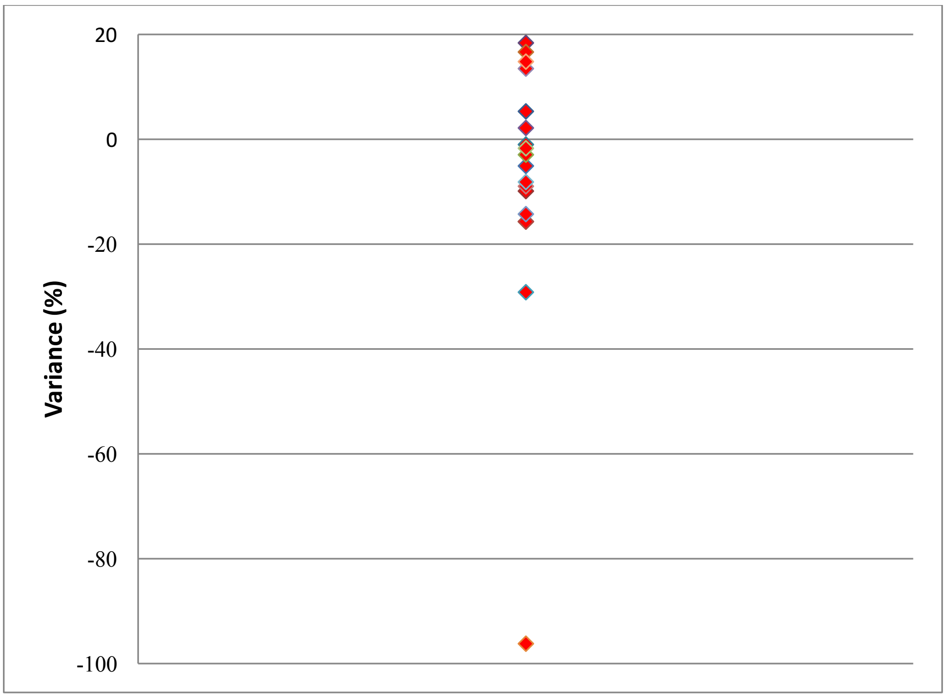


Source: Anglian Water analysis

As mentioned above, we believe that the high level of variability of the variances in Figure 4 is due to the misallocation of (in particular) power costs between WR and RWD. When the triangulated outputs of WR and Raw Water Distribution (RWD) are put together, the level of variability reduces to +18% to -29%, when the outlier is excluded.

This concatenation is shown in Figure 5 below.

Figure 5: Percentage variance between modelled and actual expenditure: WR +RWD



Source: Anglian Water analysis

4. Commentary

All of the models show that the coefficient relating to abstraction volume is strongly significant and positive. This meets the *a priori* expectation that abstraction volume should be a major driver of cost. This is therefore seen as being the key scale variable.

When Area was tried as a further scale variable, it reduced the quality of the model. For this reason, we did not persist with using Area as a scale variable.

Another recurring theme was how poorly APH.DI performed as a variable. The coefficient was often not significant. Even when coefficients were significant, they were negative, suggesting that costs would fall as the work to abstract the water increases.

This reinforces past experience which suggests that the quality of APH data is poor. This was the case when there was a single APH figure; it appears no better now APH is disaggregated between separate Business Units.

Consequently we did not continue with APH.DI as an independent variable. Replacing APH.DI with power consumed (P) led to an improvement in the quality of the models – and the coefficients are positive, as expected *a priori.*

It is recognized that power usage is endogenous and thus not desirable as an independent variable. Given the lack of alternatives, we reluctantly continued with power used as a driver.

The EA water scarcity variable (3 = serious water stress; 2 = moderate water stress; 1= low level of water stress) does not perform well, with a negative coefficient suggesting that costs fall as water stress increases.

On the other hand, 'water abstracted as a percentage of water licensed for abstraction' does perform better, with positive coefficients and coefficients which are in general statistically significant.

The use of 'the proportion of DI from different source types' as a measure of asset concentration did not appear to be successful. The results showed high levels of multicollinearity and negative coefficients which do not meet *a priori* expectations.

Replacing 'proportion of DI from different source types' with the number of sources and the aggregate volume of reservoirs led to better results: the coefficients were positive (so larger reservoirs and more sources lead to higher costs). The reservoir capacity variable is consistently statistically significant, although this is not so for the number of sources variable.

To begin with, we used 'average volume per source type' as a measure of economies of scale. This led to high levels of multicollinearity and to negative coefficients which goes against *a priori* expectations.

Moving to use the Ofwat defined variable for density improved the quality of the models. It reduced multicollinearity and generally it showed a negative coefficient which meets the *a priori* expectations.

In line with other work done, sparsity performed better than density, despite being (in broad terms) its inverse. This may well be due to D often being zero for companies while S is not. As the logarithm is used, this requires a *de minimis* value to be ascribed to D so as to avoid a undefined value (i.e. ln0).

In line with pretty much all other work done using the data during our modelling work to date, regional wages perform poorly as an independent variable. Including regional wages led to a deterioration in model quality compared to models which excluded regional wages. Moreover, they were negative, suggesting that costs fall as wages rise, and only one was significant. Consequently we did not continue with regional wages as an independent variable.

Many of the models which did not meet our criteria displayed high levels of multicollinearity, as demonstrated by the very high average VIF figures. This arises from the collinearity between abstraction volume and DI, which is used in the assets and economy of scale measures.

When the volume per source type was replaced by Ofwat's density measure, and the asset concentration measure was replaced by the number of sources and the aggregate volume of reservoirs, the average VIF fell dramatically.

High levels of multicollinearity do not invalidate the results of a multicollinear model. But it does make the interpretation of individual coefficients unreliable and does render the model susceptible to being fragile in the face of new data. Both of these problems were endemic in PR14 models and were strongly criticized by the CMA in its Bristol Determination.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Summary

This annex sets out our cost modelling for Water Network Plus (Service Area W3).

Based on only the three years' data from the August 2016 submission, we have what looks like a robust suite of botex Water Network Plus models.

1. Water Network Plus: business unit process identification

Water Network Plus comprises the business units of Raw Water Distribution, Water Treatment and Treated Water Distribution. It includes the transport of raw water to water treatment works, possibly via intermediate raw water storage bodies; the conversion of raw water to potable water via water treatment processes; and the distribution of treated water to customers. Key assets include pipes, water treatment process units, storage structures and pumps. Key activities are the pumping and treatment of water and the maintenance of assets.

Key variables are volumes of water supplied, the nature of treatment provided, pumping head and the diameter and length of pipeline assets. Exogenous botex drivers of these variables are the nature and quality of raw water sources, the age and characteristics of treatment and transport assets (many of which have asset lives of decades or even centuries) and the topology and demography of the area served.

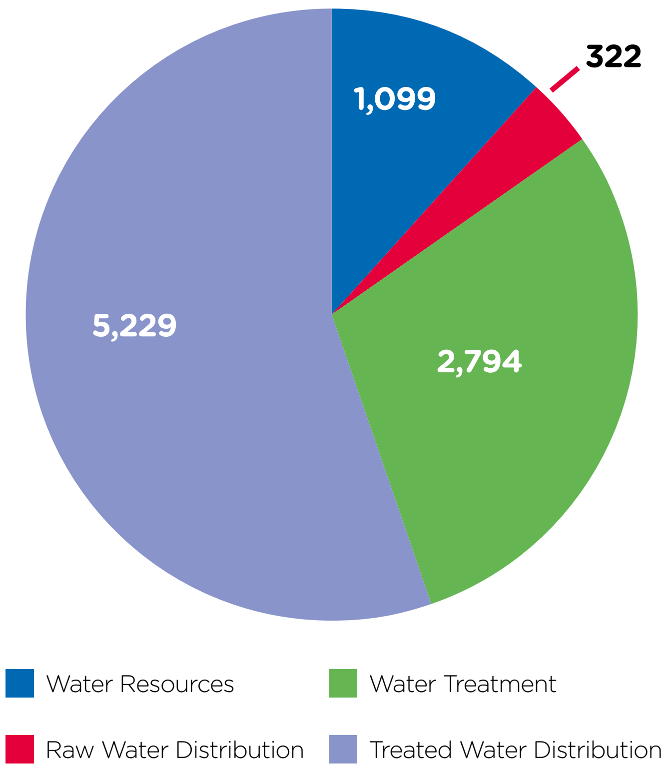
Within its Regulatory Account Guidelines (RAGs), Ofwat has defined four water Business Units. These are Water Resources (WR), Raw Water Distribution (RWD), Water Treatment (WT) and Treated Water Distribution (TWD). The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures 1 and 2 show the aggregate costs incurred within Water Network Plus over the three year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

What is immediately apparent from looking at Figure 1 is that TWD accounts for more than half of the total Water botex. WT accounts for 30%, with WR and RWD together making up around 15% of botex.

At this moment it is worth remembering that at PR19 there will be a separate cost assessment for WR (as there also will be for Bioresources on the Wastewater side). The remaining three water Business Units are grouped together as Water Network Plus. From this it can be seen that the Water Network Plus cost assessment will account for over 85% of total Water botex.

Figure 1: Industry-wide Water Botex by Business Unit



Source: 2016 August Submission, Anglian Water analysis

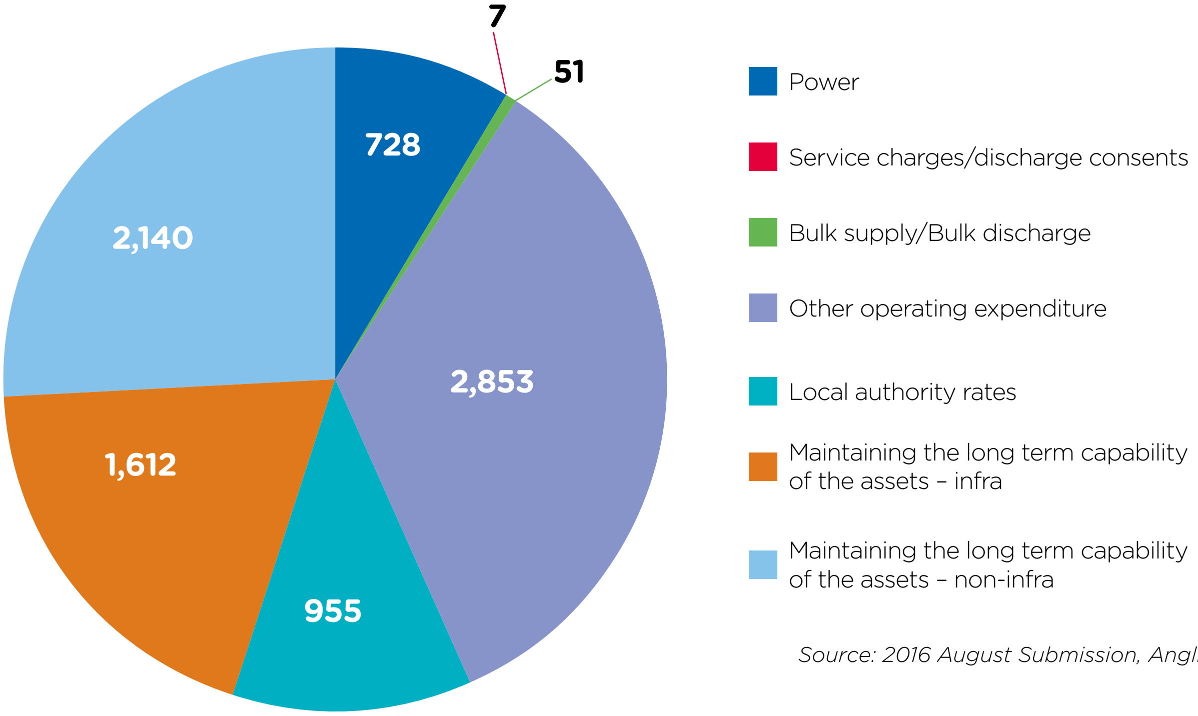
Looking at Figure 2, it is clear that if the two elements of Capital Maintenance are taken together, they make up the largest individual cost element within Water Network Plus botex. Together they account for 45% of botex. Costs within Capital Maintenance are predominantly staff costs (direct and HCS) and equipment repair or replacement costs.

The next largest cost included within botex is other operating expenditure. This category includes direct and contract staff costs, transport costs, chemicals and equipment replacement as well as company overheads. This represents 34% of Water Network Plus botex.

Local Authority Rates were excluded from modelled costs at PR14 on the grounds that they could not be controlled by management. As can be seen, they represent 11% of Water Network Plus botex.

The final large cost element is for power. This represents just short of 10% of Water Network Plus botex.

Figure 2: Water Network Plus industry-wide botex



Source: 2016 August Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Length (L): From Figure 1, TWD represents greater than 60% of Water Network Plus botex. This points to the importance of the length of the potable water network as a cost driver for Water Network Plus botex

Pre 1940 length ($L_{pre\ 1940}$): The age of the potable mains is generally accepted as a cost driver, though the precise mechanism is hard to set out straightforwardly. The interrelationship of age, material, level of maintenance and soil conditions is complicated and not easily susceptible to modelling.

Post 2000 length ($L_{post\ 2000}$): The age of the potable mains is generally accepted as a cost driver, though the precise mechanism is hard to set out straightforwardly. The interrelationship of age, material, level of maintenance and soil conditions is complicated and not easily susceptible to modelling

Raw main length (L_{raw}): The length of raw main is a key driver for capital maintenance within RWD.

Length of main replaced/renewed: ($L_{replace}$): Mains length replaced and renewed are a key driver of capital maintenance for TWD.

Average Passing Distance (APD): Average Passing Distance has long been used as a measure of network intensity. The recent development of Sparsity and Density by Ofwat in conjunction with the wider industry renders APD a (relatively) blunt measure, albeit one which is still viewed as important.

Distribution Input (DI): The DI represents the volume of water treated and put into the TWD network. As such, it is a key driver to Treatment cost (power and chemicals used are tightly related to volume treated).

Proportion of DI from surface water (DI_s): Generally speaking, surface water is more expensive to treat than ground water. All other things equal, this implies that the coefficient of this variable is expected to be positive.

Proportion of DI from ground water (DI_g): Generally speaking, surface water is more expensive to treat than ground water. All other things equal, this implies that the coefficient of this variable is expected to be negative.

Non potable water volume delivered ($V_{non\ pot}$): The volume of non-potable water is a proxy for the industrial customer base and gives another measure of economy of scale.

Leakage volume (V_{leak}): The level of leakage is a key driver of capital maintenance in TWD.

Number of households served (HH): The number of households is linked to DI via average usage and to Length via Average Passing Distance.

Sparsity (S), Density (D): Sparsity and Density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

Number of water treatment works (WTW_n): The number of WTWs affects efficiency of staff utilization. A large number of small WTWs requires significantly more staff than a small number of large WTWs.

Average Pumping Head . Abstracted volume (APH.abs): Power used in moving water is related to volume and to the Average Pumping Head, insofar as the APH is a well defined and well computed statistic

Regional Wages (RW): Qualitatively, it is uncontentious that Regional Wages vary across the country and thus will be a factor in cost modelling. Staff costs, which form a large part of Other Operating Cost, represents a third of botex in Figure 2. Quantifying this linkage in models has been generally unsuccessful.

Time Trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

3. The models

The five models which passed our acceptability criteria are set out below in Figure 3. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity. In each of the models, the dependent variable lnC is the natural log of the Water Network Plus botex. The estimations were carried out using OLS and were run on STATA v14.

The key results from the estimation of models WNP1 – WNP5 are reported in Table 1. This shows that all variables perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity is in the range 2 to 56.

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +17% to –20%, is credible and supports our view that our preferred models could be used. Excluding two outliers, the range of variances shrinks to +11% to -11%

Figure 3: Model forms

Model	Formula
WNP1	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 L_{pre1940} + \beta_3 DI_s + \beta_4 \ln WTW_n + \beta_5 S + \beta_6 D + \beta_7 \ln APD + \beta_8 \ln RW + u$
WNP2	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 L_{pre1940} + \beta_3 L_{post2000} + \beta_4 DI_s + \beta_5 S + \beta_6 D + \beta_7 TT + u$
WNP3	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 L_{pre1940} + \beta_3 L_{post2000} + \beta_4 DI_s + \beta_5 S + \beta_6 D + \beta_7 TT + \beta_8 \ln DI + u$
WNP4	$\ln C = \alpha + \beta_1 \ln HH + \beta_2 L_{pre1940} + \beta_3 L_{post2000} + \beta_4 DI_s + \beta_5 DI_g + \beta_6 \ln V_{nonpot} + \beta_7 \ln V_{leak} + \beta_8 \ln L_{raw} + \beta_9 \ln L_{replace} + \beta_{10} \ln APH.Abs + \beta_{11} S + \beta_{12} \ln RW + u$
WNP5	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 L_{pre1940} + \beta_3 \ln DI + \beta_4 \ln V_{nonpot} + \beta_5 \ln V_{leak} + \beta_6 \ln L_{raw} + \beta_7 \ln L_{replace} + \beta_8 \ln APH.Abs + \beta_9 S + u$

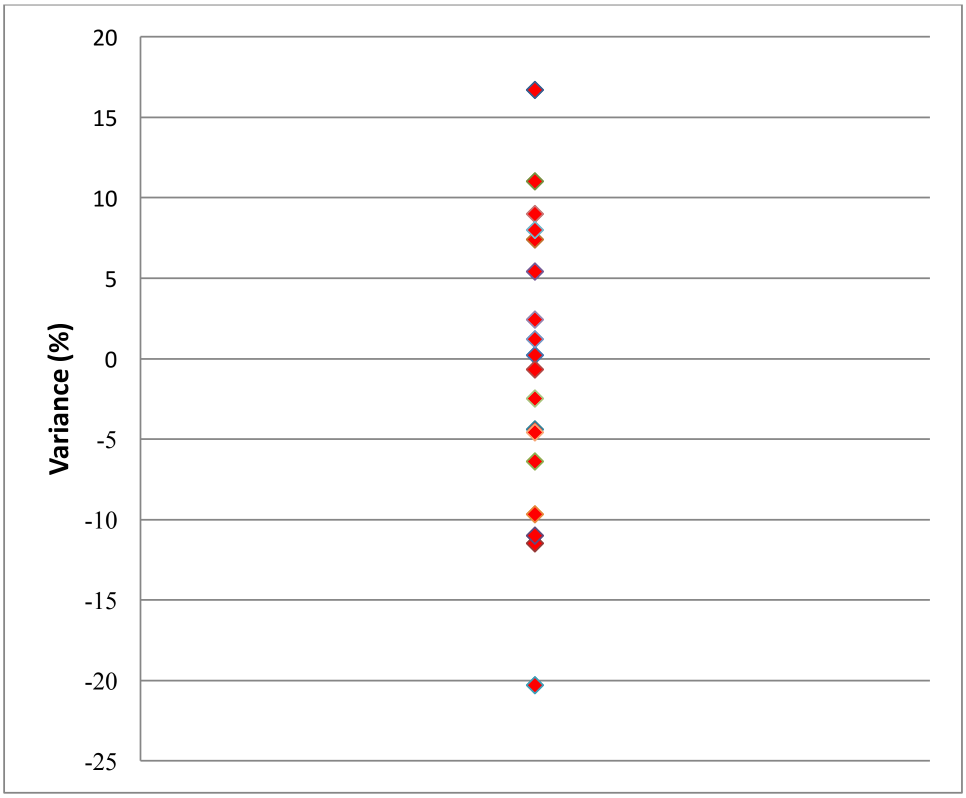
Source: Anglian Water analysis

Table 1: Model highlights

Version	WNP1	WNP2	WNP3	WNP4	WNP5
L	⊠ +	1 +	1 +		⊠ +
DI			20+		1 +
HH				1 +	
S	1 +	10+	5 +	⊠ +	⊠ +
D	5 +	1 +	1 +		
APD	20-				
WTW_n	5 +				
WTW_s	5 +				
W_s	⊠ +	20+	20+	1 +	
W_g				5 -	
Post 2000		1 +	1 +	5 -	
Pre 1940	20+	1 +	1 +	5 +	5 +
RW	⊠ +			1 +	
TT		10-	10-		
C	5 -	1 -	1 -	1 -	5 -
aph.abs				20+	
$Main_{Raw}$				⊠ +	20+
$Main_{Replace}$				1 +	1 +
V_{leak}				1 +	1 +
$V_{non\ pot}$				5 +	5 +
Adj R^2	.970	.974	.974	.984	.981
AIC	-175	-184	-185	-208	-200
RR	.57	.89	.98	.03	.40
BP	.93	.35	.42	.73	.84
VIF	56	2	13	7	13

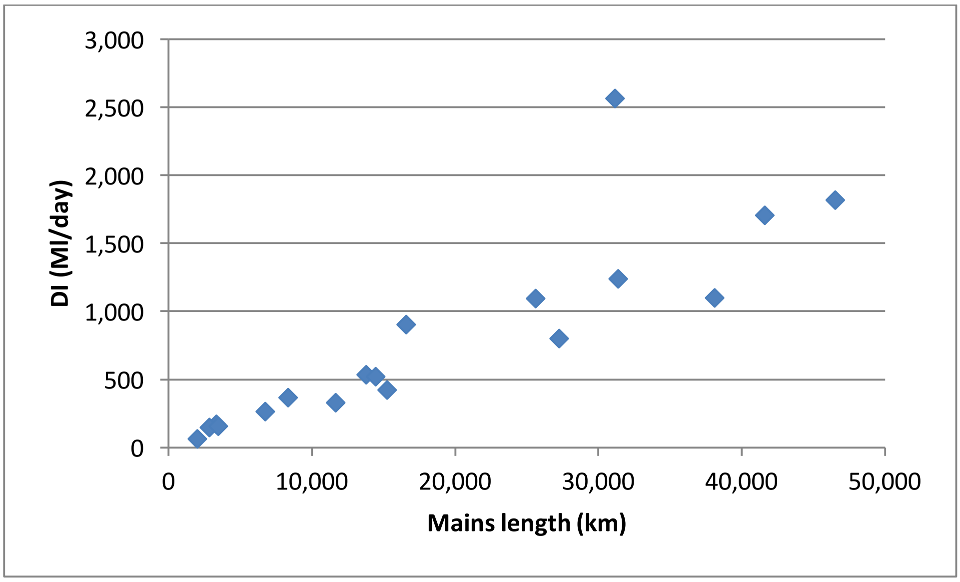
Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Water Network Plus



Source: Anglian Water analysis

Figure 5: Potable mains length vs DI, based on 2015-16 data



Source: 2016 Information Request, Anglian Water analysis

4. Commentary

Across all the models, mains length and DI were the scale variables. The reasons are set out above. As can be seen in Figure 5, the two variables are strongly correlated, with one outlier having a much higher DI for the length of main than the rest of the industry. Only one version of the model which incorporates DI, version WNP3, met the criteria set out for choosing acceptable models. In any case, it is preferable to use mains length over DI, as the latter is boosted by leakage and use of DI could thus be seen as rewarding poor leakage control.

Several environmental factors were tested. These included volumes of groundwater and surface water, and percentage of households metered, all of which featured in the PR14 models. The groundwater and surface water variables performed as expected, with positive coefficients for surface water and negative coefficients for groundwater. In each case where metering was used as a variable, the coefficient was negative.

Leakage below SELL performed spectacularly badly as a variable. In each case where it was included, it had a negative coefficient. To put it mildly, this is counter-intuitive: it would seem reasonable to assume that there is something amiss with this metric.

The number of WTWs is the only explicit asset intensity measure, although it could reasonably be argued that the length of potable mains also performs this function, given that the overall value of infrastructure (the underground assets of the companies) represents >60% of net fixed assets.

A number of economy of scale variables were tried. The most successful were the sparsity and density measures developed within the Ofwat Cost Assessment Working Group during 2016. These variables are based on the ONS Lower Super Output Area (LSOA) data. Thresholds of population density were agreed for sparsity and density: LSOAs above the upper threshold were deemed dense while LSOAs below the lower threshold were deemed sparse. The measures represent the proportion of total company population living in either dense or sparse areas. Given that the LSOA areas typically have a population of 2,000-3,000, this is a much more granular measure than has been used heretofore. By comparison, average passing distance (APD) is a very blunt measure indeed. APD was tried but models which used it did not meet our acceptability criteria.

Time Trend was significant in only a handful of models. However, the coefficients were consistently in line with expectations – that is to say, a small (1-2% pa) negative figure.

Regional Wages performed badly. This was very much in line with the experience of modelling other cost areas. The coefficient was generally insignificant and almost always negative and greater than unity. The most charitable explanation is that Regional Wages tend to be higher in heavily urbanized areas where cost of delivery may be lower. Alternatively, it may just be that the Regional Wage variable fails to capture the key aspects of water company wage behaviour.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Summary

This annex sets out our cost modelling for Raw Water Distribution (Service Area W4).

Within Water services, Raw Water Distribution (RWD) is the smallest of the four Business Units. As such, it is also the most variable. We suspect that some companies may have mis-allocated some power costs between Water Resources and RWD, leading to outstandingly good apparent performance for RWD and poorer performance for Water Resources. When both Business Units are added together, the variability of the results declines markedly.

For this reason, we would be cautious of placing too much reliance on RWD efficiency rankings on their own.

1. Raw Water Distribution: business unit process identification

Within its Regulatory Account Guidelines (RAGs), Ofwat has defined four water Business Units. These are Water Resources (WR), Raw Water Distribution (RWD), Water Treatment (WT) and Treated Water Distribution (TWD). The precise definitions and boundaries for the Business Units are set out in RAG 4.

RWD is the second stage in the water production service and consists primarily of the transport of raw or pre-treated water from sites where water is abstracted to a water treatment works and the storage of raw water. RAG 4.07 defines other potential end-points for raw water distribution to be delivery to an end customer or third party water company. Raw water distribution follows water resources and precedes water treatment and treated water distribution.

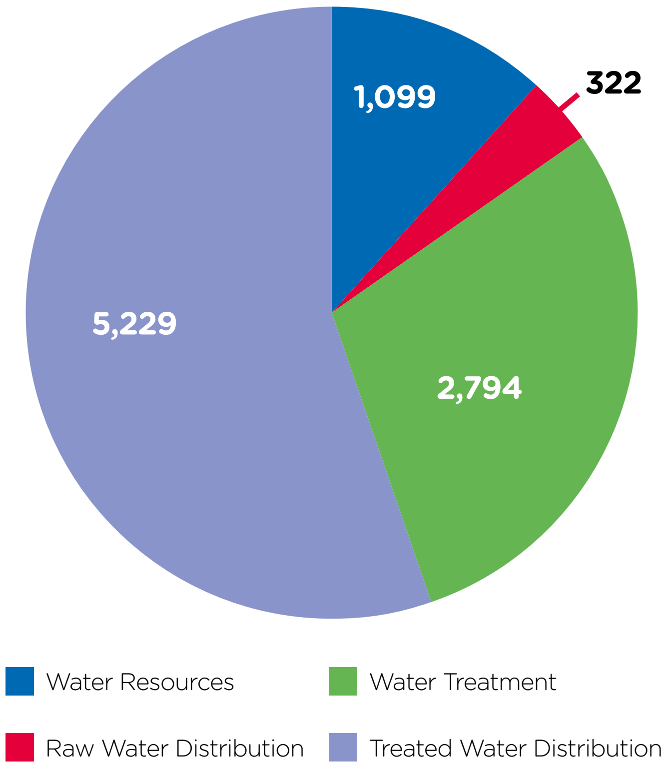
The key assets within raw water distribution are pipelines, aqueducts, raw water storage reservoirs and pumping equipment. The key activities within raw water distribution are the pumping of water and the maintenance of the raw water distribution assets and storage reservoirs. The wide variability in configurations of assets and distribution infrastructure at this point of the value chain increases the potential for inconsistent identification of the boundary between water resources and raw water distribution between companies and therefore their treatment of assets and costs.

The key variables of this stage are the volume of water transported, the scale of raw water distribution and storage assets and the lift applied to the transported volume. The extent of pre-treatment included in raw water distribution is a lesser variable.

Figures 1 and 2 show the aggregate costs incurred within Raw Water Distribution over the three year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

As can be seen from Figure 1, RWD is by far the smallest of the four Water Business Units, representing only 3% of total Water botex.

Figure 1: Industry-wide Water Botex by Business Unit



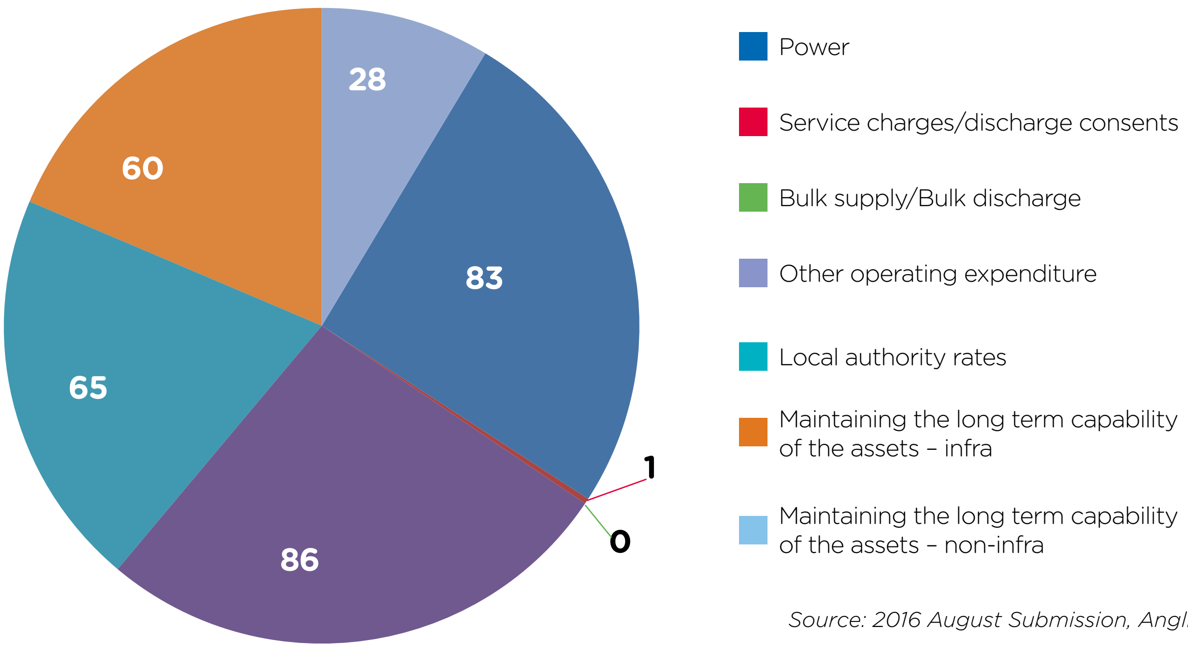
Source: 2016 August Submission, Anglian Water analysis

Figure 2 sets out the split of RWD botex by cost categories. The key points to note are:

- Local Authority rates, which we exclude from modelled costs, represent 20% of botex
- Capital Maintenance is the largest individual cost category, with 28% of botex
- This is closely followed by Other Operating Costs (27%) and by Power (26%).

For us – and, we believe, most other appointed companies - it is common for power provided to WR and RWD (and in some cases Water Treatment as well) to be supplied through a single meter without any subsequent sub-metering. Power costs are then allocated between the different Business Units by Finance. The basis on which these costs are allocated is set out in RAG 4. However, the accuracy of such estimated disaggregation is open to question. The cost modelling we have carried out of WR and RWD strongly suggests that the split of power costs in particular is very variable.

Figure 2: Raw Water Distribution Industry-wide botex



Source: 2016 August Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Raw water volume transported (V): It would seem a reasonable hypothesis that RWD costs are related to the raw water volume transported.

Appointed water area (A): The size of the appointed area is expected to be a driver of Maintenance costs. The expectation is that, all else equal, the larger the appointed area, the greater the maintenance costs incurred.

Volume Abstracted (Abs)/Licensed maximum abstraction volume (Lic): We hypothesize that Water Scarcity is a cost driver for Water Resources: a water scarce company will find itself having to use less attractive water sources (incurring higher cost of abstraction and treatment) As the Water Stress dummy based on the EA view of water stress[1] performed poorly, we developed an alternative variable to capture water scarcity. This was abstracted volume divided by the maximum licensed volume permitted for abstraction. The thinking was that more water stressed companies were likely to be abstracting a higher proportion of their licensed volume.

Length of raw mains (L): RWD mains length is a key driver of maintenance costs as well as a factor in the power requirements for moving raw water from abstraction points to Water Treatment Works.

Sparsity (S): Sparsity (and its inverse, density) affects the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

Proportion of DI from rivers (DI_r): The rationale for including DI_r is that river abstractions, being generally larger than borehole abstractions, will be more likely to justify RWD capacity.

Proportion of DI from boreholes (DI_b): Per contra, the rationale for including DI_b is that boreholes, being generally smaller than river abstractions, will be less likely to justify RWD capacity

Time Trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

[1]*The Environment Agency (EA) in 2008 developed a three level measure of water scarcity which it published, showing the categorization of each of the WOCs and WASCs. We tried using this as a dummy variable.*

3. The models

The three models which passed our acceptability criteria are set out below in Figure 3. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the RWD botex. RWD1 and RWD2 each have two variants. The first was estimated using OLS; the second was estimated using GLS with Random Effects. RWD3 was estimated using only OLS. All estimations were run on STATA v14.

The key results from the estimation of models RWD1 and RWD2 (both variants) as well as RWD3 are reported in Table 1. This shows that all variables perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 70% and all the models pass the Ramsey Reset test of model specification (RR). RWD1 and RWD2 fail the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity is low, in the range 3 to 4.

In contrast with the other Business Units, RWD has very few variables which are specific and unique to it. In fact, the only two are the length of the raw water mains and the volume of raw water transported. In the case of the volume measure, at present we only have a single year's figure, which was taken from the 2016 Annual Performance Review (APR). a second year's data will be available from the 2017 APRs. But for now, the only additional volume data dates back to the 2011 June Return.

This lack of specific RWD variables explains why we have developed only a limited number of models. Ideally, we would have wanted to include an independent variable to account for energy usage. Pumping head data for RWD alone is not available for all companies. As the total average pumping head (APH) figure has not proved robust in service-wide cost modelling, and as the specific Water Resources APH performed no better, there is no expectation on our part that a RWD APH variable would perform well. And it is the case that no data have been collected on power usage specifically for RWD. So, concerns about endogeneity to one side, this option is not open either.

In common with the other Water Business Units, at present we only have data for three years in a common format. For this reason, the modelling done has been on an unsmoothed basis for capital maintenance. Once the additional data request is available for analysis (late July at the earliest), we will have six years' data on the same cost basis.

The results of the five accepted models are set out in Table 1. None of the models appear entirely satisfactory for reasons set out above. However, we consider that they form the basis for further development as additional data become available.

Figure 3: Model forms

Model	Formula
RWD1	$\ln C = \alpha + \beta_1 \ln(V) + \beta_2 \ln(A) + \beta_3 \ln(Abs/Lic) + \beta_4 \ln(L) + \beta_5 \ln(S) + u$
RWD2	$\ln C = \alpha + \beta_1 \ln(V) + \beta_2 \ln(A) + \beta_3 \ln(Abs/Lic) + \beta_4 \ln(L) + \beta_5 \ln(S) + \beta_6 TT + u$
RWD3	$\ln C = \alpha + \beta_1 \ln(V) + \beta_2 \ln(A) + \beta_3 \ln(Abs/Lic) + \beta_4 \ln(L) + \beta_5 \ln(S) + \beta_6 TT + \beta_7 DI_r + \beta_8 DI_b + u$

Source: Anglian Water analysis

Table 1: Model highlights

Version > Driver V	RWD1 OLS	RWD1 GLS	RWD2 OLS	RWD2 GLS	RWD3 OLS
V	1 +	1 +	1 +	1 +	1 +
L	5 +	20+	5 +	20+	10+
D					
S	1 -	5 -	1 -	5 -	1 -
(abs/lic)	5 +	10+	5 +	10+	1 +
A	10+	20+	10+	20+	1 +
DI_r					10+
DI_b					☒ -
TT			☒ -	☒ -	☒ -
C	1 -	1 -	5 -	5 -	1 -
Adj R^2	.749	.865	.744	.865	.776
AIC	-7.5		-5.7		-11.3
RR	0.42		.40		.99
BP	0.00		.00		.00
VIF	3.6		3.2		3.5

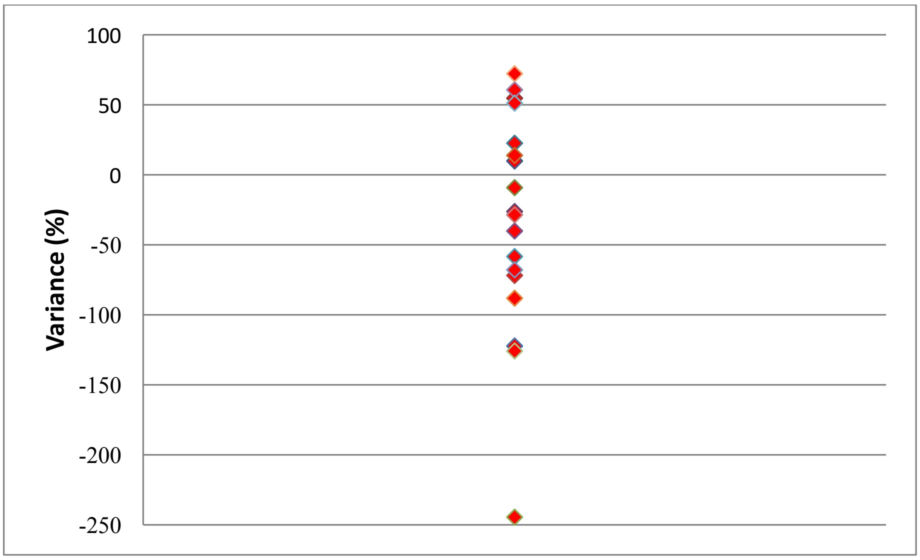
Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +72% to −245%, is very large.

Also as mentioned above, we are concerned that there may be mis-allocation of power costs between RWD and Water Resources. As power represents 34% of aggregate net opex[2] for the two services and 53% of RWD net opex, any such misallocation will lead to skewed efficiency results. Historically, the boundary between Water Resources and RWD was not considered business critical by WaSCs and WoCs. While one might expect that this will change, with Water Resources soon to be subject to its own price control, it is likely that the full implications of the change have yet to be assimilated by all companies.

[2]Opex-LA rates

Figure 4: Percentage variance between modelled and actual expenditure: Raw Water Distribution

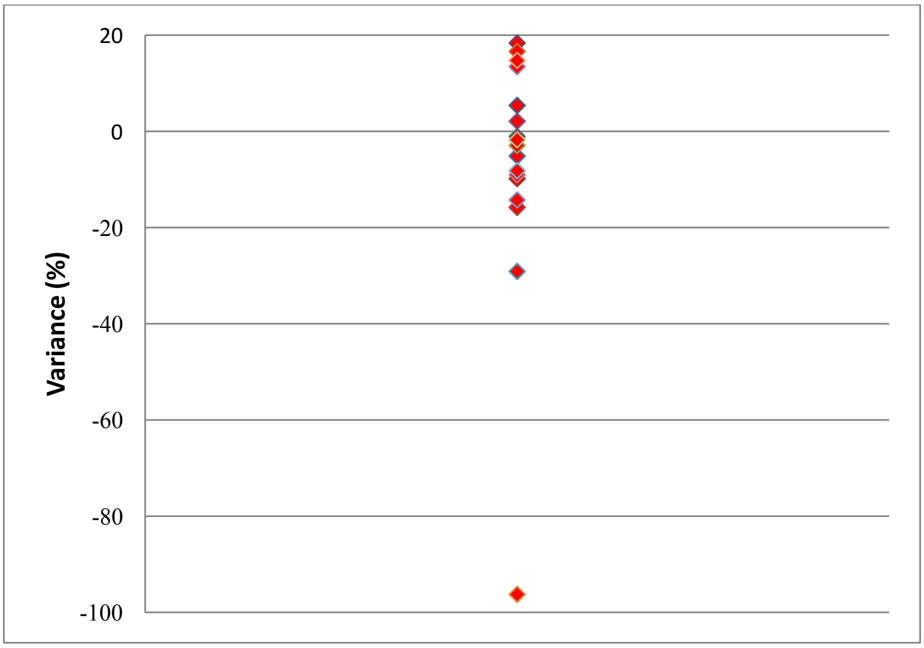


Source: Anglian Water analysis

As mentioned above, we believe that the high level of variability of the variances in Figure 4 is due to the misallocation of (in particular) power costs between Water Resources and RWD. When the triangulated output of the RWD results and the triangulated Water Resources output are put together, the level of variability reduces significantly to +18% to -96%. Moreover, it can be seen that there is one very low outlier. If this outlier is excluded, then the range narrows to +18% to -29%.

This concatenation is shown in Figure 5 below.

Figure 5: Percentage variance between modelled and actual expenditure: WR +RWD



Source: Anglian Water analysis

4. Commentary

Volume of raw water transported appears to perform well as a cost driver. The coefficient is significant and its sign and level match *a priori* expectations.

Company area performs moderately well. The sign and level of the coefficient match *a priori* expectations and the coefficient is significant in all of the models.

As was the case for Water Resource cost modelling, the Water Stress index performs poorly. The coefficient is negative, indicating that as the level of water stress increases, the costs for the company fall. This is counter-intuitive. For this reason, the variable was dropped.

The alternative water stress variable - water abstracted divided by maximum licensed abstraction volume - appears to perform well. The sign, scale and level of significance of the coefficient all appear acceptable.

The only asset related variable specific to RWD is the length of raw water mains. This performs acceptably, with the sign and size of the coefficient meeting *a priori* expectations. For five out of seven models, the coefficient is significant to a level >80%.

Moving to use the Ofwat defined variable for density improved the quality of the models. It reduced multicollinearity and generally it showed a negative coefficient which meets the *a priori* expectations.

In line with other work done, sparsity performed better than density, despite being (in broad terms) its inverse. This may well be due to density often being zero for companies while sparsity is not. As the logarithm is used, this requires a *de minimis* value to be ascribed to density so as to avoid an undefined value (i.e. ln0).

In line with pretty much all other work done using the data during PR19, regional wages perform poorly as an independent variable. The coefficient was not significant. Moreover, the coefficient was greater than unity, which makes no logical sense. Consequently we did not continue with regional wages as an independent variable.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Summary

This annex sets out our botex driver modelling for Water Treatment (Service Area W5).

We have developed a set of models which perform well from a statistical perspective, albeit only on three years' data. Adding in the additional data which will come with the 2017 Information Request should confirm whether the models are adequate in a broader context.

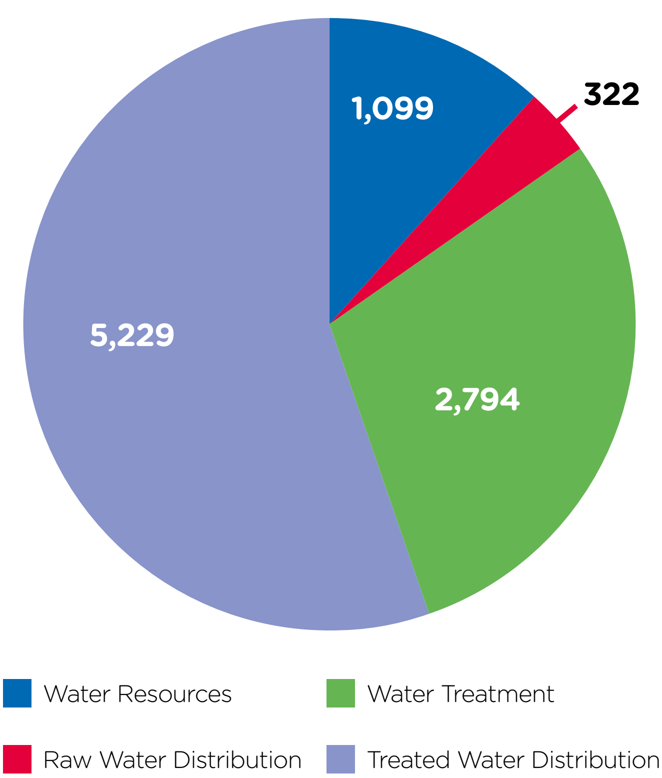
1. Water treatment: business unit process identification

Water treatment is the third stage in the water service production and it consists of the physical and chemical treatment of raw water to make it drinkable. It follows logically from raw water abstraction (WR) and distribution (RWD) and precedes the distribution of treated water to final users (TWD). RAG 4.07 defines the input to the process to be raw and pre-treated water from the raw distribution network and the output to be treated water fed into the distribution network or directly to an end-used customer. The quality of the output is assumed to be uniform since all treated water must meet the standards of the drinking water regulations but the quality of the raw water input can be very variable. Accordingly the nature of the treatment processes provided at water treatment works is very variable, with consequences for their energy, labour and power requirements. The size of treatment works is also very variable, with outputs ranging from 1 megalitre per day (Ml/d) to over 300 Ml/d.

The key variables of this stage are the volume of water treated and the number and type of treatment units (and the labour employed in them). These capture the core of this particular activity and vary across companies (and over time) depending on the size of the population (which in turn affects final output); the different raw water characteristics (that will determine the required treatment complexity); the geographical configuration of the area and its population density (that affect the number and capacity of the treatment works). This is reflected in the cost composition, which is reported below.

As can be seen from Figure 1, Water Treatment is the second largest of the four Water Business Units, representing 30% of total Water botex[1].

Figure 1: Industry-wide Water Botex by Business Unit



Source: 2016 August Submission, Anglian Water analysis

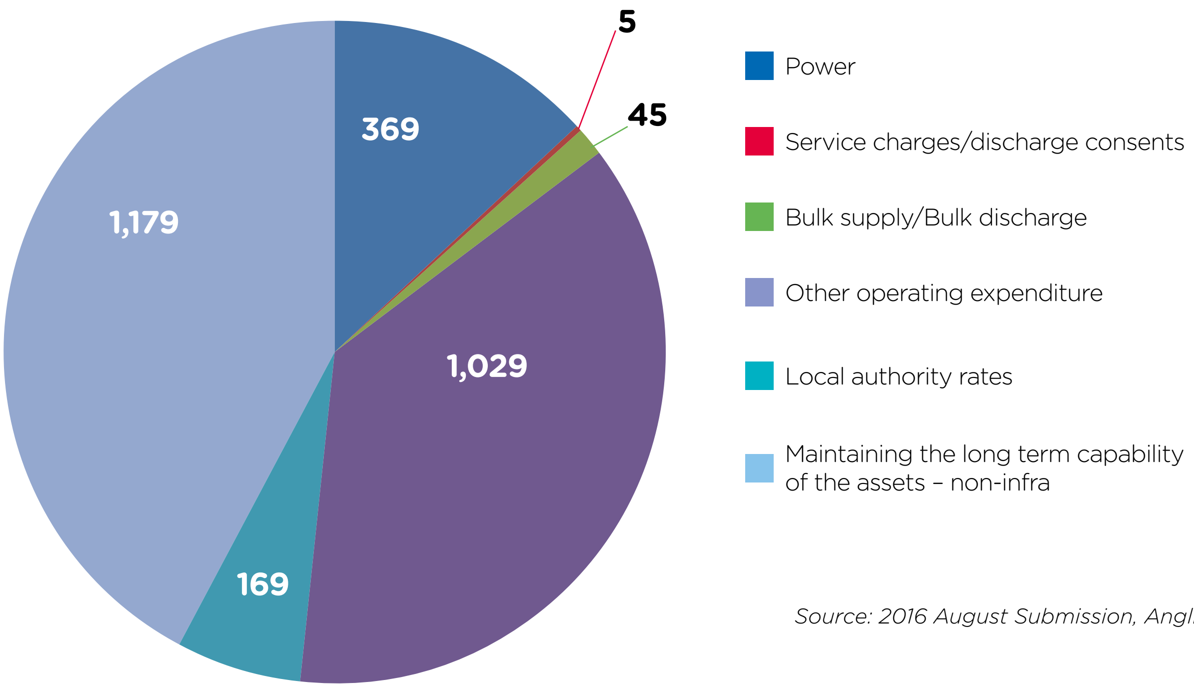
Figure 2 sets out the split of industry botex by cost categories for Water Treatment. The key points to note are:

- Local Authority rates, which we exclude from modelled costs, represent 6% of botex for Water Treatment
- Capital Maintenance represents 42% of botex
- Other Operating Costs account for 37% of botex. The primary components are labour and chemicals
- Power represents 13% of botex.

[1] *Figures 1 and 2 show the aggregate costs for the industry incurred within Water Treatment over the three year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.*

Annex 5 - Water Treatment

Figure 2: Water Treatment Industry-wide botex



Source: 2016 August Submission, Anglian Water analysis

2. Variables selection

- **Volume of abstracted water (Abs):** This is the best measure of output, representing volume of water treated. We would expect a company's costs to be positively correlated with its volume of abstracted volume.

- **Size of population served (P):** This is an alternative measure of output, which is more indirect but still reflective of the final volume of output produced. We would expect a company's costs to be positively correlated with its population served.

- **Average Pumping Head (for treatment)x abstracted volume (APHxAbs):** Their product reflects the fact that power used is proportional to volume and average pumping head jointly. We would expect a company's costs to be positively correlated with this factor.

- **Population sparsity (S):** This is the reciprocal of population density and it is a threshold measure, as proposed by Ofwat, rather than a continuous variable. A measure of sparsity was in the end preferred to a measure of density due to the high number of 0 values in the latter.

- **Number of surface and groundwater WTWs (SW, GW):** This is a measure of capital intensity and reflects also differences in required treatment. We would expect a company with more WTWs to have higher costs, all other things equal. Conventional wisdom says that surface water is more expensive to treat so would expect the costs of a company with a higher proportion of raw water from surface water sources to be higher.

- **Regional Staff Wages (RW):** Qualitatively, it is uncontentious that Regional Wages vary across the country and thus will be a factor in cost modelling. Staff costs, which form a large part of Other Operating Cost, represents a third of botex in Figure 2. Quantifying this linkage in models has been generally unsuccessful.

- **Proportion of population receiving water treated with orthophosphate (O):** Because of the cost of chemicals required for this process we would expect a company's costs to be positively correlated with this value.

- **Surface and ground water volume indices (SW_{vol} and GW_{vol}):** These variables are weighted averages of the volumes allocated by companies to the six treatment complexity categories. We would expect a company's costs to be positively correlated with these indices.

3. The models

The three models which passed our acceptability criteria are set out in Figure 3 below. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In all models the dependent variable lnC is the log of Botex and the estimation is carried out via OLS.

WT1 is nested in WT2 via the removal of the squared term on P. Given the joint significance of the output variables P and P^2 we decided to still keep this specification.

The key results from the estimation of models WT1, WT2 and WT3 are reported in Table 1. This shows that all variables perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity is also always well below 10.

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +35% to –56%, is credible and supports our view that our preferred models could be used. It is notable that there are two outliers at the negative end of the spectrum. Excluding them, the range is from +35% to -19%.

Figure 3: Model forms

Model	Formula
WT1	$lnC = \alpha + \beta_1 ln(P) + \beta_2 ln(APH*Abs) + \beta_3 ln(S) + \beta_4 RW + \beta_5 SW + \beta_6 GW + u$
WT2	$lnC = \alpha + \beta_1 P + \beta_2 P^2 + \beta_3 APH*Abs + \beta_4 lnS + \beta_5 RW + \beta_6 SW + \beta_7 GW + u$
WT3	$lnC = \alpha + \beta_1 Abs + + \beta_2 APH*Abs + \beta_3 lnS + \beta_4 RW + \beta_5 SW + \beta_6 GW + u$

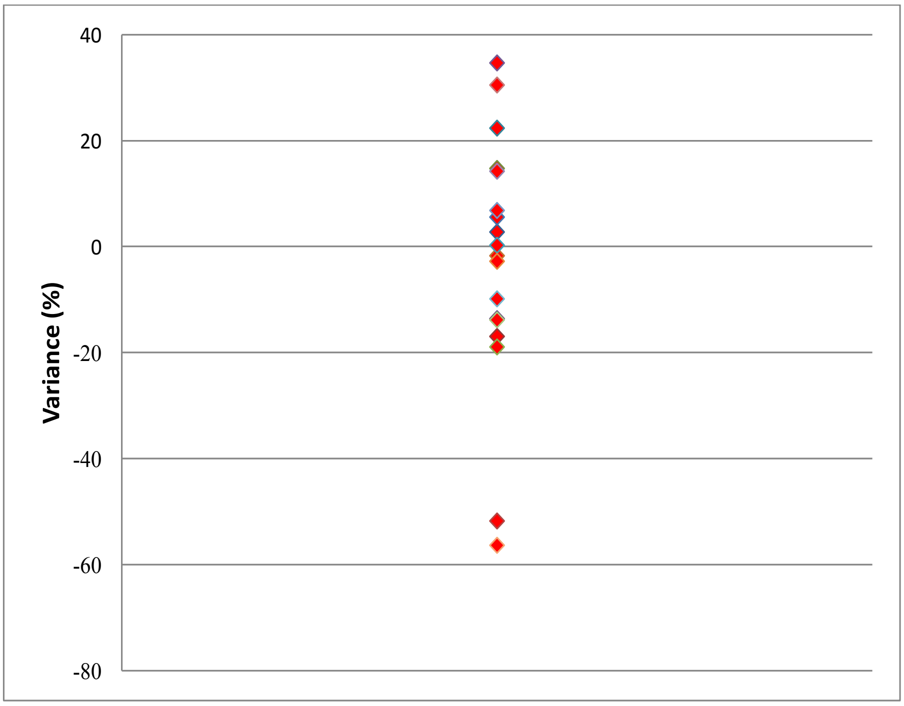
Source: Anglian Water analysis

Table 1: results of the estimation of models WT1, WT2 and WT3

Model	WT1	WT2	WT3
P	1 +	☒+	
P^2		☒+	
Abs			1 +
APH*Abs	1 +	1 +	1 +
S	5 +	5 +	1 +
RW	5 +	5 +	5 +
SW	5 +	5 +	5 +
GW	1 -	5 -	1 -
A	1 -	5 -	1 -
R^2	.927	.928	.938
RR	.00		.00
BP	.75		.66
VIF	4.9		4.6

Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Water Treatment



Source: Anglian Water analysis

4. Commentary

As expected, both population and volume abstracted perform well as scale variables. Abstracted volume is a better measure of output for this service.

The product of abstraction volume and average pumping head (APH) perform well as a variable, capturing the need for power in the treatment process.

The absolute number of surface and ground water WTWs proved to be variables which had statistically significant coefficients.

In line with other work done, sparsity performed better than density, despite being (in broad terms) its inverse. This may well be due to density often being zero for companies while sparsity is not. As the logarithm is used, this requires a *de minimis* value to be ascribed to density so as to avoid a undefined value (i.e. ln0).

The average volume of water treated by surface water and ground water WTWs was tried as a scale variable but the variables were found not to generate statistically significant coefficients.

Unusually, the Ofwat Regional Wage variable performed rather better in the Water Treatment model than in other cost modelling work done. That said, the level of the coefficient is very high: each time it is used the coefficient is greater than unity, suggesting that an increase in wage costs of 1% leads to >1% increase in overall costs. This does not seem likely.

None of the variables which attempt to capture the volume of water requiring a high or low degree of treatment (SW_{vol}, GW_{vol}, O) was found to work acceptably. This is a surprise, given our knowledge of the variation between treatment works (and, presumably, between companies) in their use of expensive treatment processes. Our best explanation is that the GW/SW variables account for differences in treatment complexity but we had assumed these to be inferior proxies for variables which measure treatment complexity directly. We propose the reporting requirements for this categorization is reviewed to identify any opportunities for improving the consistency or reporting between companies.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Summary

This annex sets out our cost modelling for Treated Water Distribution (Service Area W6).

We have developed a set of models which appear to perform well for TWD. The variability between actual costs incurred by companies and model generated estimates of costs is low; and the models appear to met Ofwat's criteria for a satisfactory model formulation. The reported models are based on only three years' data. Adding in the additional more homogenous data which will come with the 2017 Information Request should confirm whether the models are adequate in a broader context.

1. Treated Water Distribution: business unit process identification

TWD is the fourth and final stage of the water service. It consists of the delivery of drinkable (potable) water from water treatment plants to the consumers. It follows logically from Raw Water Abstraction and Resources (WR), Raw Water Distribution (RWD) and Water Treatment (WT). RAG 4.07 defines the input to the process to be potable water from treatment sites and third parties and the output to be the supply of potable water to retail customers and new appointees.

TWD represents the bulk of water service assets in the form of the network of underground water mains up to the customer boundary. Other assets include the pumps and booster pumps which push the water though the water pipes; storage reservoirs and water towers; network monitoring; and customer meters. The underground assets have long asset lives: water companies in aggregate have 7% by length of their potable water mains constructed before 1900 and 25% by length dates from before World War 2. Their ubiquity, their cost and their longevity all contribute to TWD being the water business unit which is closest to being a natural monopoly.

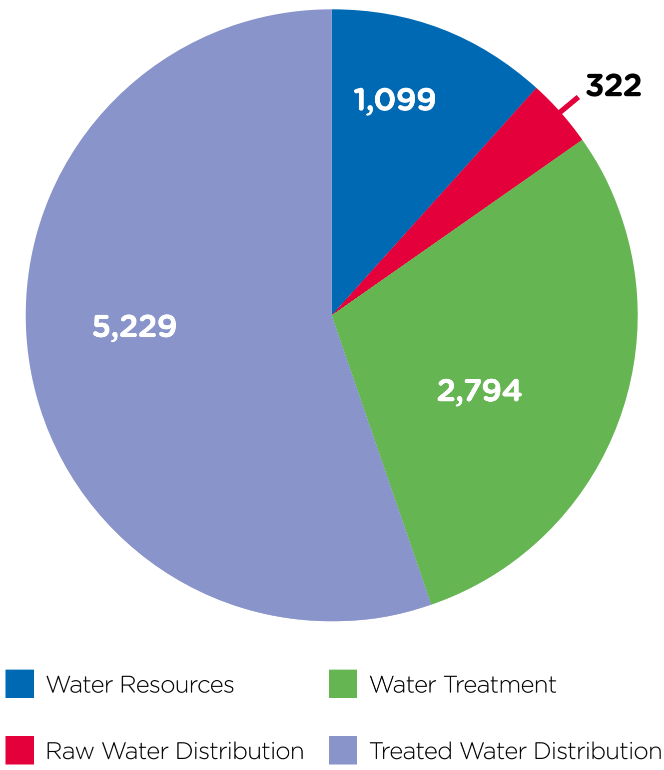
Network maintenance, leakage repair and power costs are the main costs within TWD. The key variables of this stage are the volume of distributed water, the length and diameter of water pipes and the lift applied to the water (reflecting the difference in vertical height between the point of treatment and the customer). Other variables include the age of pipes, the material from which pipes are made and companies' leakage aspirations; all of these influence companies' requirements for maintenance. Botex drivers include the geographical configuration of the area (affecting head), demographic factors (affecting volumes, pipe length and diameter) and characteristics of the asset stock (affecting maintenance requirements). It is reasonable to assume that factors such as geology and extreme weather events may be contributory factors driving levels of leakage. It has not proved possible to define or derive suitably granular measures of such variables so as to test this contention.

Figures 1 and 2 show the aggregate costs incurred within TWD over the three year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

What is immediately apparent from looking at Figure 1 is that TWD accounts for more than half of the total Water costs. WT accounts for 30%, with WR and RWD together making up around 15% of botex.

At this moment it is worth remembering that at PR19, there will be a separate cost assessment for WR (as there also will be for Bioresources on the Wastewater side). The remaining three Water Business Units are grouped together as Water Network Plus. From this it can be seen that the Water Network Plus cost assessment will account for over 85% of total Water botex.

Figure 1: Industry-wide Water Botex by Business Unit



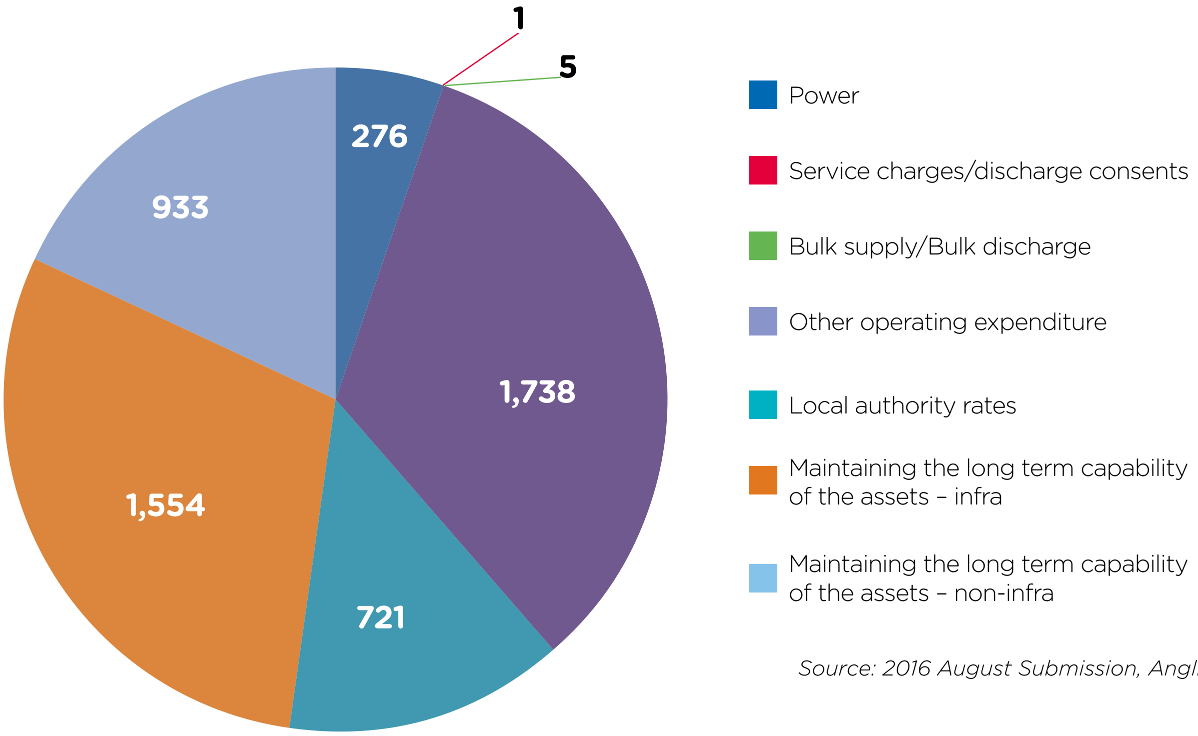
Source: 2016 August Submission, Anglian Water analysis

From Figure 1, TWD can be seen to be the largest single Water Business Unit. Representing around 55% of Water botex, it is thus larger than the other three Water Business Units put together.

Figure 2 sets out the split of botex by cost categories. The key points to note are:

- Local Authority Rates represents 12% of botex.
- TWD Capital Maintenance represents 48% of botex. TWD accounts for 63% of all Water Capital Maintenance costs.
- Industry-wide, TWD Power costs are well below the average for Water Business Units overall, at 5% of botex.
- Other Operating Costs for TWD, including staff costs and transport represent 33% of botex for the Business Unit.

Figure 2: Treated Water Distribution Industry-wide botex



Source: 2016 August Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Length (L): Mains length is a key driver of maintenance costs as well as a factor in the power requirements for moving potable water around the network.

Age range (AR): The age of the potable mains is generally accepted as a cost driver, though the precise mechanism is hard to set out straightforwardly. The interrelationship of age, construction material, level of maintenance and soil conditions is complicated and not easily susceptible to modelling.

Mains replaced (MR): The length of mains replaced and renewed is a key cost of capital maintenance for TWD.

Leakage (V_{leak}): The level of leakage is a key driver of capital maintenance in TWD.

Average Pumping Head x Distribution Input (APH.DI): The amount of power used in moving water though the mains network is related to volume and to the Average Pumping Head (APH), insofar as the APH is a well defined and computed statistic.

Population Sparsity and Density (S, D): Sparsity and density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

Average Passing Distance (APD): APD has long been used as a measure of network intensity. The recent development of Sparsity and Density by Ofwat in conjunction with the wider industry renders APD a (relatively) blunt measure, albeit one which is still viewed as important.

Area (A): The size of the appointed area is expected to be a driver of Maintenance costs.

Time Trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

3. The models

The five models which passed our acceptability criteria are set out in Figure 3 below. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the TWD botex. The estimations were carried out using OLS and were run on STATA v14.

The key results from the estimation of models TWD1 – TWD5 are reported in Table 1. This shows that all variables perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity is in the range 13 to 38.

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +7% to –15%, is credible and supports our view that our preferred models could be used. Excluding one outlier, the range of variances shrinks to +7% to -9%

Figure 3: Model forms

Model	Formula
TWD1	$\ln C = \alpha + \beta_1 \ln(AR) + \beta_2 \ln(APD) + \beta_3 \ln S + \beta_4 TT + u$
TWD2	$\ln C = \alpha + \beta_1 \ln(AR) + \beta_2 \ln(A) + \beta_3 TT + u$
TWD3	$\ln C = \alpha + \beta_1 \ln(AR) + \beta_2 \ln(APD) + \beta_3 \ln D + \beta_4 \ln(MR) + u$
TWD4	$\ln C = \alpha + \beta_1 \ln(AR) + \beta_2 \ln(APD) + \beta_3 \ln D + \beta_4 \ln(MR) + \beta_4 \ln(APH.DI) + u$
TWD5	$\ln C = \alpha + \beta_1 \ln(AR) + \beta_2 \ln(APH.DI) + \beta_3 \ln(MR) + u$

Source: Anglian Water analysis

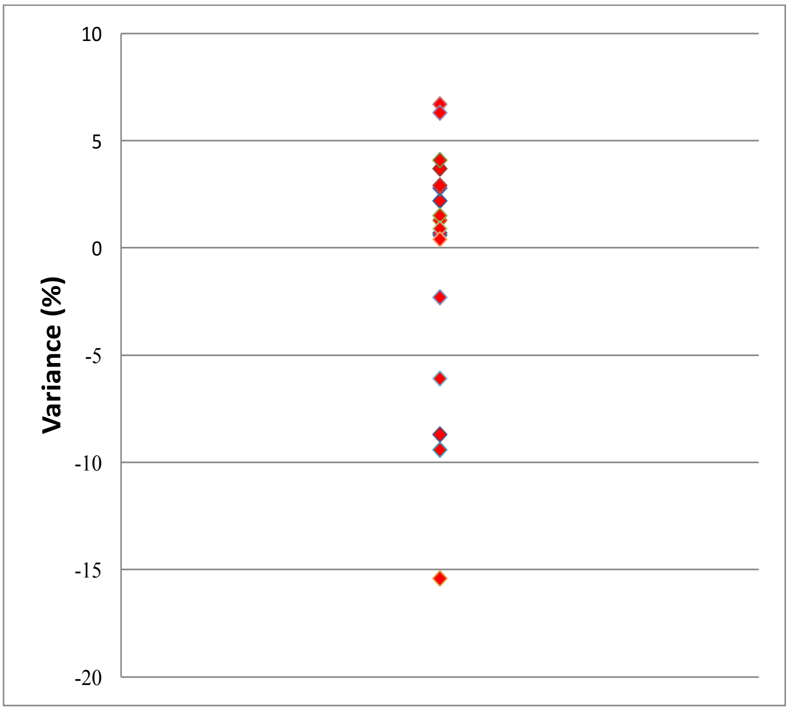
[1]Here volume is measured by Distribution Input, DI, which is a measure of the volume of potable water put into the TWD mains.

Table 1: Detailed model results

Model version	TWD1	TWD2	TWD3	TWD4	TWD5
APH.DI				20+	5 +
V leak			1 +	5 +	1+
L pre 1880	1 -	1 -	☒ -	☒ -	1 -
L 1881-1900	1 +	1 +	1 +	1 +	1 +
L 1901-20	1 +	1 +	☒ -	☒ -	☒ +
L 1921-40	1 +	1 +	5 +	5 +	1 +
L 1941-60	☒ -	☒ +	1 -	1 -	1 -
L 1961-80	1 +	1 +	1 +	1 +	1 +
L 1981-2000	1 -	1 -	1 -	1 -	1 -
L post 2000	1 +	1 +	☒ +	☒ +	10+
APD	1 -		5 +	10+	
D			20+	☒ +	
S	☒ +				
A		1 -			
MR			1 +	1 +	1 +
TT	5 -	1 -			
C	20 -	1 -	10-	5 -	1 -
Adj R^2	.981	.983	.988	.988	.988
AIC	-197	-204	-221	-222	-222
RR	.92	.93	.08	.12	.24
BP	.97	.66	.69	.72	.95
VIF	13	16	38	38	17

Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Treated Water Distribution



Source: Anglian Water analysis

4. Commentary

Data for length of water mains is used at a disaggregated level by age cohort. As can be seen from Table 1, the coefficients for the disaggregated categories are overall strongly and consistently significant (except for one category which is consistently insignificant).

Two other scale factors were also analysed but neither performed well. Both DI and the number of households served (HH) had negative coefficients, which do not fit with engineering logic. Including HH^2 improved the fit; with a significant (positive) coefficient on the squared term, though, the coefficient for the HH term remained insignificant and negative.

A variety of environmental factors were analysed. APH. DI performed as expected in TWD 4 and TWD5. The expectation is that power usage should be proportional to APH.DI, so that its coefficient should be significant and positive.

It was expected *a priori* that the greater the extent to which leakage fell below the sustainable economic level of leakage (SELL), the higher should be costs. While the coefficient on SELL was positive, it was not significant. The volume of non potable water supplied, acting as a proxy for the non-household business for each company, did perform adequately as an explanatory variable. The sign was consistently positive and it was generally significant. However, the models in which this variable was included failed our acceptance criteria and have therefore not been reported.

The disaggregated length of potable water mains performed well as a measure of asset intensity. *A priori*, the disaggregation by type of main (PVC, concrete, steel) was expected to perform better than disaggregation by age. Earlier work carried out within the Ofwat Cost Assessment Working Group and later replicated by us, showed that the split by type performed less well than by age.

The Ofwat defined density and sparsity measures did not perform well. Coefficients were either insignificant or with a sign that did not meet *a priori* expectations.

APD and Area performed better with significant coefficients.

Time Trend performed well, and as usual, Regional Wages failed to perform well.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

In line with our preferred terminology, in this report Sewage and Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

Summary

This annex sets out our cost modelling for Integrated Water Recycling (Service Area S1).

The Integrated Water Recycling models display a very low variability. If subsequent testing with additional data (from the 2017 submission) and further tests including omitting a large company produce similar results, it would appear that robust models of Water Recycling botex can be created parsimoniously.

1. Water Recycling service: business unit process identification

Water Recycling service describes the entire range of assets and activities to remove, treat and dispose of waste water, whether foul (from household toilets, baths and kitchens); Trade Effluent (from industry); surface water and highway drainage. It includes the transport of wastewater through the sewer network, the maintenance and development of that network; the treatment of the wastewater to the standard required by environmental legislation and its release back into water courses; as well as the transport, treatment and disposal of the solid residue of the treatment process.

Key assets include pipes (combined sewers, foul sewers and surface water sewers); storage tanks and pumping equipment necessary to push the contents of the sewers against gravity towards the Water Recycling Centre (WRC); along with the plant and machinery required to treat the raw sewage to an acceptable standard. Additionally they include for Bioresources pipes, pumps and vehicles (for sludge transport); a wide range of tanks and treatment units (for sludge treatment); and vehicles and incinerators (for sludge disposal).

Key variables are volumes of waste water treated; the nature of treatment provided; and the age and construction of the sewer network. For the Bioresources operations they include the amount of raw sludge to be processed; the number and size of sludge treatment centres; the type of treatment unit and the extent of transport for both raw sludge and treated biosolids.

Exogenous botex drivers of these variables include the topology of the area served (which defines the level and intensity of pumping requirements); the demographics of the area served (which defines the size of WRCs); the nature of industrial activity within the area (which defines the volume and nature of the Trade Effluent treated); and the number, nature and level of the environmental permits imposed by the Environment Agency. For Bioresources, they include the demographics of the area served (indirectly through its influence on the number and size of WRCs) and its land use (which determines the ease which treated biosolids can be recycled to land). Historical decisions about sludge investment strategies are significant factors: the extent to which these can be considered exogenous is a matter for debate.

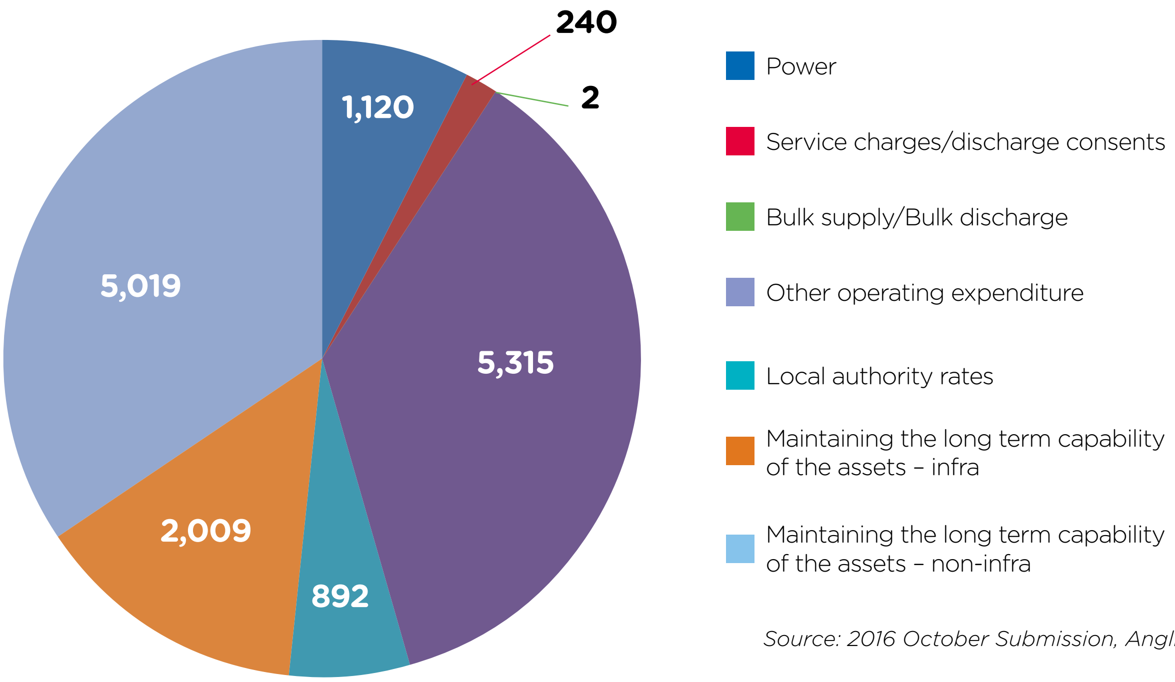
Within its Regulatory Account Guidelines (RAGs), Ofwat has defined five Wastewater Business Units. These are Water Recycling Collection, Water Recycling Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal. The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures 1, 2 and 3 show the aggregate costs incurred within Water Recycling over the five year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

The key points to note from Figure 1 are:

- At an industry level, Local Authority Rates represent 6% of botex. This is lower than for Water.
- Capital Maintenance represents 48% of botex. This compares to 51% for Water. Part of this difference may be due to Water Recycling including two more years from the latter part of AMP5: capex generally starts an AMP at a relatively low level then builds during the AMP. Hence including more years' data from later in the AMP would be expected to raise the proportion of capex within botex. However, study of capital and operational expenditure over two decades suggests that this is only part of the answer: over multiple AMPs, at an industry level capex on Water Recycling has been higher than for Water.
- The largest Water Recycling opex cost category is Other Operating Costs, covering principally staff costs, HCS, chemicals and transport. At 36% of botex, this is a similar proportion to Water.
- Power appears to represent a lower proportion of Water Recycling botex at 8%. It needs to be remembered that the Water Recycling Power number is attenuated by the generation of power by Bioresources, a revenue which is shown as a negative (power) cost. However, even after taking that into account, Water Recycling's share of botex represented by power is lower than for Water.

Figure 1: Industry-wide Water Recycling Total Botex by cost category



Source: 2016 October Submission, Anglian Water analysis

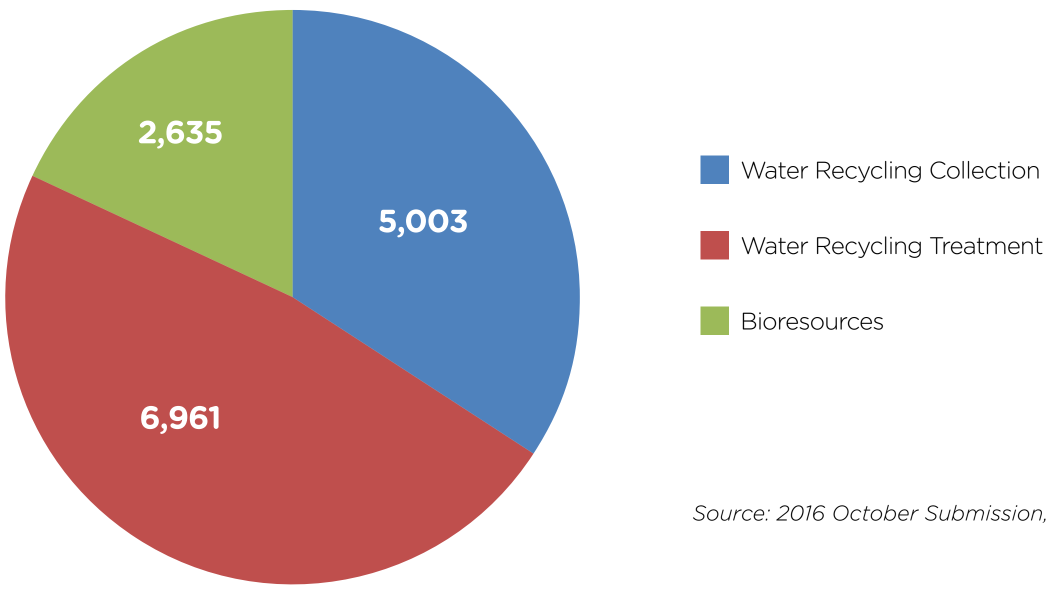
There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment - form Water Recycling's Network Plus cost control. The other three – Sludge Transport, Treatment and Disposal – forms Bioresource's cost control. In the following two Figures, we describe the relative size of the two cost controls and the shares of costs within each.

Looking at Figure 2, it can be seen that Water Recycling Network Plus accounts 82% of botex for Water Recycling.

Compared to Water, the sizes of Water Recycling's Network Plus Business Units are uniform: by contrast, TWD is larger than all the other Water Business Units put together.

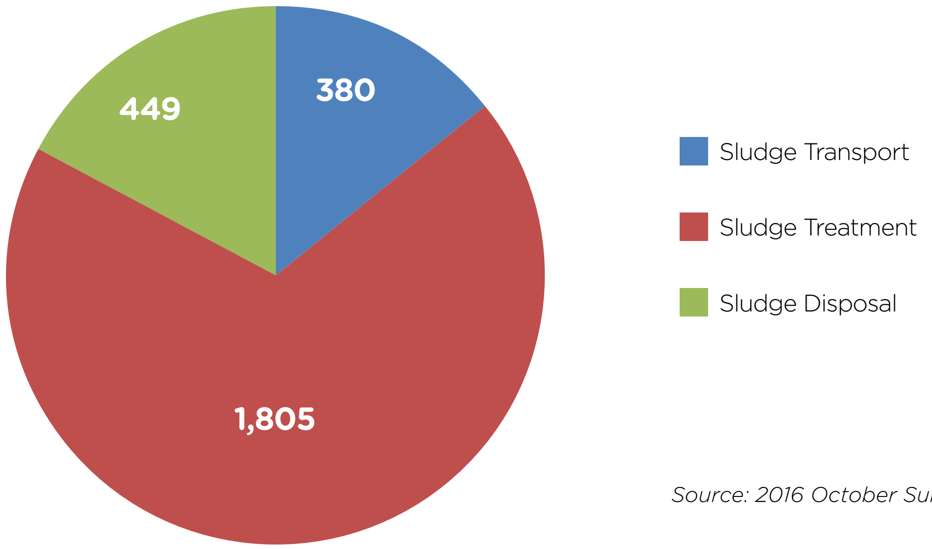
By contrast, as can be seen in Figure 3, Sludge Treatment accounts for ca 70% of botex within the Bioresources cost control (around 12% of overall Water Recycling botex). Transport and Disposal are similar in size, each representing only around 3% of overall Water Recycling botex.

Figure 2: Industry-wide Water Recycling Botex by Business Unit



Source: 2016 October Submission, Anglian Water analysis

Figure 3: Industry-wide Bioresources Botex by Business Unit



Source: 2016 October Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Aggregate length of sewers (L): The aggregate length of the sewer network is generally accepted to be a key driver of sewage collection costs.

Length of sewers dating from pre 1940 ($L_{pre\ 1940}$):
Length of sewers dating from 1940-1960 ($L_{1940-60}$):
Length of sewers dating from 1960-1980 ($L_{1960-80}$):
Length of sewers dating from 1980-2000 ($L_{1980-2000}$):
Length of sewers dating from 2000 ($L_{post\ 2000}$):

The age of the sewer network is generally accepted as a cost driver, though the precise mechanism is hard to set out straightforwardly. The interrelationship of age, material, level of maintenance & soil conditions is complicated and not easily susceptible to modelling.

Population equivalent (p.e.): As the p.e. provides a measure of the foul water received by Water Recycling Centres (WRC), it is hard to avoid the conclusion that it should be a significant cost driver

Number of properties (domestic & commercial) in appointed area (P): The number of properties connected to the sewer network is a driver of cost, although a priori it is unclear whether it will be as effective as p.e.

Sparsity (S): Sparsity is included to capture elements of scale economies. Being highly granular (based on LSOA data), this measure is believed to perform better than cruder scale measures such as average passing distance or average load per WRC

Proportion of total volume treated at Band 1-3 work (B_{1-3}): The proportion of total load treated at Band 1-3 WRC (that is serving a catchment with a p.e.<2,000) is a measure of diseconomy of scale

Tonnes of Dry Solids Treated (T): The dry solid load within sludge is a key driver of cost of sludge treatment and disposal. It is a poor driver of sludge transport as it does not capture the concentration of the solids.

Number of WRCs (WRC): The number of WRCs is a measure of asset intensity.

Work done in moving sludge between sites (W): Measured in kilometre tons of dry solids (sum of distance travelled per journey x tds per journey). Inter-siting work is a key metric driving sludge transport cost

Tight P consent (C_p): A WRC subject to sub 1mg/l P consent as % of total. Tight consents all incur additional costs in order to meet those consents (the level which represents a tight consent was chosen as below that level, companies incur additional costs)

Tight BoD[1] consent (C_{BOD}): A WRC subject to sub 10mg/l BoD consent as % of total. Tight consents all incur additional costs in order to meet those consents (the level which represents a tight consent was chosen as below that level, companies incur additional costs)

Proportion of indigenous sludge, i.e. sludge that is produced at a collocated WRC (I): T(1-I) measures the amount of sludge which does have to be transported for treatment

Length of sewers repaired or renewed (R): A driver of collection maintenance costs.

[1]*BoD: Biochemical Oxygen Demand, a measure of the amount of oxygen required to break down organic materials. A tight BoD consent requires a high proportion of organic material to be removed from the treated waste water*

3. The models

The four models which passed our acceptability criteria are set out below in Figure 4. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the total Water Recycling botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

Figure 4: Model forms

Model	Formula
WRI1	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 \ln(L^2) + \beta_3 \ln(S) + \beta_4 B_{1\text{-}3} + \beta_5 \ln T + \beta_6 \ln(W) + u$
WRI2	$\ln C = \alpha + \beta_1 \ln(p.e) + \beta_2 \ln(p.e.^2) + \beta_3 \ln(S) + \beta_4 \ln(C_p) + \beta_5 \ln(C_{BOD}) + \beta_6 \ln(W) + \beta_7 \ln(WRC) + u$
WRI3	$\ln C = \alpha + \beta_1 \ln(p.e) + \beta_2 \ln(p.e.^2) + \beta_3 \ln(S) + \beta_4 \ln(C_p) + \beta_5 \ln(C_{BOD}) + \beta_6 \ln(W) + \beta_7 \ln(WRC) + \beta_8 B_{1\text{-}3} + u$
WRI4	$\ln C = \alpha + \beta_1 \ln(P) + \beta_2 \ln(R) + \beta_3 \ln(S) + \beta_4 \ln(L_{\text{pre }1940}) + \beta_5 \ln(L_{1940\text{-}60}) + \beta_6 \ln(L_{1960\text{-}80}) + \beta_7 \ln(L_{1980\text{-}2000}) + \beta_8 \ln(L_{\text{post }2000}) + \beta_9 \ln(T(1-I)) + u$

Source: Anglian Water analysis

WRI1 –WRI4 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R2 values are all above 80% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity are all low.

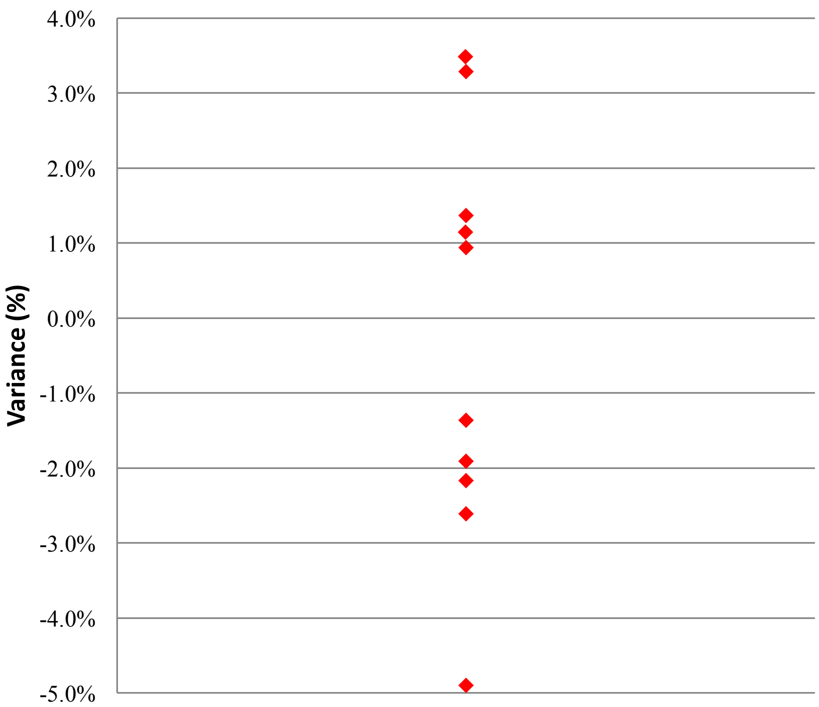
Table 1: Detailed model results

Version	WRI1	WRI2	WRI3	WRI4
L	1 -			
L^2	1 +			
$L_{pre\ 1940}$				1 +
$L_{1940-60}$				☒ -
$L_{1960-80}$				1 +
$L_{1980-00}$				1 +
$L_{post2000}$				1 +
P				1 +
p.e.		5 -	1 -	
$p.e.^2$		5 +	1 +	
T	1 +			
T(1-I)				1 +
W	1 +	1 +	1 +	
B_{1-3}	1 +		1 +	
WRC		1 +	10-	
R				5 +
C_P		1 +	20-	
C_{BoD}		1+	1+	
S	1 -	1 -	1 -	1 -
C	1 +	1 +	1 +	10+
Adj R^2	.968	.965	.972	.967
AIC	-236	-231	-241	-233
RR	.12	.00	.02	.62
BP	.31	.24	.21	.77
VIF	761	547	525	39

Source: Anglian Water analysis

We have calculated the expected valuae produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 5 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +4% to –5%, is very narrow. These results appear to be credible and support our view that our preferred models could be used.

Figure 5: Percentage variance between modelled and actual expenditure: Integrated Water Recycling



Source: Anglian Water analysis

4. Commentary

Sewer length, p.e., p.e.(1-I) and the number of properties were all used as scale variables. All performed well.

Several environmental factors were tested. They generally performed well. B_{1-3} was tried in two models. Coefficients were positive and strongly significant, which matches expectations. Similarly, inter-siting work was used in three models with strongly significant positive coefficients, once again as expected. The tight consent on BoD is also strongly significant and positive, although the tight P consent is strongly significant and positive in one model and weakly significant and negative in the other. Length of sewer by age cohort also performs well.

The number of WRCs performed indifferently as a cost driver: although it was significant when used, on one occasion it was positive and the other negative. Sewer renewals performed well on the one occasion it was used. The Ofwat defined scarcity variable performed well in all models in which it was used.

Given the very good fit of the models in the absence of regional wages or time trend, it was not felt necessary to include these variables in the integrated Water Recycling models.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data

b. To test for the models' stability when a year's data are removed.

c. Further develop and refine models

d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

In line with our preferred terminology, in this report Sewage and Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

Summary

This annex sets out our cost modelling for Water Recycling Network Plus (Service Area S2).

We have a credible suite of models developed for Water Recycling Network Plus which will form the basis for further development. More stability testing still needs to be done.

1. Water Recycling Network Plus: business unit process identification

Water Recycling Network Plus comprises the business units of Water Recycling Collection and Water Recycling Treatment. It includes the transport of used water from customers' properties to Water Recycling Centres (WRCs) and the physical and biological treatment of used water at WRCs to enable it to be returned to environmental waters with acceptable impact.

Key assets include pipes (combined sewers, foul sewers and surface water sewers), storage tanks and pumping equipment necessary to push the contents of the sewers against gravity towards the Water Recycling Centre (WRC), along with the plant and machinery required to treat the raw sewage to an acceptable standard. Key activities within Collection are the pumping and treatment of water and the maintenance of assets. Because both the quality of the incoming sewage and the quality required of the output are very variable, there are a wide range of potential treatment approaches within Water Recycling Treatment.

Key variables are volumes of waste water treated, the nature of treatment provided, and the age and construction of the sewer network. Exogenous botex drivers of these variables include the topology of the area served (which defines the level and intensity of pumping requirements); the demographics of the area served (which defines the size of WRCs); the nature of industrial activity within the area (which defines the volume and nature of the Trade Effluent treated); and the number, nature and level of the environmental permits imposed by the Environment Agency.

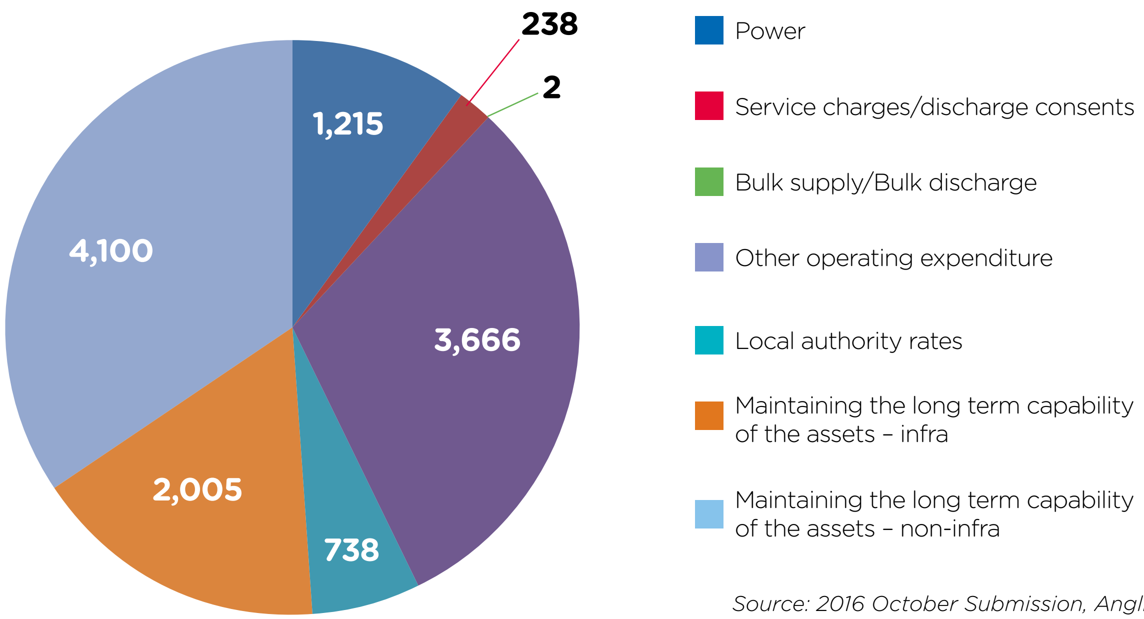
Within its Regulatory Account Guidelines (RAGs), Ofwat has defined five Water Recycling Business Units. These are Water Recycling Collection, Water Recycling Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal. The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures 1 and 2 show the aggregate costs incurred within Water Recycling Network Plus over the five year period to 31 March 2016. All costs are in 2012-13 cost base and are shown in millions of pounds.

The key points to note from Figure 1 are:

- At an industry level, Local Authority Rates represent 6% of Water Recycling Network Plus botex. This is lower than for Water.
- Capital Maintenance represents 51% of Water Recycling Network Plus botex. This compares to 45% for Water. Part of this difference may be due to Water Recycling including two more years from the latter part of AMP5: capex generally starts an AMP at a relatively

Figure 1: Industry wide Water Recycling Network Plus botex by cost category



Source: 2016 October Submission, Anglian Water analysis

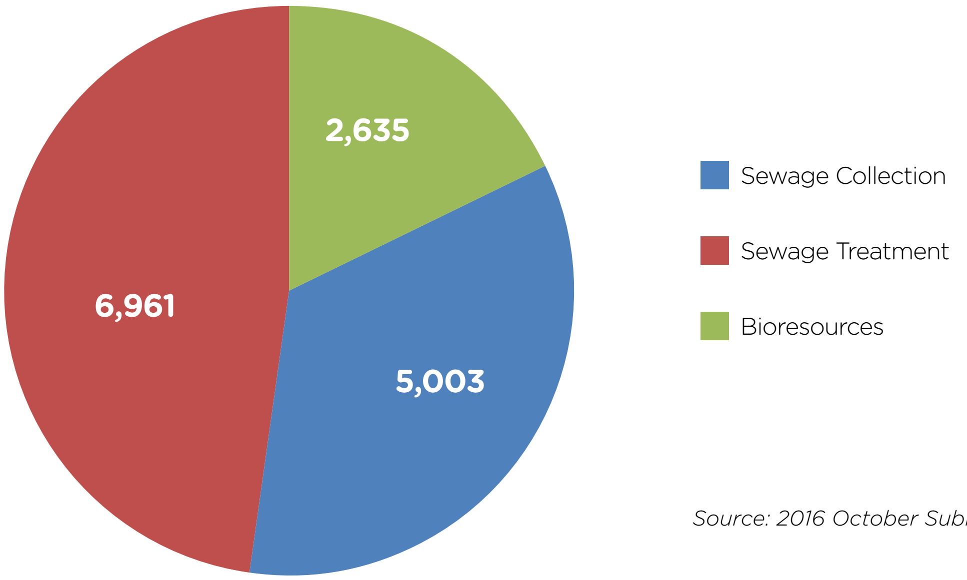
low level then builds during the AMP. Hence including more years' data from later in the AMP would be expected to raise the proportion of capex within totex. However, study of capital and operational expenditure over two decades suggests that this is only part of the answer: over multiple AMPs, at an industry level capex on Water Recycling has been higher than for Water.

- The largest Water Recycling Network Plus opex cost category is Other Operating Costs, covering principally staff costs, Hired and Contract Services (HCS), chemicals and transport. At 36%, this is similar to the proportion for Water.
- Power appears to represent a similar proportion of Water Recycling Network Plus botex at 10%. It needs to be remembered that the Water Recycling Power number is attenuated by the generation of power by Bioresources, the revenue from which is shown as a negative (power) cost. However, even after taking that into account, Water Recycling Network Plus' share of botex represented by power is higher than for Water Network Plus.

There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment - form Water Recycling's Network Plus cost control. The other three – Sludge Transport, Treatment and Disposal –forms the Bioresources cost control

Looking at Figure 2, it can be seen that Water Recycling Network Plus accounts 82% of botex for Water Recycling. Compared to Water, the sizes of Water Recycling's Network Plus Business Units are uniform: by contrast, TWD is larger than all the other Water Business Units put together.

Figure 2: Industry-wide Water Recycling Botex by Business Unit



Source: 2016 October Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Total Sewer length (L): The aggregate length of the sewer network is a key driver of sewage collection costs.

Total volume treated (V): Sewage volume is expected to be a driver of total collection and treatment costs.

Density (D), Sparsity (S): Sparsity and density are both included to capture elements of scale economies. Being highly granular (based on LSOA data), these measures appear to perform better than cruder scale measures such as average passing distance or average load per WRC.

Population equivalent (p.e.): As the p.e. provides an (albeit indirect) measure of the foul water received by Water Recycling Centres (WRC), it is hard to avoid the conclusion that it should be a significant cost driver.

Proportion of total volume treated at Band1-3[1] works (B_{1-3}): The proportion of total load treated at Band 1-3 works is a measure of diseconomy of scale. By comparison, a WRC in the highest band, Band 6, serves a catchment with a p.e. in excess of 25,000 (the largest in the UK is over 4 million).

Time trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

[1] *That is WRCs serving a catchment with a p.e.<2,000*

3. The models

The four models which passed our acceptability criteria are set out below in Figure 3. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the Water Recycling Network Plus botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

WRNP1 –WRNP4 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 80% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF values measuring potential multicollinearity are all low.

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +20% to -28%, is credible and supports our view that our preferred models could be used.

Figure 3: Model forms

Model	Formula
WRNP1	$\ln C = \alpha + \beta_1 \ln(p.e.) + \beta_2 S + \beta_3 B_{1\text{-}3} + \beta_4 TT + u$
WRNP2	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 S + \beta_3 B_{1\text{-}3} + \beta_4 TT + u$
WRNP3	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 S + \beta_3 \ln(V) + \beta_4 TT + u$
WRNP4	$\ln C = \alpha + \beta_1 \ln(L) + \beta_2 D + \beta_3 \ln(V) + \beta_4 TT + \beta_5 B_{1\text{-}3} + u$

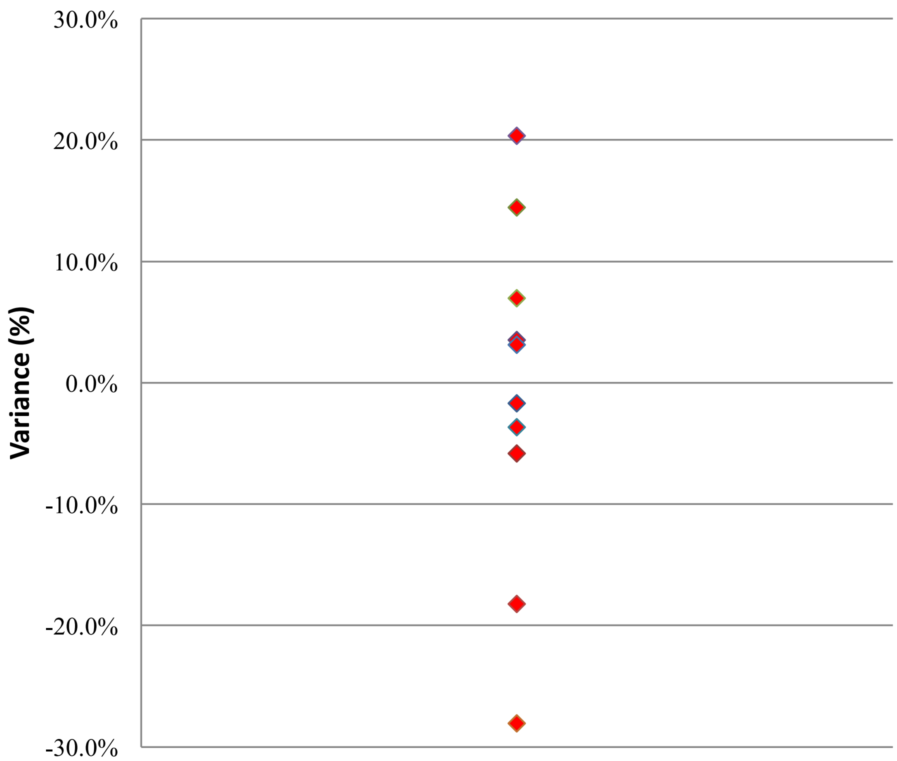
Source: Anglian Water analysis

Table 1: Detailed model results

Version	WRNP1	WRNP2	WRNP3	WRNP4
L		1 +	5 +	5 +
p.e.	1 +			
V			5 +	1 +
D				20+
S	1 -	1 -	10-	
$B_{1\text{-}3}$	1 +	1 +		1 +
TT	☒+	☒+	☒+	☒ -
C	1 -	1 -	1 -	1 -
Adj R^2	.910	.911	.855	.863
AIC	-185	-185	-161	-163
RR	.59	.60	.02	.00
BP	.51	.78	.10	.19
Avg VIF	2	2	7	5

Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Water Recycling Network Plus

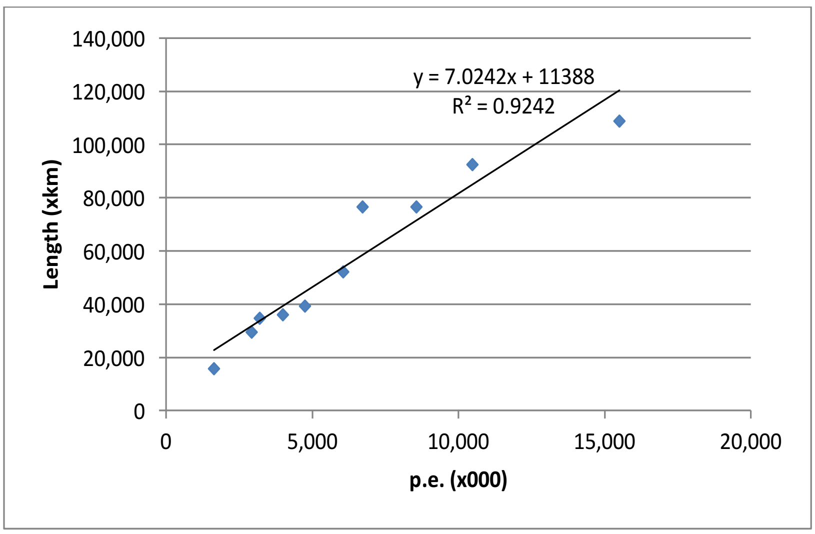


Source: Anglian Water analysis

4. Commentary

Length and p.e. generally performed well and as expected as cost drivers. This is unsurprising when one considers the tightness of the relationship between the two variables. Looking at the outliers above and below the line of best fit, it appears that the key factor leading to deviations is the extent of sparsity or density of the area served. This relationship is illustrated in Figure 5 below.

Figure 5: Sewer length vs p.e., based on 2015-16 data



Source: 2016 October Submission, Anglian Water analysis

[1]*BoD: Biochemical Oxygen Demand, a measure of the amount of oxygen required to break down organic materials. A tight BoD consent requires a high proportion of organic material to be removed from the treated waste water*

Volume performed less well but adequately. As Volume is an inferred statistic, based on the volume of water consumed by households, this finding is unsurprising. This is illustrated in Figure 6 below.
The proportion of load treated at Band 1-3 sites performed well as a cost driver, with generally strongly significant and positive coefficients.

The length of sewers renewed performed poorly as a cost driver. The coefficient was not significant each of the three times it was tried and on two occasions the coefficient was negative and once positive. While arguments could be put forward for the coefficient being either positive or negative, there is no obvious explanation for it being both at the same time.

The Ofwat defined Sparsity index generally performed well in the models. When tried, the Density index (which in theory ought to perform similarly) performed less well. It may be due to the greater range and lack of zero values of the Sparsity index.

The Time Trend did not perform well. Coefficients were generally not significant (in 16 versions tried, only one was significant and then only at 80% level). Moreover, coefficients were generally positive suggesting either a negative form of efficiency or alternatively the existence of Real Price Effects. Attempts to include Regional Wages were unsuccessful and were not reported.

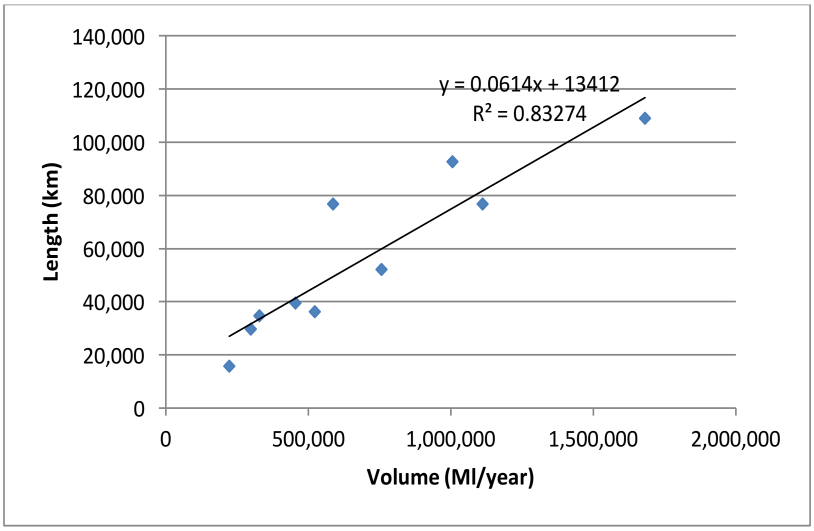
5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data
b. To test for the models' stability when a year's data are removed.
c. Further develop and refine models
d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Figure 6: Sewer length vs volume treated, based on 2015-16 data



Source: 2016 October Submission, Anglian Water analysis

In line with our preferred terminology, in this report Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

Summary

This annex sets out our cost modelling for:

i) Integrated Bioresources (Service Area S3);
ii) Sludge Transport (Service Area S6);
iii) Sludge Treatment (Service Area S7); and
iv) Sludge Disposal (Service Area S8).

We have a credible initial set of cost models for Bioresources and for the individual components. These have taken advantage of the data set collected in 2016. More work remains to be done, but we have a good starting point for further work based on the 2017 data set.

1. Bioresources: business unit process identification

Bioresources is the final stage in the Water Recycling service and consists of the transport and treatment of the solid residues of waste water treatment and production of a material (biosolids) that can be safely returned to the environment. It therefore follows sewage collection and sewage treatment, which Ofwat collectively treats as Network Plus. RAG 4.07 defines the start to the process to be the point of discharge from indigenous thickening processes or holding tanks and the end to be the point of disposal or recycling to land. The key assets within Bioresources are pipes, pumps and vehicles (for sludge transport); a wide range of tanks and treatment units (for sludge treatment); and vehicles and incinerators (for sludge disposal).

The following facts all create a particular challenge for Bioresources botex driver modelling:

Firstly, there is arguably greater variation between companies in the approaches they take to Bioresources than for any other business unit across water and waste water. This is partly a consequence of differences in exogenous factors but also a matter of strategic choice.

Second, the process of sludge production entails a gradual concentration of the solid residues of waste water treatment. The lack of clarity between partially treated waste water and sludge increases the potential for inconsistent identification of the boundary between sewage treatment and Bioresources between companies and therefore their treatment of assets and costs. This is amplified by the fact that sewage and sludge treatment frequently take place on the same sites, using shared resources.

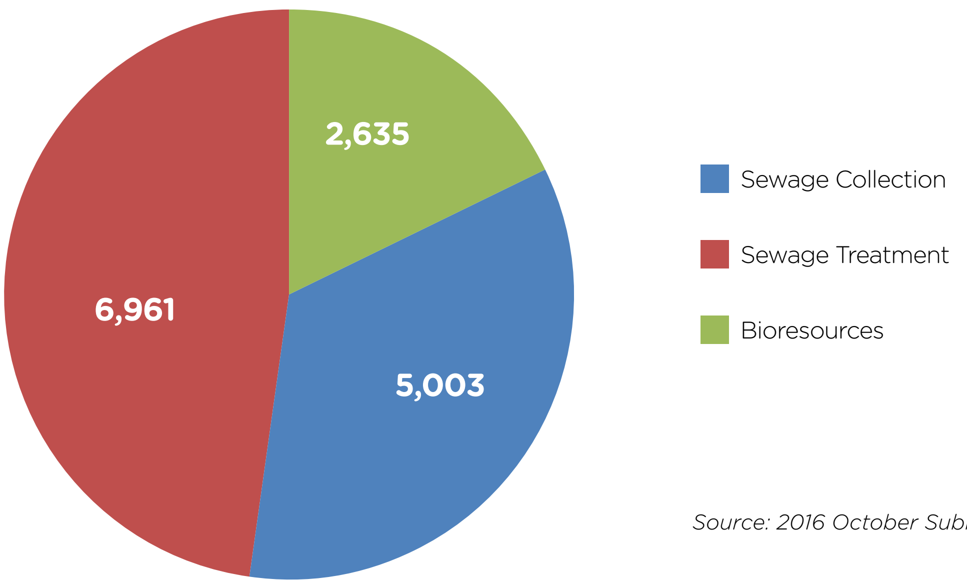
Third, there has historically not been a generally agreed method of measuring the amount if sludge produced by the sewage treatment process and requiring processing.

Finally, the quality of raw sludge is variable but no clear process for measuring and reporting quality is in place. Furthermore, the quality of treated product is variable, the key consideration being the prevention of release of harmful chemical or biological elements to the environment.

The key variables of this stage are the amount of raw sludge to be processed, the number and size of sludge treatment centres, the type of treatment unit and the extent of transport for both raw sludge and treated biosolids. Exogenous factors which drive these variables include the demography of the area served (indirectly through its influence on the number and size of Water Recycling Centres (WRCs)) and its land use (which determines the ease which treated biosolids can be recycled to land). Historical decisions about sludge investment strategies are significant factors and the extent to which these can be considered exogenous is a matter for debate.

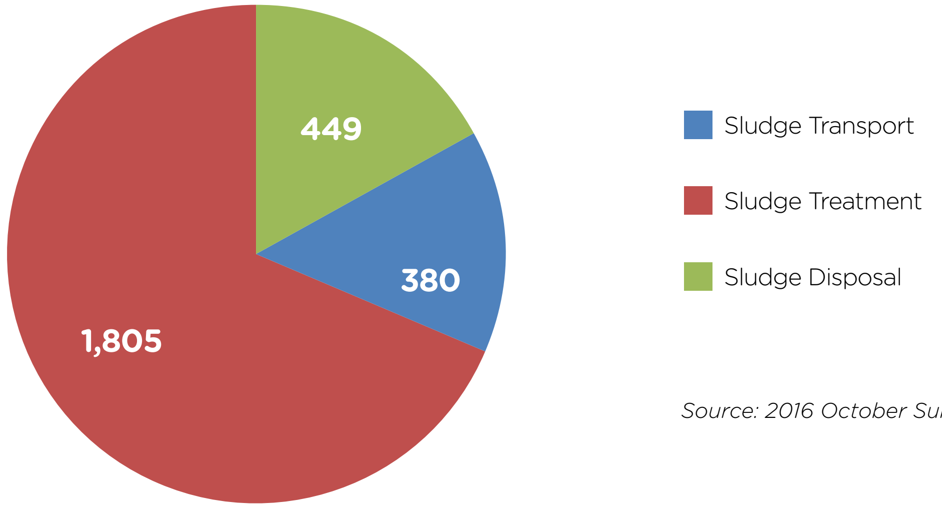
Within its Regulatory Account Guidelines (RAGs), Ofwat has defined five Wastewater Business Units. These are

Figure 1: Industry-wide Water Recycling Botex by Business Unit



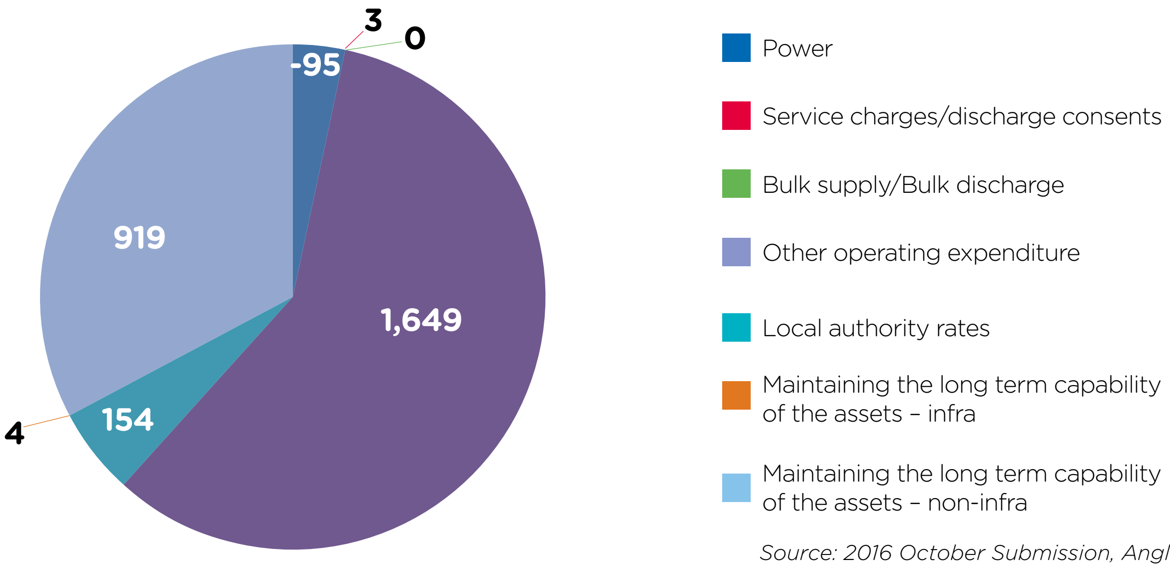
Source: 2016 October Submission, Anglian Water analysis

Figure 2: Industry-wide Bioresources Botex by Business Unit



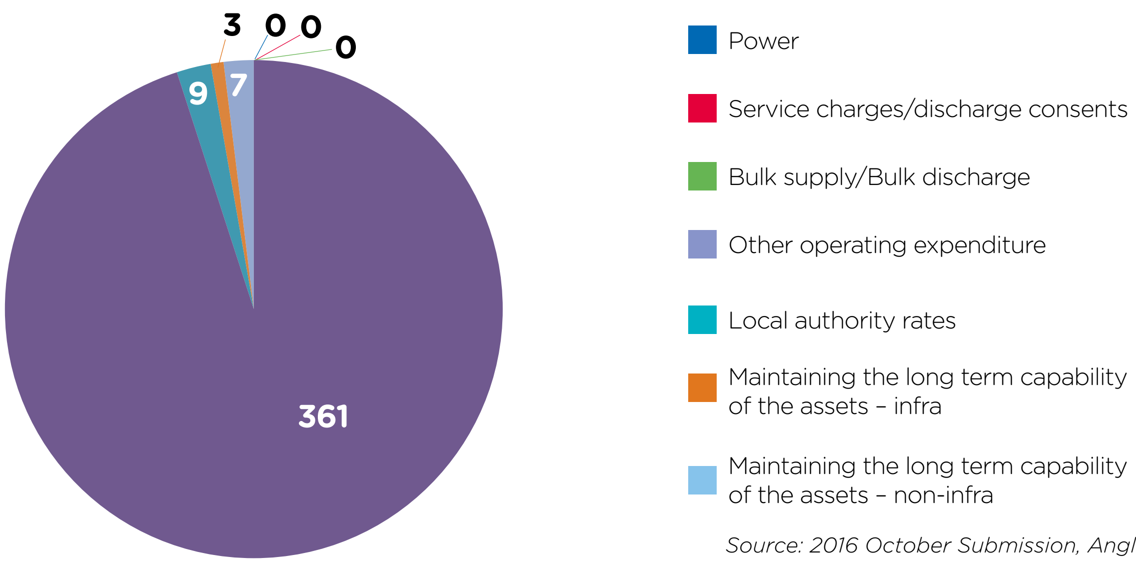
Source: 2016 October Submission, Anglian Water analysis

Figure 3: Bioresources Industry-wide Botex by cost category



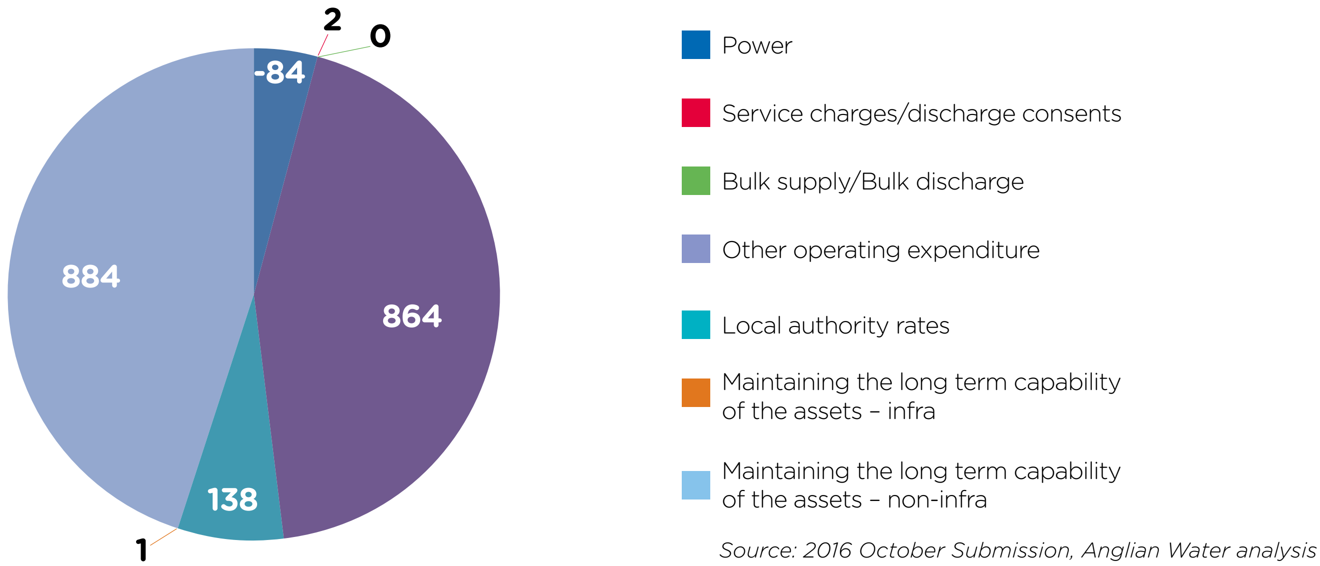
Source: 2016 October Submission, Anglian Water analysis

Figure 4: Sludge Transport Industry-wide Botex by cost category



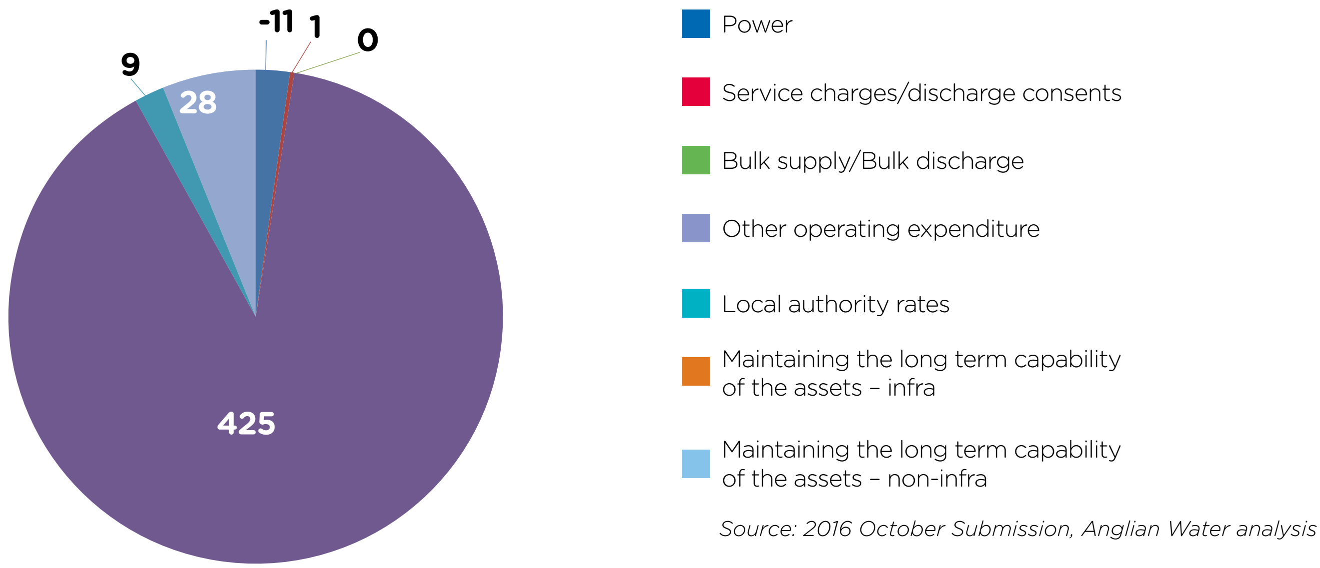
Source: 2016 October Submission, Anglian Water analysis

Figure 5: Sludge Treatment Industry-wide Botex by cost category



Source: 2016 October Submission, Anglian Water analysis

Figure 6: Sludge Disposal Industry-wide Botex by cost category



Source: 2016 October Submission, Anglian Water analysis

Sewage Collection, Sewage Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal. The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures 1 to 6 show the aggregate botex costs incurred within Bioresources over the five year period to 31 March 2016. All costs shown on the six Figures are in 2012-13 cost base and are shown in millions of pounds.

There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment - form Water Recycling's Network Plus cost control. The other three – Sludge Transport, Treatment and Disposal –forms Bioresource's cost control. In the following two Figures, we describe the relative size of the two cost controls and the shares of costs within each.

Source: Anglian Water analysis

Looking at Figure 1, it can be seen that Water Recycling Network Plus accounts for 82% of botex for Water Recycling. Compared to Water, the sizes of Water Recycling's Network Plus Business Units are uniform: by contrast, Treated Water Distribution is larger than all the other Water Business Units put together.

By contrast, as can be seen in Figure 2, Sludge Treatment accounts for around 70% of botex within the Bioresources cost control. Transport and Disposal are similar in size, each representing only around 3% of overall Water Recycling botex.

Figure 3 shows the split of Bioresources botex by cost categories. Key points to note are:

- Local Authority Rates account for 5% of the three Sludge Business Units' botex.
- Capital Maintenance represents 33% of botex for the three Sludge Business Units.

- Other Operating Expenses represent 58% of botex for Bioresources.
- Net power costs for Bioresources are -3% of botex as a result of the power generated from the methane generated as a by-product of Advanced Anaerobic Digestion (AD)

Figure 4 shows the split of Sludge Transport botex by cost categories. Key points to note are:

- Enhancement capex represents 3% of botex. This is the lowest proportion for all Business Units, both Water and Water Recycling. It reflects the widespread outsourcing of the transport function.
- The corollary of this widespread outsourcing is the fact that Other Operating Cost (which includes transport costs and bought-in services) represents 95% of botex.

Figure 5 shows the split of Sludge Treatment botex by cost categories. Key points to note are:

- Local Authority Rates account for 7% of botex.
- Capital Maintenance accounts for 45% of botex.
- The bulk of opex is represented by Other Operating Costs. This accounts for 44% of botex.
- Power is a negative cost, reflecting the importance of power generation for WaSCs which have taken the AD approach to Sludge Treatment.

Figure 6 show the split of Sludge Disposal botex by cost categories. Key points to note are:

- Local Authority Rates represents 2% of botex.
- Capital Maintenance represents 6% of botex. Compared to Sludge Transport, capex is higher for Sludge Disposal, indicating that WaSCs overall have kept more of Disposal in-house. Indeed, only one company (Welsh) has completely outsourced Sludge Disposal.
- As Sludge Disposal is mainly(though not universally) disposed to land, transport costs are a large part ofcosts. This explains Other Operating Costs representing 90% of botex.

Integrated Bioresources Models

2. Variables selection: Integrated Bioresources

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Tons of dry solids within sludge materials treated (T): Tons of dry solids is the agreed metric for the quantity of sludge treated, either as liquid or as cake. As such it is a key driver of sludge costs.

The proportion of sludge treated which was produced at a co-located WRC to the sludge treatment centre where it was treated (I): Indigenous sludge incurs no transport cost from the co-located WRC. Consequently, *ceteris paribus,* the higher is I, the lower is sludge transport cost.

Appointed area for Water Recycling activities (A): The size of the appointed area, in conjunction with density and sparsity is a determinant of the number, scale and location of sludge treatment plants.

The work undertaken in moving treated sludge from sludge treatment centres to the ultimate destination for the treated sludge (W_D)[1]: All sludge needs to be disposed. The predominant means of disposal is now to land, so the availability and proximity of a land bank (usually a list of farmers willing to accept treated sludge spread on their land) is a key driver of disposal cost

Sparsity (S), Density (D): Sparsity and density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

3. The models: Integrated Bioresources

The three models which passed our acceptability criteria are set out below in Figure 7. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the total Bioresources botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

B1 –B3 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 80% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF valuesmeasuring potential multicollinearity are all low.

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 8 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +12% to -24%, is credible and supports our view that our preferred models could be used. Excluding an outlier, the range shrinks significantly to +12% to -13%.

[1]This is the aggregate product of the weight of treated sludge moved per journey multiplied by the journey length in kilometres.

Figure 7: Model forms – Integrated Bioresources

Model	Formula
B1	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(S) + \beta_3 \ln(W_D) + \beta_4 \ln(T(1\text{-}I)) + u$
B2	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(S) + \beta_3 \ln(D) + \beta_4 \ln(W_D) + \beta_5 \ln(T(1\text{-}I)) + u$
B3	$\ln C = \alpha + \beta_1 \ln(S) + \beta_2 \ln(D) + \beta_3 \ln(W_D) + \beta_4 \ln(TI) + \beta_5 \ln(T(1\text{-}I)) + u$

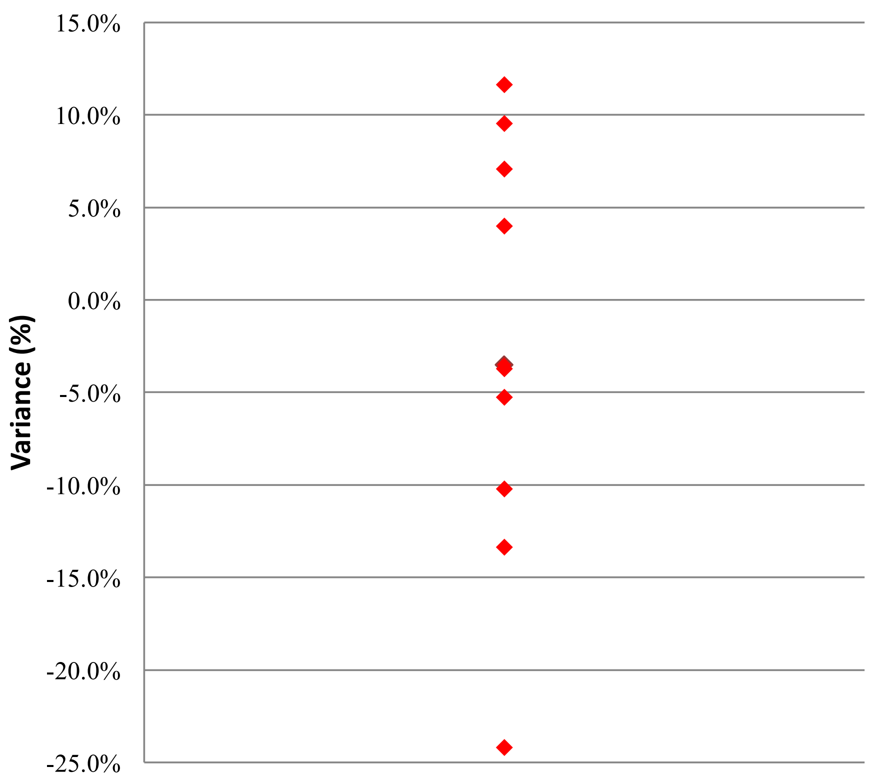
Source: Anglian Water analysis

Table 1: Detailed model results

Version	B1	B2	B3
T(1-I)	10+	1 +	1 +
T.I			1 +
W_D	1 +	1 +	5 +
A	1 +	1 +	
S	1 -	1 -	20-
D		1 -	1 -
C	1 -	1 -	☒ -
Adj R^2	.777	.820	.943
AIC	-123	-133	-138
RR	.62	.26	.94
BP	.73	.06	.02
VIF	2	2	4

Source: Anglian Water analysis

Figure 8: Percentage variance between modelled and actual expenditure: Integrated Bioresources



Source: Anglian Water analysis

4. Commentary: Integrated Bioresources

T(1-I) and TI both performed well as cost drivers with the coefficients meeting a priori expectations.

The various defined variables for work undertaken, W_I and W_L performed poorly in terms of a priori expectations. In particular, W_L consistently had the wrong sign in all models where it was used.

A and I performed well where used.

Both sparsity and density generally give consistent results, suggesting that both high sparsity and high density are associated with low costs. This in turn suggests that the relationship between costs and density for Bioresources is parabolic.

While the Time Trend performed adequately in the models where it was included, none of these models passed all our choice criteria. Regional Wages, performed poorly where used. This came as no surprise based on recent experience of using this variable.

Sludge Transport models

5. Variables selection: Sludge Transport

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Tons of dry solids within sludge materials treated (T): Tons of dry solids is the agreed metric for the quantity of sludge treated, either as liquid or as cake. As such it is a key driver of sludge transport costs.

The proportion of sludge treated which was produced at a co-located WRC to the sludge treatment centre where it was treated (I): Indigenous sludge incurs no transport cost from the co-located WRC. Consequently, ceteris paribus, the higher is I, the lower is sludge transport cost.

Appointed area for Water Recycling activities (A): The size of the appointed area, in conjunction with density and sparsity is a determinant of the number, scale and location of sludge treatment plants. It is hence a cost driver for the distance sludge needs to be transported.

The work undertaken in moving sludge between sites[2] (W_T): Inter-siting work is a key metric driving sludge transport cost

The proportion of WT moving liquid sludge between sites (W_L): Liquid sludge contains a much lower proportion of dry solid (3%-6%) compared to cake (~25%). As such it requires much more work per ton of dry solids to move liquid sludge compared to cake. Hence W_L is a driver of sludge transport cost.

Sparsity (S), Density (D): Sparsity and density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their

Time Trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

6. The models: Sludge Transport

The seven models which passed our acceptability criteria are set out below in Figure 9. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the total Bioresources botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

$ST_{rans}1$ – $ST_{rans}7$ were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R2 values are all above 80% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity are all low.

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 10 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +16% to -20%, is credible and supports our view that our preferred models could be used.

Figure 9: Sludge Transport model forms

Model	Formula
$ST_{rans}1$	$\ln C = \alpha + \beta_1 \ln(S) + \beta_2 \ln(D) + \beta_3 \ln(T(1\text{-}I)) + u$
$ST_{rans}2$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(T(1\text{-}I)) + + \beta_3 TT + u$
$ST_{rans}3$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(T(1\text{-}I)) + u$
$ST_{rans}4$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(T(1\text{-}I)) + \beta_3 \ln(S) + \beta_4 \ln(W_T) + \beta_5 \ln(I) + u$
$ST_{rans}5$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(S) + \beta_3 \ln(W_T) + \beta_4 \ln(W_L) + \beta_5 \ln(I) + \beta_6 TT + u$
$ST_{rans}6$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(S) + \beta_3 \ln(W_T) + \beta_4 \ln(W_L) + \beta_5 \ln(I) + u$
$ST_{rans}7$	$\ln C = \alpha + \beta_1 \ln(A) + \beta_2 \ln(S) + \beta_3 \ln(W_L) + \beta_4 \ln(I) + \beta_5 TT + u$

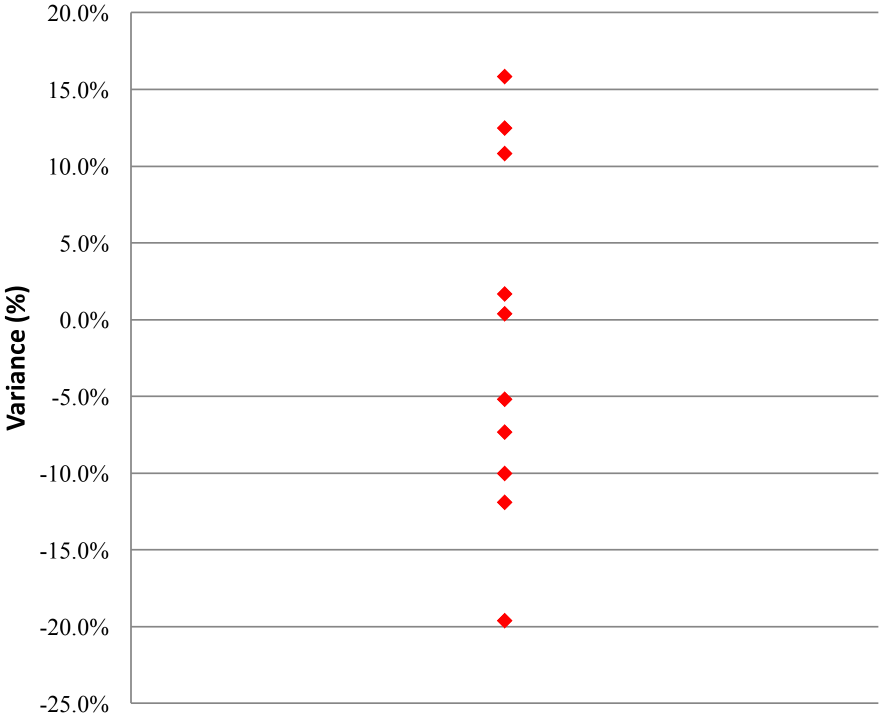
Source: Anglian Water analysis

Table 2: Detailed model results

Version	$ST_{rans}1$	$ST_{rans}2$	$ST_{rans}3$	$ST_{rans}4$	$ST_{rans}5$	$ST_{rans}6$	$ST_{rans}7$
T(1-I)	1 +	1 +	1 +	☒+			
W_T					☒+	☒+	
W_L				1 +	1 +	1 +	1 +
A		1 +	1 +	1 +	1 +	1 +	1 +
S	1 -			1 -	1 -	1 -	1 -
D	5 -						
I				10-	1 -	1 -	1 -
TT		☒+			☒+		☒+
C	1 -	1 -	1 -	1 -	1 -	1 -	1 -
Adj R^2	.718	.774	.774	.850	.847	.846	.850
AIC	-114	-126	-127	-145	-143	-143	-144
RR	.06	.90	.86	.57	.17	.33	.16
BP	.49	.23	.10	.24	.40	.34	.46
VIF	2	1	1	12	2	3	1

Source: Anglian Water analysis

Figure 10: Percentage variance between modelled and actual expenditure: Sludge Transport



Source: Anglian Water analysis

7. Commentary: Sludge Transport

T(1-I) performs well as a cost driver with strongly significant and positive coefficients in all models where it was used. As this represents the dry ton weight of untreated sludge that has to me transported, this is unsurprising.

Area, Indigenous and the Work cost drivers are all classed as environmental drivers. All perform well. The proportion of indigenous sludge treated is determined at least in part by the demographics and size of the appointed area. A high density will make feasible a large integrated Water Recycling centre and sludge treatment works which in turn will produce a higher proportion of indigenous sludge. Sludge Transport and Disposal have the lowest asset intensity of all the Water Recycling Business Units. As such, the lack of asset intensity cost drivers is not a problem.

Density and sparsity performed well uniformly across the models.

Regional Wages were not used as a cost driver for the Sludge Transport Business Unit. Time Trend performed uniformly badly with insignificant positive coefficients wherever used.

Sludge Treatment models

8. Variables selection: Sludge Treatment

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Tons of dry solids within sludge materials treated (T): Tons of dry solids is the agreed metric for the quantity of sludge treated, either as liquid or as cake. As such it is a key driver of sludge transport costs.

Appointed area for Water Recycling activities (A): The size of the appointed area, in conjunction with density and sparsity is a determinant of the number, scale and location of sludge treatment plants.

Sparsity (S), Density (D): Sparsity and density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their

Time Trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

Proportion of sludge which is untreated (S_u):
Proportion of raw sludge which is limed (S_L):
Proportion of sludge which is treated using conventional anaerobic digestion(S_C):
Proportion of sludge which is treated using advanced anaerobic digestion (S_A):
Proportion of raw sludge which is treated using incineration (S_I):
Proportion of sludge which is treated using phyto-conditioning/composting (S_P):

} The proportions of sludge represented by the different processes defines the capital intensity of the sludge treatment operation.

9. The models: Sludge Treatment

The four models which passed our acceptability criteria are set out below in Figure 11. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the total Bioresources botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

$ST_{reat}1$ – $ST_{reat}4$ were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 3. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R2 values are all above 70% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP).

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 12 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +0% to -25%, is credible and supports our view that our preferred models could be used. Excluding one outlier, the range narrows considerably to +0% to -8%.

Figure 11: Sludge Treatment model forms

Model	Formula
$ST_{reat}1$	$\ln C = \alpha + \beta_1 \ln(T) + \beta_2 \ln(S_u) + \beta_3 \ln(S_L) + \beta_4 \ln(S_C) + \beta_5 \ln(S_A) + \beta_6 \ln(S_I) + \beta_7 \ln(S_P) + \beta_8 \ln(P) + \beta_9 \ln(A) + \beta_{10} \ln(S) + \beta_{11} \ln(D) + \beta_{12} \ln(RW) + \beta_{13} (TT) + u$
$ST_{reat}2$	$\ln C = \alpha + \beta_1 \ln(T) + \beta_2 \ln(S_u) + \beta_3 \ln(S_L) + \beta_4 \ln(S_C) + \beta_5 \ln(S_A) + \beta_6 \ln(S_I) + \beta_7 \ln(S_P) + \beta_8 \ln(A) + u$
$ST_{reat}3$	$\ln C = \alpha + \beta_1 \ln(T) + \beta_2 \ln(S_u) + \beta_3 \ln(S_L) + \beta_4 \ln(S_C) + \beta_5 \ln(S_A) + \beta_6 \ln(S_I) + \beta_7 \ln(S_P) + \beta_8 \ln(D) + u$
$ST_{reat}4$	$\ln C = \alpha + \beta_1 \ln(T) + \beta_2 \ln(S_u) + \beta_3 \ln(S_L) + \beta_4 \ln(S_C) + \beta_5 \ln(S_A) + \beta_6 \ln(S_I) + \beta_7 \ln(S_P) + u$

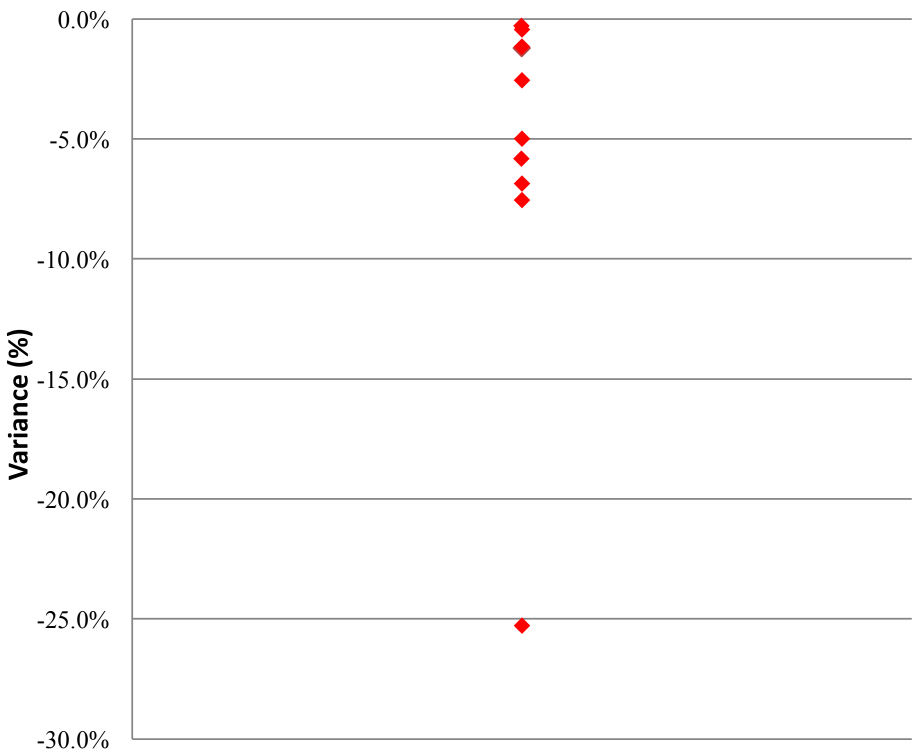
Source: Anglian Water analysis

Table 3: Detailed model results

Versions	$ST_{reat}1$	$ST_{reat}2$	$ST_{reat}3$	$ST_{reat}4$
Tds	☒+	1 +	1 +	1 +
E	5 -			
A	20+			
A^2		☒+		
S	20+			
D	20+		☒ -	
S_u	20-	5 -	20-	5 -
S_R	20+	20+	☒+	20+
S_{CD}	20-	5 -	5 -	5 -
S_{AD}	20-	10-	20-	20-
S_I	20+	5 +	20+	5 +
S_P	20+	5 +	20+	1 +
RW	20-			
TT	☒+			
C	20+	☒ -	20-	☒ -
Adj R^2	.722	.704	.710	.709
AIC	-95	-95	-96	-97
RR	.05	.92	.28	.85
BP	.65	.53	.46	.63
VIF	10^6	10	13	11

Source: Anglian Water analysis

Figure 12: Percentage variance between modelled and actual expenditure: Sludge Treatment



Source: Anglian Water analysis

10. Commentary: Sludge Treatment

Tons of dry solids was used in all models as a key cost driver and performs well.

Neither E or A performs well as a cost driver. Coefficients are not consistent in their sign and are insignificant as often as they are significant.

The proportions of sludge subject to different technologies appear to work well as cost drivers. Liming, incineration and composting show as increasing costs while AD reduces costs. Coefficients are significant.

Neither sparsity nor density performed well as cost drivers, with inconsistent signs and frequent insignificant results.

Neither RW nor TT performed well. TT was insignificant each time it was included; where RW was significant, the coefficient was negative which makes no logical sense

Sludge Disposal models

11. Variables selection: Sludge Disposal

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Volume Disposed (V_D): Tons of dry solids is the agreed metric for the quantity of sludge treated and disposed

Water Recycling Appointed Area (A): The size of the appointed area, in conjunction with density and sparsity is a determinant of the availability of suitable sites for the disposal of treated biosolids.

Sparsity (S), Density (D): Sparsity and density both affect the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance. In the case of Sludge Disposal, increased sparsity is likely to be correlated with the availability of suitable farmland.

12. The models: Sludge Disposal

Sludge Disposal is, as indicated in Figure 3 above, the second smallest of all the Water Recycling Business Units by botex. It has proved feasible to model Sludge Disposal effectively with very frugal models.

The five models which passed our acceptability criteria are set out below in Figure 13. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm *i* at time *t*. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the total Bioresources botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

SD1 –SD5 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 4. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 70% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP).

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 14 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +24% to -117%, is very wide. Excluding one outlier, the range narrows considerably to +24% to -26%. This spread is credible in the light of some companies having greater access to suitable land for disposal; that some companies are receiving revenue from biosolids sales while others do not; and given the high cost of incineration which is used by a small number of companies.

Figure 13: Sludge Disposal model forms

Model	Formula
SD1	$\ln C = \alpha + \beta_1 \ln(V_D) + \beta_2 \ln(A) + u$
SD2	$\ln C = \alpha + \beta_1 \ln(V_D) + \beta_2 \ln(A) + \beta_3 TT + u$
SD3	$\ln C = \alpha + \beta_1 \ln(V_D) + \beta_2 \ln(A) + \beta_3 \ln(D) + u$
SD4	$\ln C = \alpha + \beta_1 \ln(V_D) + \beta_2 \ln(S) + \beta_3 \ln(D) + u$
SD5	$\ln C = \alpha + \beta_1 \ln(V_D) + \beta_2 \ln(D) + u$

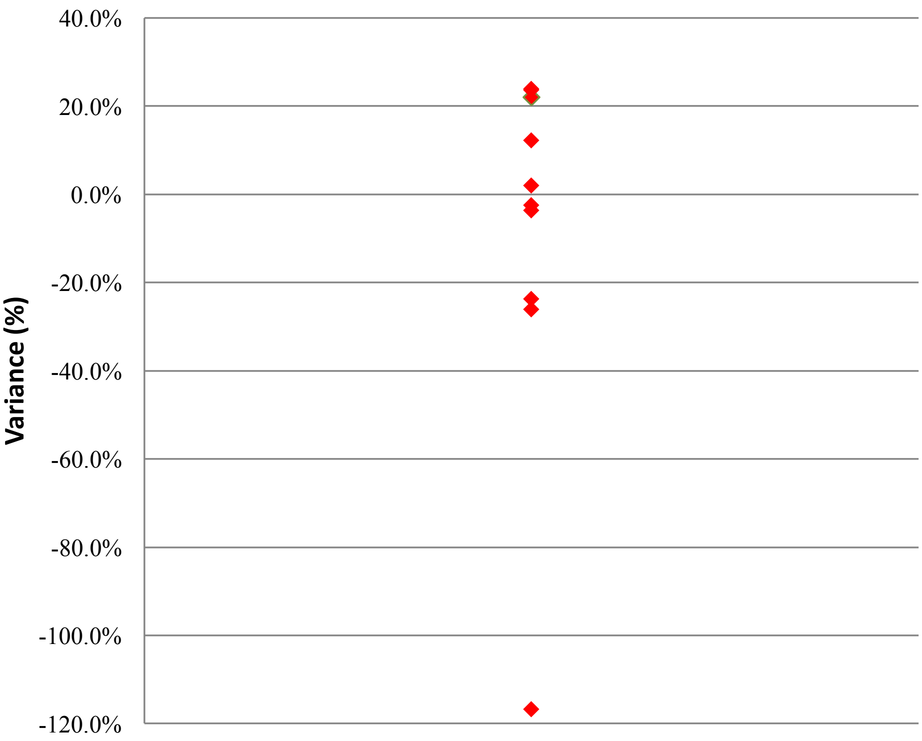
Source: Anglian Water analysis

Table 4: Detailed model results

Version	SD1	SD2	SD3	SD4	SD5
V_D	1 +	1 +	1 +	1 +	1 +
A	1 -	1 -	5 -		
D			20-	5 -	1 -
S				☒+	
S_{LR}					
S_F					
S_O					
W_D					
RW					
TT		☒ -			
C	1 +	1 +	20+	1 -	1 -
Adj R^2	.727	.728	.733	.706	.712
AIC	-93	-92	-93	-88	-90
RR	.35	.31	.04	.02	.02
BP	.44	.37	.58	.79	.83
VIF	2	1	3	2	1

Source: Anglian Water analysis

Figure 14: Percentage variance between modelled and actual expenditure: Sludge Disposal



Source: Anglian Water analysis

13. Commentary: Sludge Disposal

Unsurprisingly, the amount of sludge disposed is an effective cost driver for Sludge Disposal. The coefficients in all of the models were positive and strongly significant.

The coefficients for area were uniformly significant and negative. This can either be read as the larger the appointed area, the greater the likelihood that there will be sufficient land-bank; or that companies with a large appointed area are likely to cover large rural areas, which increases the likelihood of sufficient land-bank being available.

The proportion of sludge disposed in different manners does not perform well. In each case, the coefficient was not significant. In terms of signs on the (albeit insignificant) coefficients, these seem credible. In the case of disposal to farmland, several companies earn income from disposed Bioresources (which is recorded as negative costs). Other includes incineration which is accepted to be significantly more expensive than disposal to land.

Work done in disposal did not perform well as a cost driver. On both occasions where it was used, the coefficient was negative which cannot sensibly be explained.

Sludge Disposal as a Business Unit has very limited capital employed. This is evidenced by Figure 6 where capital maintenance can be seen to be vestigial (Only Sludge Transport has a lower proportion of botex in capital maintenance of all the Water Recycling Business Units). Consequently, the absence of any meaningful asset intensity cost driver was not felt to be a concern.

Density and sparsity do not perform well with more coefficients insignificant than significant.

Neither time trend nor regional wages behaved well as explanatory variables with consistently insignificant coefficients.

14. Next steps

Building on the work we have described here, we will update all of the Bioresources models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data
b. To test for the models' stability when a year's data are removed.
c. Further develop and refine models
d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

In line with our preferred terminology, in this report Sewage and Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

Summary

This annex sets out our cost modelling for Water Recycling Collection (Service Area S4).

The fit of the Water Recycling Collection models is almost disconcertingly good. Removing a large company from the data set resulted in limited changes to the estimated coefficients. We believe we have a good base from which to continue to develop robust models based on the 2017 data set.

1. Water Recycling Collection: business unit process identification

Water Recycling Collection is the first stage in the waste water service and consists of the transport of used water from customers' properties to Water Recycling Centres (WRCs). It therefore precedes Water Recycling Treatment and Bioresources. Used water includes foul sewage (the contents of toilets, sinks, showers, baths and washing machines) and surface water (rain water draining from roofs and hard surfaces). Foul sewage and surface water were historically transported in the same pipes (combined sewers) but in newer networks they are conveyed separately.

The key assets in Water Recycling Collection are pipes (combined sewers, foul sewers and surface water sewers), storage tanks and pumping equipment necessary to push the contents of the sewers against gravity towards the WRC. The final pumping station before the WRC (the terminal pumping station) provides the lift necessary for the used water to pass through the STW and these assets are part of sewage treatment, even though they are often not located at the WRC. Other key assets are screened overflows which act as network safety valves, allowing excess water to spill into water courses and reducing the risk of flooding.

The key activities within Water Recycling Collection are the pumping of used water and the maintenance of the distribution and pumping assets. The latter includes work to remove materials from the network which would otherwise impede flow or prevent the operation of pumps.

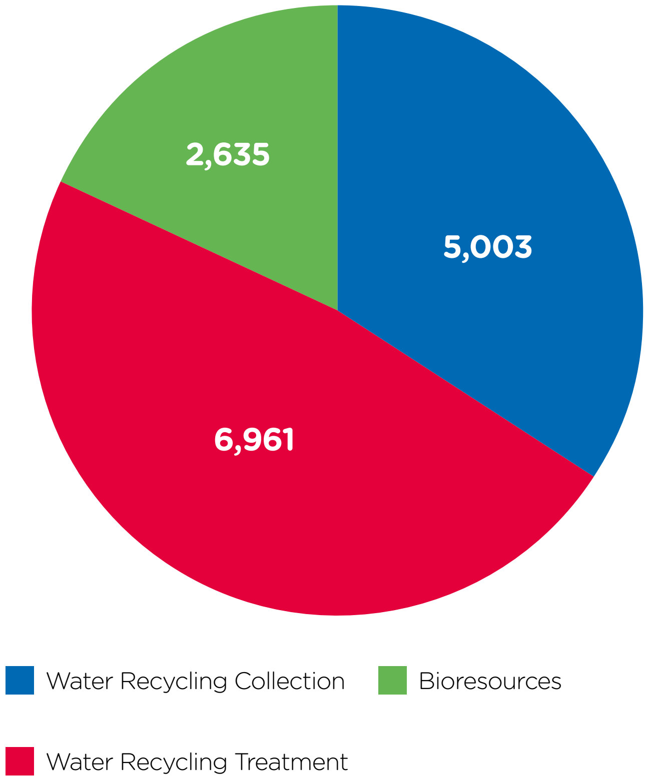
Within its Regulatory Account Guidelines (RAGs), Ofwat has defined five Water Recycling Business Units. These are Water Recycling Collection, Water Recycling Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal. The precise definitions and boundaries for the Business Units are set out in RAG 4.

Figures 1 and 2 show the aggregate botex costs incurred within Sewage Collection over the five year period to 31 March 2016. All costs shown on the two figures are in 2012-13 cost base and are shown in millions of pounds.

There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment – form Water Recycling's Network Plus cost control. The other three – Sludge Transport, Treatment and Disposal –forms the Bioresources cost control.

Looking at Figure 1, it can be seen that Water Recycling Network Plus accounts for 82% of botex for Water Recycling. Compared to Water, the sizes of Water Recycling's Network Plus Business Units are uniform: by contrast, TWD is larger than all the other Water Business Units put together.

Figure 1: Industry-wide Water Recycling Botex by Business Unit

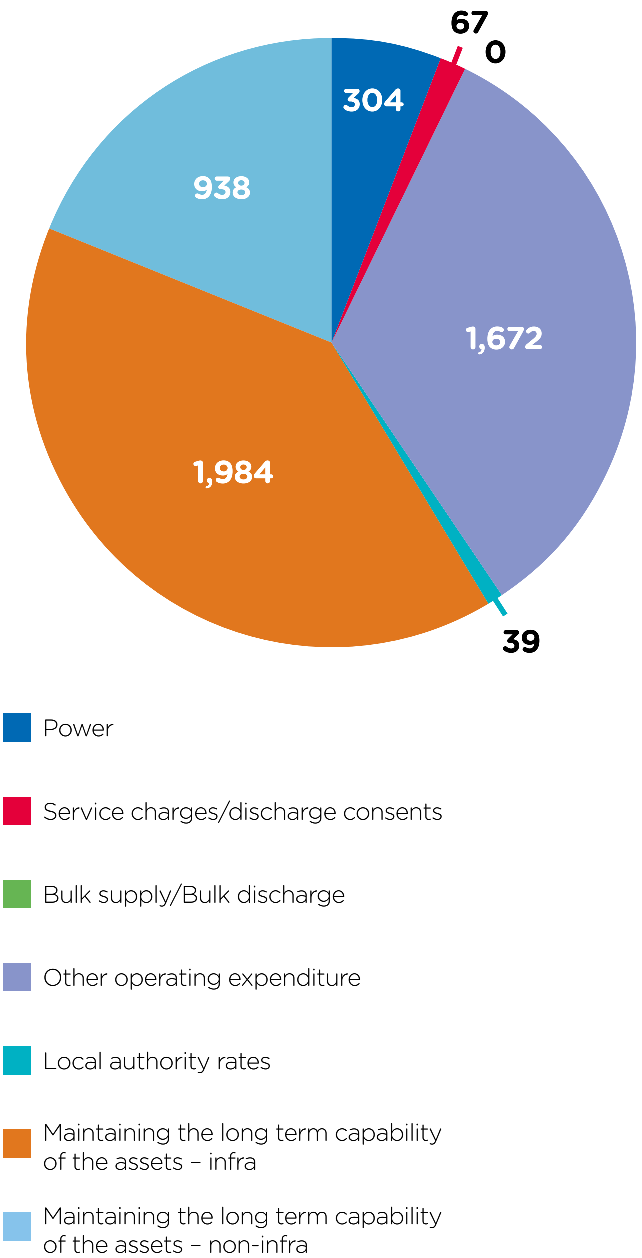


Source: 2016 October Submission, Anglian Water analysis

Figure 2 shows the split of Water Recycling Collection botex by cost categories. Key points to note are:

- Local Authority Rates account for only 1% botex.
- For Collection, Capital Maintenance accounts for 59% of botex.
- The largest single opex cost category for Collection is Other Operating Expenditure at 33% of botex.
- The only other significant cost component is power at 6% of botex, reflecting the power requirements of vacuum sewers.

Figure 2: Water Recycling Collection Industry-wide Botex by cost category



Source: 2016 October Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Band 1-3[1] treatment as % of total treatment (B_{1-3}): The volume treated at Band 1-3 works is a proxy for rurality. Our hypothesis is that rurality is a cost driver

Total length of sewers (L_T): The aggregate length of the sewer network is generally accepted to be a key driver of Water Recycling Collection costs.

Total length of sewers built before 1880 ($L_{pre1880}$):

Total length of sewers built from 1880 to 1900 ($L_{1880-1900}$):

Total length of sewers built from 1900 to 1920 ($L_{1900-20}$):

Total length of sewers built from 1920 to 1940 ($L_{1920-40}$):

Total length of sewers built from 1940 to 1960 ($L_{1940-60}$):

Total length of sewers built from 1960 to 1980 ($L_{1960-80}$):

Total length of sewers built from 1980 to 2000 ($L_{1980-2000}$):

Total length of sewers built since 2000 ($L_{post2000}$):

The age of the sewer network is generally accepted as a cost driver, though the precise mechanism is hard to set out straightforwardly. The interrelationship of age, material, level of maintenance & soil conditions is complicated and not easily susceptible to modelling.

Sparsity (S): Sparsity affects the cost of service delivery. Until recently, the extent and mechanisms have been poorly understood, although there has been widespread acceptance of their importance.

Average Passing Distance (Total sewer length / # properties) (APD): Average Passing Distance has long been used as a measure of network intensity. The recent development of measures for sparsity and density by Ofwat in conjunction with the wider industry renders APD a (relatively) blunt measure, albeit one which is still viewed as important.

Time trend (TT): If, as expected, companies improve their efficiency year on year, the Time Trend should show a small negative coefficient. In a small data sample this may be hard to discern.

Area served by company (A): The size of the appointed area is a driver of Maintenance costs.

Volume of sewage (V): Sewage volume is expected to be a driver of total collection costs.

Power consumed (P): Power used by Collection is a function of the geography of the appointed area.

[1] *WRCs serving up to 2,000 population equivalent.*

3. The models

The five models which passed our acceptability criteria are set out below in Figure 3. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm i at time t. Subscripts are omitted for notational simplicity.

In each of the models, the dependent variable lnC is the natural log of the Water Recycling Collection botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

SC1 –SC5 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity ranges from high to very high.

Figure 3: Model forms

Model	Formula
SC1	$\ln C = \alpha + \beta_1\ln(B_{1\text{-}3}) + \beta_2\ln(L_{pre1880}) + \beta_3\ln(L_{1880\text{-}1900}) + \beta_4\ln(L_{1900\text{-}20}) + \beta_5\ln(L_{1920\text{-}40}) + \beta_6\ln(L_{1940\text{-}60}) + \beta_7\ln(L_{1960\text{-}80}) + \beta_8\ln(L_{1980\text{-}2000}) + \beta_9\ln(L_{post2000}) + \beta_{10}\ln(S) + \beta_{11}TT + u$
SC2	$\ln C = \alpha + \beta_1\ln(B_{1\text{-}3}) + \beta_2\ln(L_{pre1880}) + \beta_3\ln(L_{1880\text{-}1900}) + \beta_4\ln(L_{1900\text{-}20}) + \beta_5\ln(L_{1920\text{-}40}) + \beta_6\ln(L_{1940\text{-}60}) + \beta_7\ln(L_{1960\text{-}80}) + \beta_8\ln(L_{1980\text{-}2000}) + \beta_9\ln(L_{post2000}) + \beta_{10}\ln(S) + \beta_{11}TT + \beta_{12}\ln(A) + u$
SC3	$\ln C = \alpha + \beta_1\ln(B_{1\text{-}3}) + \beta_2\ln(L_{pre1880}) + \beta_3\ln(L_{1880\text{-}1900}) + \beta_4\ln(L_{1900\text{-}20}) + \beta_5\ln(L_{1920\text{-}40}) + \beta_6\ln(L_{1940\text{-}60}) + \beta_7\ln(L_{1960\text{-}80}) + \beta_8\ln(L_{1980\text{-}2000}) + \beta_9\ln(L_{post2000}) + \beta_{10}\ln(S) + \beta_{11}TT + \beta_{12}\ln(V) + u$
SC4	$\ln C = \alpha + \beta_1\ln(B_{1\text{-}3}) + \beta_2\ln(L_T) + \beta_3\ln(P) + \beta_4\ln(APD) + \beta_5\ln(S) + \beta_6\ln(L_{pre1880}) + \beta_7\ln(L_{1880\text{-}1900}) + \beta_8\ln(L_{1900\text{-}20}) + u$
SC5	$\ln C = \alpha + \beta_1\ln(B_{1\text{-}3}) + \beta_2\ln(L_T) + \beta_3\ln(P) + \beta_4\ln(S) + \beta_5\ln(L_{pre1880}) + \beta_6\ln(L_{1880\text{-}1900}) + \beta_7\ln(L_{1900\text{-}20}) + \beta_8\ln(L_{1980\text{-}2000}) + \beta_9\ln(L_{post2000}) + \beta_{10}TT + u$

Source: Anglian Water analysis

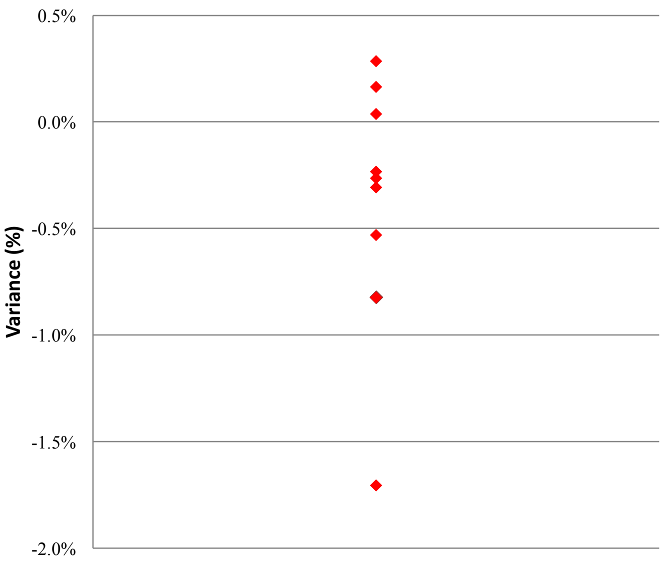
Table 1: Detailed model results

Version	SC1	SC2	SC3	SC4	SC5
$L_{pre\ 1880}$	1 -	1 -	1 -		
$L_{1881\text{-}1900}$	5 -	⊠+	5 -		
$L_{1901\text{-}20}$	1 +	1 +	1 +		
$L_{1921\text{-}40}$	1 +	1 +	1 +		
$L_{1941\text{-}60}$	1 -	1 -	1 -		
$L_{1961\text{-}80}$	1 +	1 +	1 +		
$L_{1981\text{-}2000}$	1 -	5 -	1 -		
$L_{post\ 2000}$	⊠+	10-	⊠+		
L_T				1 +	5 +
A		10+			
V			10+		
S	1 -	1 -	1 -	1 -	5 -
APD				20-	
$B_{1\text{-}3}$	1 +	5 +	1 +	1 +	5 +
P				10+	5 +
$L_{\%\ pre\ 1880}$				5 -	5 -
$L_{\%1881\text{-}1900}$				1 +	10-
$L_{\%1901\text{-}20}$				1 +	1 +
$L_{\%1981\text{-}2000}$					10+
$L_{\%\ post\ 2000}$					10+
TT	1 -	5 -	1 -		20-
C	1 +	1 +	1 +	5 +	10-
Adj R^2	.96	.96	.96	.95	.95
AIC	-220	-222	-223	-212	-214
RR	.76	.96	.67	.06	.88
BP	.84	.75	.73	.81	.66
VIF	37620	100766	34497	59	3810

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +0.3% to –1.7%, is very narrow. Excluding one outlier, the range of variances shrinks even further to a range of +0.3% to -0.8%. We consider that they are credible and support our view that our preferred models could be used.

Figure 4: Percentage variance between modelled and actual expenditure: Water Recycling Collection



Source: Anglian Water analysis

4. Commentary

Amongst water engineers, there is a poorly understood relationship between the maintenance cost of a pipe network and its age; its composition (in terms of pipe materials); the level of density or sparsity of the urban environment; and the geology of the land in which the pipes are buried. Some maintain that pipe materials (cast iron, concrete etc.) are the biggest driver of network failure; others contend that there is a non-linear relationship between network age and network failure; Ofwat has posited that there may be a U shaped curve between density, sparsity and cost, with a "sweet spot" in a suburban environment. Given this level of uncertainty over cost relationships, it is more difficult than usual to be confident *a priori* of the sign and magnitude of coefficients. It is also surprising (and a little unnerving) how good the fit is between actual costs and hindcasts.

The nature of the Water Recycling Collections Business Unit is such that the length of the sewers is a key driver of costs. It is also a measure of asset intensity. In this report, we have listed the total length of the sewer as a scale factor and the disaggregated length by age cohort as a measure of asset intensity, but in truth, both the aggregated and disaggregated numbers act as cost drivers as both a scale factor and a measure of asset intensity.

The proportion of sewage treated at Band 1-3 works is used as a proxy for rurality and hence for smaller gauge, relatively inaccessible sewers. This cost driver behaves well with significant positive coefficients throughout all of the models.

Power consumed, which acts as a proxy for the terrain of the area, also performed well in the two models in which it was included.

The Ofwat defined Sparsity index performed well in the models. When tried, the Density index (which in theory ought to perform similarly) performed poorly. It may be due to the greater range and lack of zero values of the Sparsity index.

Time Trend performed well. All attempts to incorporate Regional Wages failed: Where the coefficient was significant, it was in excess of unity, which makes no economic sense.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data
b. To test for the models' stability when a year's data are removed.
c. Further develop and refine models
d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

In line with our preferred terminology, in this report Sewage and Wastewater is referred to as Water Recycling. Bioresources are referred to as Sludge in terms of the treated material and the three Business Units. The overall price control, and the integrated model of all three services, is referred to as Bioresources.

Summary

This annex sets out our cost modelling for Water Recycling Treatment (Service Area S5).

The models developed for Water Recycling Treatment display a low level of variability between predicted and actual costs. The models will be tested using the 2017 data submission, but at this stage they appear to provide a solid basis for future model development.

1. Water Recycling Treatment: business unit process identification

Water Recycling Treatment is the second stage in the Water Recycling service and it consists of the physical and biological treatment of used water to enable it to be returned to environmental waters with acceptable impact. It follows logically from Water Recycling Collection and precedes Bioresources. RAG 4.07 defines the input to the process to be untreated sewage from the Water Recycling Collection network and the outputs to be treated waste water into receiving watercourses and sewage sludge for transporting to sludge treatment activities. The quality of the input may vary between WRC catchments because of differences in the quality of commercial and industrial waste waters (trade effluent) but is assumed to be uniform. The required quality of the treated waste water output is defined for each Water Recycling Centre (WRC, aka STW or WWTW) by the Environment Agency (in an environmental permit) according to the environmental needs of the receiving water bodies and can be very variable. Accordingly the nature of the treatment processes provided at sewage treatment works is also very variable, with consequences for their energy, labour and power requirements. The size of treatment works (measured by population equivalent served) is also very variable, ranging from under a hundred to over four million. Unlike raw and treated water, which may be transported long distances, waste water is typically treated within a few kilometres of its point of production, which has a strong bearing on the location of WRCs.

The key variables of this stage are the volume of waste water treated, the number and type of treatment units (and the labour employed in them) and the size of treatment works. These vary across companies (and over time) depending on the size of the population (which affects treated volumes), the nature of receiving water bodies (that will determine the terms of environmental permits and hence the required treatment complexity) and the demography of the area served (that affects the number and capacity of the treatment works).

The process of sludge production entails a gradual concentration of the solid residues of Water Recycling Treatment. The lack of clarity between partially treated waste water and sludge increases the potential for inconsistent identification of the boundary between Water Recycling Treatment and Bioresources between companies and therefore their treatment of assets and costs. This is amplified by the fact that sewage and sludge treatment frequently take place on the same sites, using shared resources.

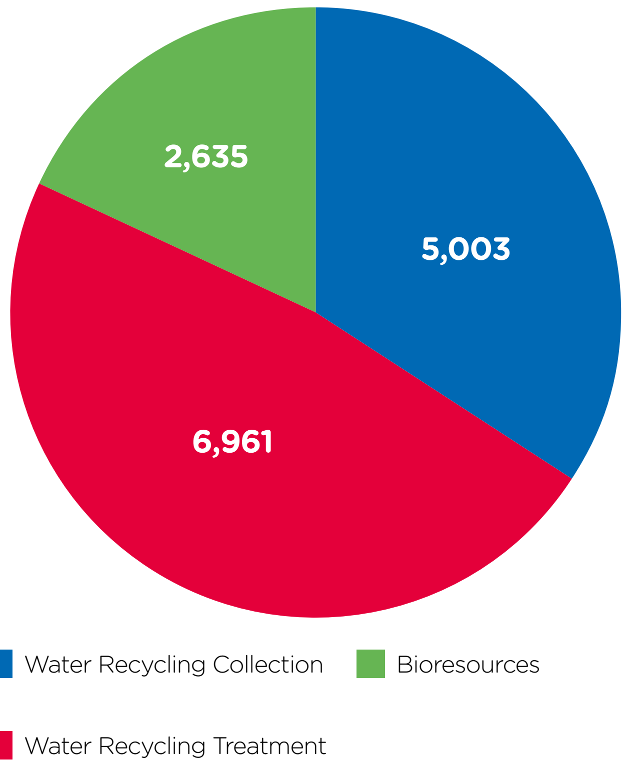
Figures 1 and 2 show the aggregate botex costs incurred within Water Recycling over the five year period to 31 March 2016. All costs shown on both the Figures are in 2012-13 cost base and are shown in millions of pounds.

Within its Regulatory Account Guidelines (RAGs), Ofwat has defined five Wastewater Business Units. These are Water Recycling Collection, Sewage Treatment, Sludge Transport, Sludge Treatment and Sludge Disposal Water Recycling The precise definitions and boundaries for the Business Units are set out in RAG 4.

There are, as already noted, five Water Recycling Business Units. Two of these – Water Recycling Collection and Water Recycling Treatment – form Water Recycling's Network Plus cost control. The other three – Sludge Transport, Treatment and Disposal –forms Sludge's cost control.

Looking at Figure 1, it can be seen that Water Recycling Network Plus accounts for 82% of botex for Water Recycling. Compared to Water, the sizes of Water Recycling's Network Plus Business Units are uniform: by contrast, TWD is larger than all the other Water Business Units put together.

Figure 1: Industry-wide Water Recycling Botex by Business Unit

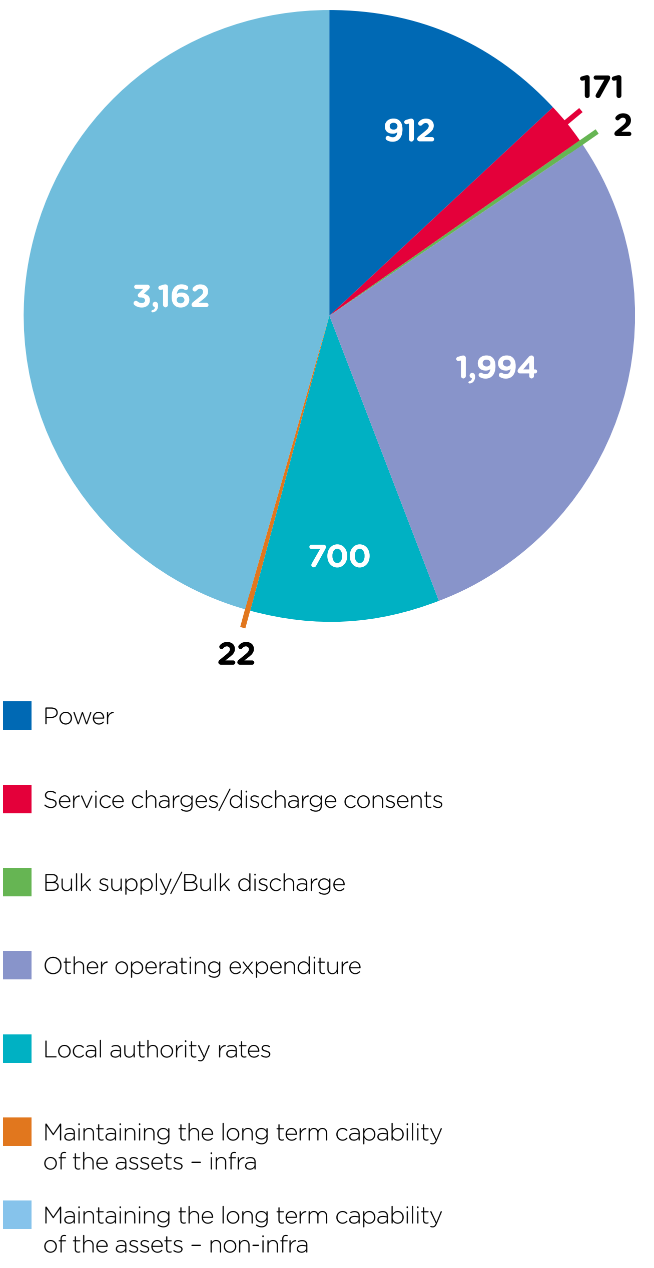


Source: 2016 October Submission, Anglian Water analysis

Figure 2 shows the split of Water Recycling Treatment botex by cost categories. Key points to note are:

- Local Authority Rates account for 10% of botex for Water Recycling Treatment.
- Capital Maintenance represents 45% of botex for Water Recycling Treatment.
- Again, the largest opex cost category is Other Operating Cost at 29% of botex for Water Recycling Treatment.
- Power is a significant element for Water Recycling Treatment costs at 13% of botex. These figures are attenuated by power which WaSCs are generating within Bioresources.

Figure 2: Water Recycling Treatment Industry-wide Botex by cost category



Source: 2016 October Submission, Anglian Water analysis

2. Variables selection

Given the discussion above, and following a series of statistical tests as discussed in Section 3 of the main report, we tested the following variables for the modelling of this service:

Population equivalent (p.e.): As the p.e. provides a measure of the foul water received by Water Recycling Centres (WRC), it is hard to avoid the conclusion that it should be a significant cost driver.

Average load treated per Water Recycling Centre ($WRC_{avg\ load}$): The average load at a WRC is measure of scale economy. Hence it is to be expected that as $WRC_{avg\ load}$ increases, overall costs decrease.

Tight P consent = load subject to sub 1mg/l P consent as % of total load (C_P): Tight consents are all understood to incur additional costs in order to meet those consents. Hence, the higher the proportion of tight consents, the higher overall costs are expected to be.

Tight BOD consent = load subject to sub 10mg/l BOD consent as % of total load (C_{BOD}): Tight consents are all understood to incur additional costs in order to meet those consents. Hence, the higher the proportion of tight consents, the higher overall costs are expected to be.

Tight ammonia consent = load subject to sub 3mg/l ammonia consent as % of total load ($C_{Ammonia}$): Tight consents are all understood to incur additional costs in order to meet those consents. Hence, the higher the proportion of tight consents, the higher overall costs are expected to be.

Sparsity (S), Density (D): Sparsity and density are both included to capture elements of scale economies. Being highly granular (based on LSOA data), these measures are believed to perform better than cruder scale measures such as average passing distance or average load per WRC.

Area served by company (A): Area covered is expected to impact treatment cost as maintenance costs in a large area incur increased transport time and costs.

Proportion of total volume treated with primary, secondary and tertiary treatment (T): Ceteris paribus, WRCs with tertiary treatment incur additional costs compared to works with only primary or primary and secondary treatment.

Proportion of total volume treated at Band 6 works (B_6): The proportion of total load treated at Band 6 works (that is serving a catchment with a p.e.>25,000) is identifying the largest works which enjoy economies of scale. Hence it is to be expected that as B6 increases, overall costs decrease.

3. The models

The four models which passed our acceptability criteria are set out below in Figure 3. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies. All variables are measured for firm i at time t. Subscripts are omitted for notational simplicity.

Figure 3: Model forms

Model	Formula
ST1	$\ln C = \alpha + \beta_1 \ln(pe) + \beta_2 \ln(pe^2) + \beta_3 \ln(WRC_{avg\ load}) + \beta_4 \ln(C_P) + \beta_5 \ln(C_{BOD}) + \beta_6 \ln(C_{ammonia}) + \beta_7 \ln(S) + u$
ST2	$\ln C = \alpha + \beta_1 \ln(pe) + \beta_2 \ln(pe^2) + \beta_3 \ln(C_P) + \beta_4 \ln(C_{BOD}) + \beta_5 \ln(C_{ammonia}) + \beta_6 \ln(S) + \beta_7 \ln(D) + \beta_8 \ln(A) + u$
ST3	$\ln C = \alpha + \beta_1 \ln(pe) + \beta_2 \ln(pe^2) + \beta_3 \ln(B_6) + \beta_4 \ln(S) + \beta_5 \ln(D) + \beta_6 \ln(A) + u$
ST4	$\ln C = \alpha + \beta_1 \ln(pe) + \beta_2 \ln(pe^2) + \beta_3 \ln(B_6) + \beta_4 \ln(S) + \beta_5 \ln(D) + \beta_6 \ln(A) + \beta_7 \ln(T) + u$

Source: Anglian Water analysis

In each of the models, the dependent variable lnC is the natural log of the Water Recycling Treatment botex. In all of the cost modelling we are reporting, we have followed the approach taken by Ofwat at PR14 and excluded Local Authority Rates from botex, on the grounds that these costs are not under the control of companies.

ST1 –ST4 were all estimated using OLS. All estimations were run on STATA v14.

The key results from the estimation of all the models are reported in Table 1. This shows that all variables generally perform well in terms of significance levels and have the theoretically expected signs. The R^2 values are all above 90% and all the models pass the Ramsey Reset test of model specification (RR) and the Breusch-Pagan test for heteroskedasticity (BP). The average VIF value measuring potential multicollinearity ranges from high to very high.

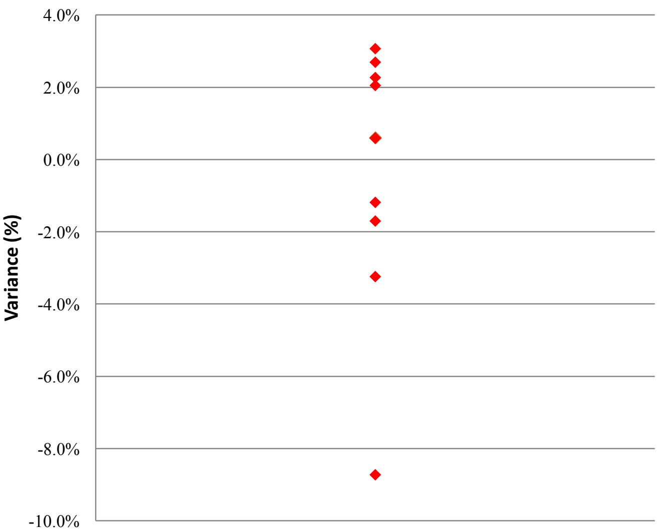
We have calculated the expected value produced by each model for the ten companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 4 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +3% to –9%, is narrow. Excluding one outlier, the range of variances shrinks even further to a range of +3% to -3%. We consider that they are credible and support our view that our preferred models could be used.

Table 1: Detailed model results

Version	ST1	ST2	ST3	ST4
p.e.	5 +	10+	1 +	1 +
$(p.e.)^2$	20-	5 -	1 -	1 -
$WRC_{avg\ load}$	5 -			
Tight P	1 +	1 +		
Tight BoD	1 +	1 +		
Tight NH_3	1 -	1 +		
S	1 -	1 -	1 -	1 -
D		1 +	1 +	1 +
A			1 +	1 +
Tertiary				10+
B6			1 -	1 -
C	☒ -	5 -	1 -	1 -
Adj R^2	.94	.95	.96	.96
AIC	-197	-208	-221	-224
RR			.09	.52
BP			.55	.49
VIF			813	735

Source: Anglian Water analysis

Figure 4: Percentage variance between modelled and actual expenditure: Water Recycling Treatment

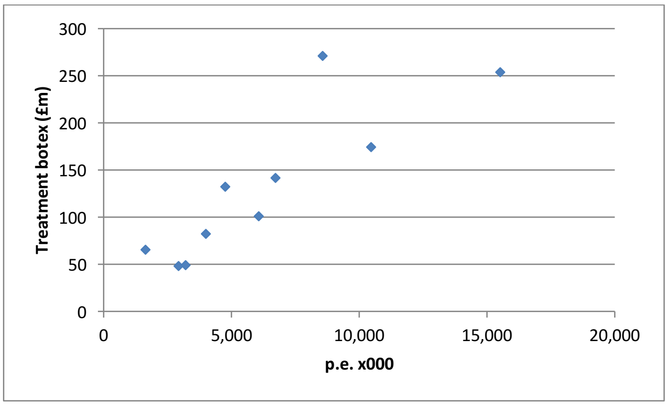


Source: Anglian Water analysis

4. Commentary

As expected, p.e performed well as a scale variable. There does, however, appear to be an issue with one company's data, as can be seen in Figure 5 below.

Figure 5: p.e vs Water Recycling botex 2015-16



Source: 2016 October Submission, Anglian Water analysis

As expected, the coefficients for tight P and BoD consents are strongly significant and positive. Those for ammonia were also strongly significant in all models, but in some models had a negative coefficient which failed to match an engineering explanation. Area as an environmental factor performed well with a strongly significant and positive coefficient.

The asset intensity variables (e.g. proportion of load treated to tertiary level) performed acceptably

The Ofwat defined Sparsity index performed well in the models. When tried, the Density index (which in theory ought to perform similarly) performed poorly. It may be due to the greater range and lack of zero values of the Sparsity index.

All attempts to include a Time Trend and/or a Regional Wages variable which had both significant and sensible coefficients failed. As the coefficients were never significant, the models which included these variables were not reported.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data
b. To test for the models' stability when a year's data are removed.
c. Further develop and refine models
d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.

Summary

This annex sets out our cost modelling for Household Retail in the following way:

i. Integrated Retail (Service Area R1);
ii. Doubtful debt and debt management (Service Area R2);
iii. Meter Reading (Service Area R3);
iv. Customer Service (Service Area R4); and
v. Other retail costs (Service Area R5).

It appears feasible to develop robust cost models for Household Retail with a very limited number of cost drivers. When the Integrated and the Disaggregated models are compared, it appears that the models developed are telling a coherent story. More work needs to be done on Household Retail cost modelling, but this appears to be a promising start.

1. Background

Our household retail cost modelling differs from nearly all of the wholesale cost modelling in that it is based upon work started by Ofwat and reported in a presentation on 9 March 2017. Within wholesale cost modelling, the cost models were, with one exception, all developed by us. The exception is the suite of Integrated Water cost models, which were replications of the CMA cost models developed for the Bristol appeal in 2015.

Figure 1 is Ofwat's slide from March 2017 setting out the key areas of cost within Household Retail, along with suggested cost drivers for each area.

Ofwat went on to develop initial models for Integrated Retail, as well as for Doubtful Debt / Debt Management and for Meter Reading. It published its initial findings in its 9 March 2017 presentation and made available its database upon which its analysis was based. These findings are set out in Figures 3, 8 and 12 in the following three sections.

Using the Ofwat database, we have recreated the Ofwat models and have gone on to develop models in a similar manner for Customer Service and for Other Retail costs. These models and their results are all reported in subsequent sections of this report.

The costs and cost drivers in Ofwat's data base were collected from a variety of sources including PR14 Business Plans and subsequent Regulatory Accounts. Data were collated from 2010-11 onwards, although there were a number of gaps, most notably of Customer Service data for 2010-11 and 2011-12. It is for this reason that our analysis of household retail uses only data for the four years from 2012-13 to 2015-16 so that it can be aggregated consistently.

The costs in the Ofwat data base are all shown in the pounds of the day and not in the cost base of a particular year. This differs from all of the work done on wholesale cost modelling at PR14 and in all of the wholesale cost modelling undertaken by us, where all costs are in 2012-13 cost base. The other difference to the wholesale cost modelling is that local authority rates are included in the Retail cost base, whereas they were excluded at PR14 and in our wholesale modelling.

Figure 1: Ofwat disaggregation of Retail costs

Drivers of household retail costs

Cost activity	Materiality	Suggested cost driver/s	Discussion
Doubtful debt / debt management	39%	- Wholesale bill size - Level of deprivation (e.g. Index of Multiple Deprivation (IMD), unemployment rate, proportion of benefits claimants) - Population transience	- IMD: Extrapolation for missing years, difference in methodology between Wales and England - Population transience potential influences costs across 2 cost categories (CS and bad debt)
Customer services	27%	- Proportion and/or number of dual-service customers - SIM score - Business rates and rental costs - Population transience	- Economies of scope - Is it feasible to include outcome measure in our model? Potential data quality issues. - Population transience data my not be publically available; use of 3rd Party data will reduce the transparency of our modelling approach owing to data sharing issues.
Other (provision of offices, insurance premiums, local authority rates)	21%	- Drivers for LA rates cover office building rates, Ofwat and other fees?	- Include in retail model but model using the key retail drivers above?
Capital maintenance (depreciation, amortisation and recharges from/to other business units)	8%	- Drivers for depreciation of IT / telephony equipment?	- Short asset lives
Metering	5%	- Proportion and/or number of metered customers - Population density and/or scarcity - Regional wage	- Low materiality relative to other areas of cost

Suitability of historical retail cost data?
- At PR14 the ACTS was based on 2013/14 data. Is it feasible to include data prior to 2013/14 in our retail models?

Source: Ofwat

2. Context

Within its Regulatory Account Guidelines (RAGs), Ofwat has defined four cost categories for Retail. Retail is further subdivided between Household and Non Household retail. The precise definitions for these different categories are set out in RAG4.05 and are reproduced below in Table 1.

Since April 2017, the Non Household market has been open to competition. For this reason, Non Household retail has been excluded from the price control regime at PR19. Consequently, all of the analysis, and all of our Retail cost modelling, focuses purely upon Household Retail costs.

For the sake of simplicity, at PR14 Ofwat made the assumption that Retail (at that time, both household and non household) had no significant capital expenditure and thus required no allocation of RCV. It was recognized that there was existing capital and thus there would be depreciation. This depreciation is shown as part of Other costs. This simplifying assumption has been extended to PR19. Consequently, while one can talk about Retail botex, there is no totex as there is no enhancement capex associated with Retail.

Table 2 sets out the various elements of cost included in the four Retail cost categories. The figures represent four years' costs; from 2012-13 to 2015-16. The data are limited to just four years as it was in the 2012-13 regulatory accounts that the current level of cost disaggregation was first introduced. Unlike the data for wholesale, all Retail cost data are in costs of the day and have not been restated into a single cost base. This is in line with Ofwat's contention that there are no inflationary pressures impinging on Retail costs.

Since Ofwat collected these data and began its programme of analysis of household retail, the 2016-17 regulatory account data have been published. Further work on Retail will incorporate the 2016-17 data, giving a five year data base.

Table 1: Costs included in Ofwat disaggregated areas of Retail

Doubtful Debt & Debt Mgt.	Meter Reading	Customer Service	Other
Cost of customer visits	Ad hoc read requests	Billing	Office rental
Monitoring outstanding debt	Cyclical reading	Payment handling	Local authority rates
Managing & monitoring external debt collection	Scheduling	Vulnerable customer schemes	Net retail costs of demand side water efficiency initiatives
Charge for bad & doubtful debts	Transport	Non network customer enquiries	Net retail costs of customer side leaks
	Physical reading	Network customer enquiries	General & support costs
	Reading queries	Investigatory visits (non-network issues)	Other business activities
	Read processing costs		Insurance
	Managing meter data		Other direct costs
	Supervision & mgt. of meter readers		Depreciation on assets used wholly or principally in HH retail

Source: Ofwat

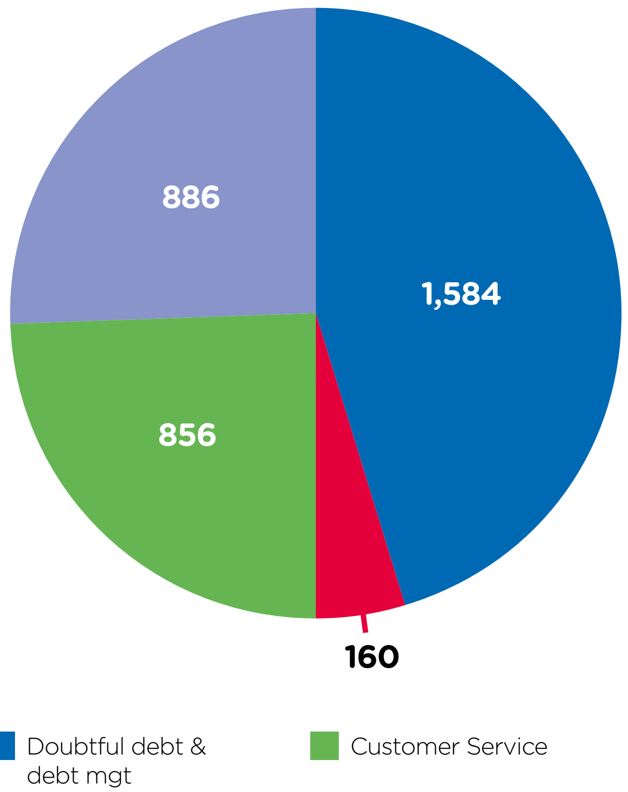
Table 2: ***Aggregate botex per cost area: 4 years to 2015-16***

£m	Doubtful Debt & Debt Mgt.	Meter Reading	Customer Service	Other Costs	Total botex
Total	1,583.7	160.0	856.2	885.9	3,485.9

Source: 2016 Information Request, Anglian Water analysis

Figure 2 sets out Table 2 in graphical form. Nearly half of botex is made up of doubtful debt and debt management. Customer Service and other costs both account for a quarter of botex each. Meter Reading is by far the smallest category of cost.

Figure 2: Household Retail botex by cost categories



Source: 2016 Information Request, Anglian Water analysis

3. Cost models

3.1. Integrated models

Ofwat developed three model forms (summarised in a slide in March 2017, replicated as Figure 3 below). All had the same two cost drivers, average bill per household and number of households. While the proposition that retail costs are driven by the number of households using the retail services is uncontentious, the use of average bill size is potentially problematic: the rationale is that average bill size is a driver of bad debt, but the average bill contains an element of retail cost as well.

The first model form (version 1 in the following three tables) uses a linear relationship. From a theoretical point of view, a linear cost function is unsatisfactory in that it does not display decreasing marginal returns as would generally be expected. From a more basic position of viewing the scatter diagrams, it can be seen that a log form gives a much better fit. This can be seen in Figures 4 – 7 below.

The second and third models (versions 2 and 3 respectively in the following tables) are both logarithmic cost functions, one using Ordinary Least Squares (OLS) and the other Generalised Least Squares with Random Effects (GLS RE). We do not intend to enter into a debate over the relative merits of OLS and GLS; the results shown here within our analysis has very similar results form both approaches.

Figure 3:

Ofwat Integrated Retail model results

Y= (Opex + depreciation costs) [£m]

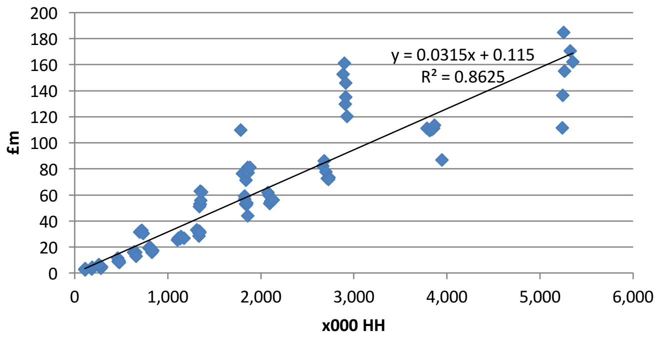
Model[1]	1	2	3
Estimation method	OLS	OLS	GLS RE
Dependent variable	y	In(y)	In(y)
Independent variables:			
Average bill per HH [£]	0.72***		
Number of HH [m]	29.24***		
In (Average bill per HH) [£]		0.58***	0.32***
In (Number of HH) [m]		0.98***	1.04***
Constant	-15.16***	0.14	1.56**
Adjust R^2	88.53%	97.54%	97.10%
Size of sample (n)	108	108	108

Level of significance (P> |t|): 10% = *; 5% = **; 1% =***

[1] In Ofwat's presentation, these models were referred to as A, B and C

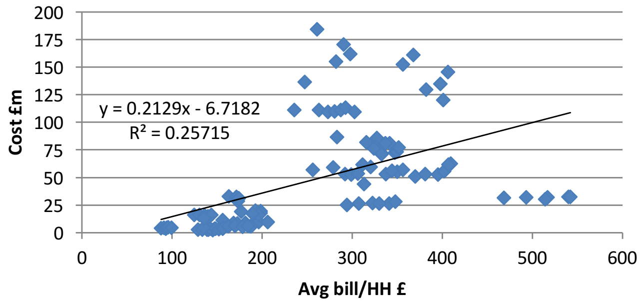
Source: Ofwat

Figure 4: Household numbers vs botex: linear form



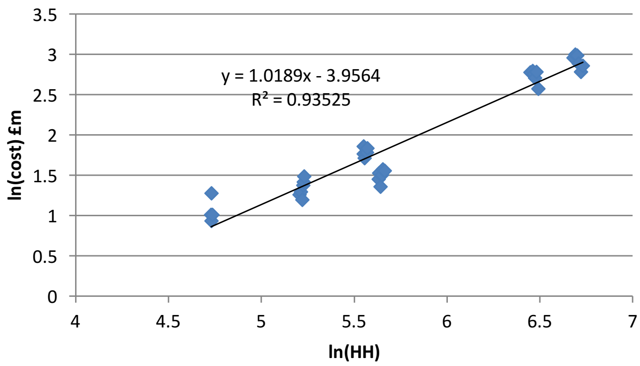
Source: 2016 Information Request, Anglian Water analysis

Figure 6: Average bill/ Household: linear form



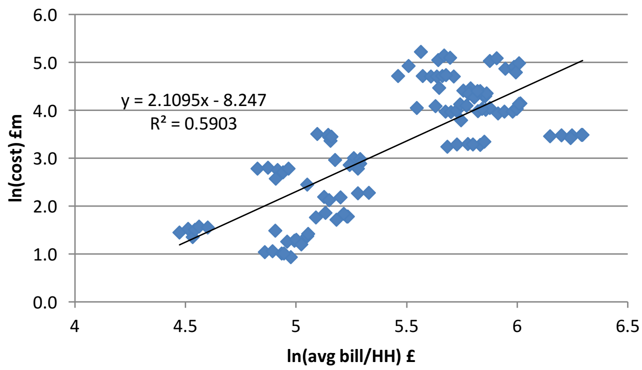
Source: 2016 Information Request, Anglian Water analysis

Figure 5: Household numbers vs botex: log form



Source: 2016 Information Request, Anglian Water analysis

Figure 7: Average bill/ Household: log form



Source: 2016 Information Request, Anglian Water analysis

Table 3 sets out the results of the three models in the same format as that used in all of the wholesale models. Table 3 matches the results reported by Ofwat in Figure 3.

Table 3: Detailed results of Retail Integrated models

Version	1 Linear OLS	2 Log OLS	3 Log GLS (RE)
HH	1 +	1 +	1 +
Avg bill/HH	1 +	1 +	1 +
C	1 -	1 -	1 -
Adj R^2	.885	.975	.971
AIC	+597	-352	
RR	.01	.08	
BP	.00	.07	
VIF	1	2	

Source: Anglian Water analysis

We have used the same criteria matrix for retail as was used for all wholesale models. This is shown for the integrated models in Table 4. This leads to the linear model being dropped for the purpose of model evaluation.

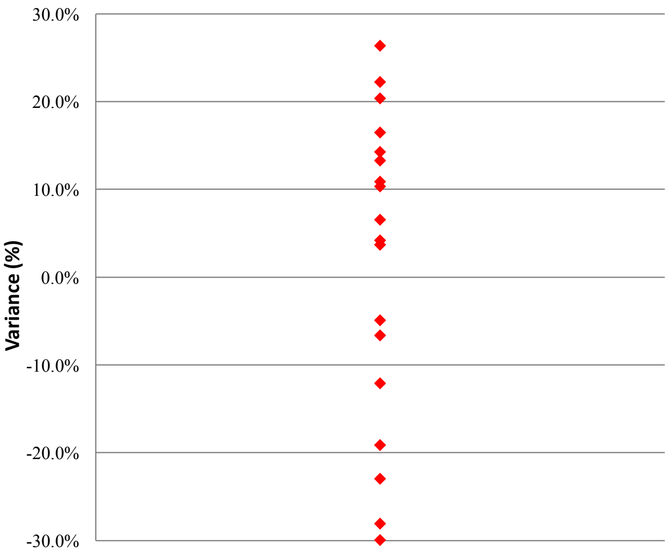
Table 4: Criteria matrix for Retail Integrated models

Version	AIC	R^2	P>80%	AIC rank	R^2 rank	>67% P>80%	Top 75% AIC	R^2 > .7	Meets *a priori*	Choose
1	596.56	0.8853	100%	3	3	☑		☑	☑	
2	-351.98	0.9754	100%	1	1	☑	☑	☑	☑	☑
3	-351.98	0.9770	100%	1	2	☑	☑	☑	☑	☑

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 8 below shows the range of variances between actual and modelled costs for the ten companies across the modelled period. The range, from +26% to –30%, is credible and supports our view that our preferred models could be used.

Figure 8: Percentage variance between modelled and actual expenditure: Integrated Retail



Source: Anglian Water analysis

3.2. Doubtful Debt & Debt Management

Ofwat developed three forms of the Doubtful Debt and Debt Management Retail cost models (summarised in a slide of March 2017, replicated as Figure 9 below). These are all logarithmic cost functions, using OLS.

The first (version 4 in the following three tables) takes the total revenue as the cost driver for doubtful debt & debt management. Figure 9 shows graphically that there is clearly a strong relationship between total revenue and debt costs. The second model adds in unemployment as an explanatory variable. It would appear that regional unemployment rates add little to the explanatory power of the model. Figure 11 indicates why the fit of this second model (version 5 below) is only very marginally better than version 4. The third model (version 6 below) adds the ONS' Indicator of Multiple Deprivation (IMD) to total Revenue. Comparing Figures 11 and 12 helps explain why the third model shows a bigger improvement in predictive power than the second compared to the first.

In Figure 9, version 6 was developed using only one year's data – that is 18 data points. This is because IMD is only calculated by the ONS on a four yearly basis. Ofwat used that one year, 2014-15, alone. We have looked back at the IMD data for 2010-11 and has interpolated figures for the intervening years. Consequently, version 6 is based on the same period as for all other models.

Members of the Cost Assessment Working Group have been working on developing a more precisely tailored and granular cost driver for Doubtful Debt and Debt Management. Although this work has now been completed, it was published too late for inclusion in this report. We intend to make use of the newly developed cost driver in the next phase of work, later in 2017.

Table 5 sets out the results of the three models in the same format as that used in all of the wholesale models.

Figure 9:

Ofwat reported Doubtful Debt & Debt Management cost models

Y= (Doubtful debt + debt management) [£m]

Model[1]	4	5	6
Estimation method	OLS	OLS	OLS
Dependent variable	ln(y)	ln(y)	ln(y)
Independent variables:			
ln (Total revenue [£m])	1.089***	1.07***	0.94***
Unemployment rate [%]		3.37	
IMD score			0.05**
Constant	(3.73)***	(3.89)***	(3.89)***
Adjust R^2	96.17%	96.19%	95.36%
Size of sample (n)	108	108	18

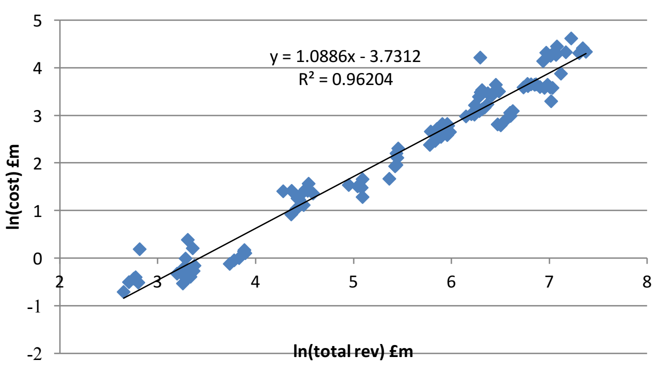
IMD only available for one year.

Level of significance (P> |t|):
10% = *; 5% = **; 1% =***

[1] In Ofwat's presentation, these models were referred to as A, B and C

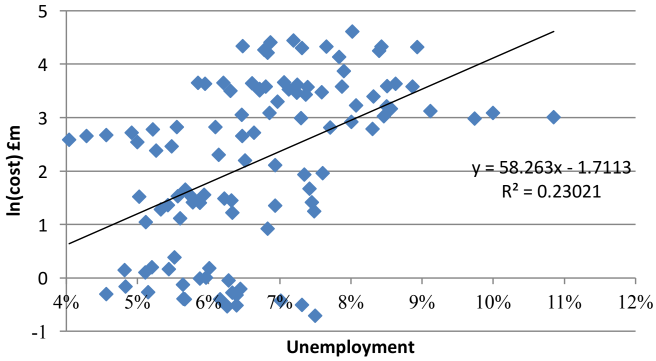
Source: Ofwat

Figure 10: Doubtful Debt & Debt Management cost vs ln total revenue



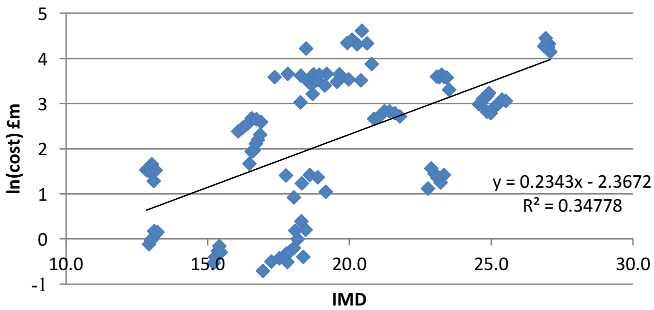
Source: 2016 Information Request, Anglian Water analysis

Figure 11: Doubtful Debt & Debt Management cost vs unemployment



Source: 2016 Information Request, Anglian Water analysis

Figure 12: Doubtful debt & Debt Management vs IMD



Source: 2016 Information Request, Anglian Water analysis

The Ramsey Reset test (RR in Table 5, below) indicates that there may be missing higher order cost drivers in all three versions. In other words, the test suggests that translog forms of the models may better describe the cost data. We have not tried translog variants on these models yet, essentially because we took the view that we should keep to the forms published by Ofwat at this stage. In the subsequent work we intend to undertake in the next six months, we intend to develop translog forms as well.

Table 5: Detailed results of Doubtful Debt and Debt Management cost models

Version	4 Log OLS	5 Log OLS	6 Log OLS
Total Revenues	1 +	1 +	1 +
Unemployment		20+	
IMD			1 +
C	1 -	1 -	1 -
Adj R^2	.962	.962	.964
AIC	-256	-256	-263
RR	.03	.04	.03
BP	.90	.89	.13
VIF	1	1	1

Source: Anglian Water analysis

Table 5 matches the results reported by Ofwat in Figure 9.

We have used the same criteria matrix for Doubtful Debt and Debt Management as was used for all wholesale models. This is shown for these three models in Table 6. This leads to the model using unemployment as a cost driver being dropped for the purpose of model evaluation.

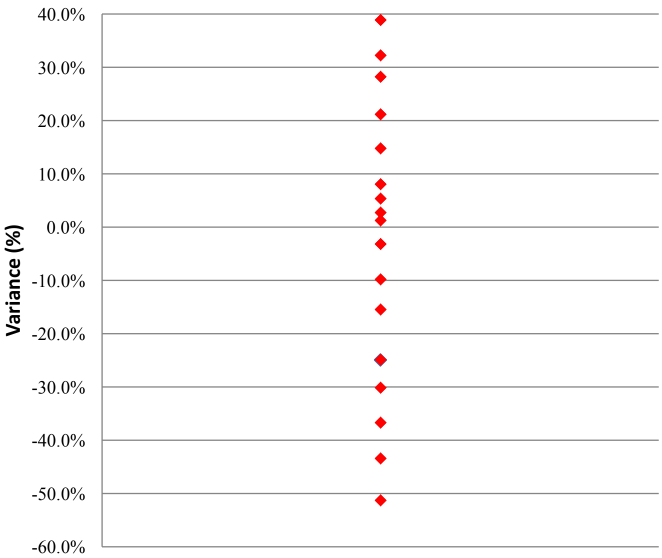
Table 6: Criteria matrix for Doubtful Debt and Debt Management models

Version	AIC	R^2	P>80%	AIC rank	R^2 rank	>67% P>80%	Top 75% AIC	R^2 > .7	Meets *a priori*	Choose
4	-256.21	0.9617	100%	2	3	☑	☑	☑	☑	☑
5	-255.93	0.9619	100%	3	2	☑		☑	☑	
6	-263.00	0.9643	100%	1	1	☑	☑	☑	☑	☑

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 13 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +39% to -51%, is large. However, in our view it is credible and supports our view that this represents a worthwhile first cut.

Figure 13: Percentage variance between modelled and actual expenditure: Doubtful Debt and Debt Management



Source: Anglian Water analysis

3.3. Retail Meter Reading costs

Ofwat developed three forms of the Retail Meter Reading cost models (summarised in a slide of March 2017, replicated as Figure 14 below). These are all linear cost functions, using OLS.

The first model (version 7 in Tables 7 and 8 below) uses the number of metered HH as the independent variable. The next two models (versions 8 and 9 in the following tables) incorporate the very granular density and sparsity measures developed by Ofwat in conjunction with the Cost Assessment Working Group during 2016. As can be seen from Figures 16 and 17, the much lower level of variability of density compared to sparsity can be matched to sparsity acting as a more potent explanatory variable.

For the purpose of this report, we have focused upon replicating the Ofwat models set out in the presentation on 9 March 2017 and shown in Figure 14. However, we have looked briefly at the question of whether the outliers below and above the line of best fit in Figure 15 could be explained by including within the model formulation a variable capturing the proportion of metered customers within the customer base. It was found that adding in this variable improved the R^2 to 0.782 from 0.725 with all three coefficients (#HH, % HH metered and the constant) being strongly sigificant. As expected, the sign on the % HH metered was negative. This model variant has not been evaluated for the purpose of this report. However, it will be included in the revised report planned for publication in early 2018.

Figure 14:

Ofwat reported Retail Meter Reading cost models

Y= (Metering costs) [£m]

Model[1]	7	8	9
Estimation method	OLS	OLS	OLS
Dependent variable	y	y	y
Independent variables:			
Number of metered HH [m]	2.97***	2.72***	2.93***
Density[2] [%]		4.55***	
Sparsity[3] [%]			-1.99***
Constant	0.13	0.17	1.30***
Adjust R^2	72.54%	75.47%	77.49%
Size of sample (n)	108	90	90

Level of significance (P> |t|): 10% = *; 5% = **; 1% =***

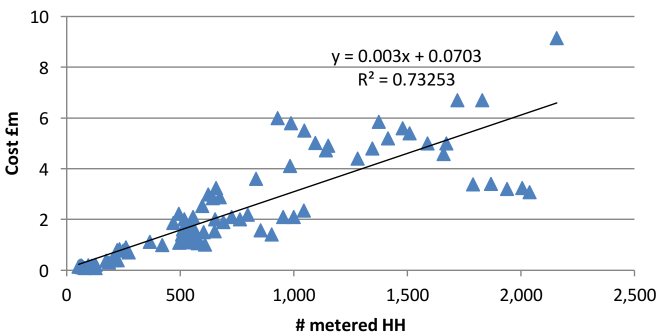
[1] In Ofwat's presentation, these models were referred to as A, B and C

[2] Proportion of LAD with a population density above 6,000 people/sq km

[3] Proportion of LAD with a population density above 1,500 people/sq km

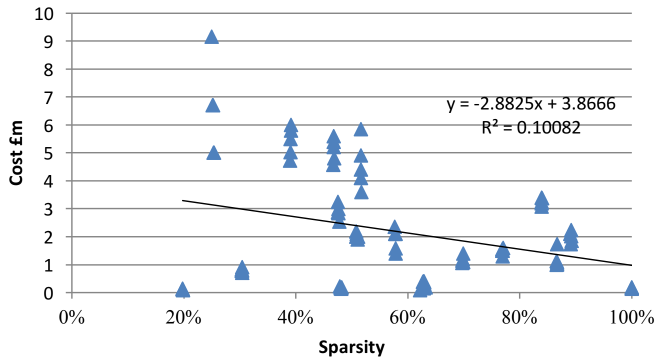
Source: Ofwat

Figure 15: Meter Reading cost vs # metered HH



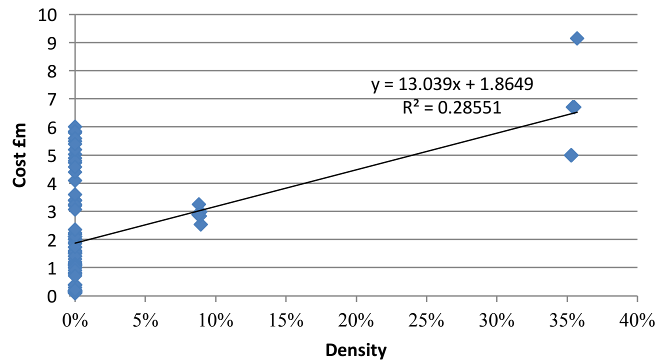
Source: 2016 Information Request, Anglian Water analysis

Figure 16: Meter Reading cost vs Sparsity



Source: 2016 Information Request, Anglian Water analysis

Figure 17: Meter Reading cost vs Density



Source: 2016 Information Request, Anglian Water analysis

The Ramsey Reset test (RR in Table 7, below) indicates that there may be missing higher order cost drivers in all three versions. In other words, the test suggests that translog forms of the models may better describe the cost data. The Brausch Pagan test (BP in Table 7, below) also suggests that the models display heteroskedasticity. We have not tried alternative variants on these models to address these shortcomings, essentially because we took the view that we should keep to the forms published by Ofwat at this stage. In the subsequent work we intend to undertake in the next six months, we intend to develop translog forms and try GLS versions as well.

Table 7: Detailed results of Meter Reading cost models

Version	7 Linear OLS	8 Linear OLS	9 Linear OLS
# Metered HH	1 +	1 +	1 +
Density			1 +
Sparsity		1 -	
C	☒ +	1 +	20+
Adj R^2	.725	.766	.742
AIC	6	-11	0
RR	.00	.00	.00
BP	.00	.00	.00
VIF	1	1	1

Source: Anglian Water analysis

We have used the same criteria matrix for retail meter reading costs as was used for all wholesale models. This is shown for these three models in Table 8. This leads to the model using only the number of metered HH as a cost driver being dropped for the purpose of model evaluation.

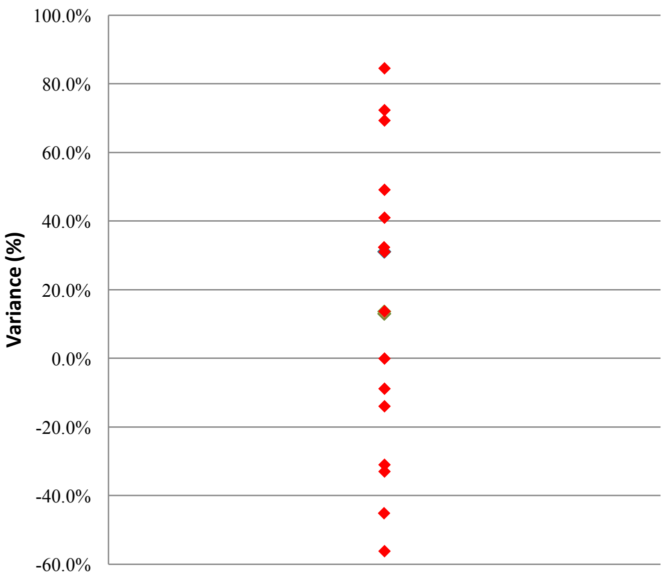
Table 8: Criteria matrix for Meter Reading models

Version	AIC	R^2	P>80%	AIC rank	R^2 rank	>67% P>80%	Top 75% AIC	R^2 > .7	Meets *a priori*	Choose
7	5.74	0.7251	50%	3	2			☑	☑	
8	-10.66	0.7660	100%	1	1	☑	☑	☑	☑	☑
9	-0.20	0.7251	100%	2	2	☑	☑	☑	☑	☑

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 18 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +85% to -56%, is very high and may reflect a combination of poor cost allocation, missing variables and actual variation in costs driven by economies of scale. It is hoped that further work on this admittedly small cost element may improve the fit of the Retail Meter Reading cost models.

Figure 18: Percentage variance between modelled and actual expenditure: Meter Reading costs

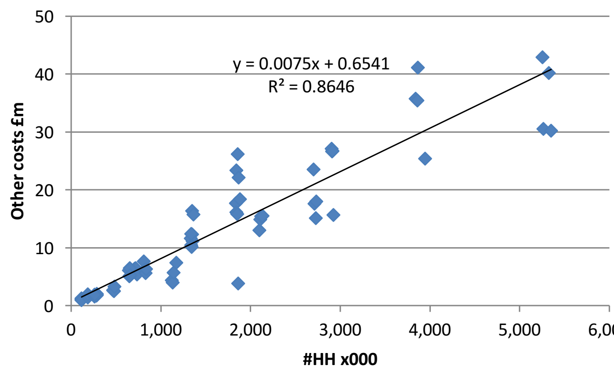


Source: Anglian Water analysis

3.4. Other Retail costs

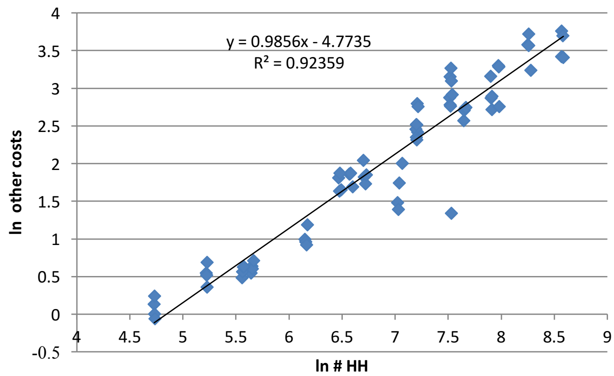
Ofwat did not put forward any cost models for Other Retail costs in its presentation on 9 March 2017. We have developed similarly frugal models for Other Retail costs, the results of which are set out in Tables 9 and 10 below. We have developed four variants of two models; one with number of households only, the second with households and households squared. The first pair, versions 10 and 11 are linear OLS. Versions 12 and 13 are GLS variants of 10 and 11. Versions 14 and 15 are log variants of versions 10 and 11. Finally, versions 16 and 17 are GLS variants of versions 14 and 15. Figures 19 -22 below demonstrate that this simple form explains a great deal of the movement of Other Retail costs.

Figure 19: Other Retail costs vs HH: linear form



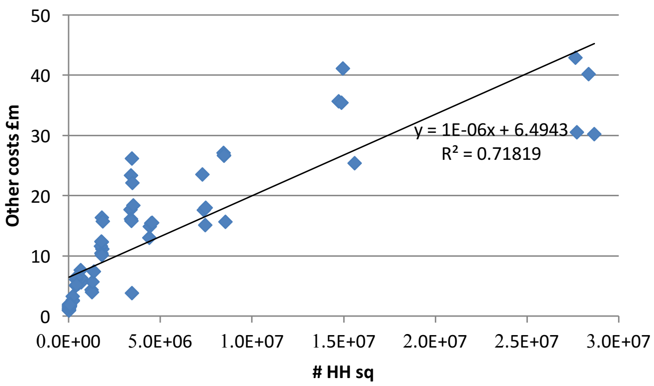
Source: 2016 Information Request, Anglian Water analysis

Figure 20: Other Retail costs vs HH: log form



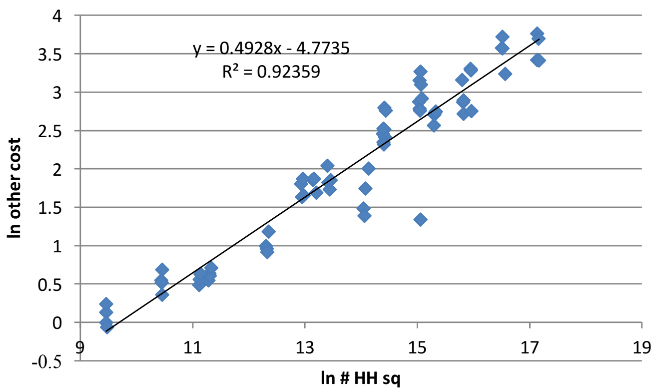
Source: 2016 Information Request, Anglian Water analysis

Figure 21: Other Retail costs vs HH²: linear form



Source: 2016 Information Request, Anglian Water analysis

Figure 22: Other Retail costs vs HH²: log form



Source: 2016 Information Request, Anglian Water analysis

Table 9: Detailed results of Other retail cost models

Version	10 Linear OLS	11 Linear GLS	12 Linear OLS	13 Linear GLS	14 Log OLS	15 Log GLS	16 Log OLS	17 Log GLS
HH	1 +	1 +	1 +	1 +	1 +	1 +	20+	☒ +
HH²			5 -	20-			☒ +	☒ +
C	☒ +	☒ +	☒ -	☒ -	1 -	1 -	5 -	10-
Adj R²	.863	.929	.872	.939	.923	.957	.922	.958
AIC	204		200		-172		-170	
RR	.02		.04		.22		.30	
BP	.00		.00		.11		.06	
VIF	1		10		1		152	

Source: Anglian Water analysis

We have used the same criteria matrix for Other Retail costs as was used for all wholesale models. This is shown for these eight models in Table 10. This leads to six out of the eight versions being dropped for the purpose of model evaluation. Only the log form based on the number of households (versions 14 and 15) passed all of the criteria and were thus used for model evaluation.

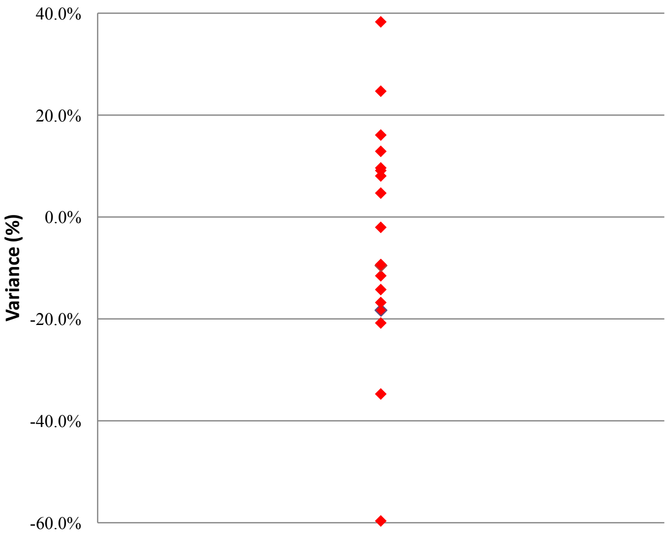
Table 10: Criteria matrix for Other Retail cost models

Version	AIC	R²	P>80%	AIC rank	R² rank	>67% P>80%	Top 75% AIC	R² > .7	Meets *a priori*	Choose
10	203.94	0.8627	50%	7	8			☑	☑	
11	203.94	0.9288	50%	7	4			☑	☑	
12	200.11	0.8715	67%	5	7		☑	☑	☑	
13	200.11	0.9394	67%	5	3		☑	☑	☑	
14	-171.61	0.9225	100%	1	5	☑	☑	☑	☑	☑
15	-171.61	0.9568	100%	1	2	☑	☑	☑	☑	☑
16	-170.38	0.9222	67%	3	6		☑	☑	☑	
17	-170.38	0.9577	33%	3	1		☑	☑		

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 23 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +38% to -60%, is large. Even excluding an outlier, which reduces the range to +38% to -35%, the range is still large. However, in our view it is credible and supports our view that this represents a worthwhile first cut.

Figure 23: Percentage variance between modelled and actual expenditure: Retail – Other



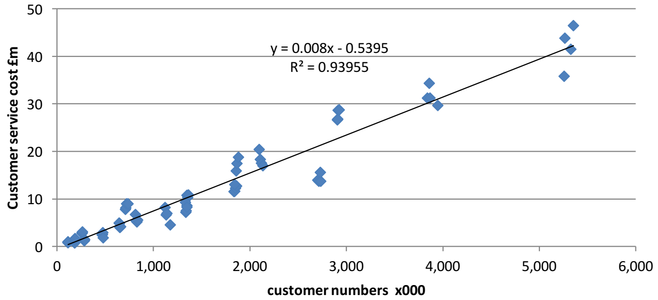
Source: Anglian Water analysis

3.5. Customer Service

As was the case for Other Retail costs, Ofwat did not put forward any cost models for Customer Service costs in its presentation on 9 March 2017. We have developed a number of similarly frugal models for customer service costs, the results of which are set out in Tables 11 and 12 below. We have developed four variants of a model with the number of households as the independent cost driver. The first, version 18, is a linear OLS variant; the second, version 19, is a linear GLS variant; the third, version 20, is a log OLS variant; and, predictably, version 21 is a log GLS variant.

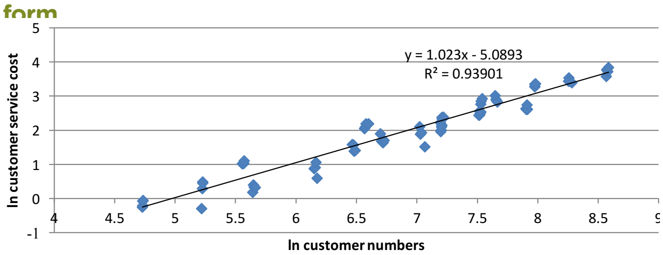
Figures 24 and 25 below demonstrate that this simple form explains a great deal of the movement of customer service costs.

Figure 24: Customer Service vs customer numbers: linear form



Source: 2016 Information Request, Anglian Water analysis

Figure 25: Customer Service vs customer numbers: log form



Source: 2016 Information Request, Anglian Water analysis

Table 11: Detailed results of Customer Service cost models

Version	18 Linear OLS	19 Linear GLS	20 Log OLS	21 Log GLS
HH	1 +	1 +	1 +	1 +
C	☒ +	☒ +	1 -	1 -
Adj R^2	.939	.952	.938	.951
AIC	149		-184	
RR	.60		.71	
BP	.00		.03	
VIF	1		1	

Source: Anglian Water analysis

We have used the same criteria matrix for Customer Service costs as was used for all wholesale models. This is shown for these four models in Table 16. This leads to two of the four versions being dropped for the purpose of model evaluation. Only the log form based on the number of households (versions 20 and 21) passed all of the criteria and were thus used for model evaluation.

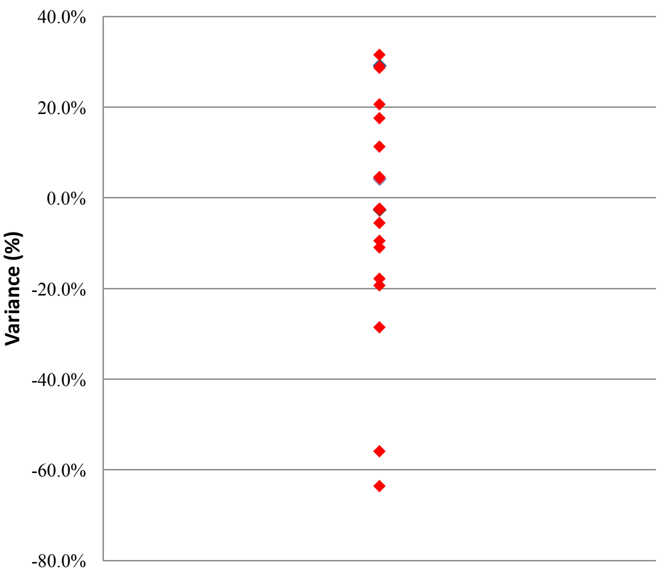
Table 12: Criteria matrix for Customer Service cost models

Version	AIC	R^2	P>80%	AIC rank	R^2 rank	>67% P>80%	Top 75% AIC	R^2 > .7	Meets *a priori*	Choose
18	149.24	0.9387	50%	2	3			☑	☑	
19	149.24	0.9519	50%	2	1			☑	☑	
20	-183.66	0.9381	100%	1	4	☑	☑	☑	☑	☑
21	-183.66	0.9508	100%	1	2	☑	☑	☑	☑	☑

Source: Anglian Water analysis

We have calculated the expected value produced by each model for the eighteen companies and triangulated the values (using our quality-adjusted approach) to produce a single modelled cost. Figure 26 below shows the range of variances between actual and modelled costs for the eighteen companies across the modelled period. The range, from +32% to -64%, is large. However, in our view it is credible and supports our view that this represents a worthwhile first cut.

Figure 26: Percentage variance between modelled and actual expenditure: Customer Services

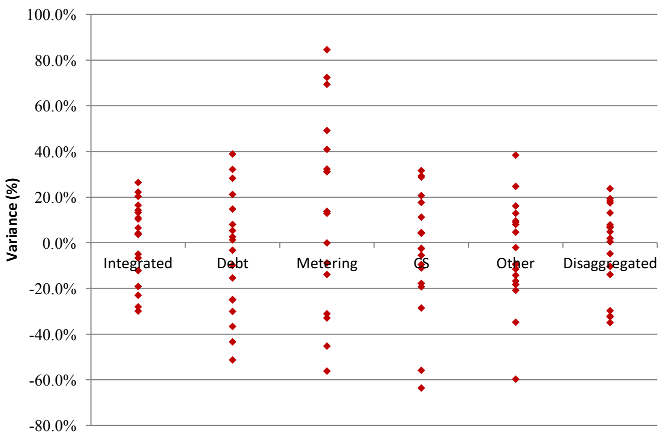


Source: Anglian Water analysis

4. Comparison of disaggregated and Integrated retail cost modelling

In conclusion, we compare the evaluation of the disaggregated retail cost models with the evaluation of the integrated model. Figure 27 brings together the evaluation of the four disaggregated elements of retail costs: Doubtful Debt and Debt Management, Meter reading costs, Customer Service costs and Other Retail costs.

Figure 27: Percentage variance between modelled and actual Retail - disaggregated



Source: Anglian Water analysis

Two things stand out from Figure 27.

First, the variability of the Disaggregated model is significantly lower than the variability of its constituent parts. This fits in with the suspicion that cost allocation across the various elements of retail costs may be less than perfect for all companies.

Second, the Disaggregated model variability is very similar to the Integrated model.

Ofwat's starting position which could be characterized by saying that all models are wrong and therefore one should have a suite of models rather than a single model could be seen to be validated by this congruence. That feeling is further strengthened by Tables 20 and 21 which look at triangulating the Integrated and Disaggregated models and at the rankings of all the models respectively. Table 19 shows that arithmetic triangulation of the Integrated and Disaggregated models further reduces the variability. Table 20 shows the remarkable correlation of the company rankings comparing the Integrated and Disaggregated models. Only one company, Portsmouth (one of the smallest) has a gap of more than three places between the two ranks. 14 companies have either the same ranking or are only one place different.

All of this suggests that the retail cost modelling appears to be robust.

5. Next steps

Building on the work we have described here, we will update the models with the data from the 2017 Information Request data. This will allow us:

a. To test the stability of models with additional data
b. To test for the models' stability when a year's data are removed.
c. Further develop and refine models
d. Incorporate model improvement suggestions from third parties

We will do this before the end of 2017 and intend to publish the results in an updated report.