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WATER INDUSTRY COST MODELLING

Update report

March 2018

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Executive Summary

At the start of 2017 we embarked on a project to determine whether it is possible to model botex expenditures 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. We reported on the first phase of this work in September 2017. Our conclusion was that econometrics can be used effectively to estimate base totex – that is, totex excluding enhancement expenditure. (We refer to base totex throughout this report as botex).

Since September 2017 we have continued our work, making use of the longer and more homogenous data set collected earlier in July 2017 and responding to the observations of our independent academic assessors from the Loughborough University Centre for Productivity and Performance (CPP).

This report presents the findings of the model development we have undertaken since September 2017. We describe changes we have made to our approach, the models we have developed and the model versions we have tested. We confirm the versions we will use in proposing botex expenditure allowances for 2020-2025 in our September 2018 business plan.

In this second phase of work we have worked in close collaboration with Professor David Saal and Dr Maria Nieswand from CPP. We publicly acknowledge and thank the significant contribution of Professor Saal and Dr Nieswand to the work we report here. Final decisions have been made by Anglian Water. The comments of CPP are included in this report.

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. Rather than Sewage Treatment Works (STWs), we refer to Water Recycling Centres (WRCs).

We have used the term Bioresources to refer to the service of recycling the solid components of used water but retain 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.

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 2017 data set which we have used also included both Bournemouth Water and Dee Valley Water which have both subsequently been acquired.

References to Business Units refer to the RAG defined entities into which Regulatory Accounts are divided - e.g. Water Resources, Sewage Treatment or Retail.

1. Introduction

This report covers work we have undertaken in response to two challenges that we face as a water company. 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 botex 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.

Since the start of 2017 we have been developing econometric models which we believe can play a significant role in helping us meet these twin challenges in respect of our base expenditure. The first phase of our modelling work made use of data submitted by companies during 2016. We reported fully on the approach we had taken and our findings in the report which we published in September 2017[1]. This report is still available on our website.

Throughout this document we refer to the work we did up to September 2017 as our Phase 1 work and our report on that work as our September report.

In our September report we committed to continue our work and to publish an update report in Spring 2018. We refer to the modelling we have done since September as Phase 2 of our project. In this second phase we have made use of the additional data supplied by companies in their 2017 Information Request submissions to Ofwat. We have also responded to the lessons we learned during the first phase.

This document reports on the second phase of our work. It describes the changes we have made to our modelling approach and the models we have created. It confirms the models that we intend to use in setting our botex cost allowances for the 2020-25 period, which we will set out in our September 2018 Business Plan.

We intend that this report should be regarded as an update to our September 2017 report. We therefore do not repeat the contextual information we set out there but refer readers seeking fuller background to that report.

2. Our approach to the second phase of our work

2.1 What's stayed the same …

Several of the key features of our approach have remained unchanged in the work we have done since September 2017:

- All of our work relates to base expenditure only, or botex. This comprises the day-to-day operating expenditure on recurrent items to deliver the ongoing service of the business plus the investment in the maintenance of assets to ensure they remain serviceable. It excludes any component of expenditure intended to provide enhancement to service.
- We have excluded certain botex elements from our modelling. These are material items of expenditure which are not associated with obvious botex drivers and over which companies have limited degree of control. They include business rates, pension deficit recovery costs and service charges to the Environment Agency.
- Our modelling is focused around the five price controls Ofwat intends to set for the period 2020-25.
- All of our models use panel data (data sets comprising observations of multiple phenomena obtained over multiple time periods for the same companies) from all of the England and Wales companies.
- In calculating botex we have generally used unsmoothed capital maintenance expenditures. There are arguments for using depreciation charges rather than capital expenditure in botex modelling but, regardless of the merits of these arguments, data availability prevents it: in company reporting maintenance depreciation is not split from enhancement depreciation
- Generally speaking, we have used Ordinary Last Squares (OLS) for estimating the parameters in our linear regression models. In a handful of cases (in particular among the models used for Water Recycling Integrated and Network Plus), we have used Generalised Least Squares (GLS) with Random Effects.
- All of the botex modelling was undertaken using the statistical software application STATA v14.

Our September report sets out the rationale for adopting these elements of our approach.

2.2 What's changed …

Building on the lessons we learned during the first phase of our work we have improved our approach for this second phase in a number of areas:

Closer collaboration with external advisers

The models we presented in our September report were all developed in-house by Anglian Water employees. Having completed this work, we invited a team led by Professor David Saal to review our work. Professor Saal is Co-Director of the Centre for Productivity and Performance (CPP) at Loughborough University with twenty years of experience in the academic and regulatory application of cost modelling to the water industry. Professor Saal and his colleagues provided valuable feedback on our Phase 1 models and our approach. Their comments on our work are included in our September report. Several of the changes we have made in this phase of the work have been in response to their Phase 1 observations.

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[1] *Water Industry Cost Modelling: Anglian Water's approach', September 2017 http://www.anglianwater.co.uk/_assets/media/cost-modelling-report.pdf*

We recognised that rather than invite external commentary on our completed work it would be preferable to utilise that expertise during our model development. All of our work in Phase 2 has therefore been undertaken in close collaboration with Professor Saal and his colleagues.

The final decisions and choices on models have been made by Anglian Water and we have given CPP free opportunity to comment on those decisions. The views of the CPP team are set out in Appendix 1.

Greater attention to economic fundamentals

A key observation from the CPP team on our first phase work was that our models would have benefited from greater initial consideration of the fundamental economic forces underlying the activity in question. They said, "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 business units 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) …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[2].

We have responded to this observation in our approach to developing our models. For each price control area we kicked off the second phase of work with a workshop to which we invited technical and financial colleagues who worked in the particular area from around Anglian Water, and which also included participation by our academic advisors from CPP. At those workshops we encouraged those colleagues to describe their work: the assets involved, the key areas of expenditure and the factors which caused pressure on their budgets. We presented a range of industry data to provoke debates about the factors which might cause costs to vary across different operating environments.

The conversations at those workshops provided the material we needed to define the production processes we were trying to model. Through lengthy debate with CPP colleagues we honed our views about those. This allowed us to identify inputs, outputs and control variables and how we expected those variables to interact. Only once we had articulated this satisfactorily did we test whether our hypotheses were supported by statistical analysis.

In some areas we think the ideas generated in this process are novel and have potential for further development. In some cases they may have broader application beyond the water industry.

In the annexes to this report we have set out the production function for each price control area.

Use of additional data

The main sources of the data for all our wholesale botex modelling in Phase 1 were 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. 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.

In 2017 the data requirements of the August and October submissions were combined into a single Information Request. For wholesale, companies re-submitted data for the years 2011-12 to 2015-16 and provided data for an additional year, 2016-17. For Retail, companies submitted data for 2016-17.

For our Phase 2 wholesale models, we used six years' data (2011-12 to 2016-17) for most models. For the Retail models, we used five years' data (2012-13 to 2016-17): 2012-13 was the first year in which companies were required to disaggregate and report wholesale and retail expenditure.

A number of data were changed by companies subsequent to their July 2017 submissions through the correction of errors or following the clarification of reporting requirements. Furthermore, we are aware that Ofwat and its consultants unilaterally amended data items where they noted inconsistency of treatment between companies. The imperative of finalising models in order to meet our September 2018 business plan deadline did not allow us to await the completion of this checking / amendment phase, which continued well into 2018. Our models therefore used October 2017 versions of the datasets.

We will re-run our models after July 2018, when we will have the benefit of both corrected data and 2017-18 data. The impact of these changes will be available to us during the later stages of the price review process. Of course, changes to data do not undermine our theories of the fundamental economic interactions underlying particular price control activities. Our expectation is therefore that the impact of substituting corrected data for the ones we used will be minimal.

We have also used other data in some of our modelling:

- **Social deprivation:** In our retail botex modelling, we have made use of the extensive data sets developed in 2016-17 by United Utilities (UU) in conjunction with Equifax and Reckon, which UU kindly shared with Ofwat and members of the Cost Assessment Working Group (CAWG).
- **Population sparsity and density:** In conjunction with the CAWG, Ofwat developed granular measures of population sparsity and density using ONS Lower Super Output Area (LSOA) population and area data. These were made available to the CAWG.
- **Regional wage differences:** Ofwat developed a regional wage series for PR14. At the suggestion of the CAWG, Ofwat updated that series for PR19, including a greater range of Standard Occupational Categories (SOCs) within the series. The SOCs chosen were specific to wholesale.

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[2] *Page 51 of our September report*

Different criteria for acceptable models

At the outset of Phase 1 we recognised that we needed to have a set of criteria against which to assess our model versions to ensure our final selection of models was objective. We set four tests which all versions had to pass to be deemed acceptable:

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. Do the statistically significant coefficients make sense from both an economic and engineering perspective?

CPP made valuable observations about the model selection process we pursued in Phase 1; their comments are set out on pages 53 and 54 of our September report. We have accepted their comments and applied a modified approach for Phase 2. The emphasis now is on ensuring that the models which are evaluated are not only statistically valid but also conceptually consistent with the economic, engineering, production, and regulatory context in which the modelled firms operate, and thus the "best" estimable theoretical models. In comparing different specifications of these economically grounded model forms, we have therefore first applied the economic and engineering logic test.

Less use of granular models

In our Phase 1 work we resolved to build models at three different levels of disaggregation, as set out in the figure 1. below. We set out our rationale for this on page 5 of our September report.

We recognised from the outset that modelling at a disaggregated level introduces the risk of bias as a consequence of inconsistent allocation by companies of expenditures across business units. Despite efforts by stakeholders to define precisely business unit boundaries, inconsistency remains because of undefined grey areas and/or the limitations of companies' measurement tools. If two companies make different decisions when faced with the same dilemma about whether to allocate expenditures to one side or the other of a business unit boundary, bias is inevitable.

We found evidence for expenditure allocation differences in our Phase 1 work. For example, the variances in our respective Water Resources and Raw Water Distribution models reduced substantially when the results of those two models were consolidated. The Water Resources / Water Network Plus boundary appears to be the most ambiguous, with substantial differences between companies in their expenditure allocations. As Water Resources is a separate price control (and is much smaller than the rest of wholesale Water), any such misallocation across this barrier may have a disproportionate impact on the Water Resources botex assessment and may require adjustments to avoid error.

In their review of our Phase 1 work, CPP expressed another concern about disaggregated modelling, namely the impact of cost interaction. This refers to the observation that inefficiencies may be observed in one business unit because decisions have been made at a price control or even service level to achieve maximum overall efficiency. Management may not focus on the efficiency of, say, Water Resources provided the decision it makes for the Water service overall results in the lowest total cost. CPP said, 'The presence of significant cost interactions between disaggregated units of assessment can result in considerable biases if not controlled for properly. Moreover, as there is considerable evidence that such cost interactions may exist in the water industry,

Figure 1: Phase 1 botex models

Service level	Price control level	Sub-price control level
Water wholesale (Water Integrated)	Water Resources	
	Water Network Plus	Raw Water Distribution
		Water Treatment
		Treated Water Distribution
Water Recycling wholesale (Water Recycling Integrated)	Water Recycling Network Plus	Sewage Collection
		Sewage Treatment
	Bioresources	Sludge Transport
		Sludge Treatment
		Sludge Disposal
	Retail	Doubtful Debt and Debt Management
		Meter Reading
		Customer Services
		Other

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

Figure 2 below shows the level at which we have developed models for Phase 2:

Figure 2: Phase 2 botex models

Service level	Price control level	Sub-price control level
Water wholesale	Water Resources	
	Water Network Plus	
Water Recycling wholesale	Water Recycling Network Plus	
	Bioresources	
	Retail	Doubtful Debt and Debt Management
		Other Retail Costs

cost assessment and regulatory price determination at inappropriate levels of disaggregation may result in perverse incentives.'

As a consequence of our concerns about expenditure allocation differences and cost interactions we have in general not developed models further in Phase 2 at a sub price control level. The only exception to this is in Retail, where we have modelled Doubtful Debt and Debt Management as well as Other Retail costs separately.

A different way of combining models and versions

Accepting the principle that no model can be perfect, our approach has always been to develop a number of alternative models and versions and to compare the results arising from each to reach a decision on the most likely answer. In applying this comparative process, which is sometimes described as 'triangulation', in Phase 1 we resolved to give greater weight to better quality models and devised an objective method for doing this (described on page 9 of our September report).

CPP had some valuable reservations about our Phase 1 approach, which are set out on page 54 of our September report. We acknowledged their comments and adopted a revised approach to combining models in Phase 2. We have persisted in computing Quality Adjusted (QA) triangulation, but now only using the adjusted R^2 as the quality weights. Generally speaking, the adjusted R^2 of the models used are uniformly high (the exception are the unit cost models used for Water Integrated and Network Plus). Consequently, the arithmetic and QA results are almost identical.

Different definition of a model

Practitioners vary in their definition of the term 'model'. We have modified our approach to modelling as suggested by CPP in their review of our Phase 1 models. Thus, we have broadly taken an approach of first developing one, or possibly several, alternative theoretical/conceptual model(s) of how engineering, economic, and regulatory factors influence costs. This conceptual model development took place through a process of discussion with our managers and CPP. Thus, we emphasize that our approach is not based on a slavish reliance on academically pure mathematical cost functions, but instead has resulted in conceptual cost driver models that embody the collective wisdom of managers as well as regulatory and academic cost modelers.

Once we had developed these conceptual models we then sought to specify them empirically, within the constraints of data available. We note that conceptual models for which we knew data would not be available would have been quickly abandoned at the conceptual stage. Moreover, at this stage multiple empirical specifications were tested and chosen between, yielding a preferred specification for each conceptual model. Finally, if robust empirical specifications were found for more than one underlying conceptual model, we then chose the best specification of a preferred conceptual model, or alternatively report the best specification of multiple conceptual models.

In contrast, our September report referred to alternative empirical specifications as alternative models, and did not focus as strongly on the development of conceptual models before specifying them.

3. Summary of results

We publish a summary of the results of all our modelling work in a common format in the following tables. The detailed description of our work in each price control is set out in Annexes 1 – 5.

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 attention should be paid to data quality and greater care needs to be taken in the application of the models.

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. Moreover, we believe this issue may be particularly relevant with regard to modelling Water Resource botex.

Service area	Water Resources
Number of models reported	2 – Geo-demographic model and Outputs model
Number of versions used	4 - Geo-demographic versions 2, 4 and 5 and Outputs version 4
Modeled expenditure	Total operating and capital maintenance expenditure for Water Resources excluding third party services, abstraction licence fees, atypical expenditures and local authority rates.
Cost drivers used in acceptable models	• Average Pumping head for Water Resources • Distribution Input (DI) • Total number of sources • Reservoir capacity • Proportion of DI from rivers and pumped storage reservoirs • Proportion of DI from boreholes • Abstracted volume as a proportion of maximum licensed volume • Population density (measure 2, percentage of population in LSOAs with sparcity <4,000/km^2) • Volume of water from pumped storage reservoirs • Volume of water from impounding reservoirs • Volume of water from rivers • Volume of water from groundwater • Volume of water from all surface water sources • Average DI from groundwater WTWs • Average DI from surface water WTWs
Other cost drivers tested	• Regional wages
Largest positive variance (where actual expenditure is most below modeled expenditure)	+29% (ignoring a solitary extreme outlier with variance >80%)
Largest negative variance (where actual expenditure is most above modeled expenditure)	-30%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	2-3 at best
Comments	
Detailed description	Annex 1

Service area	Integrated Water service
Number of models reported	3 – EV1, EV2, EV3
Number of versions used	8 – 2 versions of EV1, 4 versions of EV2, 2 versions of EV3
Modeled expenditure	Total operating and capital maintenance expenditure for the Water service excluding third party services, abstraction licence fees, atypical expenditures and local authority rates. Versions use a mixture of smoothed botex (2012-13 to 2016-17) and 7 years unsmoothed botex (2010-11 to 2016-17).
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 modeled expenditure)	+19%
Largest negative variance (where actual expenditure is most above modeled expenditure)	-26%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	These models are those created by the Competition and Markets Authority (CMA) in setting price controls for Bristol Water in 2015. We have re-run the data, replacing the oldest year's data with data from 2016-17, and discarded ten versions which did not meet quality standards.
Detailed description	Annex 2

Service area	Water Network Plus
Number of models reported	2 – EV2, EV3
Number of versions used	5 – 1 version of EV2, 4 versions of EV3
Modeled expenditure	Total operating and capital maintenance expenditure for the Water service excluding third party services, abstraction licence fees, atypical expenditures and local authority rates. Versions used a mixture of 5 years smoothed botex (2012-13 to 2016-17) and 7 years unsmoothed botex (2010-11 to 2016-17).
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 modeled expenditure)	+21%
Largest negative variance (where actual expenditure is most above modeled expenditure)	-37%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	These models are those created by the Competition and Markets Authority (CMA) in setting price controls for Bristol Water in 2015. We have re-run the data replacing the oldest year's data with data from 2016-17, and discarded thirteen versions which did not meet quality standards.
Detailed description	Annex 2

Service area	Integrated Water Recycling service
Number of models reported	2 – Extended Passing Distance and Average System (each with variants on population sparsity and sludge indigineity)
Number of versions used	12 – 4 versions of Extended Passing Distance and 8 versions of Average System
Modeled expenditure	Total operating and capital maintenance expenditure for the Water Recycling service excluding third party services, abstraction licence fees, atypical expenditures and local authority rates.
Cost drivers used in acceptable models	• Combined sewer length as a share of total sewer length • Proportion of indigenous sludge, i.e. sludge treated at a STC co-located with the WRC where it is produced • Total length of sewer • Proportion of load subject to tight (<3mg) ammonia consents • Load treated at WRCs (measured as population equivalent) • Pump capacity • Population sparsity • Number of Water Recycling Centres Time trend
Other cost drivers tested	
Largest positive variance (where actual expenditure is most below modeled expenditure)	+6%
Largest negative variance (where actual expenditure is most above modeled expenditure)	-7%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	Unlike the other models reported here, these models are partial translog models, were developed using normalized cost data and were calculated using Generalised Least Squares with Random Effects rather than OLS.
Detailed description	Annex 3

Service area	Water Recycling Network Plus
Number of models reported	2 – Extended Passing Distance and Average System (each with variants on population sparsity and sludge indigineity)
Number of versions used	11 – 5 versions of Extended Passing Distance and 6 versions of Average System
Modeled expenditure	Total operating and capital maintenance expenditure for the Water Recycling service excluding third party services, abstraction licence fees, atypical expenditures and local authority rates.
Cost drivers used in acceptable models	• Combined sewer length as a share of total sewer length • Proportion of indigenous sludge, i.e. sludge treated at a STC co-located with the WRC where it is produced • Total length of sewer • Proportion of load subject to tight (<3mg) ammonia consents • Load treated at WRCs (measured as population equivalent) • Pump capacity • Population sparsity • Number of Water Recycling Centres • Time trend
Other cost drivers tested	
Largest positive variance (where actual expenditure is most below modeled expenditure)	+9%
Largest negative variance (where actual expenditure is most above modeled expenditure)	-11%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	Unlike the other models reported here, these models are partial translog models, were developed using normalized cost data and were calculated using Generalised Least Squares with Random Effects as well as OLS.
Detailed description	Annex 3

Service area	Bioresources
Number of models reported	3 – Demographic, Network Plus and Outputs
Number of versions used	6 – Demographic version 7, Network Plus versions 10 and 11, and Outputs versions 2, 7 and 8
Modeled expenditure	Total operating and capital maintenance expenditure for Bioresources excluding third party services, atypical expenditures and local authority rates.
Cost drivers used in chosen models	• Volume of sludge produced (actual) • Population sparcity (measure 2, percentage of population in LSOAs with sparcity <600/km^2) • Population sparcity (measure 3, percentage of population in LSOAs with sparcity <1,150/km^2) • Proportion of sludge treated by conventional or anaerobic digestion • Appointed area • Sewered area • Time trend • Proportion of sewage load handled by band 1-4 STWs • Proportion of sewage load handled by band 5 STWs • Proportion of sewage load handled by band 6 STWs • Arable land in appointed area as a percentage of total arable land • Indigenous sludge (proportion of sludge produced at co-located STWs)
Other cost drivers tested	• Work done by volume in moving liquid sludge • Proportion of sewage load handled by different combinations of STW bands • Proportion of treated biosolids disposed to farmland • Volume of sludge produced (theoretical) • Volume of sludge generated by various combinations of STW bands
Largest positive variance (where actual expenditure is most below modeled expenditure)	11% (from triangulated results of all chosen models)
Largest negative variance (where actual expenditure is most above modeled expenditure)	-15% (from triangulated results of all chosen models)
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 4

Service area	Retail (integrated)
Number of models reported	1
Number of versions used	1 – version 11
Modeled expenditure	Total operating and capital maintenance expenditure for Retail excluding third party services and atypical expenditures.
Cost drivers used in acceptable models	• Number of metered customers • Number of unmetered customers • Average bill size • Regional wages • Deprivation measure 3 – 80th percentile for income with billing used as weight • Time trend • Waste water customers as a proportion of total customers • WOC billed waste water customers as a proportion of total customers • Billing complaints per 10,000 customers • Regional unemployment rate
Other cost drivers tested	• Total number of customers • Deprivation measure 1 – 99th percentile for income • Deprivation measure 2 – 90th percentile for income • Total revenue • WASC billed waste water customers as a proportion of total customers • SIM score
Largest positive variance (where actual expenditure is most below modeled expenditure)	+22%
Largest negative variance (where actual expenditure is most above modeled expenditure)	-29%
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 5

Service area	Doubtful Debt and Debt Management
Number of models reported	1
Number of versions used	1 – version 9
Modeled expenditure	Total operating and capital maintenance expenditure for doubtful debt and debt management excluding third party services and atypical expenditures.
Cost drivers used in acceptable models	• Total revenue • Average bill size • Deprivation measure 3 – 80th percentile for income with billing used as weight • Time trend
Other cost drivers tested	• Regional wages • Total number of customers • Deprivation measure 1 – 99th percentile for income • Deprivation measure 2 – 90th percentile for income
Largest positive variance (where actual expenditure is most below modeled expenditure)	+38% (when combined with the results of Doubtful Debt and Debt Management model this figure changed to +23%, similar to that for the Retail integrated model)
Largest negative variance (where actual expenditure is most above modeled expenditure)	-48% (when combined with the results of Doubtful Debt and Debt Management model this figure changed to -33%, similar to that for the Retail integrated model).
Our overall view of the robustness of the models, 1 (low) – 5 (high)	3
Comments	
Detailed description	Annex 5

Service area	Other Retail
Number of models reported	1
Number of versions used	2 – versions 6 and 7
Modeled expenditure	Total operating and capital maintenance expenditure for Retail excluding expenditures for doubtful debt and debt management, third party services and atypical expenditures.
Cost drivers used in acceptable models	• Number of metered customers • Number of unmetered customers • Regional wages • Time trend • Waste water customers as a proportion of total customers • WOC billed waste water customers as a proportion of total customers • WASC billed waste water customers as a proportion of total customers • SIM score
Other cost drivers tested	• Total number of customers • Total revenue • Metered customers as a percentage of total customers • Billing complaints per 10,000 customers • Population sparsity • Overall satisfaction with the water service (from CCWater survey) • Overall satisfaction with the water service (from CCWater survey)
Largest positive variance (where actual expenditure is most below modeled expenditure)	+22% (when combined with the results of Doubtful Debt and Debt Management model this figure changed to +23%, similar to that for the retail integrated model)
Largest negative variance (where actual expenditure is most above modeled expenditure)	-36% (when combined with the results of Doubtful Debt and Debt Management model this figure changed to -33%, similar to that for the retail integrated model).
Our overall view of the robustness of the models, 1 (low) – 5 (high)	4
Comments	
Detailed description	Annex 5

4. Conclusions

We are pleased to be able to present the results of the model development work we have undertaken since September 2017. Our view is that the models and versions we have developed are better than those on which we reported in our September report. In many cases the results are not substantially different but in every case the economic underpinning is better defined, making the models more robust to criticism. We are confident that they provide a firm foundation for the botex proposals we will include in our September 2018 business plan. Furthermore, we believe they provide valuable, if imperfect, insight into our relative efficiency across the various components of the value chain. As such, they will be useful tools in the management of our business as we face the challenges of the next regulatory period.

We publicly acknowledge and thank the significant contribution of Professor David Saal and Dr Maria Nieswand from Loughborough University CPP to the work we report here. We look forward to continuing work with CPP to develop ideas which have come out of this phase of work, which we believe may have broader benefits for the understanding of network industries.

5. How we will use the models for botex forecasting

In this report we describe the models we have developed, the versions we have created and those we are minded to use for future botex assessment. In terms of results, we show how the botex expenditures individual (unnamed) companies have actually incurred over the modelled period compare with the botex our models predict they ought to have incurred (expressed as variance).

It is a separate exercise to use botex models to forecast botex for an individual company in a future period. A key decision in this process is to identify a credible benchmark from the modelled period against which to set efficient future botex. Doing so requires us to make judgments about how the variance evident from historical periods decomposes into model error and efficiency.

This report confirms the models and versions we are minded to use in setting our base botex proposals for 2020-2025 in our September 2018 business plans. We say no more in this report about the process we will follow for this. We will set out that process in our September business plan.

Glossary

AD	Anaerobic digestion, a process widely used for treating sludge
R^2	Coefficient of determination: the proportion of 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
CPP	Centre for Productivity and Performance, School of Business and Economics, Loughborough University
Cobb Douglas (CD)	Cost function of the form $Y=x_1^{\beta 1}\, x_2^{\beta 2} \ldots x_n^{\beta n}$ 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 modelled. 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

Centre for Productivity and Performance
School of Business and Economics

Comment on Anglian Water's Phase 2 Regulatory Cost Modelling for PR19
March 2018

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Introduction and Terms of Reference

Following the Centre for Productivity and Performance's (CPP) independent review of its Phase 1 cost assessment report, which it published in September 2017, Anglian Water (AWS) engaged Professor David Saal and Dr Maria Nieswand to be more actively involved developing improved models, building from its preliminary work. Our role was to support AWS in further developing econometric cost modelling for each of the business units it had decide to model in Phase 2 Moreover, building from our suggestions in Phase 1, the project included substantial engagement between CPP and AWS managers so as to provide a deeper understanding of factors driving managerial decision making and costs. This deepened understanding facilitated model development, which took place in an iterative process between CPP and AWS.

We thus understood that the ultimate deliverable from CPP would be a significant intellectual contribution to all the models that AWS would develop in Phase 2. In practice, this meant that for some models we had extended consultation and significantly influenced AWS, but AWS was ultimately responsible for model development. In contrast, for other models, CPP took a much more direct and active role in proposing new models. In particular, we were most heavily engaged in the successful development of the Average System model and the Extended Passing Distance models employed for Integrated and Network Plus Water Recycling. We note that we also took a similarly significant role and made significant progress in developing alternative models for Integrated and Network Plus Water, but we were ultimately unsuccessful given the tight timeline we faced within PR19.

Given this description, we also wish to state where we did not play a role. Most importantly, as clearly discussed in our Phase 1 review, we have considerable reservations about the appropriateness of both Totex and Botex modelling, as well as the suitability of carrying out disaggregated business unit assessment when cost interactions exist. Nevertheless, Ofwat remains committed to some form of TOTEX-like "cost" assessment for PR19, as well as disaggregated cost assessment. Thus, absent an unexpected change in that regulatory commitment, when we began Phase 2 work, we accepted and continue to 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. Moreover, we also accepted and strongly supported AWS' decision to limit the scope of Phase 2 modelling from the very beginning by eliminating several excessively disaggregated Phase 1 models.

We also specifically note two other limits to our role. Firstly, while our advice and efforts on modelling clearly influenced what models were developed, the final choice of which models will be put forward for use in judging business performance is entirely AWS' decision. Secondly, we wish to emphasise that as our role was limited to model development, we played no role in, and do not provide comment on, how Anglian Water presented the models in the final reports, nor the methods they choose to employ when aggregating or disaggregating performance estimates employed to assess performance for modelled business units.

Finally, we state the obvious. While we were truly independent reviewers in Phase 1, this is clearly not the case in Phase 2. Our comments are therefore on models that we have discussed in great detail with and/or developed with Anglian Water, and must be taken as such.

Overall Assessment of the Modelling Undertaken in Phase 2

Our Phase 1 review raised concerns that water industry regulatory modelling was exhibiting an increasing 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. However, we also noted that this did not necessarily result from a cost driver approach to modelling, which can be an appropriate tool for regulatory benchmarking if it robustly accounts for the economic, regulatory, engineering and environmental characteristics of a firm and the context within which it operates. Thus, a robust cost driver model requires careful consideration of how variables interact within a model and controls for factors such as outputs, prices and operating characteristics. As a result, we argued that 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.

Given these arguments, Anglian Water raised the potential for us to work with them on its Phase 2 modelling. Our advice to them was that they needed to step back, carefully consider the factors influencing modelled costs and the interrelationship between them, and then develop strong conceptual models of how these factors could be translated into testable empirical specifications. Moreover, while we noted that relevant lessons could be gained from economic cost and production theory and how this might influence model specification, we also emphasized that getting the conceptual framework right was at least as important, if we sought parsimonious and appropriate regulatory botex models.

The resulting Phase 2 modelling has been the result of Anglian having taken our advice. Moreover, it is the result of a considerable investment of several hundred hours of operational managerial resources to a consultative process. This process not only provided important insights that significantly informed Anglian's modellers directly, but also dramatically influenced our own understanding of the drivers of water and sewerage industry costs.

As a result, almost every model that Anglian has reported in Phase 2 was much more carefully conceptually developed and considered before estimation began, and we judge these models to be unequivocally superior to those reported in Phase 1. A notable exception to this is the application of identical CMA models for Integrated and Network Plus water, which by definition could not have improved as they have not changed. Nevertheless, substantial internal and external resources were invested in providing an alternative conceptual model, which unfortunately could not be finalized within the project time constraints. We are heartened that Anglian has indicated that it intends to pursue further modelling in this area.

In practice there is variation in the quality of the Phase 2 Models. We have already commented on the Integrated Water and Network Plus Water models. Beyond this, we believe that in general the Water Recycling and Bioresources models have strong conceptual frameworks that should be considered carefully by Ofwat and other companies, and the strength of these models is evidenced by the fact we plan to pursue the application of these models academically.

The Water Resources and the three Retail models provide strong answers to the regulatory cost assessment exercise. However, in both cases we have raised concerns with regard to how regulatory accounting guidelines, boundaries and definitions for these activities may influence the potential to accurately model botex

In sum, our assessment is that Anglian Water's Phase 2 models provide a strong suite of models for regulatory cost assessment,

Wholesale Water Integrated & Network Plus Models

In its Phase 1 modelling AWS reproduced the Competition Market Authority's (CMA) modelling from its 2015 Bristol Water decision for Fully Integrated Water Activities, and developed its own models for Water Network Plus. Our Phase 1 review noted some merits of the CMA models including their consistent inclusion 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. However, we also noted economically untenable and very strong restrictions on these models that we believe reduced their effectiveness in explaining variation between firms' botex expenditures.

In Phase 1 we also noted that, as with the Integrated model, the Water Network Plus model should be consistent with modelling firms that seek to minimize the total input usage (but net of raw water abstraction costs for Network Plus) required to deliver water to its customers. Thus, at a conceptual level, we would expect a model with water volumes as a key 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. Moreover, a hypothetical integrated or 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 overall costs.

Given these comments from Phase 1, Anglian asked us to directly develop an alternative integrated Water model for application in Phase 2, with the intention of then adapting the developed model for application to the Network Plus model. However, while we made considerable progress in developing a model that not only addressed the comments we raised but also employed a common academic approach to capturing the trade-off between distribution losses and network costs, we were unable to refine the model sufficiently within the time constraints set by Anglian and resulting from the PR19 timetable. We therefore appreciate and concur with Anglian's stated desire in their Phase 2 report to pursue further modelling later in the year.

We therefore also accept Anglian's resulting decision to rely on the CMA models it employed in Phase 1, particularly as they have been applied by a regulatory authority in a legally binding price determination. However, we have noted to Anglian Water that while the CMA models were statistically robust in Phase 1, this is less so when they are applied to the databases employed in Phase 2. Thus, many of the control variables that were statistically significant in both the CMA's analysis and Anglian's Phase 1 analysis, are not significant in their Phase 2 versions. Similarly, the implied elasticities of botex with respect to properties, water delivered, and length of main has also shifted in a manner which suggests a deterioration in the model's overall robustness.

Water Resources

In our Phase 1 review of Anglian's Water Resource models, our overall conclusion was that there was a strong potential to develop a satisfactory model building from Anglian's efforts, but that Anglian had not identified clear models and had simply reported an excessive number of empirical specifications. We also noted that "water abstraction" was a potentially a clearly defined activity, but that existing water supply 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 these all create considerable differences in input requirements. We therefore note again issues raised in our Phase 1 report about whether the boundary between Water Resources and Network Plus is clearly defined, and if cost allocations are fully accurate. However, given that PR19 will have a separate Water Resources price control, we suggested that Anglian should develop conceptual models that highlight the engineering and economic drivers of Water Resources botex, and then test down and report a limited number of empirical specifications of these conceptual models.

The resulting models developed by Anglian in Phase 2 were an **Output Model** and a **Geo/Demographic Model.** The **Output Model** "stays within" Water Resources conceptually and attempts to focus on how the characteristics of Water Resource influence botex requirements. In contrast, the **Geo/Demographic Model**, focuses conceptually on how geographic and demographic factors external to a water company determine botex requirements.

However, in contrast to the Bioresources models discussed below, the empirical implementation of these conceptual models resulted in estimated models that are not fully distinguished from each other. Thus, all the reported models share several output variables, which are the logged values of the numbers of sources and reservoir capacity. Similarly, one of the Geo/Demographic models includes the Abs/lic variable designed to capture water availability, which also appears in the single reported Output model. Furthermore, the reported Output model includes the natural log of average pumping head in Water Resources multiplied by Distribution Input. But this variable, which is designed to capture the pumping work required for water abstraction, also appears in one of the Geo/Demographic models. Thus, while we would agree with Anglian's assessment that the four reported models include relevant variables, and that they represent a significant improvement from Phase 1, the practical implementation does not fully provide the distinct models envisioned during the Phase 2 conceptual model development stage.

Given this, are the models reasonable in explaining modelled Water Resources botex? We believe this question deserves two contradictory replies. The first reply would focus on the elegant and parsimonious model specifications that explain considerable variance in reported Water Resources botex, and which are best exemplified by versions 4 and 5 of the Geo/Demographic model and the single reported version of the output model. However, the second reply would focus on the wide dispersion in actual versus modelled expenditure coming from these models as reported in Figure 8 of the Water Resources Annex. In our opinion, this dispersion may result from the implications of this business unit's poorly defined boundaries, the resulting likelihood of cost allocation differences and, given this business unit's small scale, the magnification of any such misreporting on model results, particularly when we consider the diversity of water abstraction sources employed by companies.

Thus, in our opinion, the models developed by Anglian for Water Resources provide a good answer to what still appears to be a poorly set and therefore extremely difficult exam question. For this reason, we encourage Anglian to pursue the further development of integrated water modelling they suggest in their Wholesale Water Integrated & Network Plus Models Annex.

Wholesale Water Recycling Integrated & Network Plus Models

In our Phase 1 review we noted that the range of variables considered by Anglian in its integrated Water Recycling models included key data on sludge and sewage treatment, as well as collection activities. However, we commented that none of Anglian's selected models fully struck the appropriate balance between controlling significantly for the complex activities being modelled and the likely collinearity between these explanatory factors. We therefore suggested that stronger models could be fostered via better consideration of the underlying relationships between chosen variables and how they interact. Moreover, we also suggested that 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 for the close correlation and interrelationship between these factors.

Regarding Water Recycling Network Plus, our Phase 1 review made somewhat similar comments. Thus, we noted that Anglian's modelling had largely been too parsimonious and had excluded crucial determinants of the production processes of sewage treatment and collection. We therefore argued that at a conceptual level a model should include water volumes, connections and transportation (sewer length) as output variables. Moreover, we suggested modelling that allows for cost interactions between these activities, while also retaining a focus on the parsimony of the model given the limited number of available observations.

Given these comments from Phase 1, Anglian asked us to directly develop alternative integrated Water Recycling models for application in Phase 2, with the intention of adapting the developed models for application to a Network Plus variant. The resulting models were developed because of input from two sources. Firstly, the incredibly fruitful and fully collaborative interaction with Anglian's operational and regulatory managers, which gave practical insights into the engineering and economic determinants of managerial decision making in sewerage system design and how this influences sewage treatment and sludge treatment works size, location and network transportation costs. And secondly, reference to and understanding of some key academic approaches to modelling the trade-off between the economies of scale in production (sewage treatment and sludge treatment) and increased network transportation costs.

As we were intrinsically involved in their development, we cannot give an unbiassed assessment of these models and, therefore simplify emphasize what we believe are their strengths.

Given the limited data available, the Extended Passing Distance model parsimoniously models botex at integrated company level. Moreover, with only five key variables (not including further control variables) it:

1. Captures differences in sewage (and sludge) treatment costs based on demographic and geographic characteristics via splitting the treatment output using Ofwat's population sparsity measures and/or the data on indigenous treatment of sludge.
2. Controls for the impact of network length on input characteristics as well as allowing for a nonlinear impact to capture increasing botex costs as network length increases ceteris paribus.
3. Captures that at aggregate company level when a firm has, on average, a larger network connected to each Water Recycling Centre (WRC), it benefits because it has a less fragmented network and treatment system, thereby allowing it to benefit from economies of scale in treatment that justify and outweigh the costs of additional interconnecting network length.

The Average System model resulted from further consideration of the variation in system design within companies and a desire to meaningfully model the impact of population sparsity and indigenous treatment of sludge in a more robust way than simply including these variables as control variables.

Moreover, our collaborative interaction with Anglian's managers led to several, in hindsight obvious, conclusions.

Firstly, companies do not optimize costs at aggregate company level but in fact are more likely to optimize costs at system level, with a system defined as the area and connections that have a direct physical network connection to a given WRC.

Secondly, the decision not to treat sludge indigenously at a given WRC is prima facie evidence that, for such WRCs, the increased costs of the additional interconnecting network needed to allow combined sewage and sludge treatment at a larger site are large enough to outweigh the potential benefits of treatment plant scale economies. In contrast, the decision to indigenously treat sludge suggests that for such plants the benefits of increased plant size outweigh the increased costs of networking required to connect sufficient properties. By extension, while Ofwat's population sparsity measures do not directly reveal the decision making of managers, similar logic will apply for WRCs respectively located in sparsely and non-sparsely populated areas.

Taken together, these considerations suggest that if we could model at sewerage system level, and allow for cost interactions between WRC size and network lengths, we would find that systems located in more rural areas will have positive cost increasing interactions between treatment and network activities while those in in more populated areas would have negative cost reducing interactions. Or stated differently, controlling for and allowing for differences in cost interactions between network and treatment activities at system level (that is, the WRC and its associated sewer network) is fundamental to explaining how demographic and geographic characteristics influence a company's overall cost of providing Water Recycling services.

Unfortunately, while this conceptual approach is clearly relevant in explaining intercompany differences in Water Recycling botex, the required system level data is not available for this project. However, we have been able to demonstrate that our conceptual model is empirically supported via an Average System model. This models average system botex (botex per WRC) as a function of average indigenous and nonindigenous (non-sparse and sparse) treatment per WRC, and further allowing for interactions between these load variables and average network length per WRC.

As we expected, based on our conceptualisation of this model, the interaction between average system indigenously treated (the share of non-sparse) sewage load and average system network length was negative, while a positive cost interaction parameter was found for the interaction between average non-indigenously treated (the share of sparse) sewage load and average network length.

In sum, we believe that the Average System model developed for Anglian Water is a significant contribution that captures how system level differences in cost interactions between network, sewage treatment and sludge treatment account for observed differences in company level botex requirements.

Bioresources Models

In our Phase 1 review of Anglian's suite of Water Recycling models, we argued for models that both control for the likely presence of cost interactions and also provide for a more consistent approach between disaggregated and aggregate models. With regard to Bioresources, we specifically noted that Ofwat's intention to assess Bioresources and Network Plus activities separately required consideration of cost interactions, as sludge is always treated at Sludge Treatment Centres (STCs) co-located with WRCs. Moreover, as argued above, the size and location of both WRCs and STCs, as well as the decision to transport sludge rather than increase system size to allow the scale required for indigenous sludge treatment, are determined by the trade-off between the benefits of increased WRC size and the costs of increased networking to facilitate it.

Given these comments, we believe that Anglian's Phase 2 Integrated Water Recycling models have addressed the above issues. Moreover, the conceptual understanding and models we developed with Anglian Water suggests that cost interactions between network, sewage treatment and sludge treatment are so important that only an integrated modelling approach can adequately control for them. However, we must accept that we are working in a context where Ofwat has a regulatory commitment to using a separate cost determination for Bioresources. We therefore advised and supported Anglian's efforts to develop stand-alone Bioresources models that could somehow still capture the importance of cost interaction with Network Plus activities.

The result was the development of the three alternative conceptual Bioresources models detailed in Anglian's Phase 2 report.

The **Output model** is an extension of Anglian's Phase 1 modelling: this model essentially "stays within" Bioresources and attempts to capture the cost of activities that happen within it such as sludge treatment, transportation and disposal. We can see this conceptual framework as essentially attempting to control for cost interactions with Network Plus by controlling for Bioresources specific characteristics that influence the cost of sludge treatment and disposal.

In contrast, the conceptual framework of the **Demographic model** rests on the reasonable assumption that the demographic and geographic characteristics of the region served by a company influence sewerage system design, WRC size and location, and hence sludge treatment and transportation costs. Stated differently, this approach concurs with the development and application of population sparsity measures by Ofwat, by emphasising that population density matters. However, the conceptual framework really emphasises that sparsity matters because it influences the nature of cost interactions between Network Plus and sludge treatment activities. Given the limited company level data available to implement this conceptual model, this approach has been empirically developed by separating the sludge treatment output based on population sparsity and thereby revealing increased estimated marginal costs of sludge treatment in sparsely settled areas relative to more densely populated areas.[1]

Finally, the conceptual framework of the **Network Plus model** explicitly considers that the configuration of Network Plus activities results from the cumulated impact of past decisions with regard to sewerage system design and WRC scale and location. The resulting Network Plus

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[1] We note that while the coefficient estimates reported by Anglian do not clearly demonstrate this, calculation of estimated marginal costs that were not reported are consistent with higher marginal costs for sparse sludge treatment. Note, this is also the case for the preliminary Network Plus driven Bioresource models that CPP has modelled while reviewing Anglian's Bioresources report.

configuration is not realistically changeable in the short or- medium term. In essence this implies that the location and characteristics of the sludge to be treated, and the requirements to transport it, are largely determined by the existing configuration of Network Plus, thereby necessitating controls for this to capture the resulting impact on botex in Bioresources activities.

Given the limited company level data available to implement the Network Plus conceptual model, this approach has been empirically developed in the models presented by Anglian by separating sludge treatment output based on the size of the WRC it is derived from. However, while the WRC size bands defined in the RAGs may appropriately capture how plant size influences sewage treatment costs, our impression is that that these size categories do not directly align with how the scale and configuration of WRCs influences sludge treatment costs. This is perhaps best evidenced by the reported model "Output 2: Network Plus model v10" where Anglian has presented a model which includes a control for arable land in the operating area, which is significant and positive. As this variable will be closely related to the degree of population sparsity a company faces, we interpret this variable as effectively capturing the increased costs associated with treating and transporting sludge in sparsely populated areas.

We therefore suggest that further refinements of the Network Plus variant of the Bioresources model be developed. We would favour developing models based on splitting sludge treatment load according to whether it is indigenously or non-indigenously treated. This approach would have two benefits. Firstly, as argued above, the decision whether or not to indigenously treat sludge is prima facie evidence that managers do or do not face high enough network costs that they chose to transport sludge for treatment. Secondly, it would also have the advantage of improving alignment between the Integrated Water Recycling and Network Plus models and the Bioresources models. Moreover, our own preliminary modelling suggests that using the indigenous treatment information will result in models with similar implications to those reported above for the Demographic models based on splitting sludge treatment load by population sparsity.

Retail Models

In our Phase 1 review, we suggested that Anglian should focus on an integrated approach to Retail cost assessment, and noted the potential for significant cost interactions between debt management and customer services, and between meter reading, customer services and billing. Our review also challenged the aggregation of doubtful debts and debt management costs: debt management activities aim to reduce doubtful debt and thereby maximize realized revenue from a company's potential regulatory revenue. As a result, managers should increase debt management expenditure only when the marginal cost of doing so is less than the reduction in doubtful debt (increase in realized revenue). Given this, the aggregation of doubtful debt and debt management is in fact the aggregation of an input (debt management) and the negative of the output created with that input (reduced doubtful debt).

At the outset of Phase 2, Anglian largely took a position consistent with our Phase 1 review critique and determined that it would primarily pursue only an integrated Retail model. Moreover, our interaction with Anglian's Retail managers confirmed the presence of significant interactions between Retail activities. However, given existing regulatory mechanisms regarding bad debt recovery, and its understanding of Ofwat's position with regard to the need to model debt management, Anglian also understandably chose to provide a model for doubtful debt & debt management and the aggregation of all other Retail activities.

With regard to the Doubtful Debt & Debt Management (DDDM)model, we suggested to Anglian that a practical solution to the conceptually flawed input-output relationship implicit in Ofwat's regulatory cost accounting guidelines was a simple re-specification of the model with debt management botex being the input, and realized revenue net of doubtful debt being the appropriate output. This suggestion rested on the fact that such a model would be consistent with an incentive to increase debt management only if it increased realized revenue. In the end, while Anglian has provided considerable discussion of this alternative approach within its report, it also decided to retain consistency with Ofwat's regulatory accounting guidelines.

The single reported DDDM model provides a parsimonious specification of this modelled botex definition as a function of revenue squared, average bill size (revenue/customer), a deprivation measure, a time trend and a constant. This specification captures the essence of an alternative restricted translog model directly including revenues and customers as the key outputs, which we suggested to Anglian. While there was little difference between these models in predicting costs, we have noted to Anglian that we believed the economic interpretation of the coefficients was clearer in this alternative specification, and that was particularly the case given that their model includes a squared log or revenue term but does not have the log of revenue included. However, both our alternative suggested model and Anglian's reported model capture the key relationship between revenues, customer numbers and deprivation that drive the regulatory accounting based definition of botex for DDDM.

We focus next on the Integrated Retail model, and the details of the single model reported by Anglian. We fully support the position taken by Anglian that the Retail relationship between metered and unmetered customers is sufficiently different to warrant the inclusion of metered and unmetered customers as key outputs in the model: Our interaction with Anglian's Retail managers and involvement in the actual modelling supports this, as within Retail services the distinction between water and sewerage customers is less important than the distinction between metered and unmetered customers. Similarly, customer interaction, debt management and other Retail functions are appropriately modelled by including the log of revenue per customer (A), although we must admit that our own preference would be to allow a translog model to more flexibly capture these interactions between revenues and customer numbers. As interrelated customer service and debt management activities are also likely to be higher with increased deprivation and in regions/times with increased unemployment, the related control variables to capture this have the expected sign and are statistically significant. Moreover, while we might question the incentive compatibility of including it in the cost assessment, increased billing complaints do lead to increased Retail expenditures as we should expect. Thus, on balance the overall impression of the Integrated Retail model is that it provides a parsimonious and appropriate specification, although the very large estimated elasticity of Retail botex with respect to regional wages supports a general view that the regional wage measure does not perform well or measure relevant wages appropriately.

However, we have not yet considered the variables included to control for differences in how a WaSC bills its water and sewerage services. Moreover, it is worth noting that Retail services is the one modelled service where Ofwat's approach maintains an assumption that water and sewerage services are fully integrated, while in all other business units its approach explicitly assumes that water and sewerage activities are fully separable. However, our interaction with Anglian's managers suggested to us that a variety of different arrangements are employed by WaSCs to bill their sewerage only customers, and that it was highly unlikely that the reporting of costs associated with this could consistently capture the cost implications of these different approaches. Moreover, while Ofwat's approach assumes that the appointed provider of sewerage services provides all of the Retail services, the actual billing and DDDM function is often provided by WoCs, and customers often contact the wrong company in the first instance for other customer service functions. These characteristics firstly suggest that the output and botex definitions for Retail services are not aligned with the reality of Retail service provision. More significantly, these issues, and the practical impossibility of being able to meaningfully control for them, may be the reason for the otherwise difficult to explain negative sign on the control variable for WoC billing of sewerage customers, However, rather than undermining the overall model, we believe that this result should give Ofwat cause for thought, and consideration of its regulatory accounting definitions and how they capture the outsourcing of Retail services to other appointed businesses. The very high variability of actual to modelled Retail services for DDDM reported by Anglian in Figure 3 of the Retail Annex further supports this conclusion

We finally focus on the reported models for all Other Retail Services, and note that version 6 includes a similar set of variables to the reported integrated model, but replaces billing complaints with SIM, and reasonably excludes variables for deprivation, average bill size and unemployment that are most closely associated with debt management activities. The other reported model, version 7, is identical to version 6 except for the inclusion of population sparsity instead of the controls for sewerage billing included in version 6 and the integrate model. We therefore first note that these models represent a reasonable restriction of the variables so as to exclude debt management from the relationship and seem appropriate.

The coefficients of the sewerage billing control variables are again difficult to interpret and supports our above discussion on this issue. In contrast, controlling for population sparsity, which has the potential to increase the costs associated with customer contact and which may also influence the potential to exploit scale economies in provision of Retail services, has the expected positive coefficient. Focussing on the SIM variable reveals a negative coefficient, which is significant in the model with population sparsity. This supports an expected relationship that botex in Retail services will be lower for companies with higher customer satisfaction and therefore less propensity by customers to contact customer services.

In sum, given the constraints imposed by the regulatory context, and the resulting data definitions and required modelling, we believe that the Retail models provided by Anglian are appropriate and an improvement on the work carried out in Phase 1. However, in what the reader will recognize as a familiar refrain, we are most comfortable with the Integrated Retail model, as it is best capable to capture the cost implications of significant interactions between various Retail services, which consultation with Anglian's Retail managers confirmed. Moreover, this conclusion is supported by the fact that in Figure 3 of Anglian's Retail Annex, the lowest variance in of actual to modelled Retail costs was found in the Integrated Retail models .

1. Models to be created

As there will be a price control for Water Resources at PR19 which is separate from the rest of the wholesale Water operations, there is a need to assess the cost requirements for Water Resources separately from the rest of wholesale water.

Ofwat highlighted in its PR19 Methodology statements that there are a variety of ways in which the Water Resources cost assessment could be undertaken using econometrics. These include developing a stand-alone Water Resources model; developing separate Integrated Water and Water Network Plus models and viewing the difference between the two cost assessments as the required cost assessment for Water Resources; and taking a fixed proportion of an Integrated model and attributing that to Water Resources.

We have been developing a suite of cost models based on the data collected in the 2016 and 2017 Ofwat Information Requests. In September 2017, we published the findings of Phase 1 of our cost modelling. This involved developing cost models for each of the individual Business Units identified in the Ofwat Regulatory Accounts Guidance (RAGs). For Water, this involved creating models for

- Water Resources
- Raw Water Distribution
- Water Treatment, and
- Treated Water Distribution.

We also used the models developed by the Competition and Markets Authority (CMA) for the Bristol PR14 determination as an integrated Water model.

The Phase 1 work identified significant problems with disaggregated models, principally due to issues with cost allocation and cost interaction. Despite the intention and expectation that the RAGs ought to lead to a homogenous treatment of costs and cost allocation between companies, supported by the efforts of the Ofwat Cost Assessment Working Group which has been active since early 2016, there are still significant differences in the way costs are handled by different companies.

In Phase 2 of our cost modelling, we have developed just three sets of wholesale Water models:

i) Models for Water Resources
ii) Models for Water Network Plus
iii) Integrated Water Models, covering all aspects of wholesale Water.

These three types of models allow us to take all the different approaches to assessing Water Resources cost requirements set out in the PR19 methodology. Our main focus in this Annex is the set of results from the stand-alone models for Water Resources. However, we also review the other two approaches and show the extent to which they all suggest similar results.

2. The production function for Water Resources

2.1. Functional form development for Water Resources models

We began Phase 2 of our cost modelling work with a workshop involving the key operational, regulatory and finance managers involved in Water Resources within Anglian Water, as well as our academic advisors. This was part of a series of workshops which covered all of the price control areas for PR19.

The aim of the workshop was to investigate the main cost drivers for the various processes involved in Water Resources. This was necessarily with a particular focus on our own operations, but looked more broadly at the way in which the other WaSCs and WoCs operate their Water Resources functions.

The conclusion reached at the workshop is that our cost structure for Water Resources is fundamentally driven by geographic and demographic factors.

The importance of geographic factors is obvious:

- The north and west of the country is more mountainous and has higher rainfall. Consequently, these areas have more reliance on impounding reservoirs and have less need for pumping.
- The south and east is flatter and is more water stressed. These areas have more reliance on river sources and small ground sources. By contrast with the north and west, the need for pumping is ubiquitous.

The importance of demography is perhaps less obvious. A thought experiment illustrates its significance:

Question: What if in the 1960s the Government had decided to build Milton Keynes in North Norfolk rather than North Buckinghamshire?

Answer: Then Anglian Water would have built a reservoir in Norfolk to serve the new town. In reality, of course, in the absence of such a large conurbation, we instead rely on large numbers of small boreholes across hundreds of square kilometres.

So-

- Demographic / geographic / population dispersion factors …

  lead to …

- The choices of size, type and location of water sources and reservoirs…

  which lead to …

- The observed Water Resources cost structure.

Of course, this example also highlights that the least cost solution at any point in time will be fundamentally influenced by past decisions, given the probable higher cost alternative of a major relocation of water sources and redesign of the existing water supply system that is a based on a cumulative series of past decisions.

This suggests two possible model forms for Water Resources:

1. This is based on demographic and geographic factors. It is the most fundamental: causation factors are completely exogenous to WaSCs and WoCs. This is the **Geo/demographic model**.
2. This takes the Water Resources' operational parameters as the causation factors. For a single five year regulatory period, these causation factors are exogenous. This is the **Outputs model**. The cost modelling work done in Phase 1 of our report for Water Resources focused on different variants of the Outputs model.

The centrality of geographic and demographic factors in determining cost structures is not confined to Water Resources. This became a leitmotiv of the series of workshops, covering all of the wholesale workshops, and our subsequent model development with our academic advisors. **We strongly believe that this insight needs to be incorporated into cost models in order effectively to represent the cost dynamics of wholesale water operations.**

2.2. The Geo-demographic model

Based on the discussion in section 2.1 above, the general form of the Geo-demographic model is set out in Table 1 below.

Putting to one side concerns about cost allocation, the costs pose no problem. The data are available and well understood. See section 3 below for further discussion of the cost data.

As the physical geography of the appointed area defines the available water sources, so the outputs are defined as the volume of DI from different types of sources. These all have different characteristics in terms of quality, quantity and ease of extraction. Groundwater sources (boreholes) tend to be small in terms of volume per individual borehole and by definition require pumping to access the water. Groundwater also tends to require less treatment – in some cases all it requires is a dose of chlorine to reach DWI standards for potable water. By contrast, river water sources can be much larger on average than groundwater sources. They generally require less pumping for abstraction but will require considerably more treatment as the water quality is generally much poorer than groundwater. Again, by contrast, upland impounding reservoirs will have little or no pumping cost associated with abstraction as the water arrives courtesy of gravity. Moreover, there may be an associated benefit from hydroelectric power generated from the outflow of an impounding reservoir. Water quality from impounding reservoirs also tends to be higher than from river sources.

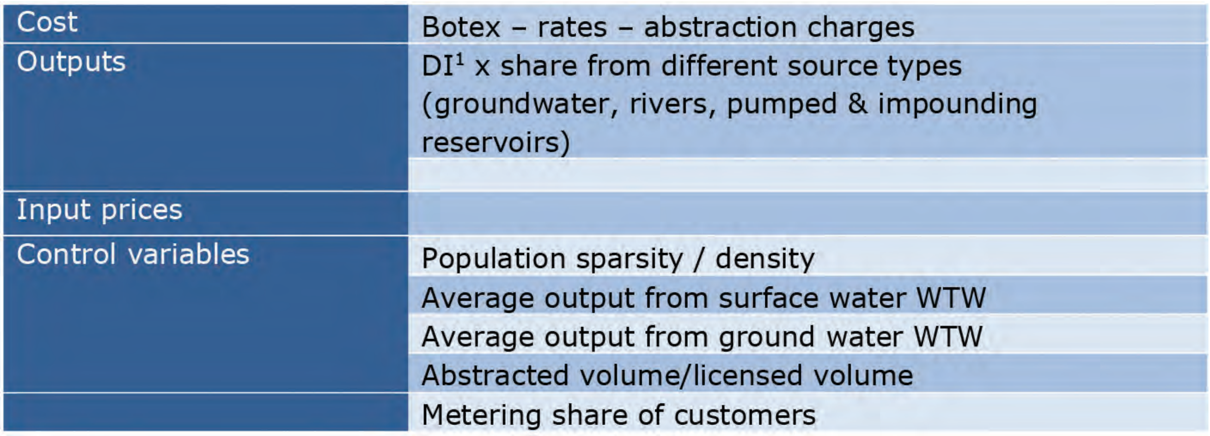
All of these factors affect the relative costs of abstracting water from the different sources and are thus pertinent for a geo-demographic model.

During 2016, in conjunction with industry protagonists through the Cost Assessment Working Group, Ofwat developed a set of population density and sparsity variables for all WaSCs and WoCs which were made available to the members of the Working Group. We have used these measures in our cost modelling.

We included variables for the average DI for ground and surface water source types as a measure of economies of scale.

Finally, we suspected that the level of water stress suffered by a particular company would affect its abstraction costs: the greater the level of water stress, the more marginal the sources that will be used (at greater unit cost). There may also be a tendency to use lower quality sources, although this will have a cost impact at treatment and not in abstraction. After trying and rejecting the Environment Agency's rating of water stress set out in a 2008 publication[2], we tried two indirect measures of water stress. The first was the ratio of abstracted to licensed volume per company. The argument is that a water stressed company is more likely to use a higher proportion of licensed water volume than a company with a superfluity of water. The second idea was to use the share of customers using a water meter as a proxy for water stress. The rationale was that the key driver for a water company to promote metering is to reduce usage and the key reason to reduce usage is to mitigate water stress and thus avoid the risk of water shortages.

Table 1: Geo-demographic model form



Cost	Botex – rates – abstraction charges
Outputs	DI[1] x share from different source types (groundwater, rivers, pumped & impounding reservoirs)
Input prices	
Control variables	Population sparsity / density
	Average output from surface water WTW
	Average output from ground water WTW
	Abstracted volume/licensed volume
	Metering share of customers

---

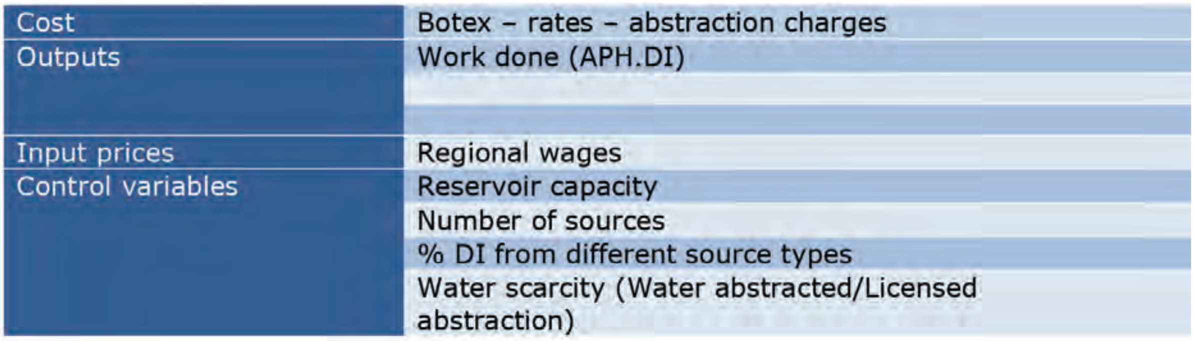
[1] DI: Distribution Input, the volume of treated water put into the distribution network. It differs from water delivered to customers principally by leakage. It can differ markedly from volume abstracted in a particular year due to changes in the volume stored in reservoirs.

[2] Water resources in England and Wales - current state and future pressures. December 2008 . The variable was only available for a single year and performed poorly when tested.

2.3. The Outputs model

Based on the discussion in section 2.1 above, the general form of the Outputs model is set out in Table 2 below.

Table 2: Outputs model form



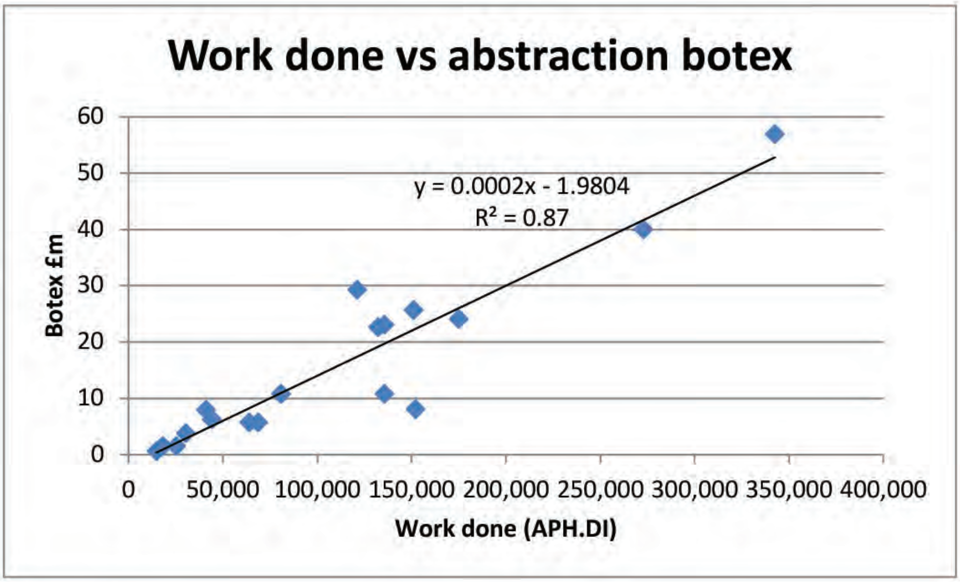
Cost	Botex – rates – abstraction charges
Outputs	Work done (APH.DI)
Input prices	Regional wages
Control variables	Reservoir capacity
	Number of sources
	% DI from different source types
	Water scarcity (Water abstracted/Licensed abstraction)

The Outputs model broadly accords with the cost models reported in our Phase 1 cost modelling report published in September 2017.

The key cost drivers used are discussed in detail in section 4 below.

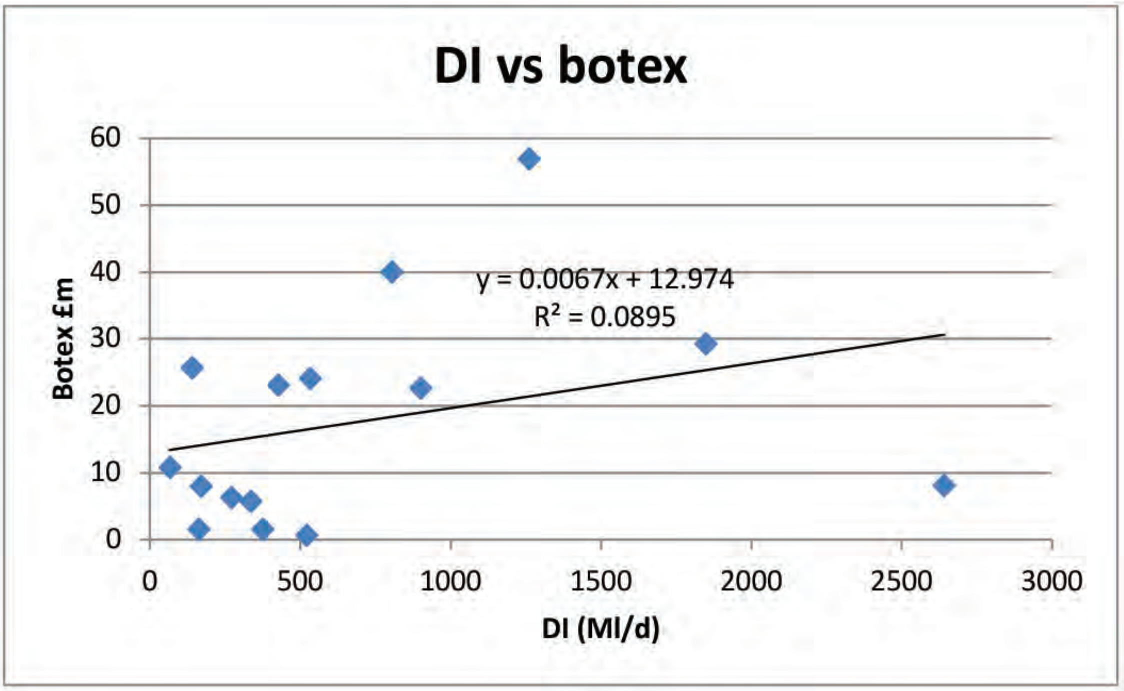
The choice of work done (defined as the product of DI and Average Pumping Head, APH) as the output is driven by logic. As can be seen from Figures 1 and 2 below, while there is a strong correlation between work done and botex, the correlation between DI and botex is very poor.

Figure 1: Work done vs abstraction botex for 2016-17



Source: 2017 Information Request, Anglian Water analysis

Figure 2: DI vs abstraction botex for 2016-17



Source: 2017 Information Request, Anglian Water analysis

As far as the control variables are concerned, both reservoir capacity and the number of sources are included as scale variables. The proportions of water from different types of sources – specifically, from rivers and from groundwater – were used both by Ofwat and by the CMA at PR14 to reflect the differing costs involved in abstracting (and treating) different types of water. And, as set out previously, the use of abstracted volume divided by licensed volume is designed to take account of the degree of water stress faced by the company.

3. Costs to be used

3.1. The data used

The source files for the data used in the Water resources cost modelling were as follows:

- 20171013 hc Master wholesale water July 2017
- Company specific labour cost indices
- High density and scarcity indices hc.

We recognize that even now at the time of writing (mid February 2018), the data set has yet to be confirmed and that the key data file (20171013 hc Master wholesale water July 2017) is still subject to modification. However, given the time constraints imposed on us by the PR19 timetable, we cannot wait until the data set has been finally confirmed to start the cost modelling. It is regrettable but inevitable that Ofwat will have a more accurate data set to work with when it begins its cost modelling. However, given the concerted efforts of the members of the Ofwat Cost Assessment Working Group in highlighting shortcomings within the data, it may be hoped that further changes will be relatively minor.

We will re-run our models after July 2018, when we will have the benefit of both corrected data and 2017-18 data. The impact of these changes will be available to us during the later stages of the price review process.

The costs included in Botex were as follows:

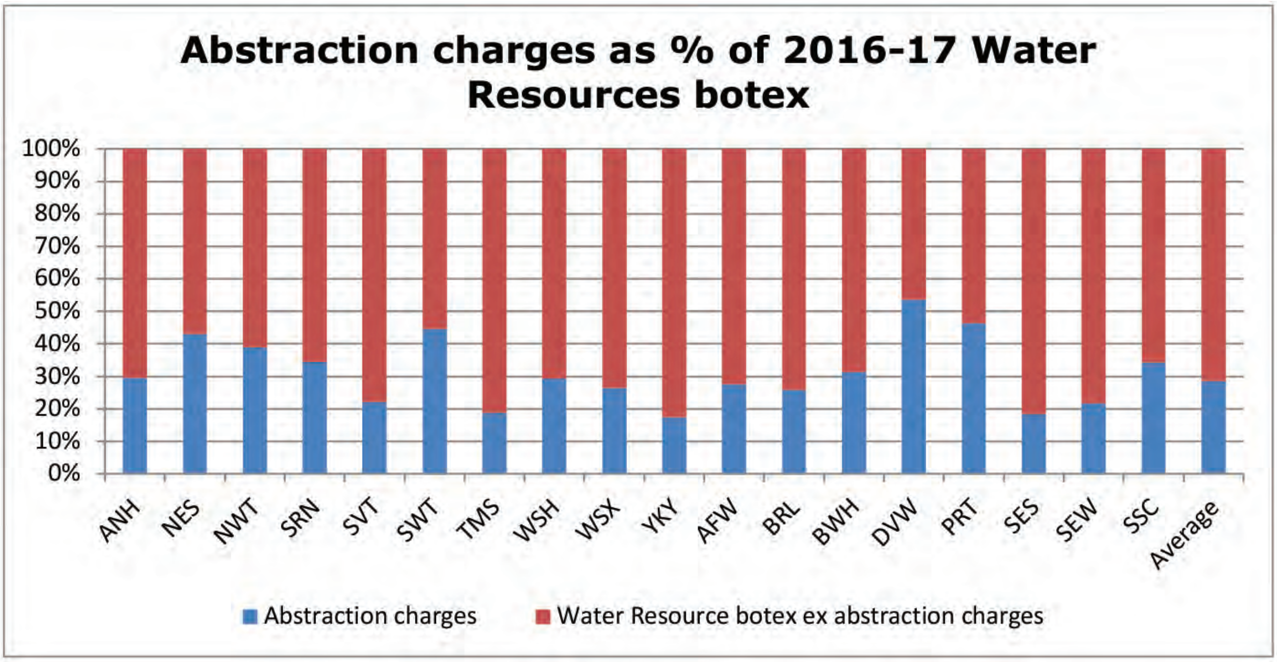
- Total operating expenditure (excluding third party services); minus
- Local authority and Cumulo rates; minus
- Environment Agency abstraction licence fees; plus
- Maintaining the long term capability of the assets – infra; plus
- Maintaining the long term capability of the assets - non-infra.

The costs are all taken from the Regulatory Accounts filed by appointed companies. All costs exclude atypical expenditure as reported by companies.

All costs are rebased in 2012-13 prices.

Abstraction licence costs are set on a regional basis by the Environment Agency and are variable between companies. In the December 2017 PR19 Final Methodology document, Ofwat indicated that it was not minded to exclude abstraction charges. As can be seen from Figure 3 below, abstraction charges account for 29% of 2016-17 botex across the industry. However, within this average figures for individual companies range from under 20% to over 50%. With companies generally having little control over the level of the charges, we still feel that the exclusion of abstraction charges from botex is warranted. Consequently, our cost modelling in Phase 2, like our Phase 1 work, excluded abstraction charges from botex.

Figure 3: Abstraction charges as a share of botex



Source: 2017 Information Request; Anglian Water analysis

In our Phase 1 report, we highlighted potential problems for cost modelling which flow from cost allocation. One area we recognize is particularly vulnerable is Water Resources. This is principally due to the relative size of Water Resources and Network Plus. As Network Plus botex is around ten times the size of Water Resources botex, it only takes a small difference in cost allocation approaches across companies to make a big difference to the Water Resources cost assessment.

In our Phase 1 report, we pointed out that the range of variances between actual and forecast results for Water Resources and Raw Water Distribution together is much less than for each individually. We also noted the practical difficulties in allocating power costs given the general absence of power sub-metering, especially at smaller sites. However, we now point out a further disparity in the handling of Water Resources' costs: the way capital maintenance is handled across different companies.

In Table 3, we set out the absolute and relative amounts of capital maintenance for all companies.

Table 3: Water Resources Capital Maintenance in context

	Water Resources		Total Water		Water Resources as % of Total			
	CM infra	CM non infra	CM infra	CM non infra	CM infra	CM non infra	Infra +non infra CM	£/Ml/day
ANH	14.1	31.3	200.0	373.6	7%	8%	8%	113.17
NES	9.6	44.1	206.8	311.9	5%	14%	10%	132.77
NWT	45.8	15.1	321.2	723.3	14%	2%	6%	96.51
SRN	0.5	12.8	176.8	198.4	0%	6%	4%	68.47
SVT	0.0	19.2	385.0	604.1	0%	3%	2%	28.51
SWT	16.0	2.9	89.5	163.4	18%	2%	7%	121.11
TMS	16.8	30.5	686.1	896.8	2%	3%	3%	49.13
WSH	11.8	20.7	74.0	466.1	16%	4%	6%	110.87
WSX	3.1	7.7	93.2	144.4	3%	5%	5%	87.46
YKY	47.5	12.4	248.0	345.2	19%	4%	10%	130.12
AFW	0.0	23.8	218.5	236.0	0%	10%	5%	72.26
BRL	14.0	12.2	134.0	82.3	10%	15%	12%	263.89
SBW	0.0	1.2	13.8	27.4	0%	4%	3%	22.53
DVW	0.0	0.5	10.9	24.8	0%	2%	1%	20.66
PRT	0.0	0.8	0.5	23.9	0%	3%	3%	12.69
SES	0.0	2.6	35.7	53.9	0%	5%	3%	42.68
SEW	0.1	10.0	133.1	155.4	0%	6%	4%	53.30
SSC	0.0	15.0	45.1	86.5	0%	17%	11%	109.46
All	179.6	262.7	3,072.3	4,917.4	6%	5%	6%	84.13

We have looked at Water Resources' capital maintenance against two metrics.

First, Water Resources' capital maintenance as a share of total capital maintenance varies from 1% to 12%. Moreover, Infra capital maintenance for Water Resources appears to be zero for some companies with groundwater. This seems odd.

Second, looking at Water Resources' capital maintenance per Ml/d of DI, there is a range of more than 20 to 1 between the highest and lowest companies.

Both of these measures show a very wide range of values.

Overall then, while we are confident that the models we propose are conceptually robust, we are concerned that the data used in developing the models is not similarly robust.

4. Key cost drivers

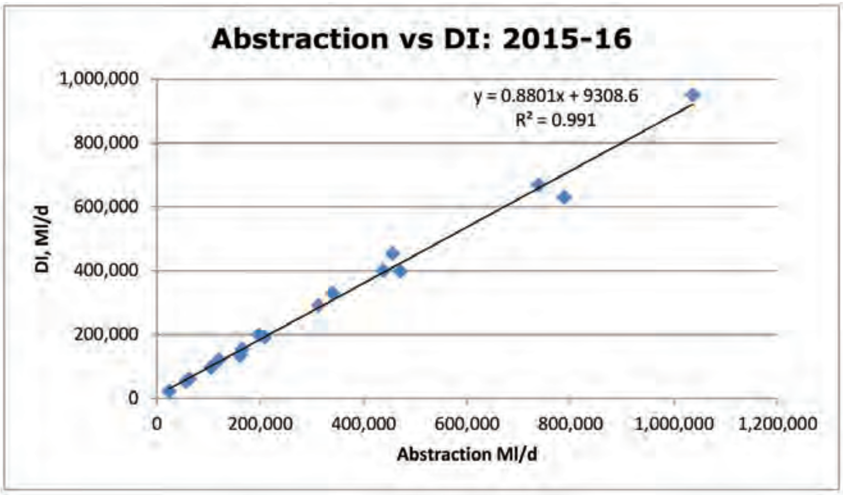
4.1. Water volume data

Abstracted volume would on the face of it be a better cost driver for Water Resources than Distribution Input (DI) as it is a more direct measure of performance. However:

- Abstraction data are only available for the latest two years through the Annual Performance Report (APR), Table 4D
- Similarly, the licensed volume data are only available for the last two years, also through the APR in Table 4D
- By comparison, DI data are available for all years back to privatisation
- Furthermore, the data series of shares of DI by source type are available back to the days of the June Return
- As can be seen in Figure 4 below, DI and abstracted volumes are strongly correlated across companies.

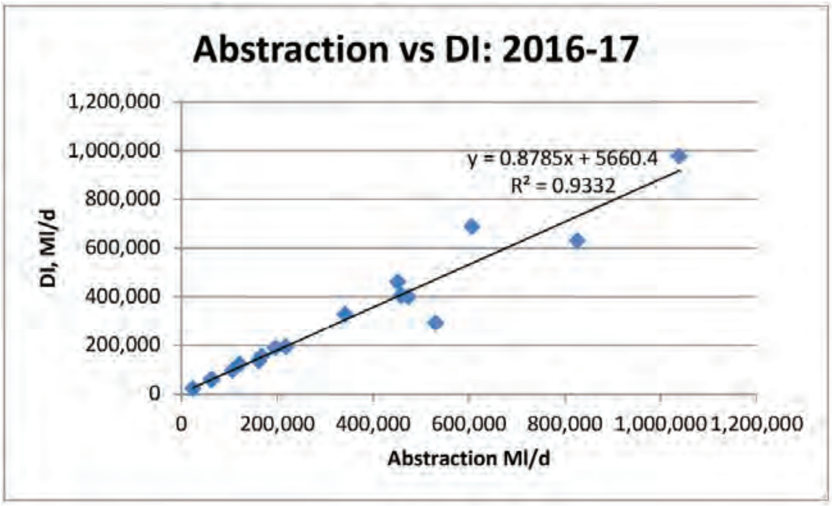
In conclusion, we are comfortable that DI acts as an acceptable proxy for abstracted volume in Water Resources models.

Figure 4: Relationship between abstraction and DI volume in 2015-16



Source: 2015-16 APR, Anglian Water analysis

Figure 5: Relationship between abstraction and DI volume in 2016-17



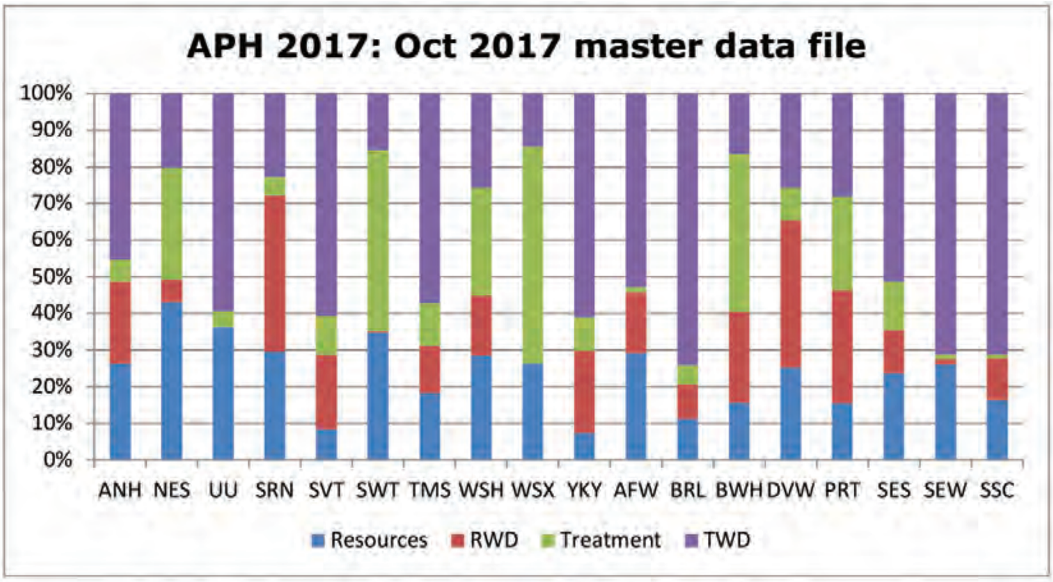
Source: 2015-16 APR, Anglian Water analysis

4.2. Average Pumping Head, APH

As set out in Section 2.3 above, APH is a key cost driver for Water Resources. At PR14, both Ofwat and the CMA also used APH in their respective cost modelling.

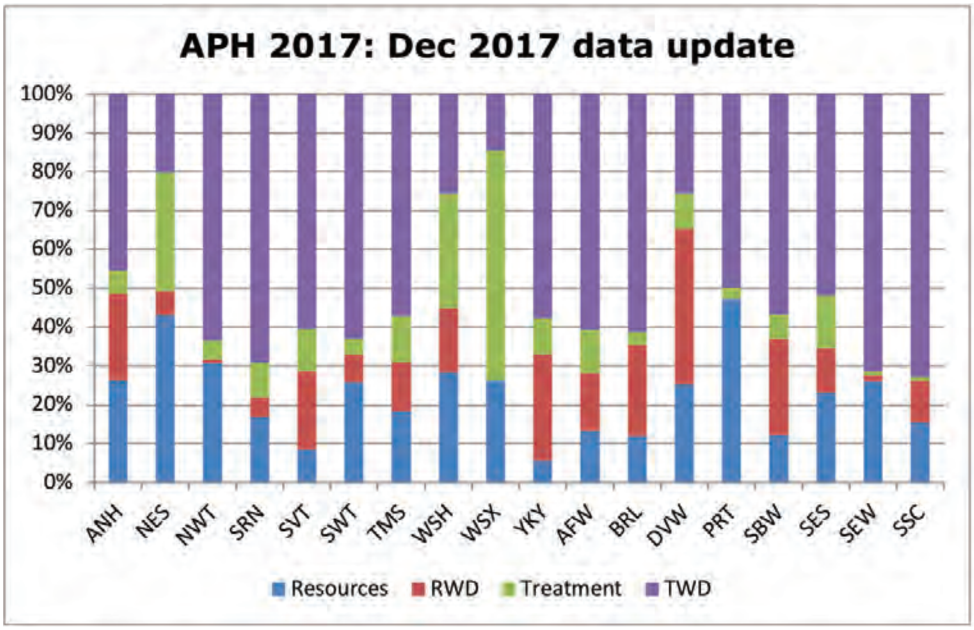
Unfortunately, APH has long been seen as a problematic statistic. Through more precise data definitions, Ofwat has been trying to improve the quality of the statistics as part of the preparation for its cost modelling work, using the 2017 Information Request data. Figure 6 below shows the split of APH between companies as shown in Ofwat's October 2017 Master data file. Figure 7, which follows, shows the updates submitted by companies in December 2017 following further guidance by Ofwat.

Figure 6: APH shares from October 2017 master data file



Source: 20171013 hc Master wholesale water July 2017, Anglian Water analysis

Figure 7: APH shares from December 2017 update



Source: Data made available by Ofwat 07/12/17, Anglian Water analysis

It is clear both that there have been some significant restatements of APH and that there remain some significant differences in split of APH between Business Units. While it is to be expected that there will be some significant differences of APH proportions between Business Units, the level of variability is still large.

The cost modelling which we have undertaken and are reporting here has been based on the October data. We have not had the opportunity to re-run the models using the new data. However, as we are confident that our models are well grounded both in economic and business logic, we feel justified in expecting the new data will improve the fit of our models rather than invalidate them.

4.3. Reservoir capacity & number of sources

Reservoir capacity and the total number of sources both act as scale variables for Water Resources. It appears that these variables should be sufficiently deterministic to allow for a common and accurate reporting of the data. Unlike APH, the data are the same for all apart from one company in one year between the October and the December data sets.

4.4. Regional Wages

At PR14, Ofwat developed a regional wage variable. Ofwat has further developed that series for PR19 based on SOC2 codes for wholesale based activities. We have taken the data made available by Ofwat for the years up to 2014-15. These have been put into 2102-13 cost base and have been trended forward up to 2016-17 for cost modelling purposes.

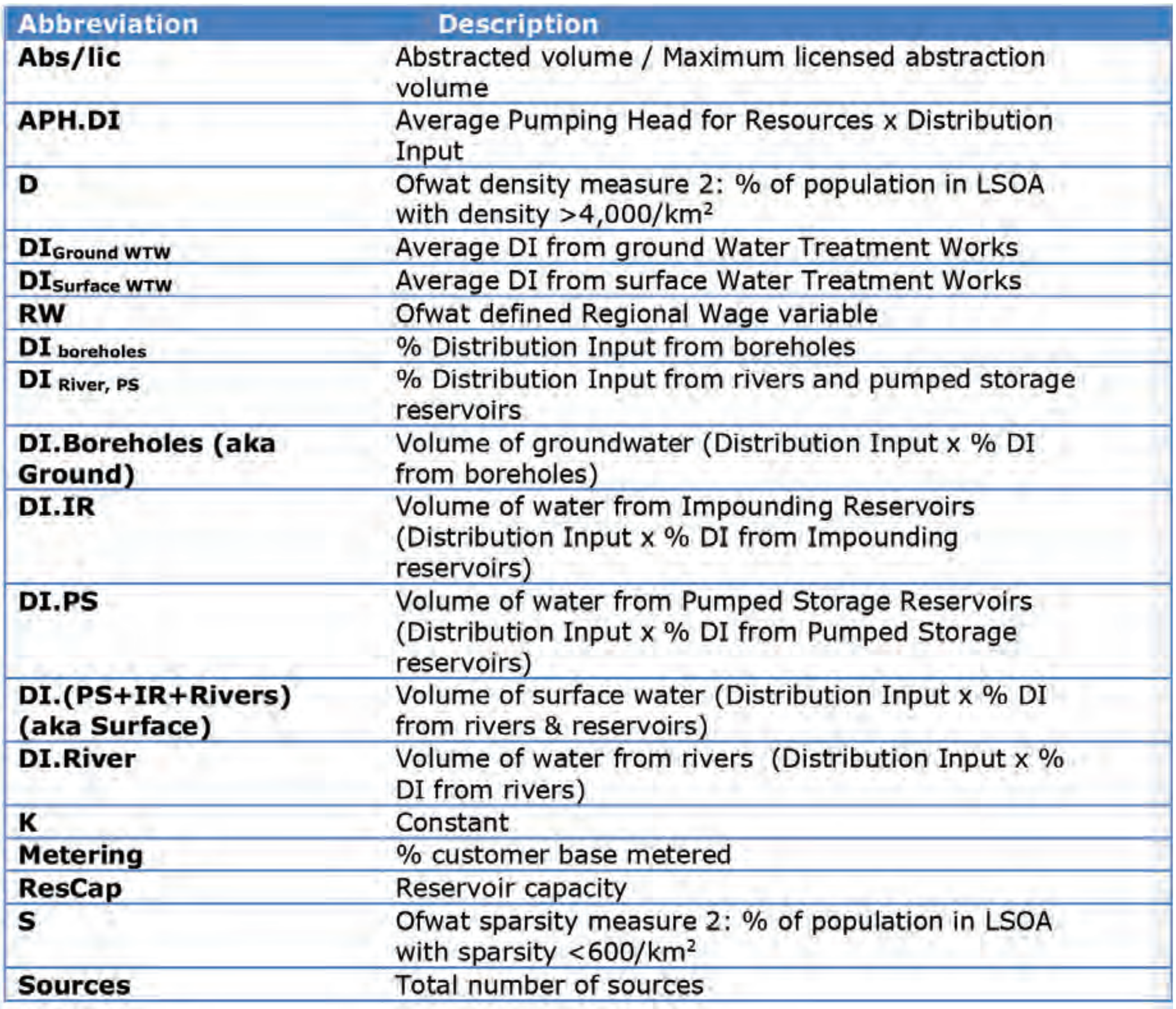
The regional wage variable did not perform well in Phase 1 of our cost modelling. Nor, for that matter, did its predecessor work well at PR14. It was tried again in Phase 2 but fared no better. The coefficient was both unrealistic (negative) and insignificant. As such, it has not been reported in Section 5.

5. Cost modelling development

We have used STATA v14 in our cost modelling. The outputs shown below in section 5 are the STATA outputs for the various models.

The key to the abbreviations used in section 5 are given in Table 4 below.

Table 4: Key for Section 5 cost models



Abbreviation	Description
Abs/lic	Abstracted volume / Maximum licensed abstraction volume
APH.DI	Average Pumping Head for Resources x Distribution Input
D	Ofwat density measure 2: % of population in LSOA with density >4,000/km^2
$\mathbf{DI}_{\text{Ground WTW}}$	Average DI from ground Water Treatment Works
$\mathbf{DI}_{\text{Surface WTW}}$	Average DI from surface Water Treatment Works
RW	Ofwat defined Regional Wage variable
$\mathbf{DI}_{\text{boreholes}}$	% Distribution Input from boreholes
$\mathbf{DI}_{\text{River, PS}}$	% Distribution Input from rivers and pumped storage reservoirs
DI.Boreholes (aka Ground)	Volume of groundwater (Distribution Input x % DI from boreholes)
DI.IR	Volume of water from Impounding Reservoirs (Distribution Input x % DI from Impounding reservoirs)
DI.PS	Volume of water from Pumped Storage Reservoirs (Distribution Input x % DI from Pumped Storage reservoirs)
DI.(PS+IR+Rivers) (aka Surface)	Volume of surface water (Distribution Input x % DI from rivers & reservoirs)
DI.River	Volume of water from rivers (Distribution Input x % DI from rivers)
K	Constant
Metering	% customer base metered
ResCap	Reservoir capacity
S	Ofwat sparsity measure 2: % of population in LSOA with sparsity <600/km^2
Sources	Total number of sources

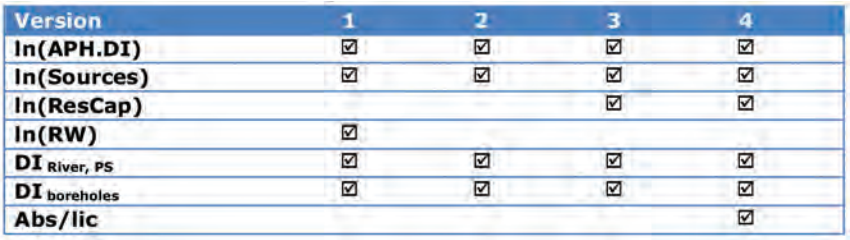
5.1. Outputs model

We developed four versions of the outputs model described in Section 2.3. The cost drivers in these versions are set out in Table 4 below.

The starting point for the Outputs analysis was version 1. With the exception of regional wages, the coefficients of all variables were significant and the adjusted R^2 was 0.88. Version 2 dropped regional wages, leaving the adjusted R^2 unchanged at 2 decimal places. Version 3 added in reservoir capacity. R^2 increased to 0.89, still with all coefficients significant. Finally, in version 4, abstracted/licensed was included to take the level of water stress faced by companies into account. Once again, all coefficients were significant and the adjusted R^2 again increased to 0.90.

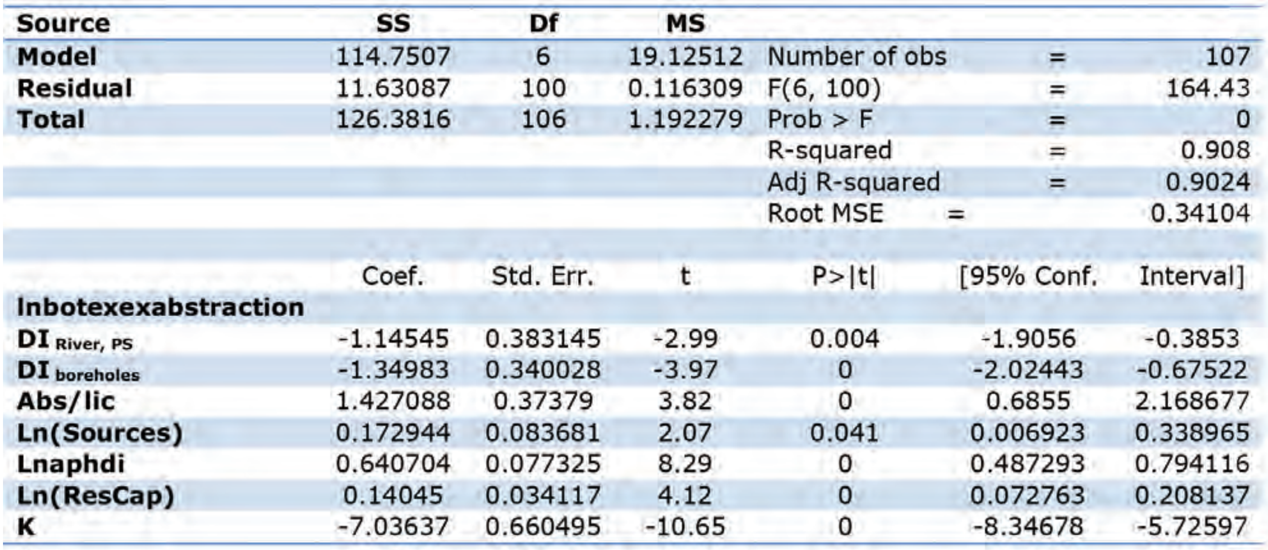
Version 4 was the preferred version of the Output model. It had the highest adjusted R^2, it passed the Brausch Pagan heteroskedasticity test and it was the only one of the four versions to pass the Ramsey Reset Test. **Version 4 is reported in detail as Table 6 below.**

Table 5: Cost drivers in Outputs model versions



Version	1	2	3	4
ln(APH.DI)	☑	☑	☑	☑
ln(Sources)	☑	☑	☑	☑
ln(ResCap)			☑	☑
ln(RW)	☑			
$DI_{River, PS}$	☑	☑	☑	☑
$DI_{boreholes}$	☑	☑	☑	☑
Abs/lic				☑

Table 6: Outputs model v4



Source	**SS**	**Df**	**MS**			
Model	114.7507	6	19.12512	Number of obs	=	107
Residual	11.63087	100	0.116309	F(6, 100)	=	164.43
Total	126.3816	106	1.192279	Prob > F	=	0
				R-squared	=	0.908
				Adj R-squared	=	0.9024
				Root MSE	=	0.34104
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnbotexexabstraction						
$DI_{River, PS}$	-1.14545	0.383145	-2.99	0.004	-1.9056	-0.3853
$DI_{boreholes}$	-1.34983	0.340028	-3.97	0	-2.02443	-0.67522
Abs/lic	1.427088	0.37379	3.82	0	0.6855	2.168677
Ln(Sources)	0.172944	0.083681	2.07	0.041	0.006923	0.338965
Lnaphdi	0.640704	0.077325	8.29	0	0.487293	0.794116
Ln(ResCap)	0.14045	0.034117	4.12	0	0.072763	0.208137
K	-7.03637	0.660495	-10.65	0	-8.34678	-5.72597

5.2. Geo-demographic model

We developed five versions of the geo-demographic model described in Section 2.2. The cost drivers in these versions are set out in Table 7 below.

As set out in Table 7, the starting point for the Geo-demographic model development was version 1. This took the volume of water from the different source types as the output variable. The number of sources, reservoir capacity and abstracted volume/licensed volume (controlling for water stress) were included as control variables. The coefficients of all variables were significant and the adjusted R^2 for version 1 was 0.89, similar to the level of the Outputs model versions.

In version 2, population density and sparsity were added as variables. Adjusted R^2 rose to 0.90. However, the coefficients for both the DI from pumped storage reservoirs and the sparsity variable were insignificant.

Version 3 replaced the separate variables for DI from pumped storage reservoirs, from impounding reservoirs and from rivers with a composite variable for DI from surface water. The abstracted / licensed water stress variable was also replaced with an alternative variable measuring the extent of metering. Although all coefficients were significant and adjusted R^2 rose to 0.93, some coefficients were not capable of rational interpretation. For this reason, version 3 was not reported.

Version 4 took a different tack, looking at the average size of different ground and surface WTW. All coefficients were significant and adjusted R^2 was 0.91.

Version 5 drops the metering control variable from version 3. In this case, all coefficients are significant and explicable. Adjusted R^2 was 0.92.

Our preferred versions of the geo-demographic models were therefore, 2, 4 and 5. These are set out in Tables 8, 9 and 10 below.

Table 7: Cost drivers in Geo-demographic models

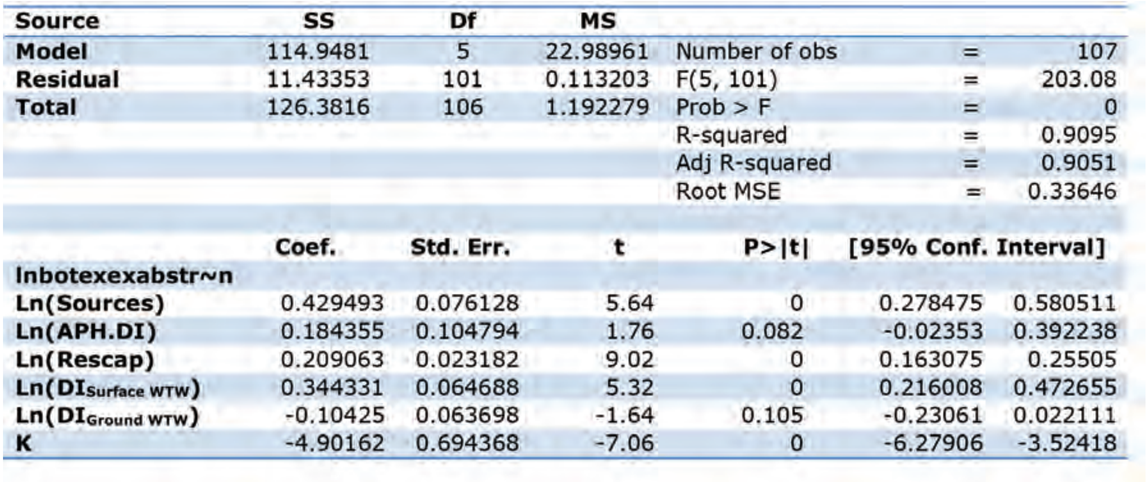
	1	2	3	4	5
ln(APH.DI)				☑	
ln(DI.PS)	☑	☑			
ln(DI.IR)	☑	☑			
ln(DI.River)	☑	☑			
ln(DI.Boreholes) (aka ln(Ground)	☑	☑	☑		☑
ln(Surface) i.e. ln(DI.(PS+IR+Rivers))			☑		☑
ln(Sources)	☑	☑	☑	☑	☑
ln(ResCap)	☑	☑	☑	☑	☑
ln($DI_{Surface\ WTW}$)				☑	
ln($DI_{Ground\ WTW}$)				☑	
Abs/lic	☑	☑			
D		☑			
S		☑			
Metering			☑		

Table 8: Geo-demographics model v2

Source	SS	Df	MS			
Model	115.1288	9	12.79209	Number of obs	=	107
Residual	11.25281	97	0.116008	F(9, 97)	=	110.27
Total	126.3816	106	1.192279	Prob > F	=	0
				R-squared	=	0.911
				Adj R-squared	=	0.9027
				Root MSE	=	0.3406

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnbotexexab~n						
Abs/lic	1.419715	0.370077	3.84	0	0.685214	2.154216
Ln(Sources)	0.268114	0.071193	3.77	0	0.126815	0.409413
Ln(ResCap)	0.304179	0.029631	10.27	0	0.24537	0.362987
S	-0.28428	0.196183	-1.45	0.151	-0.67365	0.105088
D	0.685654	0.313926	2.18	0.031	0.062597	1.308711
ln(DI.IR)	0.000717	0.000354	2.03	0.046	1.45E-05	0.001419
Ln(DI.PS)	-3.9E-05	0.00015	-0.26	0.797	-0.00034	0.000259
Ln(DI.River)	0.000433	0.000266	1.63	0.107	-9.5E-05	0.000962
Ln(DI.Boreholes)	0.00073	0.000295	2.48	0.015	0.000146	0.001315
K	-3.30704	0.409829	-8.07	0	-4.12044	-2.49365

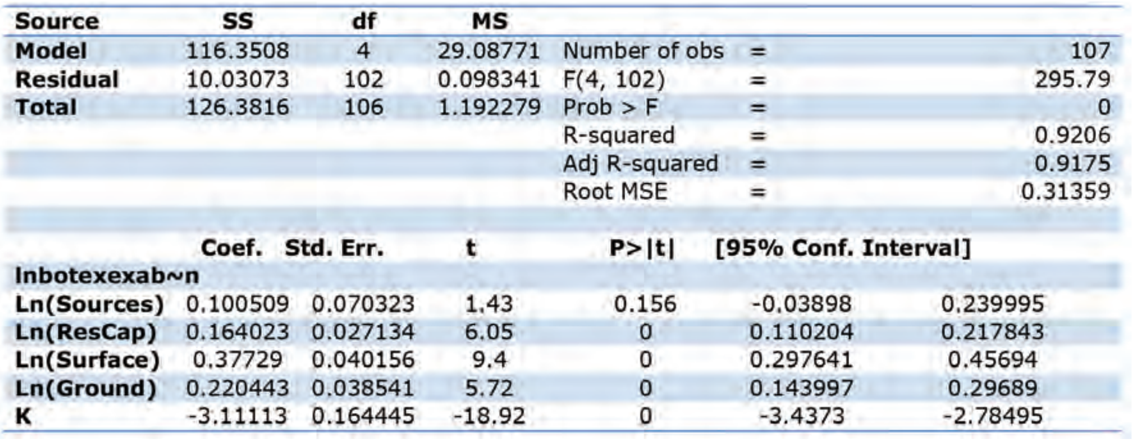
Table 9: Geo-demographics model v4



Source	SS	Df	MS			
Model	114.9481	5	22.98961	Number of obs	=	107
Residual	11.43353	101	0.113203	F(5, 101)	=	203.08
Total	126.3816	106	1.192279	Prob > F	=	0
				R-squared	=	0.9095
				Adj R-squared	=	0.9051
				Root MSE	=	0.33646

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Inbotexexabstr~n						
Ln(Sources)	0.429493	0.076128	5.64	0	0.278475	0.580511
Ln(APH.DI)	0.184355	0.104794	1.76	0.082	-0.02353	0.392238
Ln(Rescap)	0.209063	0.023182	9.02	0	0.163075	0.25505
Ln($DI_{Surface\ WTW}$)	0.344331	0.064688	5.32	0	0.216008	0.472655
Ln($DI_{Ground\ WTW}$)	-0.10425	0.063698	-1.64	0.105	-0.23061	0.022111
K	-4.90162	0.694368	-7.06	0	-6.27906	-3.52418

Table 10: Geo-demographics model v5



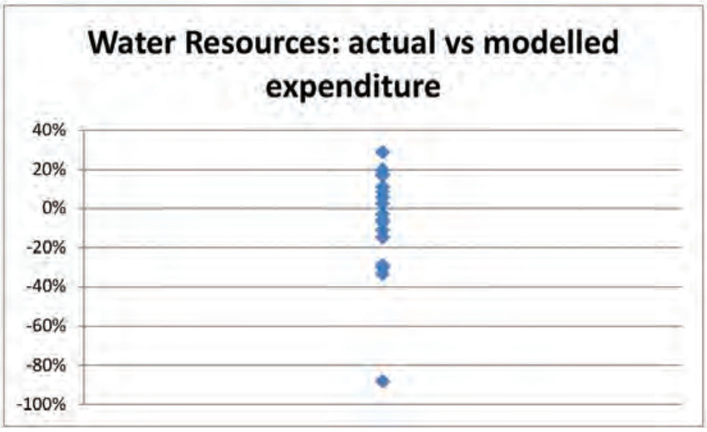
Source	SS	df	MS			
Model	116.3508	4	29.08771	Number of obs	=	107
Residual	10.03073	102	0.098341	F(4, 102)	=	295.79
Total	126.3816	106	1.192279	Prob > F	=	0
				R-squared	=	0.9206
				Adj R-squared	=	0.9175
				Root MSE	=	0.31359

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Inbotexexab~n						
Ln(Sources)	0.100509	0.070323	1.43	0.156	-0.03898	0.239995
Ln(ResCap)	0.164023	0.027134	6.05	0	0.110204	0.217843
Ln(Surface)	0.37729	0.040156	9.4	0	0.297641	0.45694
Ln(Ground)	0.220443	0.038541	5.72	0	0.143997	0.29689
K	-3.11113	0.164445	-18.92	0	-3.4373	-2.78495

5.3. Forecast results

We have calculated the expected value produced by each of our preferred versions (Outputs version 4 plus Geo-demographic versions 2, 4 and 5) for the eighteen companies and triangulated the values to produce a single modelled cost. The variances between modelled and actual costs for the companies are shown below as the blue markers in Figure 8 below. The range is from -30% to +29% if one outlier (a small WoC) is excluded.

Figure 8: Variability of actual vs modelled for stand-alone Water Resources costs



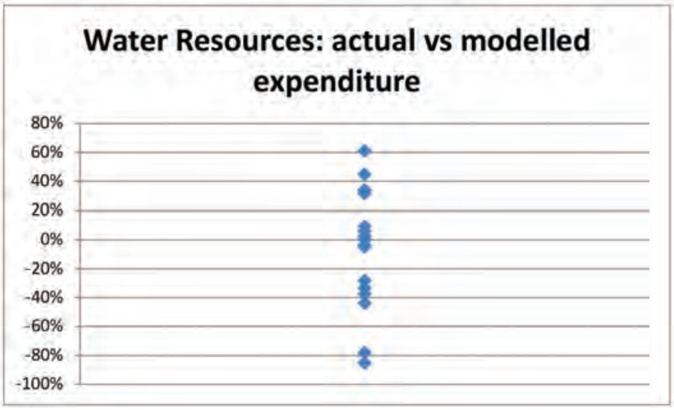
Source: 2017 Information Request; Anglian Water analysis

5.4. Alternative approaches to assessing Water Resources costs

As set out in section 1, there are alternative ways of assessing Water Resources costs, given the set of models which we have developed for wholesale Water. It is possible to infer Water Resources costs as well as look at the results of the stand-alone Water Resources models. We look at the variability of two inference approaches. First, in Figure 9, we compute Water Resources costs as the difference between the Integrated and Network Plus models. Then, in Figure 10, we compute them as a fixed proportion of the Integrated model, based on historical evidence.

The differencing approach shown in Figure 9 gives a higher range of variance than the stand-alone models. While this is particularly pronounced for small WoCs, this applies to WaSCs as well.

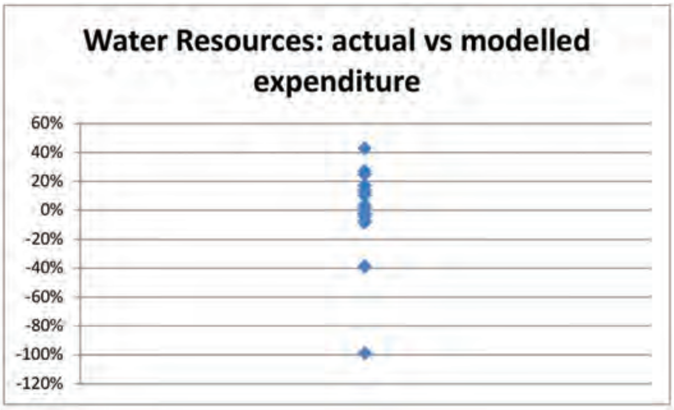
Figure 9: Variance of actual vs modelled for Water Resources costs computed as difference between Integrated and Network Plus models



Source: 2017 Information Request; Anglian Water analysis

To estimate Water Resources' cost assessment element as a share of the Wholesale Water Integrated cost assessment, we have looked at the share of Integrated botex represented by Water Resources over the last six years. We have used this proportion (8.5% as an industry average) as the share of the Integrated model output to compute a figure for Water Resources. The result of this calculation is shown in Figure 10 below.

Figure 10: Variance of actual vs modelled for Water Resources costs computed as a share of Integrated Water model

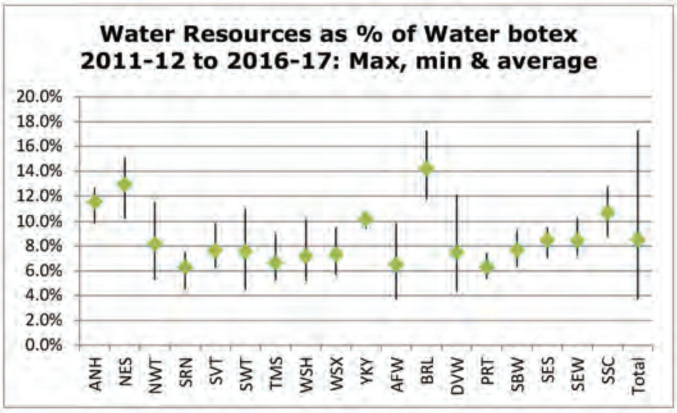


Source: 2017 Information Request; Anglian Water analysis

By comparison to the differencing approach in Figure 9, the range of variances of the share of Integrated set out in Figure 10 is significantly attenuated, though still greater than the variability of the stand-alone models. Once again, the big outlier is a small WoC.

A key question relating to this potential approach to setting the Water Resources cost assessment is how stable is the share of total botex represented by Water Resources, both over time and between companies. This is set out in Figure 11 below.

Figure 11: Variability of Water Resources share of wholesale water botex 2011-12 to 2016-17



Source: 2017 Information Request; Anglian Water analysis

In terms of averages between companies, five companies are well above the average for all companies; two are very close to the average and the remaining 11 companies are well below the average. In terms of the variability across the six years, this is quite significant: seven companies have a range (max-min)/ average greater than 50% and only three have a range/average less than 30%. Some of this variability may be down to different cost allocation approaches by companies between Water Resources and Network Plus. Some may just be down to the lumpiness of some capital maintenance. Whatever the reason, this approach of computing Water Resource's cost assessment as a share of the Integrated Water cost assessment appears to be problematic.

Overall, then, Figures 8 to 10 suggest that the stand-alone models should be viewed as more reliable than the alternative approaches to inferring a Water Resource cost assessment.

1. Models to be created

Since late 2016, we have been developing a suite of cost models. In September 2017, we published the findings of Phase 1 of our cost modelling. This involved developing cost models based on the August 2016 data submission for each of the individual Business Units identified in the Ofwat Regulatory Accounts Guidance (RAGs). For Water, this involved creating models for

- Water Resources
- Raw Water Distribution
- Water Treatment
- Treated Water Distribution.

We also used the models developed by the Competition and Markets Authority (CMA) for the Bristol PR14 determination as an Integrated Water model.

The Phase 1 work identified significant problems with disaggregated models, principally due to issues with cost allocation and cost interaction. Despite the intention and expectation that the RAGs ought to lead to a consistent treatment of costs and cost allocation between companies, supported by the efforts of the Ofwat Cost Assessment Working Group which has been active since early 2016, there are still significant differences in the way costs are handled by different companies.

In the light of these findings, Phase 2 of our cost modelling has focused on developing just three sets of wholesale Water models based on the price controls Ofwat intends to set at PR19:

i) Models for Water Resources
ii) Models for Water Network Plus
iii) Integrated Water models, covering all aspects of wholesale Water.

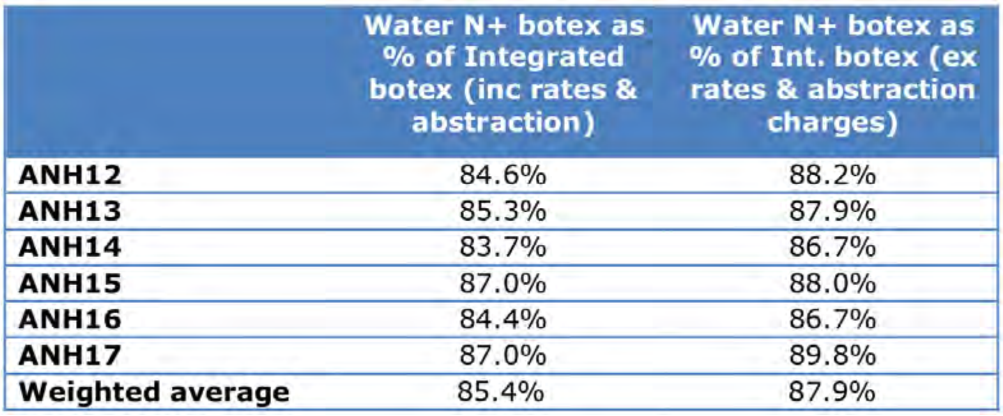
2. Approach taken

In Phase 2, we have again used the models developed by the Competition and Markets Authority (CMA) in 2015 for the Bristol Final Determination for the wholesale Water Integrated model. However, where at Phase 1 we used the August 2016 data submission, for Phase 2 we have used data from the 2017 Information Request.

Our academic assessor was critical of the CMA models in Phase 1 of our work. Accordingly we resolved to try and develop superior models during Phase 2. However, despite concerted efforts to develop superior models in the latter part of 2017, we were unable in the time available to develop robust models which were an improvement on what we already have from the CMA. We believe that it should be possible to develop models which are an improvement on what we have used and we intend to do so for cost efficiency purposes later in the year. However, given the constraints placed on us by the PR19 calendar, we felt compelled to use the suite of botex models developed and used at PR14 by the CMA for our proposed Water Integrated model.

For Water Network Plus in Phase 2, we have taken a different approach to the one followed in Phase 1. Whereas in Phase 1 we developed our own models for Water Network Plus, in Phase 2 we have used the same model forms as used for the Water Integrated model - that is to say, the CMA models. The reason for taking this approach is that Network Plus botex represents a high and stable proportion of Integrated Water botex; so the cost drivers which explain Water Integrated botex ought also to be able to explain Water Network Plus botex. The relationship between Water Integrated and Network Plus botex is set out for Anglian Water in Table 1 below.

Table 1: Network Plus botex as a share of Integrated botex



	Water N+ botex as % of Integrated botex (inc rates & abstraction)	Water N+ botex as % of Int. botex (ex rates & abstraction charges)
ANH12	84.6%	88.2%
ANH13	85.3%	87.9%
ANH14	83.7%	86.7%
ANH15	87.0%	88.0%
ANH16	84.4%	86.7%
ANH17	87.0%	89.8%
Weighted average	85.4%	87.9%

Source: 2017 Information Request, Anglian Water analysis

In our Phase 1 report , we described in detail the CMA model formats and approach. In line with our approach to the Phase 2 report, we do not propose to recapitulate this but instead would point interested readers to the earlier report. For Phase 2, we have recreated the various models (with 2017 data) and followed the same approach as the CMA in choosing which of the 18 versions of the three models should be reported. These are reported in Section 4 below.

In Sections 4 and 5 below, we set out the STATA outputs for the chosen model versions for Integrated and Network Plus respectively.

To assess modelled costs, Water Network Plus can be computed in three ways. First, we can use the Network Plus models we have developed and which we are reporting in Section 5. Second, we can compute a cost assessment for Network Plus as the difference between the Water Integrated model and the Water Resources model. Third, we can take a share of the Water Integrated cost assessment and use that as an estimate of the Network Plus cost assessment. The most obvious metric for determining the share of the Water Integrated cost assessment would seem to be the share of Water Integrated's botex represented by Network Plus' botex over an appropriate historical period. We set out the variability of these three methods of computing the Network Plus cost assessment in Section 5. We will set out in our business plan the approach we take to assessing our cost allowance for the next regulatory period.

3. Data used

The source files for the data used in the Water resources cost modelling were as follows:

- 20171013 hc Master wholesale water July 2017
- Company specific labour cost indices
- High density and scarcity indices hc.

We recognize that even now at the time of writing (mid February 2018), the data set has yet to be confirmed and that the key data file (20171013 hc Master wholesale water July 2017) is still subject to modification. However, given the time constraints imposed on us by the PR19 timetable, we cannot wait until the data set has been finally confirmed to start the cost modelling. It is regrettable but inevitable that Ofwat will have a more accurate data set to work with when it begins its cost modelling. However, given the concerted efforts of the members of the Ofwat Cost Assessment Working Group in highlighting shortcomings within the data, it may be hoped that further changes will be relatively minor.

We will re-run our models after July 2018, when we will have the benefit of both corrected data and 2017-18 data. The impact of these changes will be available to us during the later stages of the price review process.

The costs included in Botex were as follows:

- Total operating expenditure (excluding third party services), minus
- Local authority and Cumulo rates, plus
- Maintaining the long term capability of the assets – infra, plus
- Maintaining the long term capability of the assets - non-infra

The costs are all taken from the Regulatory Accounts filed by appointed companies. All costs exclude atypical expenditure as reported by companies.

All costs are rebased in 2012-13 prices.

4. Integrated Water results

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 2.

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 2: Outputs model form

Model name	Ln unit cost models	Linear UC models	Ln 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 2008-08). Botex is here defined as being the operating expenditure in that year plus the maintenance capex in that year.

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).

In line with the approach taken by the CMA, we have reported botex with smoothed capital maintenance data over 5 years and unsmoothed data over 7 years. Consequently, the number of observations might be expected to be 90 for smoothed and 126 for unsmoothed. Instead, as can be seen from the following tables, the figures are 89 and 125. The reason for this discrepancy is that Bournemouth and West Hampshire reported costs up to 2015-16. During 2016-17, the company was acquired by South West Water. For the most recent year, Bournemouth did not report a figure for costs, although it did report non-cost data. Instead, its costs are included in the South West Water figures.

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. We have taken the same approach to model selection, discarding 10 models. The remaining eight models, listed in Table 3, are all reported below in Tables 5 – 12.

Table 3: Summary of Integrated Water results

Model	EV1	EV2	EV3
Log Unit Cost		Unsmoothed: T5	Smoothed: T6
Log Aggregate		Unsmoothed: T7	Smoothed: T8
Linear Unit Cost	Unsmoothed: T9 Smoothed: T11	Unsmoothed: T10 Smoothed: T12	

We have used STATA v14 in our cost modelling. The outputs shown below in are the STATA outputs for the various models. The key to the abbreviations used in section 4 are given in Table 4 below.

Table 4: Key for Section 4 Section and 5 cost models

Abbreviation	Description
APH	Average Pumping Head. In the context of 2017 Information Request, this is the sum of the four APH – for Water Resources, Raw Water Distribution, Water Treatment and Treated Water Distribution.
DI_{Rivers}	Proportion of DI coming from Rivers
$DI_{Reservoirs}$	Proportion of DI coming from (both impounding and pumped storage) reservoirs
DI_{W3W4}	Proportion of DI treated using multiple treatment approaches. In the context of 2017 Information Request, this equates to the sum of proportions from GW3-6 and SW3-6
K	Constant
L	Aggregate length of potable mains
NHH	Proportion of Water delivered to Non Household customers
P	Aggregate number of properties
RW	Regional Wages
TD_i	Time Dummies
W_D	Water Delivered

Table 5: CMA Model ev2: unsmoothed log unit cost version

Source	SS	df	MS			
Model	2.236219	13	0.172017	Number of obs	=	125
Residual	4.062393	111	0.036598	F(13, 111)	=	4.7
Total	6.298613	124	0.050795	Prob > F	=	0
				R-squared	=	0.355
				Adj R-squared	=	0.2795
				Root MSE	=	0.19131
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex/P)						
Ln(W_d/P)	0.686528	0.311063	2.21	0.029	0.070137	1.302919
Ln(L/P)	0.551645	0.110251	5	0	0.333176	0.770114
Ln(RW)	0.839938	0.589021	1.43	0.157	-0.32725	2.007122
DI_{rivers}	0.045244	0.094015	0.48	0.631	-0.14105	0.23154
$DI_{reservoir}$	0.375437	0.080749	4.65	0	0.215428	0.535445
Ln(APH)	0.003707	0.070623	0.05	0.958	-0.13624	0.143652
NHH	-0.73123	0.503527	-1.45	0.149	-1.72901	0.266539
TD_1	-0.2414	0.086578	-2.79	0.006	-0.41296	-0.06984
TD_2	-0.15336	0.074466	-2.06	0.042	-0.30092	-0.0058
TD_3	-0.08165	0.07414	-1.1	0.273	-0.22857	0.06526
TD_4	-0.11008	0.067642	-1.63	0.106	-0.24412	0.023955
TD_5	-0.11746	0.067771	-1.73	0.086	-0.25175	0.016838
TD_6	-0.14869	0.06635	-2.24	0.027	-0.28016	-0.01721
K	1.683628	1.942412	0.87	0.388	-2.16539	5.532647

Table 6: CMA Model ev3: smoothed log unit cost version

Source	**SS**	**df**	**MS**			
Model	2.176314	10	0.217631	Number of obs	=	89
Residual	2.081123	78	0.026681	F(10, 78)	=	8.16
Total	4.257437	88	0.04838	Prob > F	=	0
				R-squared	=	0.5112
				Adj R-squared	=	0.4485
				Root MSE	=	0.16334
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex/P)						
Ln(W_d/P)	0.646122	0.168148	3.84	0	0.311366	0.980878
Ln(L/P)	0.418483	0.107427	3.9	0	0.204613	0.632353
Ln(RW)	0.005662	0.498416	0.01	0.991	-0.98661	0.997931
Ln(APH)	0.0011	0.06822	0.02	0.987	-0.13471	0.136915
NHH	-0.83585	0.378265	-2.21	0.03	-1.58892	-0.08279
DI_{w3w4}	0.314591	0.092672	3.39	0.001	0.130095	0.499086
TD_1	-0.102	0.063999	-1.59	0.115	-0.22941	0.025416
TD_2	-0.08018	0.059149	-1.36	0.179	-0.19793	0.037581
TD_3	-0.03521	0.058489	-0.6	0.549	-0.15165	0.081231
TD_4	-0.02984	0.057149	-0.52	0.603	-0.14361	0.083939
K	4.076717	1.580005	2.58	0.012	0.931169	7.222266

Table 7: CMA Model ev2: unsmoothed log aggregate version

Source	**SS**	**df**	**MS**			
Model	128.4797	14	9.177118	Number of obs	=	125
Residual	3.90225	110	0.035475	F(14, 110)	=	258.69
Total	132.3819	124	1.067596	Prob > F	=	0
				R-squared	=	0.9705
				Adj R-squared	=	0.9668
				Root MSE	=	0.18835
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex)						
Ln(W_d/P)	0.790313	0.310931	2.54	0.012	0.174121	1.406505
Ln(L/P)	-0.49222	0.111166	-4.43	0	-0.71252	-0.27191
Ln(RW)	0.718604	0.582725	1.23	0.22	-0.43622	1.873427
Ln(L)	1.044626	0.02331	44.81	0	0.998432	1.090821
DI_{rivers}	0.014139	0.094021	0.15	0.881	-0.17219	0.200467
$DI_{reservoir}$	0.34564	0.081401	4.25	0	0.184322	0.506958
Ln(APH)	0.079354	0.079824	0.99	0.322	-0.07884	0.237547
NHH	-0.48366	0.510905	-0.95	0.346	-1.49616	0.52883
TD_1	-0.23866	0.08507	-2.81	0.006	-0.40724	-0.07007
TD_2	-0.15344	0.073277	-2.09	0.039	-0.29865	-0.00822
TD_3	-0.07536	0.073023	-1.03	0.304	-0.22007	0.069356
TD_4	-0.1073	0.066597	-1.61	0.11	-0.23928	0.024678
TD_5	-0.11634	0.066717	-1.74	0.084	-0.24856	0.015878
TD_6	-0.14667	0.065321	-2.25	0.027	-0.27612	-0.01722
K	-5.55992	1.915006	-2.9	0.004	-9.35501	-1.76482

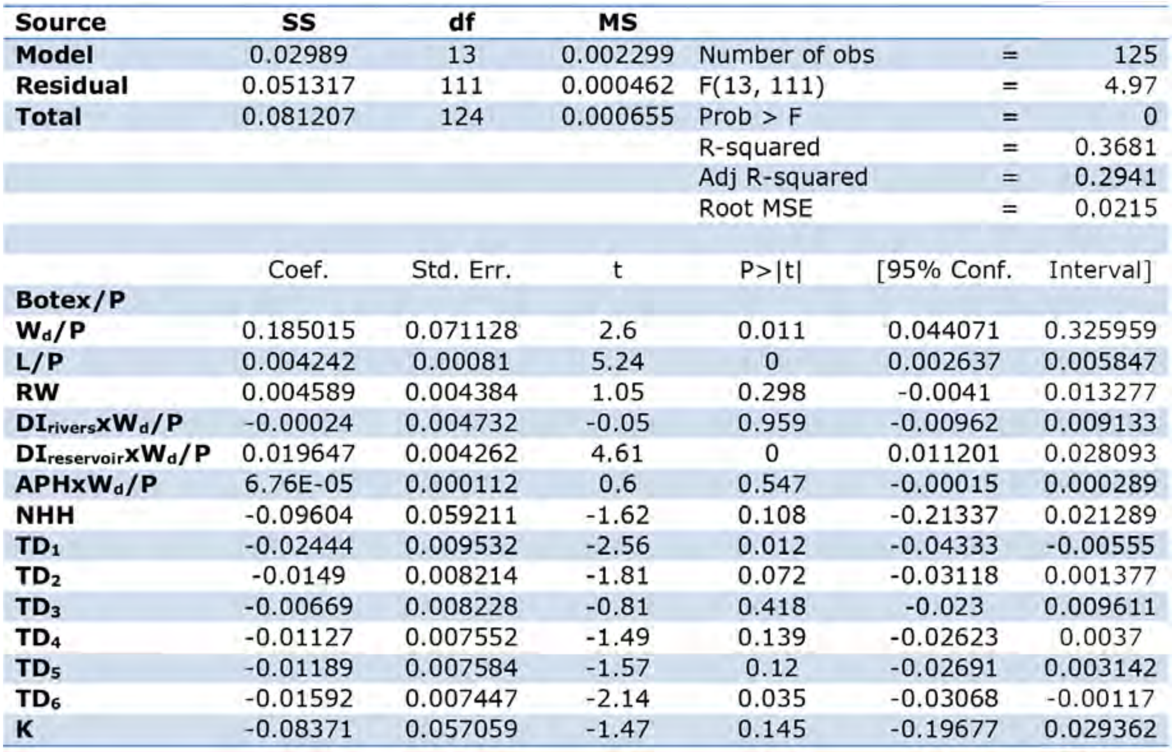
Table 8: CMA Model ev3: smoothed log aggregate version

Source	**SS**	**df**	**MS**			
Model	87.76873	11	7.978976	Number of obs	=	89
Residual	2.051129	77	0.026638	F(11, 77)	=	299.53
Total	89.81986	88	1.02068	Prob > F	=	0
				R-squared	=	0.9772
				Adj R-squared	=	0.9739
				Root MSE	=	0.16321
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(W_d/P)	0.650159	0.168055	3.87	0	0.315518	0.984799
Ln(L/P)	-0.60583	0.109759	-5.52	0	-0.82439	-0.38728
Ln(RW)	0.02037	0.498207	0.04	0.967	-0.97169	1.012426
Ln(L)	1.025123	0.023676	43.3	0	0.977979	1.072267
Ln(APH)	0.046332	0.080395	0.58	0.566	-0.11376	0.20642
NHH	-0.65773	0.413558	-1.59	0.116	-1.48123	0.165768
DI_{w3w4}	0.291698	0.095077	3.07	0.003	0.102375	0.48102
TD_1	-0.10215	0.063947	-1.6	0.114	-0.22949	0.025184
TD_2	-0.07937	0.059106	-1.34	0.183	-0.19706	0.038327
TD_3	-0.035	0.058442	-0.6	0.551	-0.15137	0.081371
TD_4	-0.02883	0.057111	-0.5	0.615	-0.14255	0.084897
K	-3.29499	1.638156	-2.01	0.048	-6.55698	-0.03301

Table 9: CMA Model ev1: unsmoothed linear unit cost version

Source	**SS**	**df**	**MS**			
Model	0.028673	12	0.002389	Number of obs	=	125
Residual	0.052533	112	0.000469	F(12, 112)	=	5.09
Total	0.081207	124	0.000655	Prob > F	=	0
				R-squared	=	0.3531
				Adj R-squared	=	0.2838
				Root MSE	=	0.02166
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Botex/P						
W_d/P	0.094327	0.044286	2.13	0.035	0.00658	0.182073
L/P	0.004308	0.000815	5.29	0	0.002694	0.005923
RW	0.009558	0.003159	3.03	0.003	0.003299	0.015818
DI_{rivers}xW_d/P	-0.00192	0.004652	-0.41	0.681	-0.01113	0.007299
$DI_{reservoir}$xW_d/P	0.020245	0.004277	4.73	0	0.01177	0.028719
APHxW_d/P	3.49E-05	0.000111	0.32	0.753	-0.00018	0.000254
TD_1	-0.03103	0.008684	-3.57	0.001	-0.04824	-0.01383
TD_2	-0.01894	0.007883	-2.4	0.018	-0.03456	-0.00332
TD_3	-0.01158	0.007711	-1.5	0.136	-0.02686	0.003697
TD_4	-0.01367	0.007459	-1.83	0.07	-0.02845	0.001112
TD_5	-0.01482	0.007419	-2	0.048	-0.02952	-0.00012
TD_6	-0.01808	0.00738	-2.45	0.016	-0.0327	-0.00346
K	-0.13084	0.049462	-2.65	0.009	-0.22884	-0.03283

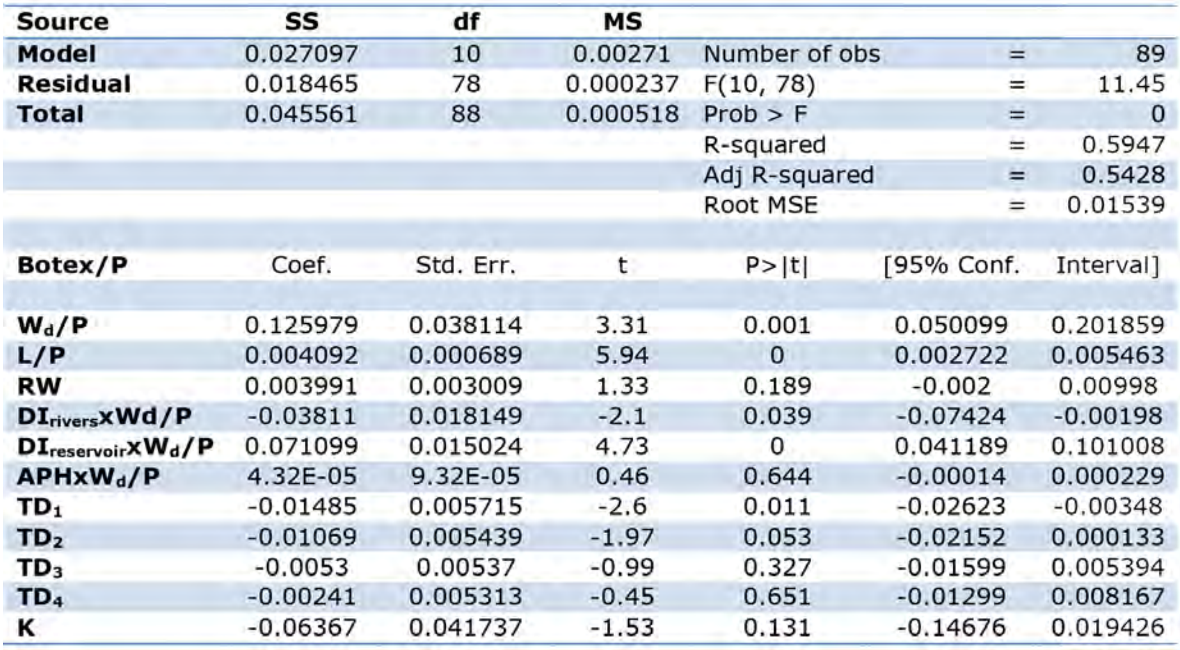
Table 10: CMA Model ev2: unsmoothed linear unit cost version



Source	SS	df	MS			
Model	0.02989	13	0.002299	Number of obs	=	125
Residual	0.051317	111	0.000462	F(13, 111)	=	4.97
Total	0.081207	124	0.000655	Prob > F	=	0
				R-squared	=	0.3681
				Adj R-squared	=	0.2941
				Root MSE	=	0.0215

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Botex/P						
W_d/P	0.185015	0.071128	2.6	0.011	0.044071	0.325959
L/P	0.004242	0.00081	5.24	0	0.002637	0.005847
RW	0.004589	0.004384	1.05	0.298	-0.0041	0.013277
$DI_{rivers}xW_d/P$	-0.00024	0.004732	-0.05	0.959	-0.00962	0.009133
$DI_{reservoir}xW_d/P$	0.019647	0.004262	4.61	0	0.011201	0.028093
$APHxW_d/P$	6.76E-05	0.000112	0.6	0.547	-0.00015	0.000289
NHH	-0.09604	0.059211	-1.62	0.108	-0.21337	0.021289
TD_1	-0.02444	0.009532	-2.56	0.012	-0.04333	-0.00555
TD_2	-0.0149	0.008214	-1.81	0.072	-0.03118	0.001377
TD_3	-0.00669	0.008228	-0.81	0.418	-0.023	0.009611
TD_4	-0.01127	0.007552	-1.49	0.139	-0.02623	0.0037
TD_5	-0.01189	0.007584	-1.57	0.12	-0.02691	0.003142
TD_6	-0.01592	0.007447	-2.14	0.035	-0.03068	-0.00117
K	-0.08371	0.057059	-1.47	0.145	-0.19677	0.029362

Table 11: CMA Model ev1: smoothed linear unit cost version



Source	SS	df	MS			
Model	0.027097	10	0.00271	Number of obs	=	89
Residual	0.018465	78	0.000237	F(10, 78)	=	11.45
Total	0.045561	88	0.000518	Prob > F	=	0
				R-squared	=	0.5947
				Adj R-squared	=	0.5428
				Root MSE	=	0.01539

Botex/P	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
W_d/P	0.125979	0.038114	3.31	0.001	0.050099	0.201859
L/P	0.004092	0.000689	5.94	0	0.002722	0.005463
RW	0.003991	0.003009	1.33	0.189	-0.002	0.00998
$DI_{rivers}xWd/P$	-0.03811	0.018149	-2.1	0.039	-0.07424	-0.00198
$DI_{reservoir}xW_d/P$	0.071099	0.015024	4.73	0	0.041189	0.101008
$APHxW_d/P$	4.32E-05	9.32E-05	0.46	0.644	-0.00014	0.000229
TD_1	-0.01485	0.005715	-2.6	0.011	-0.02623	-0.00348
TD_2	-0.01069	0.005439	-1.97	0.053	-0.02152	0.000133
TD_3	-0.0053	0.00537	-0.99	0.327	-0.01599	0.005394
TD_4	-0.00241	0.005313	-0.45	0.651	-0.01299	0.008167
K	-0.06367	0.041737	-1.53	0.131	-0.14676	0.019426

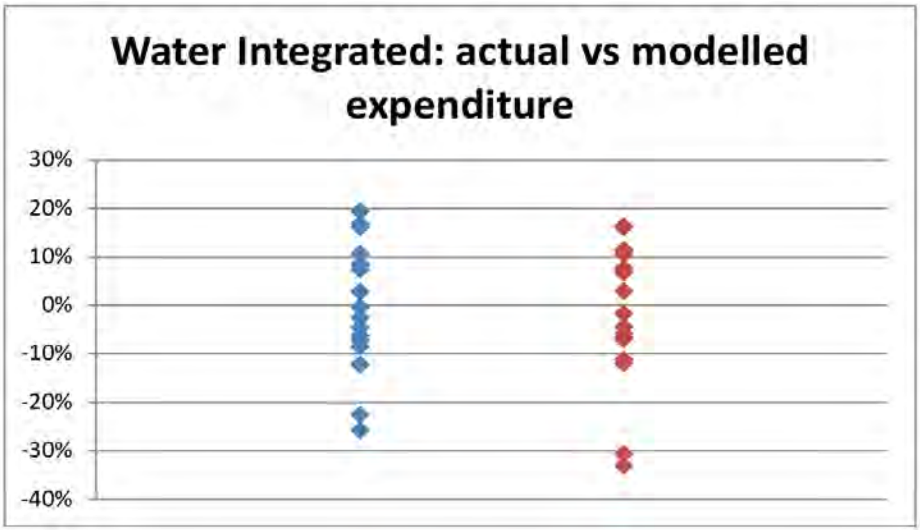
Table 12: CMA Model ev2: smoothed linear unit cost version

Source	SS	df	MS			
Model	0.027241	11	0.002476	Number of obs	=	89
Residual	0.01832	77	0.000238	F(11, 77)	=	10.41
Total	0.045561	88	0.000518	Prob > F	=	0
				R-squared	=	0.5979
				Adj R-squared	=	0.5405
				Root MSE	=	0.01542
	Coef.	Std. Err.	T	P>|t|	[95% Conf.	Interval]
Botex/P						
W_d/P	0.143367	0.044244	3.24	0.002	0.055267	0.231467
L/P	0.004039	0.000694	5.82	0	0.002658	0.005421
RW	0.002651	0.003471	0.76	0.447	-0.00426	0.009563
$DI_{rivers}xW_d/P$	-0.03289	0.019386	-1.7	0.094	-0.0715	0.005708
$DI_{reservoir}xW_d/P$	0.070119	0.015114	4.64	0	0.040023	0.100215
$APHxW_d/P$	5.21E-05	9.42E-05	0.55	0.582	-0.00014	0.00024
NHH	-0.03514	0.04507	-0.78	0.438	-0.12488	0.054609
TD_1	-0.01373	0.005907	-2.32	0.023	-0.0255	-0.00197
TD_2	-0.01024	0.005483	-1.87	0.066	-0.02116	0.000675
TD_3	-0.0047	0.005437	-0.87	0.39	-0.01553	0.006122
TD_4	-0.00209	0.005342	-0.39	0.697	-0.01273	0.00855
K	-0.0449	0.048274	-0.93	0.355	-0.14102	0.05123

We have calculated the expected value produced by each of our preferred versions of the Integrated Water models for the eighteen companies and triangulated the values to produce a single modelled cost. The variance between actual and modelled costs are shown below as the blue markers in Figure 1 below. The range is from -26% to +19%. If two outliers are excluded, the range is from -12% to +19%.

As mentioned in section 3 above, we also took the sum of the expected values of the Water Resources models and the Network Plus for all eighteen companies. The variances on this basis are shown as the red markers in Figure 1. Excluding the two outliers, the range is from -11% to +16%. The ranking of the individual companies in both cases are very similar, as set out in Figure 2.

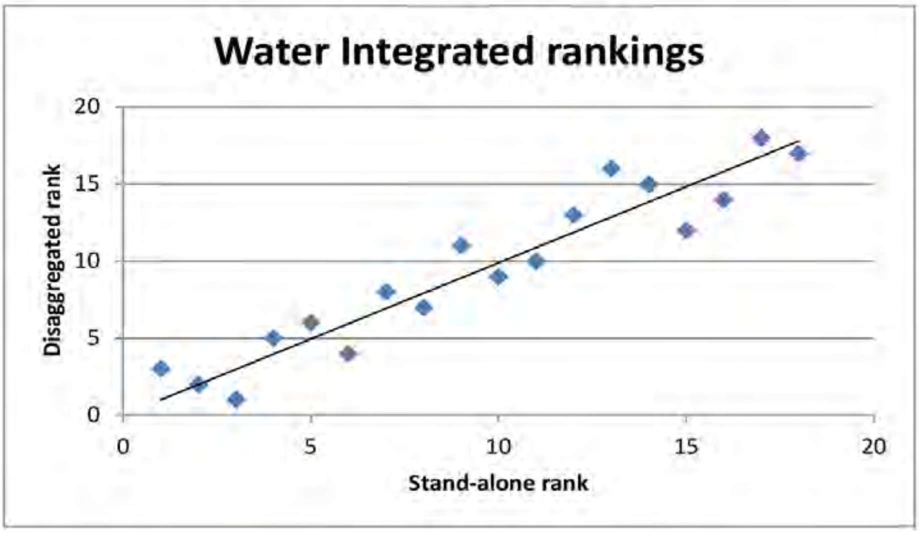
Figure 1: Variability of actual vs modelled for Integrated Water costs



Source: 2017 Information Request; Anglian Water analysis

In Figure 2, the ranking of the eighteen companies using the wholesale Water Integrated models described in Tables 2 -9 are shown on the X axis. The ranking of the companies using the sum of the Water Resources and the Water Network Plus models is shown on the Y axis.

Figure 2: Ranking of companies for Water Integrated



Source: 2017 Information Request; Anglian Water analysis

In conclusion, the two separate ways of computing the Water Integrated botex give similar results. Both provide a credible basis for estimating the PR19 cost assessment. This gives us confidence that the trio of models together represent a coherent picture of botex for wholesale water.

5. Water Network Plus results

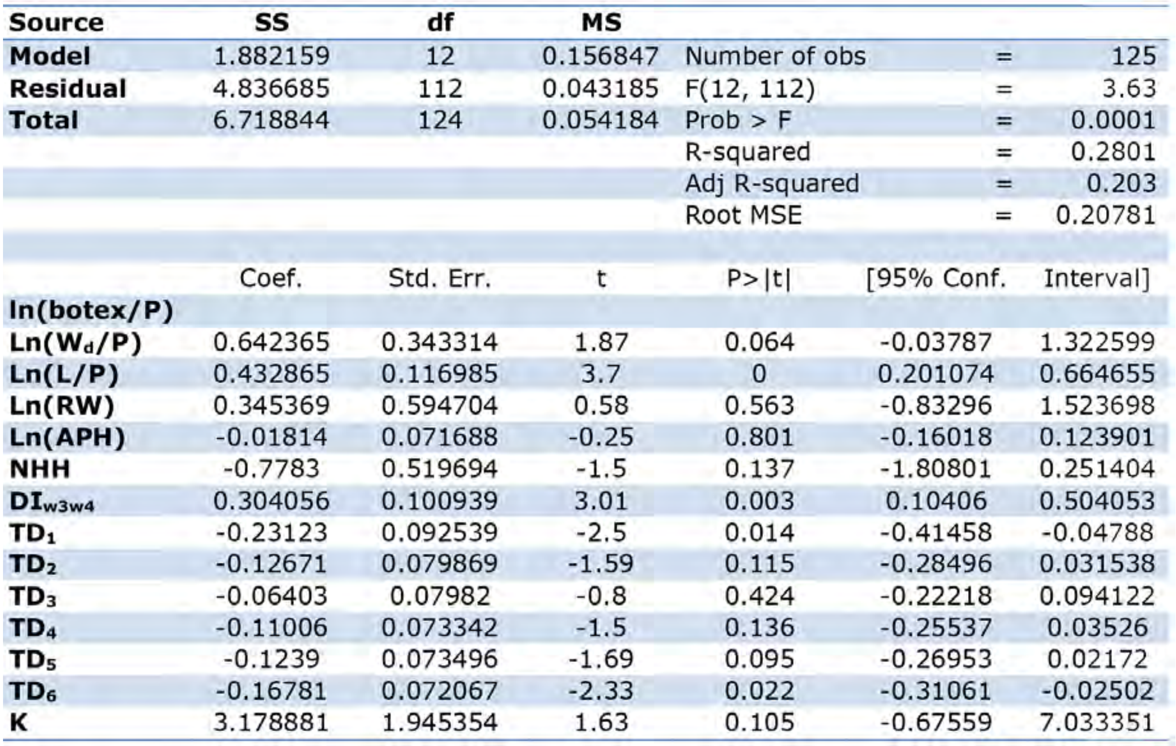
For the reasons set out in Section 2 above, we have used the CMA model forms to model wholesale Water Network Plus. Although it may be possible to add in additional control variables, we were not able to do so in the time available.

For Network Plus, of these 18 models CMA models, we discarded 13 models. The remaining five models are all listed below in Table 13 and reported in Tables 14-18.

Table 13: Summary of Water Network Plus results

Model	EV1	EV2	EV3
Log Unit Cost		Unsmoothed: T16	Unsmoothed:T15 Smoothed: T14
Log Aggregate			Unsmoothed:T17 Smoothed: T18
Linear Unit Cost			

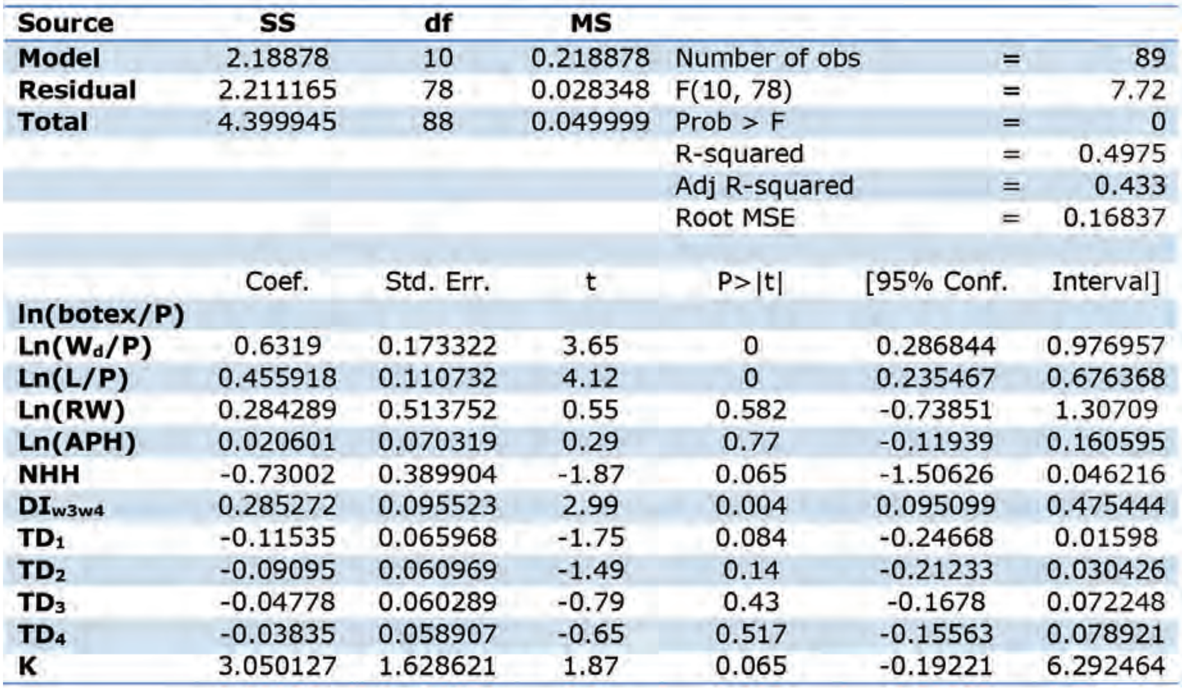
Table 14: CMA Model ev3: unsmoothed log unit cost version



Source	**SS**	**df**	**MS**			
Model	1.882159	12	0.156847	Number of obs	=	125
Residual	4.836685	112	0.043185	F(12, 112)	=	3.63
Total	6.718844	124	0.054184	Prob > F	=	0.0001
				R-squared	=	0.2801
				Adj R-squared	=	0.203
				Root MSE	=	0.20781

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln(botex/P)						
Ln(W_d/P)	0.642365	0.343314	1.87	0.064	-0.03787	1.322599
Ln(L/P)	0.432865	0.116985	3.7	0	0.201074	0.664655
Ln(RW)	0.345369	0.594704	0.58	0.563	-0.83296	1.523698
Ln(APH)	-0.01814	0.071688	-0.25	0.801	-0.16018	0.123901
NHH	-0.7783	0.519694	-1.5	0.137	-1.80801	0.251404
DI_{w3w4}	0.304056	0.100939	3.01	0.003	0.10406	0.504053
TD_1	-0.23123	0.092539	-2.5	0.014	-0.41458	-0.04788
TD_2	-0.12671	0.079869	-1.59	0.115	-0.28496	0.031538
TD_3	-0.06403	0.07982	-0.8	0.424	-0.22218	0.094122
TD_4	-0.11006	0.073342	-1.5	0.136	-0.25537	0.03526
TD_5	-0.1239	0.073496	-1.69	0.095	-0.26953	0.02172
TD_6	-0.16781	0.072067	-2.33	0.022	-0.31061	-0.02502
K	3.178881	1.945354	1.63	0.105	-0.67559	7.033351

Table 15: CMA Model ev3: smoothed log unit cost version



Source	**SS**	**df**	**MS**			
Model	2.18878	10	0.218878	Number of obs	=	89
Residual	2.211165	78	0.028348	F(10, 78)	=	7.72
Total	4.399945	88	0.049999	Prob > F	=	0
				R-squared	=	0.4975
				Adj R-squared	=	0.433
				Root MSE	=	0.16837

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln(botex/P)						
Ln(W_d/P)	0.6319	0.173322	3.65	0	0.286844	0.976957
Ln(L/P)	0.455918	0.110732	4.12	0	0.235467	0.676368
Ln(RW)	0.284289	0.513752	0.55	0.582	-0.73851	1.30709
Ln(APH)	0.020601	0.070319	0.29	0.77	-0.11939	0.160595
NHH	-0.73002	0.389904	-1.87	0.065	-1.50626	0.046216
DI_{w3w4}	0.285272	0.095523	2.99	0.004	0.095099	0.475444
TD_1	-0.11535	0.065968	-1.75	0.084	-0.24668	0.01598
TD_2	-0.09095	0.060969	-1.49	0.14	-0.21233	0.030426
TD_3	-0.04778	0.060289	-0.79	0.43	-0.1678	0.072248
TD_4	-0.03835	0.058907	-0.65	0.517	-0.15563	0.078921
K	3.050127	1.628621	1.87	0.065	-0.19221	6.292464

Table 16: CMA Model ev2: unsmoothed log aggregate version ln agg uns v2

Source	**SS**	**df**	**MS**				
Model	127.4017	14	9.100118	Number of obs		=	125
Residual	4.376636	110	0.039788	F(14, 110)		=	228.72
Total	131.7783	124	1.062728	Prob > F		=	0
				R-squared		=	0.9668
				Adj R-squared		=	0.9626
				Root MSE		=	0.19947
	Coef.	Std. Err.	t	P>|t|	[95% Conf.		Interval]
Botex							
Ln(W_d/P)	0.799875	0.329287	2.43	0.017	0.147305		1.452445
Ln(L/P)	-0.48238	0.117729	-4.1	0	-0.71569		-0.24907
Ln(RW)	0.914447	0.617126	1.48	0.141	-0.30855		2.137446
Ln(L)	1.048508	0.024686	42.47	0	0.999586		1.097431
DI_{rivers}	0.028243	0.099573	0.28	0.777	-0.16909		0.225574
$DI_{reservoirs}$	0.307488	0.086208	3.57	0.001	0.136644		0.478332
Ln(APH)	0.106922	0.084537	1.26	0.209	-0.06061		0.274454
NHH	-0.38759	0.541091	-0.72	0.475	-1.45991		0.684723
TD_1	-0.27716	0.090093	-3.08	0.003	-0.4557		-0.09862
TD_2	-0.17577	0.077603	-2.26	0.025	-0.32956		-0.02198
TD_3	-0.09435	0.077334	-1.22	0.225	-0.24761		0.058904
TD_4	-0.12719	0.070529	-1.8	0.074	-0.26696		0.012578
TD_5	-0.13502	0.070657	-1.91	0.059	-0.27505		0.005
TD_6	-0.16286	0.069178	-2.35	0.02	-0.29995		-0.02576
K	-6.36421	2.028072	-3.14	0.002	-10.3834		-2.34505

Table 17: CMA Model ev3: unsmoothed log aggregate version

Source	**SS**	**df**	**MS**				
Model	127.0974	13	9.776726	Number of obs		=	125
Residual	4.680857	111	0.04217	F(13, 111)		=	231.84
Total	131.7783	124	1.062728	Prob > F		=	0
				R-squared		=	0.9645
				Adj R-squared		=	0.9603
				Root MSE		=	0.20535
	Coef.	Std. Err.	t	P>|t|	[95% Conf.		Interval]
Ln(botex)							
Ln(W_d/P)	0.777687	0.346484	2.24	0.027	0.091106		1.464268
Ln(L/P)	-0.60298	0.117096	-5.15	0	-0.83501		-0.37095
Ln(RW)	0.25741	0.589454	0.44	0.663	-0.91063		1.425452
Ln(L)	1.04901	0.025497	41.14	0	0.998487		1.099534
Ln(APH)	0.075724	0.086039	0.88	0.381	-0.09477		0.246216
NHH	-0.57179	0.524669	-1.09	0.278	-1.61145		0.46788
DI_{w3w4}	0.254919	0.102969	2.48	0.015	0.050879		0.458958
TD_1	-0.23253	0.091447	-2.54	0.012	-0.41374		-0.05132
TD_2	-0.12999	0.078944	-1.65	0.102	-0.28643		0.026439
TD_3	-0.06016	0.078903	-0.76	0.447	-0.21651		0.096194
TD_4	-0.10892	0.072477	-1.5	0.136	-0.25254		0.034697
TD_5	-0.1223	0.072632	-1.68	0.095	-0.26623		0.021622
TD_6	-0.1654	0.071226	-2.32	0.022	-0.30654		-0.02426
K	-4.24855	1.94128	-2.19	0.031	-8.09533		-0.40178

Table 18: CMA Model ev3: smoothed log aggregate version

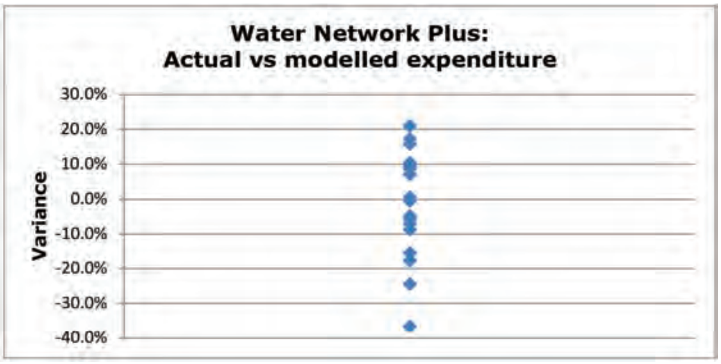
Source	SS	df	MS			
Model	87.29728	11	7.936116	Number of obs	=	89
Residual	2.16735	77	0.028147	F(11, 77)	=	281.95
Total	89.46463	88	1.016643	Prob > F	=	0
				R-squared	=	0.9758
				Adj R-squared	=	0.9723
				Root MSE	=	0.16777

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex)						
Ln(W_d/P)	0.63678	0.172751	3.69	0	0.29279	0.980771
Ln(L/P)	-0.57347	0.112826	-5.08	0	-0.79814	-0.34881
Ln(RW)	0.302083	0.512127	0.59	0.557	-0.71769	1.321858
Ln(L)	1.030366	0.024337	42.34	0	0.981905	1.078828
Ln(APH)	0.07527	0.082642	0.91	0.365	-0.08929	0.239831
NHH	-0.51473	0.425113	-1.21	0.23	-1.36124	0.331778
DI_{w3w4}	0.257604	0.097734	2.64	0.01	0.062991	0.452216
TD_1	-0.11554	0.065734	-1.76	0.083	-0.24643	0.015352
TD_2	-0.08998	0.060758	-1.48	0.143	-0.21096	0.031007
TD_3	-0.04752	0.060075	-0.79	0.431	-0.16715	0.072101
TD_4	-0.03713	0.058707	-0.63	0.529	-0.15403	0.079768
K	-4.41845	1.683927	-2.62	0.01	-7.77158	-1.06533

5.1. Cost assessment results

We have calculated the expected value produced by each of our preferred versions set out in Tables 10-14 for the eighteen companies and triangulated the values to produce a single modelled cost. The variances between actual and modelled costs are shown below as the blue markers in Figure 8 below. The range is from -27% to +21%. Excluding one outlier, the range narrows to -24% to +21%.

Figure 3: Variability of actual vs modelled for Water Network Plus costs



Source: 2017 Information Request; Anglian Water analysis

5.2. Alternative approaches to assessing Water Network Plus costs

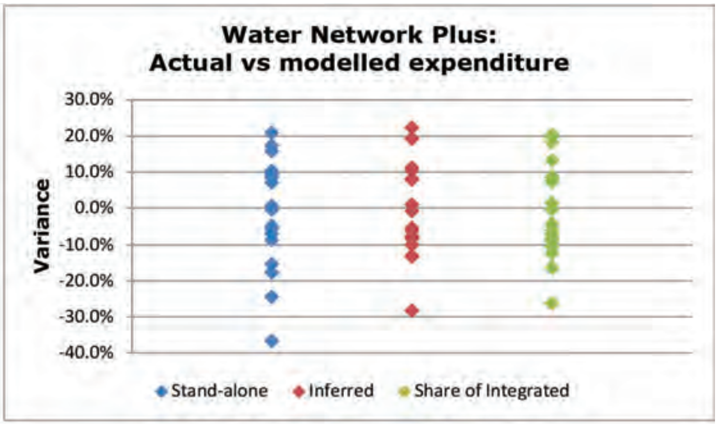
As set out in section 3, there are three alternative ways of assessing Water Network Plus costs, given the set of models which we have developed for wholesale Integrated Water. We have the stand-alone models set out above. Second, it is possible to infer Network Plus costs from the difference between the Integrated and the Water Resources model. Finally we can calculate Network Plus botex as a fixed proportion of the Integrated model, based on historical evidence. In Figure 4 below, we show the results of all three approaches together. The stand-alone results are as shown above in Figure 3.

The inferred or differencing approach shown in Figure 4 gives a lower level of variability than the stand-alone models. Overall, the range is from -28% to +22%. Excluding the outlier, the range is from -13% to +22%.

To estimate Water Network Plus' cost assessment element as a share of the Wholesale Water Integrated cost assessment, we have looked at the share of Integrated Water botex represented by Water Network Plus over the last six years. We have used this proportion (91.2% as an industry average – see Table 19) as the share of the Integrated Water model output to compute a figure for Water Network Plus.

The sharing approach also gives a lower level of variability than the stand-alone models. The overall range is from -26% to +20%: excluding the outlier, the range is from -16% to +20%.

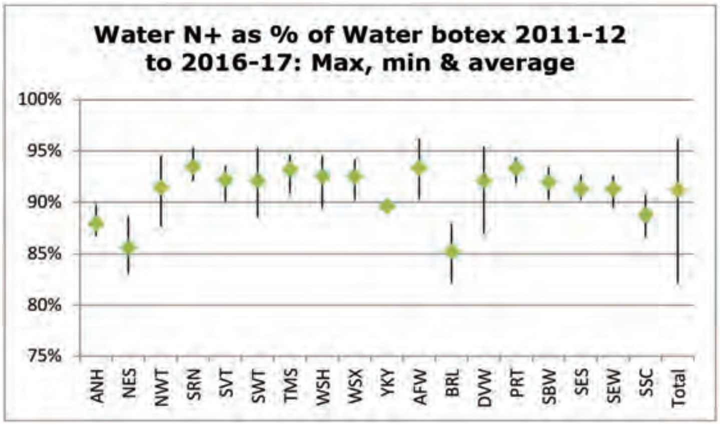
Figure 4: Variability of actual vs modelled for Water Network Plus costs



Source: 2017 Information Request; Anglian Water analysis

A key question relating to this potential approach to setting the Water Network Plus cost assessment is how stable is the share of total botex represented by Water Network Plus, both over time and between companies. This is set out in Figure 5 below.

Figure 5: Variability of Water Network Plus share of wholesale water botex 2011-12 to 2016-17

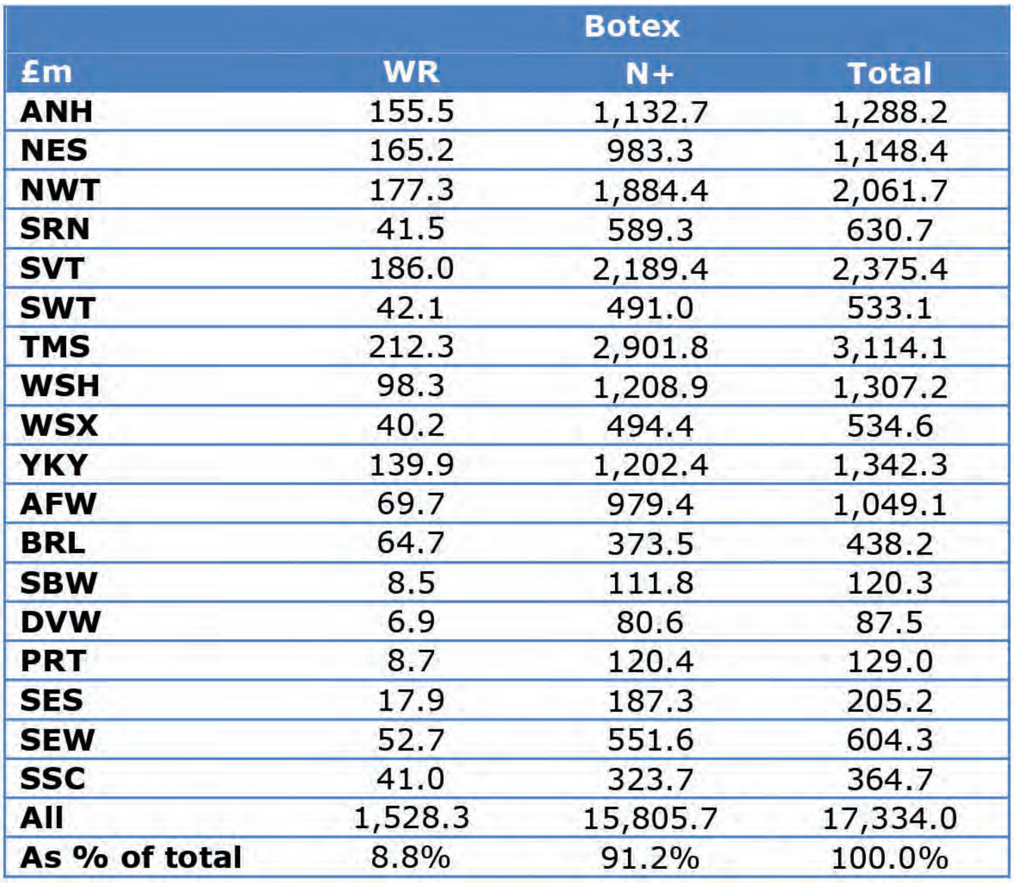


Source: 2017 Information Request; Anglian Water analysis

In terms of averages between companies, 14 companies are between 90%-95%, with the remaining four between 85%-90%. In terms of the variability across the six years, this is quite limited: 11 companies have a range (max-min)/ average less than 5%; six have a range/average between 5% - 7.5%. The remaining company has a range (max-min)/ average of between 7.5% - 10%.

Overall, then, Figures 3 to 5 suggest that the three approaches to estimating the cost assessment for Water Network Plus all give very similar results.

Table 19: Aggregate Botex for years 2011-12 to 2016-17



		Botex	
£m	**WR**	**N+**	**Total**
ANH	155.5	1,132.7	1,288.2
NES	165.2	983.3	1,148.4
NWT	177.3	1,884.4	2,061.7
SRN	41.5	589.3	630.7
SVT	186.0	2,189.4	2,375.4
SWT	42.1	491.0	533.1
TMS	212.3	2,901.8	3,114.1
WSH	98.3	1,208.9	1,307.2
WSX	40.2	494.4	534.6
YKY	139.9	1,202.4	1,342.3
AFW	69.7	979.4	1,049.1
BRL	64.7	373.5	438.2
SBW	8.5	111.8	120.3
DVW	6.9	80.6	87.5
PRT	8.7	120.4	129.0
SES	17.9	187.3	205.2
SEW	52.7	551.6	604.3
SSC	41.0	323.7	364.7
All	1,528.3	15,805.7	17,334.0
As % of total	8.8%	91.2%	100.0%

This analysis suggests that the three sets of Water Wholesale models Integrated, Water Resources and Network Plus appear to be in alignment with each other. As a result, using any of the three approaches set out at the end of Section 1 for estimating Network Plus botex requirements will provide similar quality estimates of botex. We will set out in our business plan the approach we take to assessing our cost allowance for the next regulatory period.

1. Models to be created

Since late 2016, we have been developing a suite of cost models. In September 2017[1], we published the findings of Phase 1 of our cost modelling . For Water Recycling, this involved developing cost models based on the October 2016 data submission for each of the individual Business Units identified in the Ofwat Regulatory Accounts Guidance (RAGs). This involved creating models for:

- Sewage Collection
- Sewage Treatment
- Sludge Transport
- Sludge Treatment and
- Sludge Disposal.

We also developed three more aggregated models:

- Water Recycling Integrated
- Water Recycling Network Plus, and
- Bioresources integrated.

The Phase 1 work identified significant problems with disaggregated models, principally due to issues with cost allocation and cost interaction. Despite the intention and expectation that the RAGs ought to lead to a homogenous treatment of costs and cost allocation between companies, supported by the efforts of the Ofwat Cost Assessment Working Group which has been active since early 2016, there are still significant differences in the way costs are handled by different companies.

In the light of these findings, Phase 2 of our cost modelling has focused on developing just three sets of wholesale Water Recycling models based on the July 2017 Information Request data:

i) Models for Bioresources at the integrated level
ii) Models for Water Recycling Network Plus, and
iii) Integrated Water Recycling Models, covering all aspects of wholesale Water Recycling.

Ofwat's PR19 Methodology Statement in December 2017 confirmed that there will be separate price controls for Water Recycling Network Plus and for Bioresources. So, this suite of models gives us the ability to compute the cost assessments for the two price controls directly.

However, in addition, there are other ways of addressing the same issue. Taking this approach let us compare the direct and implied cost assessments for each area. Firstly, Network Plus and Bioresources can be assessed from their respective chosen stand-alone models. Secondly, each price control can be viewed from the difference between the Integrated and the other price control's models. Finally, as Ofwat points out in its PR19 Methodology, both Network Plus and Bioresources can be estimated as shares of the Integrated Water Recycling model.

CPP has noted that, given our findings of substantial cost interactions and particularly given the impact that we find below with regard to cost interactions between network costs and indigenous and non-indigenous treatment of sewage and sludge, there is a potential for bias in estimated costs from this third approach, just as there are with separate estimation when cost interactions exist. In CPP's opinion, the Integrated model is best able to capture the implications of these cost interactions accurately.

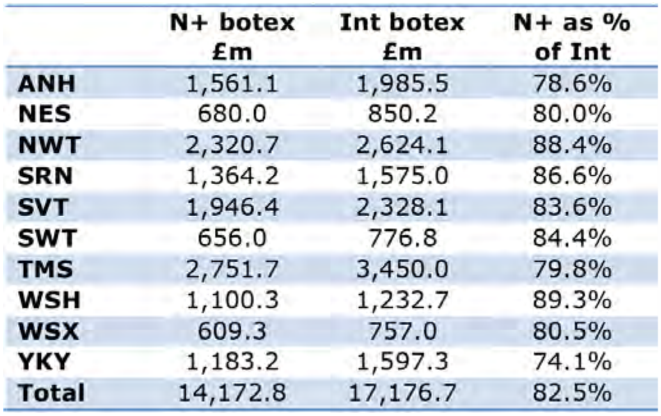
We have developed stand-alone models for Water Recycling Integrated and Network Plus. These we report in Sections 5.2 and 5.3. In Sections 5.4 and 5.5 we look at how coherent the other two approaches are with the stand-alone models. **In this report, we do not set out how we intend to use the reported models and approaches. This will be set out in our Business Plan.**

2. The production function for Water Recycling

2.1. Overview

Table 1 below shows that Water Recycling Network Plus accounts for around four fifths of Water Recycling Integrated botex over the last 6 years, the balance representing the botex for Bioresources. Given this, it seems reasonable to assume that any model form which successfully describes Water Recycling Integrated should also reasonably successfully explain Water Recycling Network Plus.

Table 1: The link between Water Recycling Integrated and Network Plus



	N+ botex £m	Int botex £m	N+ as % of Int
ANH	1,561.1	1,985.5	78.6%
NES	680.0	850.2	80.0%
NWT	2,320.7	2,624.1	88.4%
SRN	1,364.2	1,575.0	86.6%
SVT	1,946.4	2,328.1	83.6%
SWT	656.0	776.8	84.4%
TMS	2,751.7	3,450.0	79.8%
WSH	1,100.3	1,232.7	89.3%
WSX	609.3	757.0	80.5%
YKY	1,183.2	1,597.3	74.1%
Total	14,172.8	17,176.7	82.5%

Source: July 2017 Information Request. Anglian Water analysis

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[1] Water Industry Cost Modelling: Anglian Water's approach', September 2017 http://www.anglianwater.co.uk/_assets/media/cost-modelling-report.pdf

CPP, in conjunction with Anglian Water, has developed two Water Network Plus models. These models grew out of detailed discussions with Water Recycling Operations personnel within Anglian Water about the operational processes underlying Network Plus. Moreover, they also build from lessons drawn from the academic literature and CPP's previous academic and policy related work in the UK water industry, while also providing readily estimable and understandable models for the current regulatory application. These models were initially developed on the basis of integrated water recycling costs, given CPP's strong opinion concerning the importance of modelling integrated costs in the presence of cost interactions. Versions of these models were then applied to Network Plus modelling.

2.2. Model 1: The Extended Passing Distance model

The first model is an integrated network and production model in which the key outputs are the length of sewers managed and the treatment of sewage load as measured by population equivalent. However, given the importance of geographic and demographic characteristics in determining the method and cost of sewage treatment, the model separates the overall output into two distinct outputs as discussed further below, thereby capturing how the marginal cost of sewage treatment will differ within these output categories. Additionally, the model allows for the increasing costs associated with increased network length, ceteris paribus, by including the log of network length directly and as a squared term.

Finally, and critically, to capture the complex cost complementarities between sewage treatment and network transportation costs, the model includes a term which interacts the natural log of total network length with the natural log of the total number of Water Recycling Centres (WRCs). The careful reader should recognize this variable as being related to average passing distance. However, the approach we have applied here is more general and does not impose the same implicit restrictions on the other network length variable coefficients that would occur if we simply included the natural log of passing distance. **The consistent negative coefficient estimate for this variable suggests that a firm benefits when it has, on average, a larger network connected to each WRC because it has a less fragmented network and treatment system. It is therefore able to benefit from economies of scale in treatment that justify and outweigh additional interconnecting network length.**

Finally, a wide variety of control variables were tested. The two which were consistently significant were the proportion of total sewer length represented by combined sewers and the amount of pumping capacity per WRC. This model is referred to as the **Extended Passing Distance model.**

2.3. Model 2: The Average System model

The second model resulted from extended conversations and consideration of how one would model botex for English and Wales' water recycling companies, all of whom have optimized their overall operations by operating multiple distinct sewerage systems with distinct networks connected to distinct WRCs. Thus, for example, Anglian Water does not have a single integrated sewerage network but instead has 1,138 individual networks. The insight underlying the model is that the cost complementarity / trade off between network transportation costs and economies of scale in sewage treatment differ significantly by plant type. As a result, the average size of the (individual) networks drives system level economies of scale and cost complementarities between network costs and treatment costs, in contrast to the aggregate size of the network or sewage treatment.

Moreover, the expected cost interactions between treatment and network costs are observed. Thus, the estimated cost interaction between systems that tend to have larger WRCs (non-sparse population, or plants with indigenous treatment of sludge) and network length is negative, suggesting cost benefits from increased volume which allows greater economies of scale in treatment, thereby reflecting the findings at aggregate level from the Extended Passing Distance Model. However, as we would expect, the estimated cost interaction between network length and sewage treatment loads for systems that would tend to be smaller (sparse population or non-indigenous treatment of sludge) is positive, thereby explaining, for example, why firms do not choose to have the larger networks that would allow the economies of scale required for indigenous sludge treatment. Most fundamentally, these models clearly demonstrate the trade-off between network costs and treatment scale, which cannot be estimated separately, and which also varies by system size and design.

This second model is both robust and innovative and was proposed by CPP, which is developing a working paper based on this model that will be presented at the North American Productivity Workshop in June, and in an industry oriented workshop to be held at Loughborough University in May. CPP considers this model to be an important development, which highlights the significance of disaggregated network size and is planning to publish an article based on it in an academic journal later this year. There is also international academic interest in this model and its implications based on interactions Professor Saal has had with industry and policy makers in both Japan and Australia. This second model is known as the **Average System model.**

2.4. Model versions

In sum, the models developed are based on the contention that fundamentally, Water Recycling costs are based on demographic, geographic and population distribution features within an appointed area. Moreover, the models highlight the important role of adequately modelling cost complementarities between network and treatment costs. It can be seen from the separate annexes for Bioresources and for Water Resources that this has been a persistent theme of the work done in Phase 2.

There are two variants on the models developed:

- **The sparsity variant.** This is based on population sparsity measures developed by Ofwat in conjunction with companies via the Cost Assessment Working Group
- **The indigenous sludge variant.** The logic behind this is that the proportion of indigenous sludge treated is determined by rational economic decisions which in turn are determined by the demography of the appointed area.

Table 1: Water Recycling model options

	p.e. split by			
	Sparsity		**Indigenous**	
	Smoothed	Unsmoothed	Smoothed	Unsmoothed
Average System				
Passing Distance				

In each case, population – or more exactly, population equivalent (p.e.) - is divided into sparse and not sparse or indigenous and non-indigenous. Table 1 below shows the key categories of models developed.

3. Costs to be used

The source files for the data used in the wholesale Water Recycling cost modelling were as follows:

- 20171013 hc Master wholesale waste July 2017
- Company specific labour cost indices
- High density and scarcity indices hc.

We recognize that even now at the time of writing (February 2018), the data set has yet to be confirmed and that the key data file (20171013 hc Master wholesale waste July 2017) is still subject to modification. However, given the time constraints imposed on us by the PR19 timetable, we cannot wait until the data set has been finally confirmed to start the cost modelling. It is regrettable but inevitable that Ofwat will have a more accurate data set to work with when it begins its cost modelling. However, given the concerted efforts of the members of the Ofwat Cost Assessment Working Group in highlighting shortcomings within the data, it may be hoped that further changes will be relatively minor.

We will re-run our models after July 2018, when we will have the benefit of both corrected data and 2017-18 data. The impact of these changes will be available to us during the later stages of the price review process.

The costs included in Botex were as follows:

- Total operating expenditure (excluding third party services), minus
- Local authority and Cumulo rates, minus
- Environment Agency service charges, plus
- Maintaining the long term capability of the assets – infra, plus
- Maintaining the long term capability of the assets - non-infra.

The costs are all taken from the Regulatory Accounts filed by appointed companies. All costs exclude atypical expenditure as reported by companies.

All costs are rebased in 2012-13 prices.

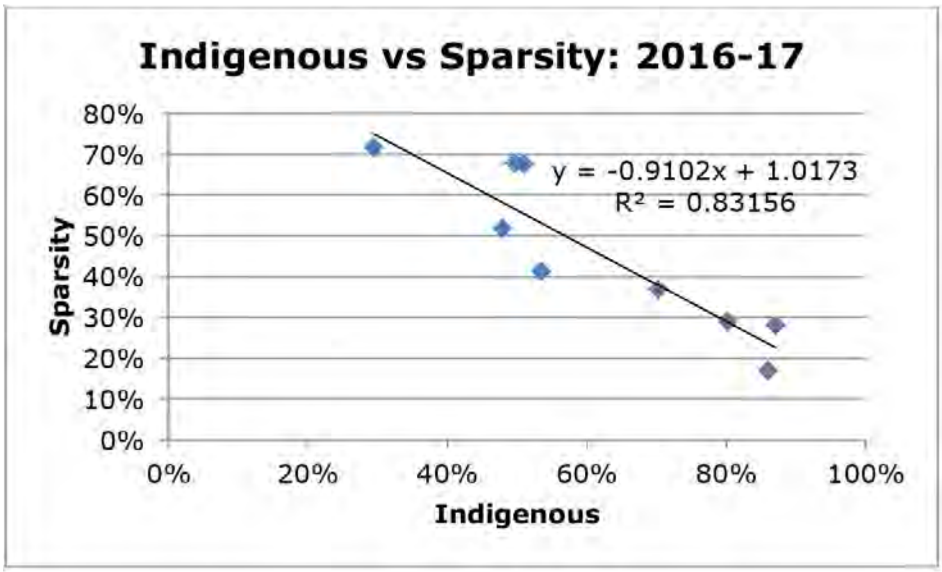
The 2017 Information Request (IR17) restated all cost data based on IFRS. This was a sizeable step forward compared to the 2016 Information Requests which were partly in UKGAAP and partly in IFRS. Given that the two accounting systems differ substantially in how they handle Capital Maintenance, this had an impact on botex, especially if smoothing of capex is used.

4. Key cost drivers

Correlation between population sparsity & indigenous sludge

As set out in Section 2, the two model forms developed – average system and extended passing distance – both have variants which use population sparsity and proportion of indigenous sludge as weights for splitting population equivalent into low marginal cost sewage (low sparsity and high indigenous) and high marginal cost sewage (high sparsity, low indigenous shares). Figure 1 demonstrates the basis for these alternatives - that there is a strong correlation between population sparsity (here defined as the medium level of sparsity, that is 600/km^2>S>250/km2) and the proportion of sludge generated at a WRC co-located with a Sludge Treatment Centre.

Figure 1: Relationship between Indigenous and Sparsity

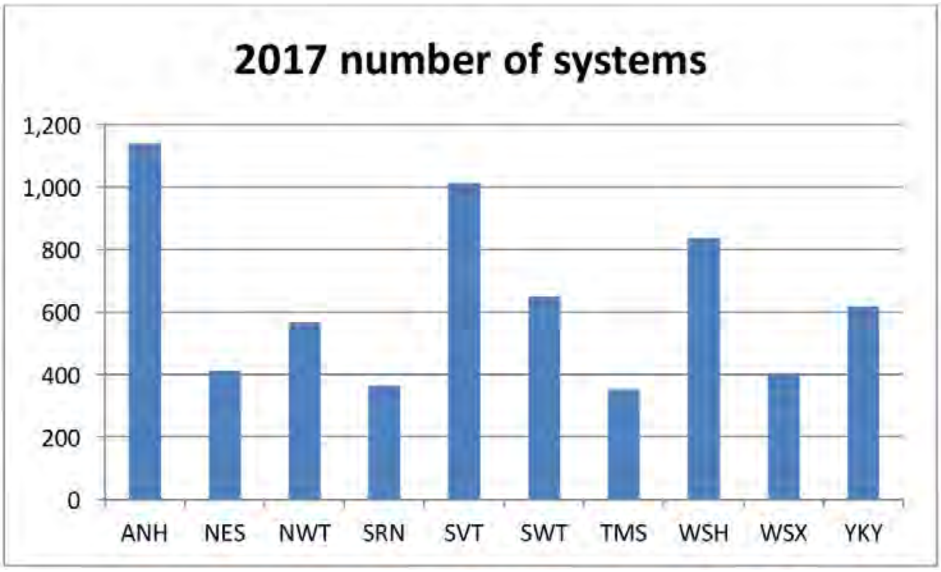


Source: 2017 Information Request

Number of systems

A critical metric for the average system model is the number of systems (that is, Water Recycling Centres, WRCs, with their connected networks of sewers) operated by each WaSC. As can be seen from Figure 2, there is a more than 3:1 ratio between the largest and smallest number of systems across the ten WaSCs.

Figure 2: Number of systems

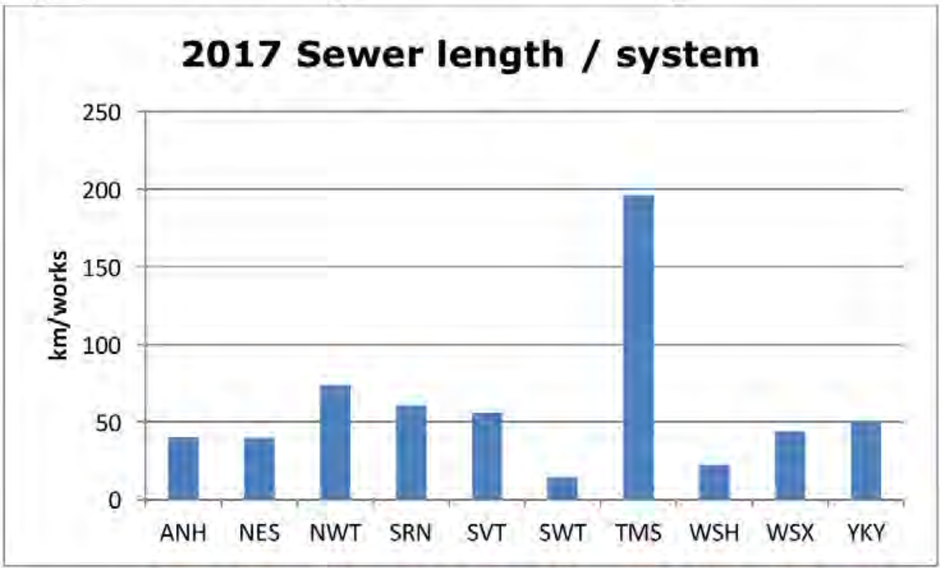


Source: 2017 Information Request

Sewer length / system

The ratio of largest to smallest sewer length per system shown in Figure 3 is even more pronounced than the number of system in Figure 2 above. Here the ratio is over 13:1, with a clear distinction between urban / metropolitan based companies and rural based companies.

Figure 3: Relationship between sewer length and number of systems



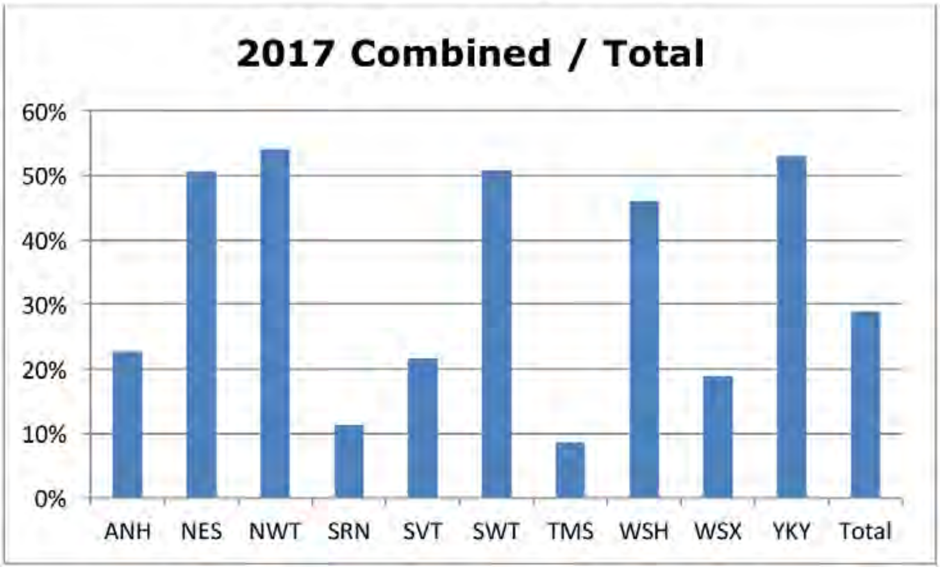
Source: 2017 Information Request

Combined sewers

The logic behind including the share of total sewer length represented by combined sewers is as follows. Combined sewers deliver run-off rainwater along with foul sewer contents to WRCs. As a result they add to the load to be treated and thus act to increase cost of treatment. There is a countervailing factor: the extra volume acts to reduce the risk of blockages building up. Looking at Figure 4 demonstrates the considerable variation in the reliance on combined sewers between the companies.

We also note an important distinction between the specification of network length in the extended passing distance model, which was developed first, and the average system model. The former model includes all traditional network length (net of transferred sewers) which has been the standard industry proxy for network length for many years. In contrast, the average system model uses the same measure, but net of storm drains. The logic of this is that the conceptual model underlying the average system model relies on the inter-relationship between network actually connected to a WRC and WRC size. Excluding storm drains from this model, by definition excludes those drains which do not form part of the calculus that managers and engineers undertake when optimizing sewerage systems.

Figure 4: Combined sewers as share of total sewer length



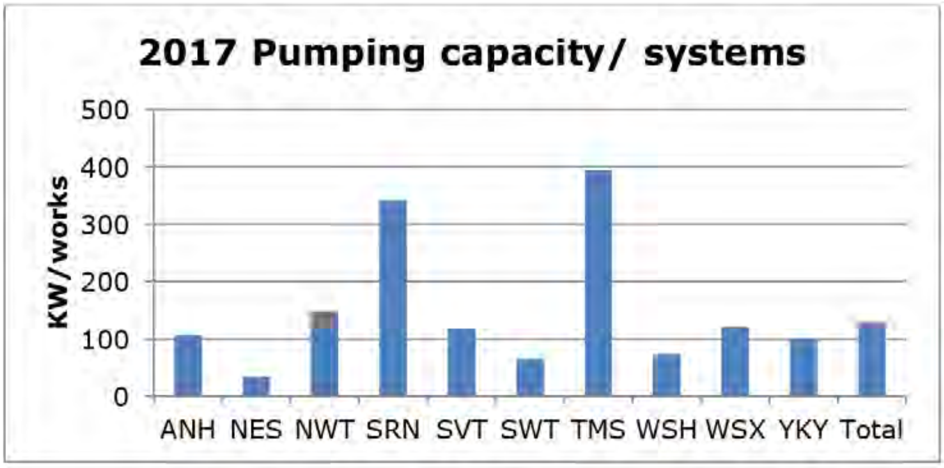
Source: 2017 Information Request

Pumping capacity

Within the versions of the models reported in Section 5, there are two control variables which involve pumping capacity. The first is the ratio of pump capacity to systems, illustrated in Figure 5 below. With a range from the lowest to highest of over 11:1, there is considerable variability across the ten companies, with a clear relationship between pump capacity per system and sewer length per system.

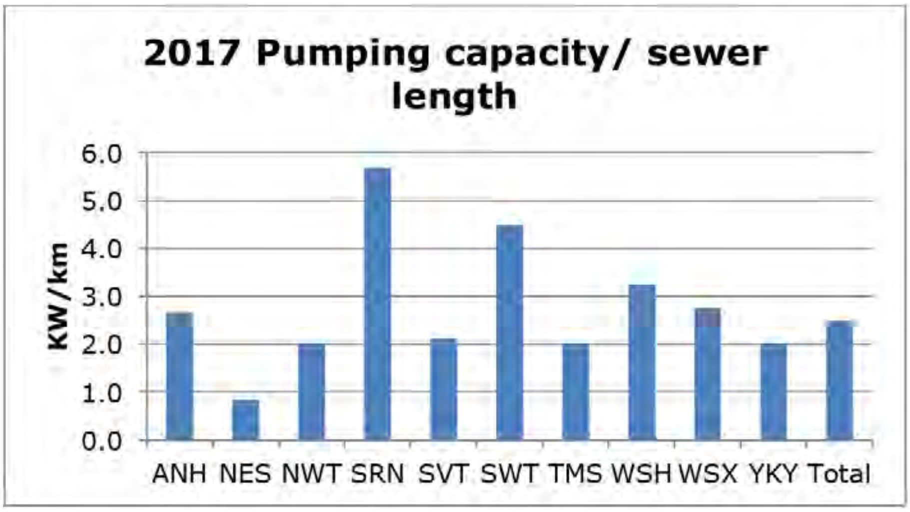
The second of the pumping capacity control variables is pumping capacity per km of sewer, set out in Figure 6. Once again, there is a clear distinction between the urban and rural WaSCs with the urban companies incurring more power costs in order to access the economies of scale in treatment associated with the larger systems (and higher share of indigenous sludge).

Figure 5: Relationship between aggregate pumping capacity and number of systems



Source: 2017 Information Request

Figure 6: Relationship between aggregate pumping capacity and aggregate length of sewers

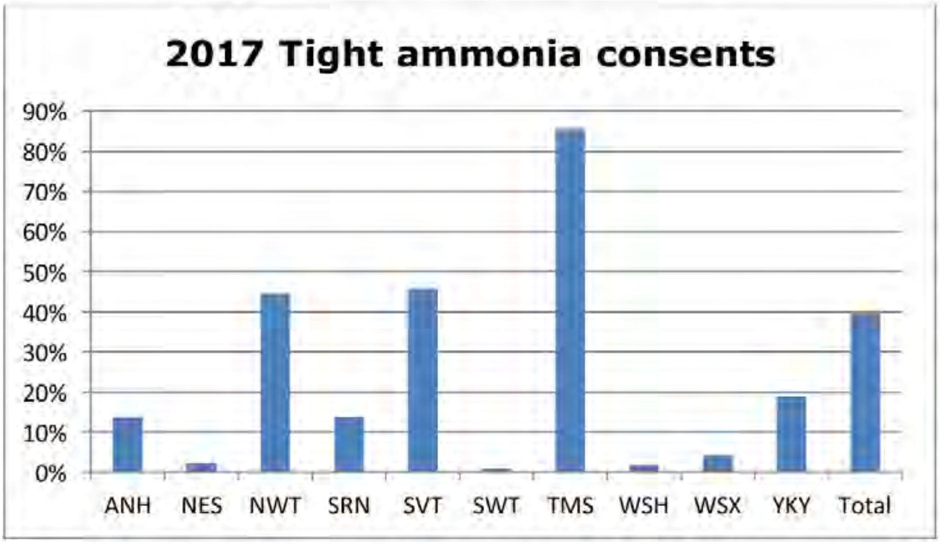


Source: 2017 Information Request

Tight ammonia consents

As part of the model development work, when looking for relevant control variables, we started by looking at tight WRC discharge consents for Phosphorous, Ammonia and BoD. We also looked at the share of total load treated with secondary activated sludge (SAS) and with tertiary treatment. We confidently expected to find a stable relationship between most if not all these measures. We did not. The only measure which showed any consistency in terms of significance was the tight Ammonia consents, as defined by consents <3mg/litre. The incidence of tight Ammonia consents is set out in Figure 7 below.

Figure 7: Proportion of load subject to tight ammonia consents



Source: 2017 Information Request

5. Cost modelling development

5.1. The approach taken to cost modelling

In Sections 5.2 and 5.3 below, we set out the STATA outputs for the chosen model versions for Integrated Water Recycling and Network Plus respectively. These can be thought of as "stand-alone models"

Water Recycling Network Plus botex can also be estimated as providing an alternative estimate of the modelled costs that are obtained as the difference between the botex estimates generated by the Integrated Water Recycling model and the Bioresources model (the differencing approach).

Furthermore, we can take a share of the Water Recycling Integrated cost assessment and use that as an estimate of the Network Plus cost assessment (the sharing approach). The most obvious metric for determining the share of the Water Recycling Integrated cost assessment would be the share of Water Recycling Integrated's botex represented by Network Plus' botex over an appropriate historical period. We set out the variability of these three methods of computing the Network Plus cost assessment in Sections 5.4 and 5.5

For Water Recycling Network Plus in Phase 2, we have taken a different approach to cost modelling to the one followed in Phase 1. Whereas in Phase 1 we developed a separate set of models for Water Recycling Network Plus, in Phase 2 we have used the same model forms as used for the Water Recycling Integrated model - that is to say, those set out in Section 2 above. The reason for taking this approach is that Network Plus botex represents a high and stable proportion of Integrated Water Recycling botex; so the cost drivers which explain Water Recycling Integrated botex ought also to be able to explain Water Recycling Network Plus botex. The relationship between Water Recycling Integrated and Network Plus botex is set out for Anglian Water in Table 2 below.

Table 2: Network Plus botex as a share of Integrated botex

	Water Recycling Network Plus botex as % of total Water Recycling Integrated botex	Water Recycling Network Plus botex as % of Water Recycling Integrated botex (ex rates)
ANH12	77.1%	76.5%
ANH13	76.9%	76.1%
ANH14	78.6%	77.9%
ANH15	80.6%	80.1%
ANH16	82.2%	81.8%
ANH17	79.6%	79.1%
Weighted average	79.2%	78.6%

Source: July 2017 Information Request. Anglian Water analysis

We have used STATA v14 in our cost modelling. The outputs shown below in Sections 5.2 and 5.3 are the STATA outputs for the various Integrated and Network Plus models respectively.

The key to the abbreviations used in Section 5.2 and 5.3 are given in Table 3 below.

Table 3: Key for Section 5 cost models

Abbreviation	Description
C	Combined sewer length as a share of total sewer length
I	Proportion of indigenous sludge, i.e. proportion of sludge produced by Network Plus at a WRC co-located with the STC where it is treated
K	Constant
L	Total length of sewer
NH_3	Proportion of load subject to tight (<3mg) ammonia consents
p.e.	Population Equivalent
P	Pump capacity
S	Population sparsity measures developed by Ofwat in conjunction with the Cost Assessment Working Group
T	Time trend
W	Number of Water Recycling Centres (a.k.a. systems, STWs, WWTWs)

5.2. Integrated Cost models

Table 4 describes at a high level the 12 preferred versions of the two models used for the Integrated Water Recycling cost assessment. What follows, in Tables 5- 16, are the STATA outputs for these versions.

The choice criteria of these versions of the two models have been based firmly on the engineering and economic validity of these particular versions of the models.

The models developed for Wholesale Water Recycling differ from the rest of the models reported by us in this update report in three respects.

First, and most obviously, these models are partial translog models, where all of the other models reported display more basic, non power-based set of relationships. Translog terms which had coefficients which were insignificant or illogical were dropped. The partial translog form was used to identify more detailed and subtle relationships than are feasible otherwise.

Second, all of the versions of the average system and passing distance models which we report were developed using normalized cost data. This is in order to enable to make more straightforward the interpretation of the reported coefficients. This is standard econometric practice for econometric models including interactions between logged variables, and allows conversion of difficult to interpret models to more readily interpretable models where the direct coefficients can be interpreted as elasticity estimates for the sample average firm.

Third, all of the models reported are calculated using Generalised Least Squares rather than Ordinary Least Squares. In each case we report results using GLS with Random Effects. We ran versions of all of the versions using both OLS and GLS (RE) but in all cases found the GLS approach led to superior quality results. Moreover, this approach is more consistent with the academic practice of performance measurement with conventional panel econometrics, and its application to performance measurement.

For clarity, we finally also note that the key modelled variables in the average system model are modelled as the average per WRC plant operated by the firm, while unless otherwise noted the variables in the extended passing distance models are modelled in aggregate levels before taking logs.

Table 4: Wholesale Integrated Water Recycling models

	p.e. split by			
	Sparsity		**Indigenous**	
# versions	Smoothed	Unsmoothed	Smoothed	Unsmoothed
Average System	2	2	2	2
Passing Distance	-	-	2	2

Table 5: Integrated Average System unsmoothed sparsity model with combined share – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	60
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
Within	=	0.4411	min	=	6
between	=	0.9827	avg	=	6
Overall	=	0.9651	max	=	6
			Wald chi^2(11)	=	193.85
corr(u_i, X)	=	0 (assumed)	**Prob > chi^2**	=	0.0000

Lnbotex	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Ln(p.e.(1-S))	0.414506	0.1010471	4.1	0	0.216457	0.612554
Ln(p.e.S)	0.965869	0.2973281	3.25	0.001	0.3831163	1.548621
Ln(p.e.(1-S))ln(L)	-0.71339	0.4138341	-1.72	0.085	-1.524485	0.097715
Ln(p.e.S)ln(L)	1.308786	0.5804493	2.25	0.024	0.1711259	2.446446
Ln(p.e.(1-S))sqr	0.557589	0.3964662	1.41	0.16	-0.2194704	1.334648
C	0.008517	0.0039944	2.13	0.033	0.0006876	0.016346
Y_{13}	0.070386	0.0423855	1.66	0.097	-0.0126883	0.15346
Y_{14}	0.076899	0.0423084	1.82	0.069	-0.0060239	0.159822
Y_{15}	0.009542	0.0426739	0.22	0.823	-0.0740979	0.093181
Y_{16}	0.081887	0.0425252	1.93	0.054	-0.0014614	0.165235
Y_{17}	0.171105	0.0426797	4.01	0	0.0874543	0.254756
K	-0.1155	0.0742156	-1.56	0.12	-0.2609561	0.029964
sigma_u	0.134					
sigma_e	0.087825					
Rho	0.699516	(fraction of variance due to u_i)				

Table 6: Integrated Average System unsmoothed sparsity model with combined share and pumping- GLS (RE)

Random-effects GLS regression			**Number of obs**	=	60
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
within	=	0.4527	Min	=	6
between	=	0.9967	Avg	=	6
overall	=	0.979	Max	=	6
			Wald chi^2(12)	=	602.74
corr(u_i, X)	=	0 (assumed)	**Prob > chi^2**	=	0.0000

	Coef.	Std. Err.	Z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.366939	0.0574182	6.39	0	0.2544017	0.479477
Ln(p.e.S)	0.450567	0.2520316	1.79	0.074	-0.0434063	0.944539
Ln(p.e.(1-S))ln(L)	-0.47699	0.266982	-1.79	0.074	-1.000266	0.046284
Ln(p.e.S)ln(L)	0.482173	0.472403	1.02	0.307	-0.4437196	1.408066
Ln(p.e.(1-S))sqr	0.487428	0.2362825	2.06	0.039	0.0243224	0.950533
C	0.009391	0.0023666	3.97	0	0.0047524	0.014029
P/W	0.002543	0.0008749	2.91	0.004	0.0008283	0.004258
Y_{13}	0.075857	0.0419988	1.81	0.071	-0.0064593	0.158173
Y_{14}	0.080292	0.0419404	1.91	0.056	-0.0019093	0.162494
Y_{15}	0.016986	0.0421379	0.4	0.687	-0.0656028	0.099575
Y_{16}	0.084758	0.0420107	2.02	0.044	0.0024184	0.167097
Y_{17}	0.164933	0.0420863	3.92	0	0.0824457	0.247421
K	-0.07989	0.0470631	-1.7	0.09	-0.1721367	0.012347
sigma_u	0.06596119					
sigma_e	0.08872591					
Rho	0.35595349 (fraction of variance due to u_i)					

Table 7: Integrated Average System smoothed sparsity model with combined share – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	50	
Group variable: CompID			**Number of groups**	=	10	
R-sq:			**Obs per group:**			
within	=	0.6863	min	=	5	
between	=	0.9873	avg	=	5	
overall	=	0.9846	max	=	5	
			Wald chi^{2}(10)	=	320.11	
corr(u_i, X)	= 0 (assumed)		**Prob > chi^{2}**	=	0.0000	
	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.449094	0.0721619	6.22	0	0.3076591	0.590529
Ln(p.e.S)	0.874257	0.2105068	4.15	0	0.4616717	1.286843
Ln(p.e.(1-S))ln(L)	-0.84852	0.2583769	-3.28	0.001	-1.354934	-0.34212
Ln(p.e.S)ln(L)	1.300014	0.4079089	3.19	0.001	0.500527	2.0995
Ln(p.e.(1-S))sqr	0.71838	0.2570447	2.79	0.005	0.2145817	1.222178
C	0.008103	0.0028916	2.8	0.005	0.0024356	0.01377
Y_{14}	0.023547	0.0163049	1.44	0.149	-0.0084101	0.055504
Y_{15}	0.029252	0.0166539	1.76	0.079	-0.0033891	0.061893
Y_{16}	0.054444	0.0165566	3.29	0.001	0.0219938	0.086895
Y_{17}	0.092653	0.0166315	5.57	0	0.0600561	0.12525
K	-0.07662	0.0546681	-1.4	0.161	-0.183768	0.030527
-----------------------+---						
sigma_u	0.10601					
sigma_e	0.033184					
Rho	0.910757	(fraction of variance due to u_i)				

Table 8: Integrated Average System smoothed sparsity model with combined share and pumping– GLS (RE)

Random-effects GLS regression			**Number of obs**	=	50	
Group variable: CompID			**Number of groups**	=	10	
R-sq:		**Obs per group:**				
Within	=	0.6887	min	=	5	
Between	=	0.9969	avg	=	5	
Overall	=	0.9942	max	=	5	
			Wald chi^{2}(11)	=	778.28	
corr(u_i, X)	= 0 (assumed)		**Prob > chi^{2}**	=	0.0000	
	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.400303	0.0476703	8.4	0	0.3068709	0.493735
Ln(p.e.S)	0.49708	0.2037049	2.44	0.015	0.0978255	0.896334
Ln(p.e.(1-S))ln(L)	-0.57309	0.2051913	-2.79	0.005	-0.9752556	-0.17092
Ln(p.e.S)ln(L)	0.620918	0.3821578	1.62	0.104	-0.1280976	1.369934
Ln(p.e.(1-S))sqr	0.565885	0.1825736	3.1	0.002	0.2080473	0.923723
C	0.008446	0.0019737	4.28	0	0.0045779	0.012315
P/W	0.001818	0.0007317	2.48	0.013	0.0003834	0.003252
Y_{14}	0.021512	0.0163068	1.32	0.187	-0.010449	0.053472
Y_{15}	0.029181	0.0165034	1.77	0.077	-0.0031652	0.061527
Y_{16}	0.051247	0.0164534	3.11	0.002	0.0189993	0.083495
Y_{17}	0.083013	0.0168207	4.94	0	0.0500454	0.115981
K	-0.03997	0.0353945	-1.13	0.259	-0.1093443	0.029399
sigma_u	0.062019					
sigma_e	0.033516					
Rho	0.773961	(fraction of variance due to u_i)				

Table 9: Integrated Average System unsmoothed Indigenous model with combined share – GLS (RE)

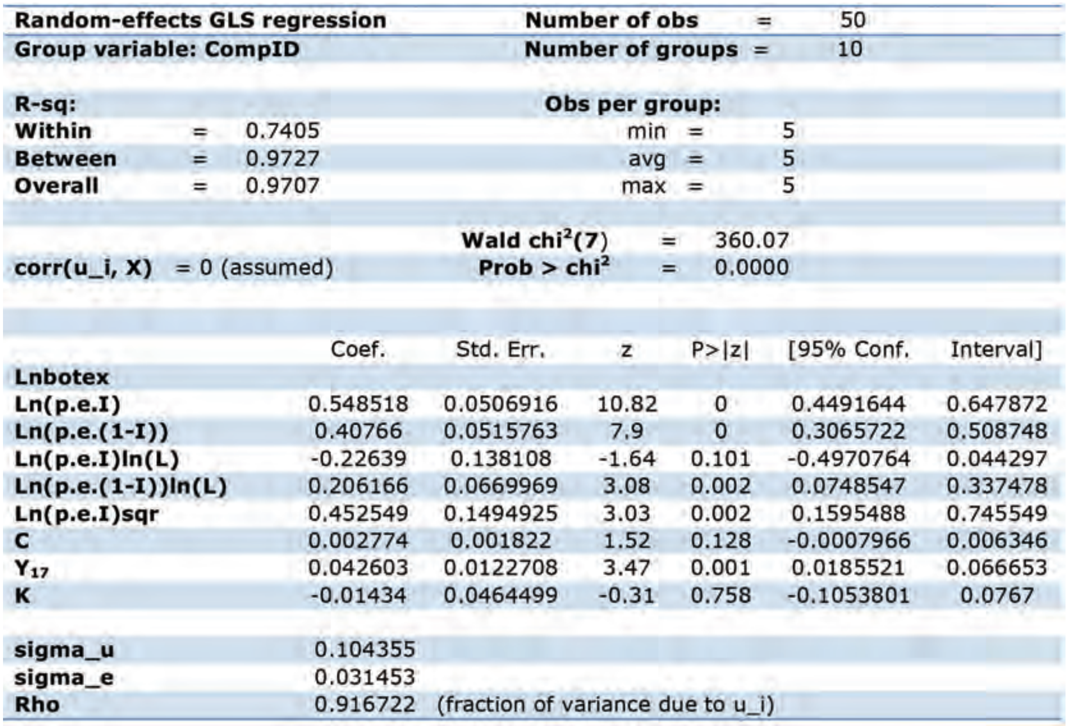
Random-effects GLS regression			**Number of obs**	=	60	
Group variable: CompID			**Number of groups**	=	10	
R-sq:			**Obs per group:**			
Within	=	0.5113	min	=	6	
Between	=	0.9786	avg	=	6	
Overall	=	0.9633	max	=	6	
			Wald chi^{2}(11)	=	268.46	
corr(u_i, X)	= 0 (assumed)		**Prob > chi^{2}**	=	0.0000	

Lnbotex	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
--------------------	------------	------------	--------	-------	---------------	----------
Ln(p.e.I)	0.574418	0.0722492	7.95	0	0.4328124	0.716024
Ln(p.e.(1-I))	0.535992	0.0992377	5.4	0	0.3414898	0.730495
Ln(p.e.I)ln(L)	-0.2559	0.2328667	-1.1	0.272	-0.7123099	0.200511
Ln(p.e.(1-I))ln(L)	0.415674	0.1363935	3.05	0.002	0.1483474	0.683
Ln(p.e.I)sqr	0.387627	0.2548514	1.52	0.128	-0.1118725	0.887126
C	0.003316	0.0022446	1.48	0.14	-0.001083	0.007716
Y_{13}	0.084919	0.0405346	2.09	0.036	0.0054727	0.164366
Y_{14}	0.076579	0.0409608	1.87	0.062	-0.0037026	0.156861
Y_{15}	-0.00363	0.0411233	-0.09	0.93	-0.0842317	0.076969
Y_{16}	0.04858	0.042109	1.15	0.249	-0.0339521	0.131112
Y_{17}	0.127068	0.0420598	3.02	0.003	0.0446321	0.209504
K	-0.06666	0.0597231	-1.12	0.264	-0.1837109	0.0504
sigma_u	0.121472					
sigma_e	0.091971					
Rho	0.635623	(fraction of variance due to u_i)				

Table 10: Integrated Average System unsmoothed Indigenous model with combined share and pumping – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	60	
Group variable: CompID			**Number of groups**	=	10	
R-sq:		**Obs per group:**				
Within	=	0.5094	min	=	6	
between	=	0.9992	avg	=	6	
Overall	=	0.9833	max	=	6	
			Wald chi^{2}(12)	=	2744.61	
corr(u_i, X)	= 0 (assumed)		**Prob > chi^{2}**	=	0.0000	
	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
ln(p.e.I)	0.461059	0.0376517	12.25	0	0.3872626	0.534855
Ln(p.e.(1-I))	0.356727	0.0510783	6.98	0	0.2566157	0.456839
Ln(p.e.I)ln(L)	-0.39454	0.0948269	-4.16	0	-0.5803941	-0.20868
Ln(p.e.(1-I))ln(L)	0.313588	0.0833188	3.76	0	0.1502857	0.47689
Ln(p.e.I)sqr	0.50448	0.1004499	5.02	0	0.3076015	0.701358
C	0.007874	0.0009983	7.89	0	0.0059177	0.009831
P/W	0.002368	0.0003721	6.36	0	0.001639	0.003098
Y_{13}	0.083214	0.0397964	2.09	0.037	0.0052141	0.161213
Y_{14}	0.076421	0.0398489	1.92	0.055	-0.0016816	0.154523
Y_{15}	0.002629	0.0399382	0.07	0.948	-0.0756489	0.080906
Y_{16}	0.056392	0.040151	1.4	0.16	-0.0223025	0.135087
Y_{17}	0.130153	0.0402042	3.24	0.001	0.0513539	0.208951
K	-0.05902	0.0303469	-1.94	0.052	-0.1184971	0.00046
sigma_u	0.002917					
sigma_e	0.093156					
Rho	0.000979	(fraction of variance due to u_i)				

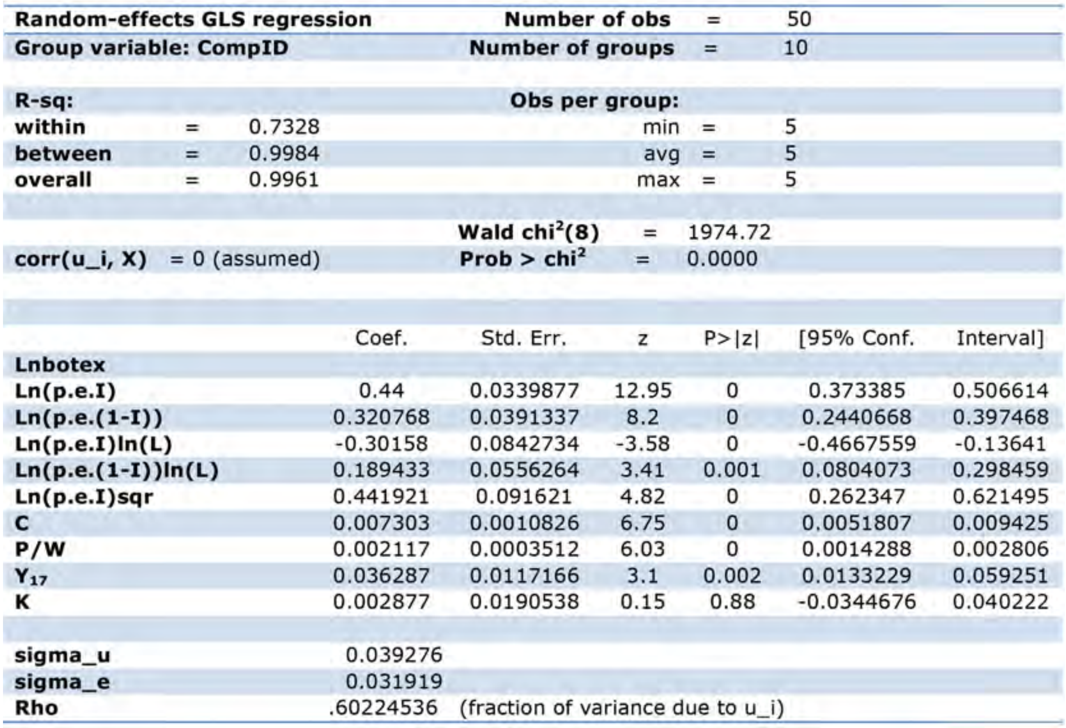
Table 11: Integrated Average System smoothed Indigenous model with combined share – GLS (RE)



Random-effects GLS regression			**Number of obs**	=	50	
Group variable: CompID			**Number of groups**	=	10	
R-sq:			**Obs per group:**			
Within	=	0.7405	min	=	5	
Between	=	0.9727	avg	=	5	
Overall	=	0.9707	max	=	5	
			Wald chi²(7)	=	360.07	
corr(u_i, X)	= 0 (assumed)		**Prob > chi²**	=	0.0000	

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.548518	0.0506916	10.82	0	0.4491644	0.647872
Ln(p.e.(1-I))	0.40766	0.0515763	7.9	0	0.3065722	0.508748
Ln(p.e.I)ln(L)	-0.22639	0.138108	-1.64	0.101	-0.4970764	0.044297
Ln(p.e.(1-I))ln(L)	0.206166	0.0669969	3.08	0.002	0.0748547	0.337478
Ln(p.e.I)sqr	0.452549	0.1494925	3.03	0.002	0.1595488	0.745549
C	0.002774	0.001822	1.52	0.128	-0.0007966	0.006346
Y_{17}	0.042603	0.0122708	3.47	0.001	0.0185521	0.066653
K	-0.01434	0.0464499	-0.31	0.758	-0.1053801	0.0767
sigma_u	0.104355					
sigma_e	0.031453					
Rho	0.916722	(fraction of variance due to u_i)				

Table 12: Integrated Average System smoothed Indigenous model with combined share and pumping – GLS (RE)



Random-effects GLS regression			**Number of obs**	=	50	
Group variable: CompID			**Number of groups**	=	10	
R-sq:			**Obs per group:**			
within	=	0.7328	min	=	5	
between	=	0.9984	avg	=	5	
overall	=	0.9961	max	=	5	
			Wald chi²(8)	=	1974.72	
corr(u_i, X)	= 0 (assumed)		**Prob > chi²**	=	0.0000	

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.44	0.0339877	12.95	0	0.373385	0.506614
Ln(p.e.(1-I))	0.320768	0.0391337	8.2	0	0.2440668	0.397468
Ln(p.e.I)ln(L)	-0.30158	0.0842734	-3.58	0	-0.4667559	-0.13641
Ln(p.e.(1-I))ln(L)	0.189433	0.0556264	3.41	0.001	0.0804073	0.298459
Ln(p.e.I)sqr	0.441921	0.091621	4.82	0	0.262347	0.621495
C	0.007303	0.0010826	6.75	0	0.0051807	0.009425
P/W	0.002117	0.0003512	6.03	0	0.0014288	0.002806
Y_{17}	0.036287	0.0117166	3.1	0.002	0.0133229	0.059251
K	0.002877	0.0190538	0.15	0.88	-0.0344676	0.040222
sigma_u	0.039276					
sigma_e	0.031919					
Rho	.60224536	(fraction of variance due to u_i)				

Table 13: Integrated Extended Passing Distance unsmoothed Indigenous model with combined share and pumping – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	60
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
within	=	0.4912	min	=	6
between	=	0.9795	avg	=	6
overall	=	0.958	max	=	6
			Wald chi^2(12)	=	173.34
corr(u_i, X)	=	0 (assumed)	**Prob > chi^2**	=	0.0000

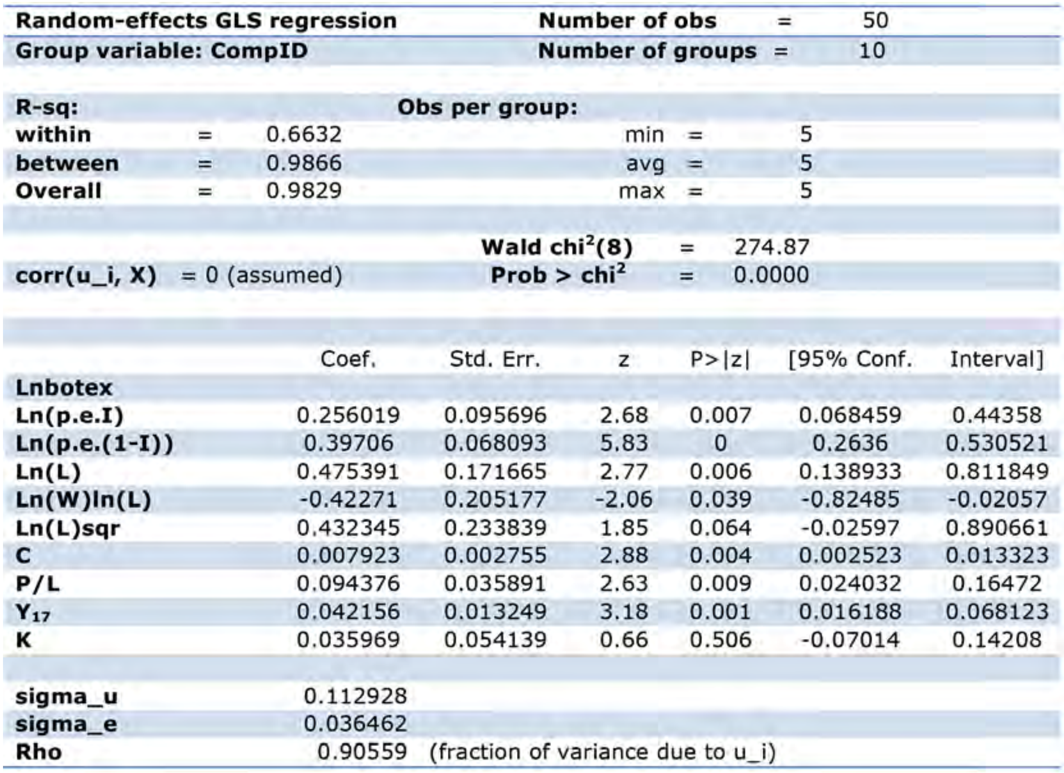
Lnbotex	Coef.	Std. Err.	Z	P>|z|	[95% Conf.	Interval]
Ln(p.e.I)	0.373251	0.164986	2.26	0.024	0.049885	0.696617
Ln(p.e.(1-I))	0.50922	0.149643	3.4	0.001	0.215925	0.802514
Ln(L)	0.324716	0.279338	1.16	0.245	-0.22278	0.872208
Ln(W) ln(L)	-0.4499	0.277398	-1.62	0.105	-0.99359	0.09379
Ln(L)sqr	0.541542	0.317122	1.71	0.088	-0.08001	1.163089
C	0.008776	0.003598	2.44	0.015	0.001724	0.015829
P/L	0.118492	0.046205	2.56	0.01	0.027931	0.209053
Y_{13}	0.081521	0.040281	2.02	0.043	0.002571	0.160471
Y_{14}	0.073373	0.040572	1.81	0.071	-0.00615	0.152892
Y_{15}	0.000741	0.041034	0.02	0.986	-0.07968	0.081165
Y_{16}	0.054627	0.042165	1.3	0.195	-0.02802	0.137269
Y_{17}	0.133622	0.042417	3.15	0.002	0.050487	0.216758
K	-0.01377	0.073338	-0.19	0.851	-0.15751	0.129975
sigma_u	0.134874					
sigma_e	0.091122					
Rho	0.686603	(fraction of variance due to u_i)				

Table 14: Integrated Extended Passing Distance unsmoothed Indigenous model with combined share pumping and ammonia tight consents – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	60
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
Within	=	0.4812	min	=	6
Between	=	0.9897	avg	=	6
Overall	=	0.9673	max	=	6
			Wald chi^2(13)	=	1297.00
corr(u_i, X)	=	0 (assumed)	**Prob > chi^2**	=	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.1269	0.090659	1.4	0.162	-0.05079	0.304588
Ln(p.e.(1-I))	0.360114	0.079134	4.55	0	0.205014	0.515215
Ln(L)	0.488193	0.124421	3.92	0	0.244332	0.732054
Ln(W)ln(L)	-0.45441	0.099396	-4.57	0	-0.64923	-0.2596
Ln(L)sqr	0.311668	0.121366	2.57	0.01	0.073795	0.549541
C	0.007771	0.00124	6.27	0	0.005341	0.010201
P/L	0.122407	0.015665	7.81	0	0.091705	0.153109
NH_3	0.005197	0.00189	2.75	0.006	0.001493	0.0089
Y_{13}	0.0823	0.047177	1.74	0.081	-0.01016	0.174765
Y_{14}	0.055586	0.047879	1.16	0.246	-0.03826	0.149427
Y_{15}	-0.01352	0.048079	-0.28	0.779	-0.10775	0.080711
Y_{16}	0.026919	0.049845	0.54	0.589	-0.07077	0.124613
Y_{17}	0.12245	0.048516	2.52	0.012	0.027361	0.21754
_cons	-0.0308	0.038165	-0.81	0.42	-0.10561	0.043998
sigma_u	0.009993					
sigma_e	0.091608					
Rho	0.011759	(fraction of variance due to u_i)				

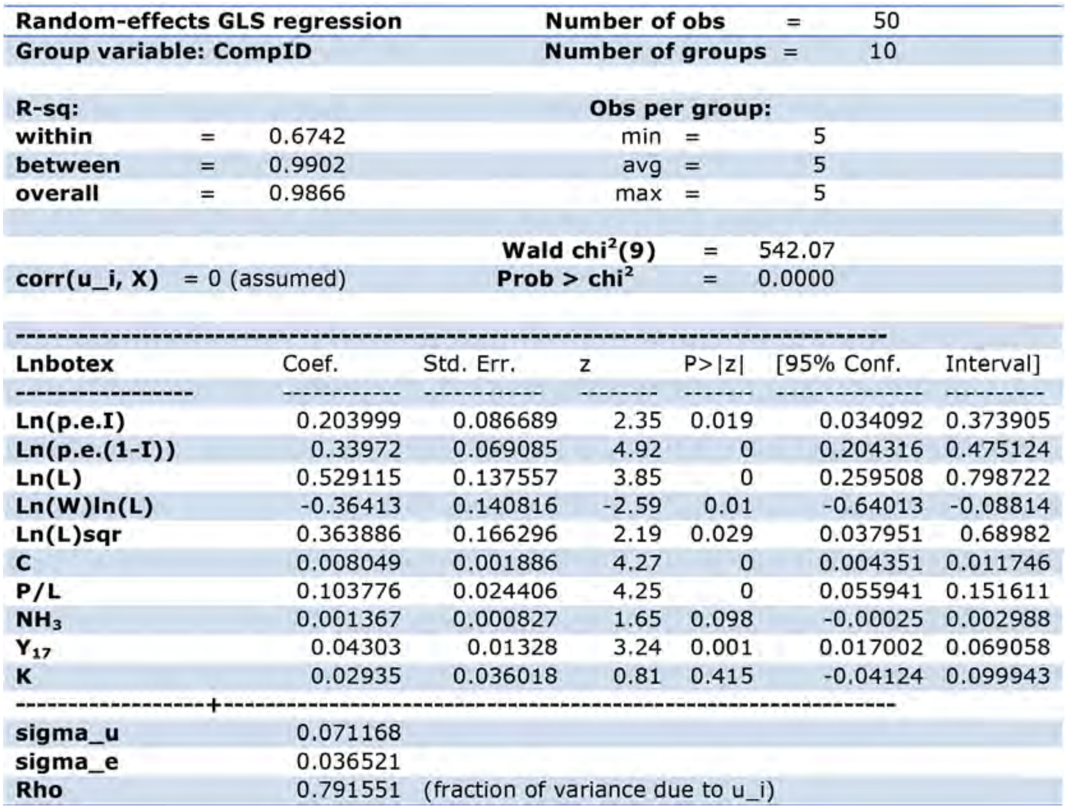
Table 15: Integrated Extended Passing Distance smoothed Indigenous model with combined share and pumping – GLS (RE)



Random-effects GLS regression			**Number of obs**	=	50
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
within	=	0.6632	min	=	5
between	=	0.9866	avg	=	5
Overall	=	0.9829	max	=	5
			Wald chi²(8)	=	274.87
corr(u_i, X)	= 0 (assumed)		**Prob > chi²**	=	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.256019	0.095696	2.68	0.007	0.068459	0.44358
Ln(p.e.(1-I))	0.39706	0.068093	5.83	0	0.2636	0.530521
Ln(L)	0.475391	0.171665	2.77	0.006	0.138933	0.811849
Ln(W)ln(L)	-0.42271	0.205177	-2.06	0.039	-0.82485	-0.02057
Ln(L)sqr	0.432345	0.233839	1.85	0.064	-0.02597	0.890661
C	0.007923	0.002755	2.88	0.004	0.002523	0.013323
P/L	0.094376	0.035891	2.63	0.009	0.024032	0.16472
Y_{17}	0.042156	0.013249	3.18	0.001	0.016188	0.068123
K	0.035969	0.054139	0.66	0.506	-0.07014	0.14208
sigma_u	0.112928					
sigma_e	0.036462					
Rho	0.90559	(fraction of variance due to u_i)				

Table 16: Integrated Extended Passing Distance smoothed Indigenous model with combined share pumping and ammonia tight consents – GLS (RE)



Random-effects GLS regression			**Number of obs**	=	50
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
within	=	0.6742	min	=	5
between	=	0.9902	avg	=	5
overall	=	0.9866	max	=	5
			Wald chi²(9)	=	542.07
corr(u_i, X)	= 0 (assumed)		**Prob > chi²**	=	0.0000

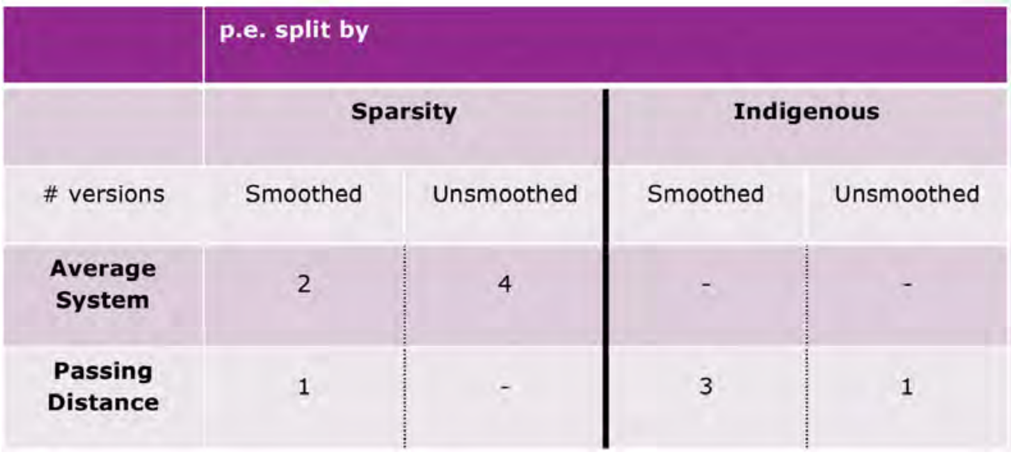
Lnbotex	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Ln(p.e.I)	0.203999	0.086689	2.35	0.019	0.034092	0.373905
Ln(p.e.(1-I))	0.33972	0.069085	4.92	0	0.204316	0.475124
Ln(L)	0.529115	0.137557	3.85	0	0.259508	0.798722
Ln(W)ln(L)	-0.36413	0.140816	-2.59	0.01	-0.64013	-0.08814
Ln(L)sqr	0.363886	0.166296	2.19	0.029	0.037951	0.68982
C	0.008049	0.001886	4.27	0	0.004351	0.011746
P/L	0.103776	0.024406	4.25	0	0.055941	0.151611
NH_3	0.001367	0.000827	1.65	0.098	-0.00025	0.002988
Y_{17}	0.04303	0.01328	3.24	0.001	0.017002	0.069058
K	0.02935	0.036018	0.81	0.415	-0.04124	0.099943
sigma_u	0.071168					
sigma_e	0.036521					
Rho	0.791551	(fraction of variance due to u_i)				

5.3. Network Plus results

Table 17 describes at a high level the 11 preferred versions of the two models used for the Water Recycling Network Plus cost assessment. What follows, in Tables 18-28, are the STATA outputs for these versions.

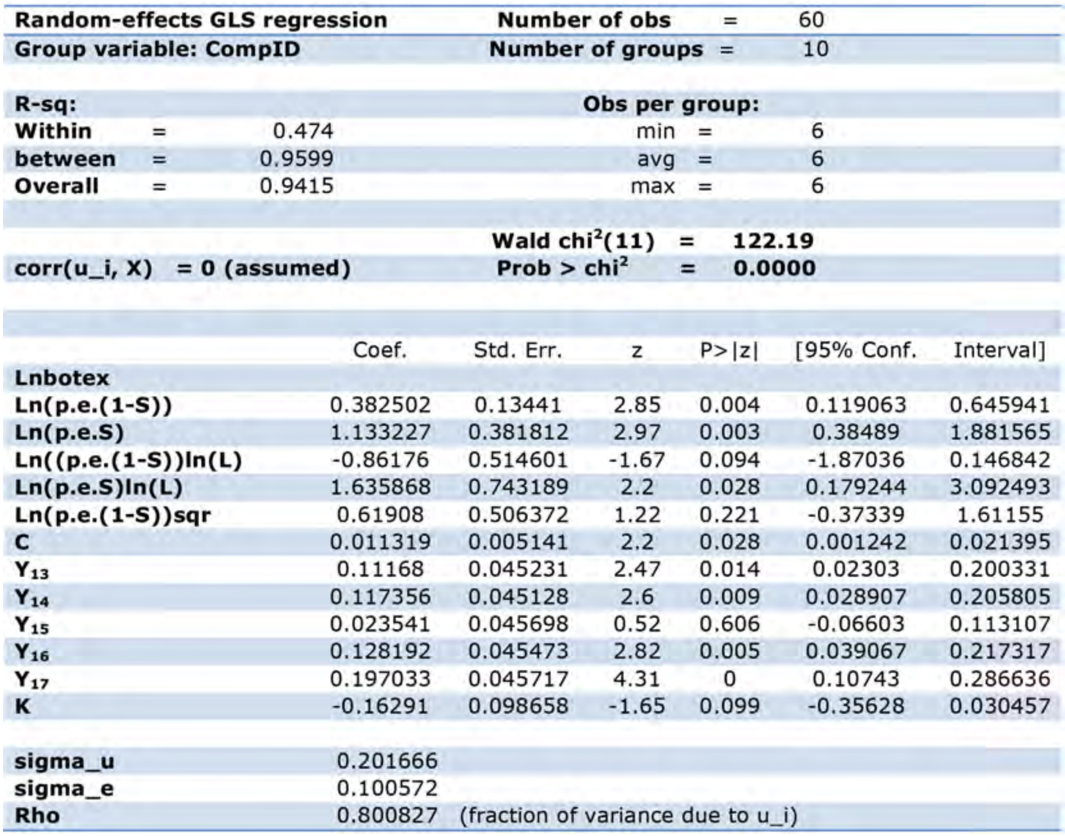
In developing the Network Plus models, we have followed the same approach as used for the Integrated models, set out at the start of Section 5.2. The only difference is that whereas all of the 12 chosen Integrated models were developed using GLS (RE), seven of the 11 Network Plus models were developed using OLS.

Table 17: Wholesale Water Recycling Network Plus models



	p.e. split by			
	Sparsity		Indigenous	
# versions	Smoothed	Unsmoothed	Smoothed	Unsmoothed
Average System	2	4	-	-
Passing Distance	1	-	3	1

Table 18: Network Plus Average System unsmoothed sparsity model with combined share – GLS (RE)



Random-effects GLS regression			**Number of obs**	=	60	
Group variable: CompID			**Number of groups**	=	10	
R-sq:			**Obs per group:**			
Within	=	0.474	min	=	6	
between	=	0.9599	avg	=	6	
Overall	=	0.9415	max	=	6	
			Wald chi^2(11)	**=**	**122.19**	
corr(u_i, X)	**= 0 (assumed)**		**Prob > chi^2**	**=**	**0.0000**	
	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.382502	0.13441	2.85	0.004	0.119063	0.645941
Ln(p.e.S)	1.133227	0.381812	2.97	0.003	0.38489	1.881565
Ln((p.e.(1-S))ln(L)	-0.86176	0.514601	-1.67	0.094	-1.87036	0.146842
Ln(p.e.S)ln(L)	1.635868	0.743189	2.2	0.028	0.179244	3.092493
Ln(p.e.(1-S))sqr	0.61908	0.506372	1.22	0.221	-0.37339	1.61155
C	0.011319	0.005141	2.2	0.028	0.001242	0.021395
Y_{13}	0.11168	0.045231	2.47	0.014	0.02303	0.200331
Y_{14}	0.117356	0.045128	2.6	0.009	0.028907	0.205805
Y_{15}	0.023541	0.045698	0.52	0.606	-0.06603	0.113107
Y_{16}	0.128192	0.045473	2.82	0.005	0.039067	0.217317
Y_{17}	0.197033	0.045717	4.31	0	0.10743	0.286636
K	-0.16291	0.098658	-1.65	0.099	-0.35628	0.030457
sigma_u	0.201666					
sigma_e	0.100572					
Rho	0.800827	(fraction of variance due to u_i)				

Table 19: Network Plus Average System unsmoothed sparsity model with combined share – OLS

Source	SS	df	MS			
Model	21.39277	11	1.944797	Number of obs	=	60
Residual	1.225296	48	0.025527	F(11, 48)	=	76.19
Total	22.61806	59	0.383357	Prob > F	=	0
				R-squared	=	0.9458
				Adj R-squared	=	0.9334
				Root MSE	=	0.15977

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.327378	0.047276	6.92	0	0.232323	0.422433
Ln(p.e.S)	1.128527	0.147868	7.63	0	0.831219	1.425835
Ln(p.e.(1-S))ln(L)	-0.52755	0.222486	-2.37	0.022	-0.97489	-0.08021
Ln(p.e.S)ln(L)	1.448303	0.298005	4.86	0	0.849123	2.047483
Ln(p.e.(1-S))sqr	0.264197	0.203008	1.3	0.199	-0.14398	0.672372
C	0.009664	0.001997	4.84	0	0.005648	0.01368
Y_{13}	0.112878	0.071475	1.58	0.121	-0.03083	0.256587
Y_{14}	0.116626	0.07146	1.63	0.109	-0.02705	0.260305
Y_{15}	0.019553	0.071512	0.27	0.786	-0.12423	0.163338
Y_{16}	0.124503	0.07149	1.74	0.088	-0.01924	0.268244
Y_{17}	0.193301	0.071512	2.7	0.009	0.049517	0.337084
K	-0.14052	0.055565	-2.53	0.015	-0.25224	-0.0288

Table 20: Network Plus Average System smoothed sparsity model with combined share – GLS (RE)

Random-effects GLS regression			**Number of obs**	=	50
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
within	=	0.7234	min	=	5
between	=	0.9746	avg	=	5
overall	=	0.972	max	=	5
			Wald chi2(10)	=	232.72
corr(u_i, X)	= 0 (assumed)		**Prob > chi2**	=	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnbotex						
Ln(p.e.(1-S))	0.381968	0.090478	4.22	0	0.204635	0.559302
Ln(p.e.S)	1.037475	0.250131	4.15	0	0.547226	1.527723
Ln(p.e.(1-S))ln(L)	-0.76192	0.293885	-2.59	0.01	-1.33792	-0.18591
Ln(p.e.S)ln(L)	1.504061	0.496808	3.03	0.002	0.530336	2.477786
Ln(p.e.(1-S))sqr	0.524903	0.303397	1.73	0.084	-0.06974	1.11955
C	0.010109	0.003467	2.92	0.004	0.003315	0.016904
Y_{14}	0.026142	0.01676	1.56	0.119	-0.00671	0.058991
Y_{15}	0.030915	0.017192	1.8	0.072	-0.00278	0.064611
Y_{16}	0.07342	0.017077	4.3	0	0.039949	0.10689
Y_{17}	0.110024	0.01718	6.4	0	0.076352	0.143695
K	-0.0883	0.070448	-1.25	0.21	-0.22638	0.049771
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sigma_u	0.157855					
sigma_e	0.038352					
Rho	0.944263	(fraction of variance due to u_i)				

Table 21: Network Plus Average System smoothed sparsity model with combined share – OLS

Source	SS	df	MS			
Model	16.87174	7	2.410248	Number of obs	=	50
Residual	0.454881	42	0.010831	F(7, 42)	=	222.54
Total	17.32662	49	0.353604	Prob > F	=	0
				R-squared	=	0.9737
				Adj R-squared	=	0.9694
				Root MSE	=	0.10407
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.361044	0.033411	10.81	0	0.293617	0.428471
Ln(p.e.S)	0.945645	0.105144	8.99	0	0.733456	1.157835
Ln(p.e.(1-S))ln(L)	-0.46735	0.156182	-2.99	0.005	-0.78254	-0.15217
Ln(p.e.S)ln(L)	1.190212	0.206887	5.75	0	0.772698	1.607726
Ln(p.e.(1-S))sqr	0.272099	0.143511	1.9	0.065	-0.01752	0.561716
C	0.007811	0.001431	5.46	0	0.004923	0.010699
Y_{17}	0.076147	0.036808	2.07	0.045	0.001866	0.150429
K	-0.03548	0.023345	-1.52	0.136	-0.08259	0.011636

Table 22: Network Plus Average System smoothed sparsity model with combined share and pumping– GLS (RE)

Random-effects GLS regression			**Number of obs**	=	50	
Group variable: CompID			**Number of groups**	=	10	
R-sq:		**Obs per group:**				
Within	=	0.7249	min	=	5	
Between	=	0.9841	avg	=	5	
Overall	=	0.9814	max	=	5	
			Wald chi2(11)	=	273.91	
corr(u_i, X)	= 0 (assumed)		**Prob > chi2**	=	0.0000	
--						
Lnbotex	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
----------------------	------------	------------	---------	-------	----------------	----------
Ln(p.e.(1-S))	0.342486	0.086558	3.96	0	0.172836	0.512137
Ln(p.e.S)	0.757838	0.305136	2.48	0.013	0.159783	1.355893
Lnp.e.(1-S))ln(L)	-0.58028	0.303666	-1.91	0.056	-1.17546	0.01489
Ln(p.e.S)ln(L)	0.946658	0.601124	1.57	0.115	-0.23152	2.124839
Ln(p.e.(1-S))sqr	0.462127	0.285395	1.62	0.105	-0.09724	1.021491
C	0.01101	0.003336	3.3	0.001	0.004472	0.017548
P/W	0.001616	0.001177	1.37	0.17	-0.00069	0.003924
Y_{14}	0.024827	0.016804	1.48	0.14	-0.00811	0.057761
Y_{15}	0.031335	0.017188	1.82	0.068	-0.00235	0.065021
Y_{16}	0.071237	0.017123	4.16	0	0.037676	0.104798
Y_{17}	0.101705	0.018123	5.61	0	0.066184	0.137226
K	-0.0675	0.064315	-1.05	0.294	-0.19355	0.058559
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sigma_u	0.141256					
sigma_e	0.039007					
Rho	0.929147	(fraction of variance due to u_i)				

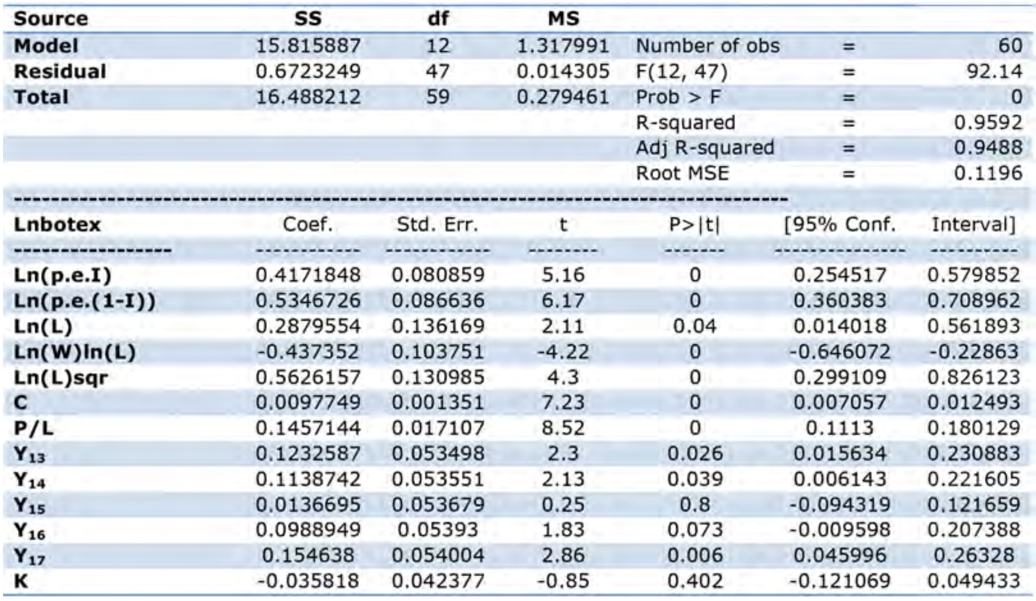
Table 23: Network Plus Average System smoothed sparsity model with combined share and pumping – OLS

Source	**SS**	**df**	**MS**			
Model	17.0715	11	1.551954	Number of obs	=	50
Residual	0.255118	38	0.006714	F(11, 38)	=	231.16
Total	17.32662	49	0.353604	Prob > F	=	0
				R-squared	=	0.9853
				Adj R-squared	=	0.981
				Root MSE	=	0.08194
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.338206	0.026737	12.65	0	0.284081	0.392332
Ln(p.e.S)	0.464151	0.125554	3.7	0.001	0.209981	0.718321
Ln(p.e.(1-S))ln(L)	-0.27083	0.129544	-2.09	0.043	-0.53307	-0.00858
Ln(p.e.S)ln(L)	0.366263	0.23048	1.59	0.12	-0.10032	0.832846
Ln(p.e.(1-S)sqr	0.275998	0.113141	2.44	0.019	0.046957	0.505039
C	0.008377	0.001132	7.4	0	0.006086	0.010668
P/W	0.002211	0.000433	5.1	0	0.001333	0.003088
Y_{14}	0.022448	0.036651	0.61	0.544	-0.05175	0.096645
Y_{15}	0.029207	0.036688	0.8	0.431	-0.04506	0.103478
Y_{16}	0.067599	0.036677	1.84	0.073	-0.00665	0.141848
Y_{17}	0.096629	0.036732	2.63	0.012	0.02227	0.170988
K	-0.03724	0.029729	-1.25	0.218	-0.09742	0.022942

Table 24: Network Plus Extended Passing Distance smoothed sparsity model with combined share and pumping – OLS

Source	**SS**	**df**	**MS**			
Model	12.511657	7	1.78738	Number of obs	=	50
Residual	0.3005345	42	0.007156	F(7, 42)	=	249.79
Total	12.812192	49	0.261473	Prob > F	=	0
				R-squared	=	0.9765
				Adj R-squared	=	0.9726
				Root MSE	=	0.08459
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.(1-S))	0.3883246	0.066647	5.83	0	0.253826	0.522824
Ln(p.e.S)	0.4862795	0.112592	4.32	0	0.259061	0.713498
Ln(L)	0.2753323	0.145105	1.9	0.065	-0.017501	0.568165
Ln(W)ln(L)	-0.171772	0.070093	-2.45	0.019	-0.313225	-0.03032
Ln(L)sqr	0.4606089	0.103611	4.45	0	0.251513	0.669704
C	0.0085268	0.001009	8.45	0	0.006491	0.010563
P/L	0.1221417	0.015253	8.01	0	0.091361	0.152923
K	0.0476897	0.018825	2.53	0.015	0.009699	0.085681

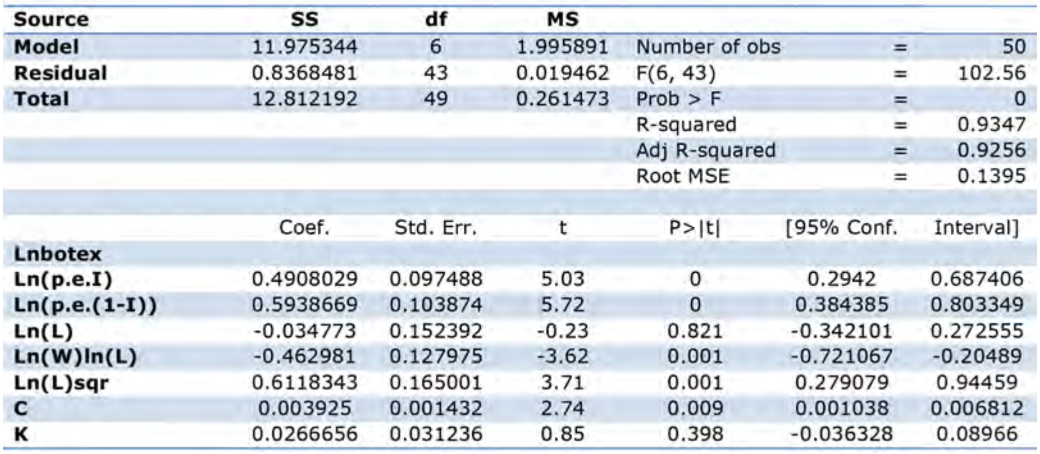
Table 25: Network Plus Extended Passing Distance unsmoothed Indigenous model with combined share and pumping – OLS



Source	**SS**	**df**	**MS**			
Model	15.815887	12	1.317991	Number of obs	=	60
Residual	0.6723249	47	0.014305	F(12, 47)	=	92.14
Total	16.488212	59	0.279461	Prob > F	=	0
				R-squared	=	0.9592
				Adj R-squared	=	0.9488
				Root MSE	=	0.1196

Lnbotex	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
-----------------	------------	------------	--------	-------	---------------	----------
Ln(p.e.I)	0.4171848	0.080859	5.16	0	0.254517	0.579852
Ln(p.e.(1-I))	0.5346726	0.086636	6.17	0	0.360383	0.708962
Ln(L)	0.2879554	0.136169	2.11	0.04	0.014018	0.561893
Ln(W)ln(L)	-0.437352	0.103751	-4.22	0	-0.646072	-0.22863
Ln(L)sqr	0.5626157	0.130985	4.3	0	0.299109	0.826123
C	0.0097749	0.001351	7.23	0	0.007057	0.012493
P/L	0.1457144	0.017107	8.52	0	0.1113	0.180129
Y_{13}	0.1232587	0.053498	2.3	0.026	0.015634	0.230883
Y_{14}	0.1138742	0.053551	2.13	0.039	0.006143	0.221605
Y_{15}	0.0136695	0.053679	0.25	0.8	-0.094319	0.121659
Y_{16}	0.0988949	0.05393	1.83	0.073	-0.009598	0.207388
Y_{17}	0.154638	0.054004	2.86	0.006	0.045996	0.26328
K	-0.035818	0.042377	-0.85	0.402	-0.121069	0.049433

Table 26: Network Plus Extended Passing Distance smoothed Indigenous model with combined share– OLS



Source	**SS**	**df**	**MS**			
Model	11.975344	6	1.995891	Number of obs	=	50
Residual	0.8368481	43	0.019462	F(6, 43)	=	102.56
Total	12.812192	49	0.261473	Prob > F	=	0
				R-squared	=	0.9347
				Adj R-squared	=	0.9256
				Root MSE	=	0.1395
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.4908029	0.097488	5.03	0	0.2942	0.687406
Ln(p.e.(1-I))	0.5938669	0.103874	5.72	0	0.384385	0.803349
Ln(L)	-0.034773	0.152392	-0.23	0.821	-0.342101	0.272555
Ln(W)ln(L)	-0.462981	0.127975	-3.62	0.001	-0.721067	-0.20489
Ln(L)sqr	0.6118343	0.165001	3.71	0.001	0.279079	0.94459
C	0.003925	0.001432	2.74	0.009	0.001038	0.006812
K	0.0266656	0.031236	0.85	0.398	-0.036328	0.08966

Table 27: Network Plus Extended Passing Distance smoothed Indigenous model with combined share and pumping – OLS

Source	SS	df	MS			
Model	12.641233	8	1.580154	Number of obs	=	50
Residual	0.1709587	41	0.00417	F(8, 41)	=	378.96
Total	12.812192	49	0.261473	Prob > F	=	0
				R-squared	=	0.9867
				Adj R-squared	=	0.9841
				Root MSE	=	0.06457

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.3653212	0.046245	7.9	0	0.271928	0.458715
Ln(p.e.(1-I))	0.4451424	0.049581	8.98	0	0.345012	0.545273
Ln(L)	0.3921596	0.078212	5.01	0	0.234208	0.550111
Ln(W)ln(L)	-0.298758	0.060669	-4.92	0	-0.421281	-0.17624
Ln(L)sqr	0.5395657	0.076686	7.04	0	0.384696	0.694435
C	0.009234	0.00079	11.68	0	0.007638	0.01083
P/L	0.1257492	0.010124	12.42	0	0.105303	0.146196
Y_{17}	0.0487388	0.022957	2.12	0.04	0.002377	0.095101
K	0.0313666	0.015218	2.06	0.046	0.000633	0.0621

Table 28: Network Plus Passing Distance smoothed Indigenous model with combined share and pumping – GLS

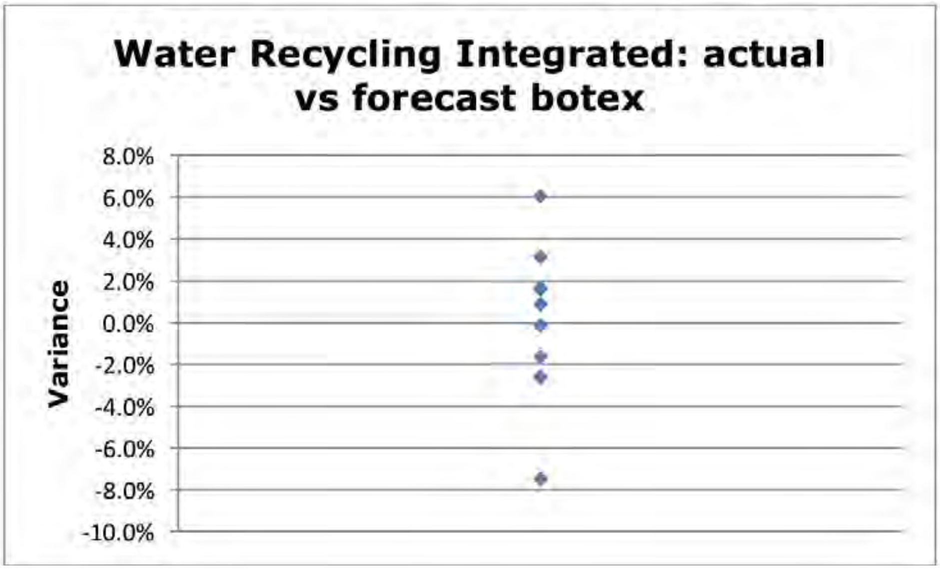
Random-effects GLS regression			**Number of obs**	=	50
Group variable: CompID			**Number of groups**	=	10
R-sq:			**Obs per group:**		
Within	=	0.6717	min	=	5
between	=	0.9867	avg	=	5
Overall	=	0.9825	max	=	5
			Wald $chi^2(11)$	=	328.47
corr(u_i, X)	= 0 (assumed)		**Prob > chi^2**	=	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Lnbotex						
Ln(p.e.I)	0.3312722	0.099857	3.32	0.001	0.135556	0.526988
Ln(p.e.(1-I)	0.2856825	0.078565	3.64	0	0.131697	0.439668
Ln(L)	0.5110853	0.172339	2.97	0.003	0.173307	0.848864
Ln(W)ln(L)	-0.1803	0.190714	-0.95	0.344	-0.554092	0.193493
Ln(L)sqr	0.3796727	0.214719	1.77	0.077	-0.041169	0.800514
C	0.0088884	0.002527	3.52	0	0.003937	0.01384
P/L	0.1300109	0.032784	3.97	0	0.065755	0.194267
Y_{14}	0.0201431	0.018474	1.09	0.276	-0.016065	0.056351
Y_{15}	0.0254746	0.018646	1.37	0.172	-0.01107	0.06202
Y_{16}	0.0570251	0.01944	2.93	0.003	0.018924	0.095126
Y_{17}	0.0812215	0.019349	4.2	0	0.043299	0.119144
K	0.0140647	0.0498	0.28	0.778	-0.083542	0.111671
sigma_u	0.0955495					
sigma_e	0.039827					
Rho	0.8519781	(fraction of variance due to u_i)				

5.4. Stand-alone Cost Assessment results

We have calculated the expected value produced by each of our preferred versions for Water Recycling Integrated, set out in Tables 5-16 for the ten WaSCs and triangulated the values to produce a single modelled botex. The variance between the modelled and actual botex expenditures are shown below as the blue markers in Figure 8. The range is from -7% to +6%. This is a startlingly tight range and gives us considerable confidence in the validity of these models.

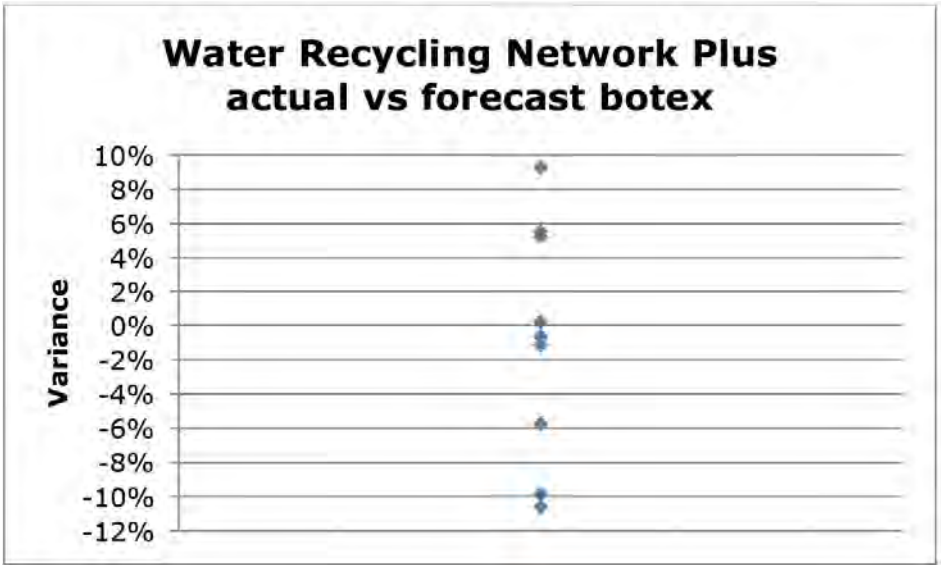
Figure 8: Variance of actual vs modelled for Water Recycling Integrated



Source: July 2017 Information Request. Anglian Water analysis

We have also calculated the expected botex expenditure produced by each of our preferred versions for Water Recycling Network Plus, set out in Tables 17-28 for the ten WaSCs and triangulated the values to produce a single modelled cost. The variance between modelled and actual botex is shown below as the blue markers in Figure 9. The range is from -11% to +9%. Although less tight than the Integrated results, this is still a tight range and gives us considerable confidence in the validity of these models.

Figure 9: Variance of actual vs modelled for Water Recycling Network Plus



Source: July 2017 Information Request. Anglian Water analysis

5.5. Alternative approaches to assessing Water Network Plus costs

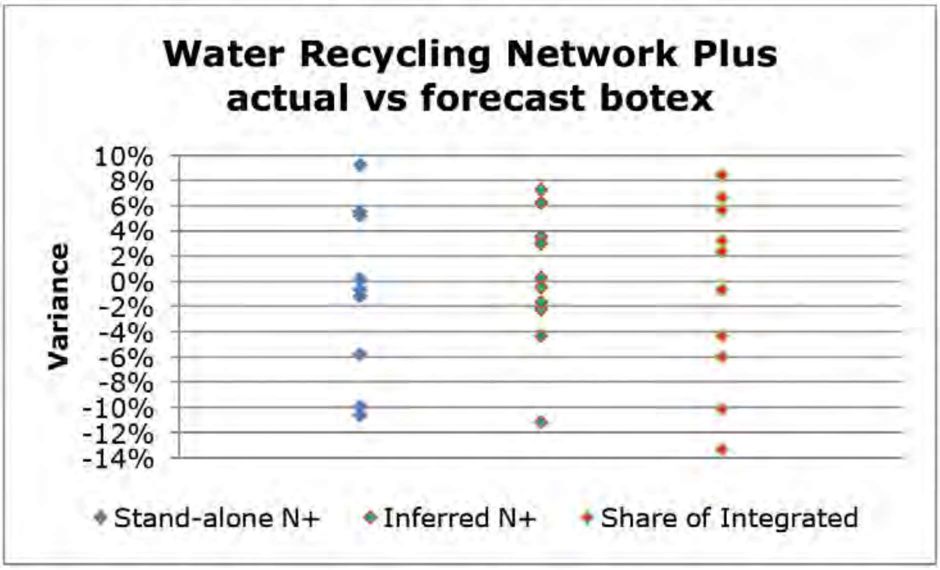
As set out in Section 5.1, there are three alternative ways of assessing Water Recycling Network Plus costs, given the set of models which we have developed for Wholesale Water Recycling. We have the stand-alone models set out above in Section 5.4. Second, it is possible to infer Network Plus costs from the difference between the Integrated model and the Bioresources model. Finally, we can calculate Network Plus botex as a fixed proportion of the Integrated model, based on historical evidence. In Figure 10 below, we show the results of all three approaches together. The stand-alone results are as shown above in Figure 9.

The differencing approach shown in Figure 10 gives a lower range of variances than the stand-alone models, the same result as in the case of the Wholesale Water models. Overall, the range is from -11% to +7%.

To estimate Water Recycling Network Plus' cost assessment element as a share of the Wholesale Water Recycling Integrated cost assessment, we have looked at the share of Integrated Water Recycling botex represented by Water Recycling Network Plus over the last six years. We have used this proportion (82.5% as an industry average – see Table 29) as the share of the Integrated Water Recycling model output to compute a figure for Water Recycling Network Plus. The result of this calculation is also shown in Figure 4 below.

By comparison to the differencing approach and the stand-alone cost models shown in Figure 10, the range of variances from the sharing approach is slightly increased. The overall range is from -13% to +9%.

Figure 10: Variance of actual vs modelled for Water Recycling Network Plus costs

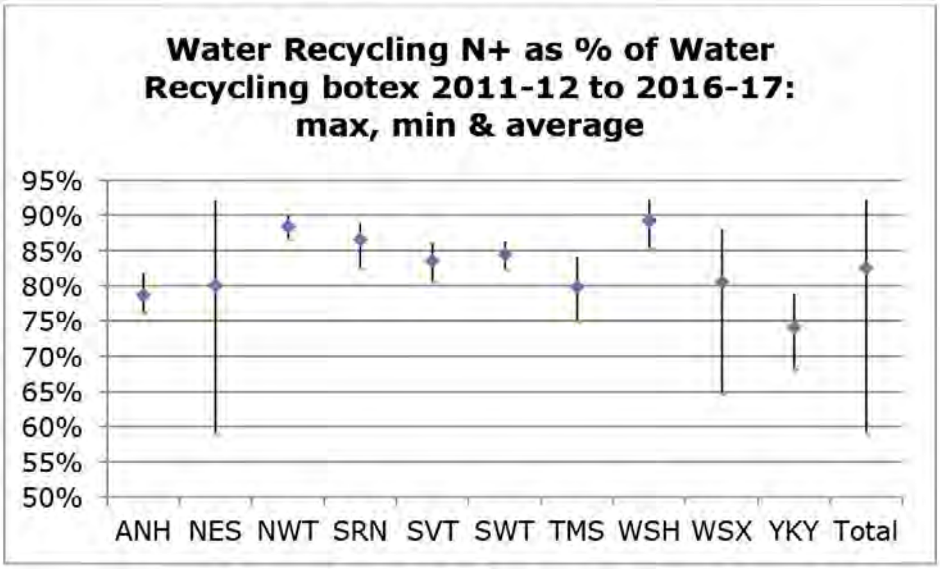


Source: July 2017 Information Request. Anglian Water analysis

The conclusion we draw from Figure 10 is that all three approaches display notably low variability between the actual and forecast botex. This gives us further confidence that these models are robust and reflect reality.

A key question relating to this potential approach to setting the Water Recycling Network Plus cost assessment is how stable is the share of total botex represented by Water Network Plus, both over time and between companies. This issue of stability is considered in Figure 11 below.

Figure 11: Variability of Water Recycling Network Plus share of wholesale Water Recycling botex 2011-12 to 2016-17



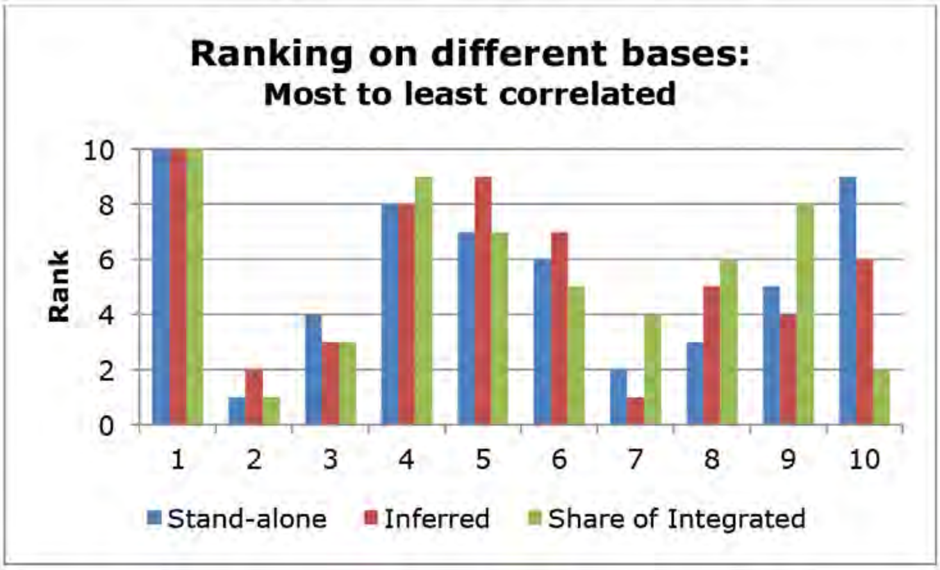
Source: July 2017 Information Request. Anglian Water analysis

This graph shows more variability than its equivalent for water. This in turn reflects greater absolute size and variability of Bioresources compared to Water Resources.

A final way of looking at the three approaches is to consider how well correlated the rankings are on the different approaches. This is set out in Figure 12. It can be seen that seven out of ten companies have a gap of two or fewer ranking places between the three approaches. Of the remaining three companies, two have a gap of three places. It should be noted that we have randomized the companies to prevent identification.

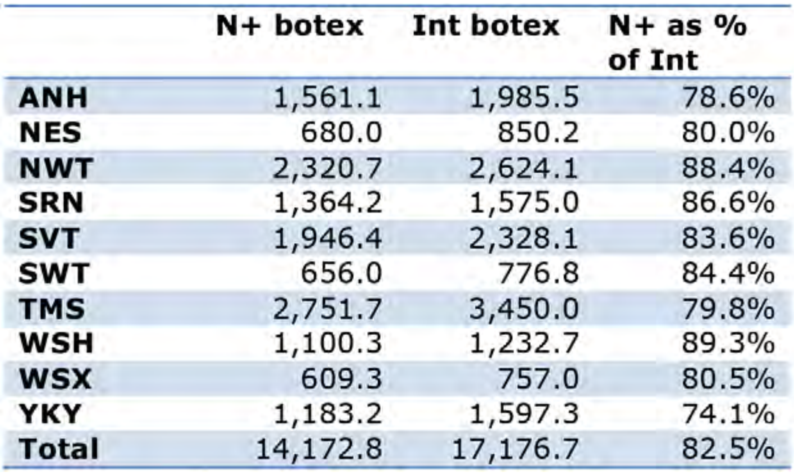
In this report, we reserve judgment about how we will use the reported models and approaches. This will be set out in our Business Plan.

Figure 12: Variability of ranking of companies



Source: Anglian Water analysis

Table 29 Network Plus botex as a share of total wholesale Water Recycling botex



	N+ botex	Int botex	N+ as % of Int
ANH	1,561.1	1,985.5	78.6%
NES	680.0	850.2	80.0%
NWT	2,320.7	2,624.1	88.4%
SRN	1,364.2	1,575.0	86.6%
SVT	1,946.4	2,328.1	83.6%
SWT	656.0	776.8	84.4%
TMS	2,751.7	3,450.0	79.8%
WSH	1,100.3	1,232.7	89.3%
WSX	609.3	757.0	80.5%
YKY	1,183.2	1,597.3	74.1%
Total	14,172.8	17,176.7	82.5%

1. Models to be created

As there will be a price control for Bioresources at PR19 which is separate from the rest of Water Recycling, there is a need for separate Bioresources and Water Recycling Network Plus cost models. Anglian Water has been developing a suite of cost models based on the data collected in the 2016 and 2017 Ofwat Information Requests.

In our Phase 1 report on initial cost modelling results published in September 2017, we created four cost models for Bioresources. These were:

- An integrated model, encompassing all aspects of Bioresources
- A disaggregated model of sludge transport
- A disaggregated model of sludge treatment
- A disaggregated model for sludge disposal.

The three disaggregated models followed the Regulatory Account Guidelines (RAG) form of disaggregation of costs.

These four models were then triangulated so as to produce a single overall output.

The Phase 1 work identified significant problems with disaggregated models, principally due to issues with cost allocation and cost interaction. Despite the intention and expectation that the RAGs ought to lead to a homogenous treatment of costs and cost allocation between companies, supported by the efforts of the Ofwat Cost Assessment Working Group which has been active since early 2016, there are still significant differences in the way costs are handled by different companies.

For Phase 2 of our Bioresources cost modelling work, we have decided to avoid the cost allocation problems and dispense with the need for triangulation by developing cost models of only the integrated model. While recognizing the potential value of the disaggregated models for benchmarking purposes, we felt it sensible to focus just on the single integrated model at this stage.

2. The production function for Bioresources

2.1. Functional form development for Bioresources models

We began Phase 2 of our cost modelling work with a workshop involving the key operational, regulatory and finance managers involved in Bioresources within Anglian Water, and our academic advisors who were closely involved in developing our modelling approach.

The aim of the workshop was to investigate the main cost drivers for the various processes involved in Bioresources. This was necessarily with a particular focus on our own operations, but looked more broadly at the way in which the other nine WaSCs operate their Bioresources functions.

Our starting point was that our cost structure is driven by the technology which we have implemented and those technology choices were driven by geographic and demographic factors. To put it another way:

1. Demographic / geographic / population dispersion factors *lead to*
2. The choices of size, type and location of Water Recycling Centres (WRCs) *lead to*
3. The choices of size, type and location of Sludge Treatment Centres (STCs) *lead to*
4. The observed Bioresources cost structure.

This suggests three possible model forms for Bioresources:

1. The first is based on demographic and geographic factors. This can be seen as being the most fundamental – the causation factors are completely exogenous to the companies. We have called this the **Demographic model**.
2. The second is based on the nature of the Network Plus asset base which produces the raw sludge which in turn is the treatment input for the Bioresources function. Both from the point of view that:
    - The existing Network Plus fixed asset base cannot realistically be changed in the short to medium term; and
    - Bioresources as a stand-alone function cannot control the Network Plus technology used to produce the sludge it is treating

the causation factors are exogenous so far as the Bioresources function is concerned. We have called this the **Network Plus model**.

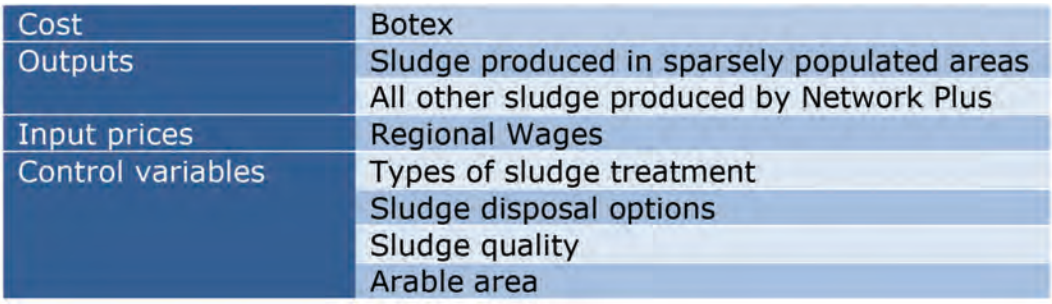
3. The third takes the operational parameters of the Bioresources function as being the causation factors. Given the asset lives of Bioresources assets, except in the short term, these causation factors are not exogenous so far as the Bioresources function is concerned. We have called this the **Outputs model**.

The models we developed in Phase 1 were variants on the Outputs model. It is clear from the consideration of exogeneity that the Demographic and Network Plus models would be preferable from a theoretical standpoint.

2.2. The Demographic model

Based on the discussion in section 2.1 above, the general form of the Demographic model is set out in Table 1 below.

Table 1: Demographic model form

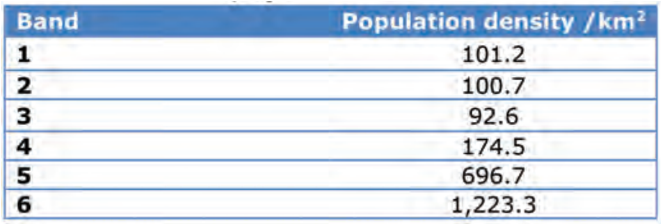


Cost	Botex
Outputs	Sludge produced in sparsely populated areas
	All other sludge produced by Network Plus
Input prices	Regional Wages
Control variables	Types of sludge treatment
	Sludge disposal options
	Sludge quality
	Arable area

Leaving aside differences of cost allocation and the issue discussed in section 3.1, the costs pose no problem. The data are available and well understood.

While the sludge produced figures are available through the Information Request, the key question in the demographic model is what level of population sparsity differentiates between small and large WRCs. We have looked at the population density of the Post Code districts (e.g. CB1 or PE29) in which our WRCs are located. Given the size of the Post Code districts, for the small WRCs, this is thought to be a reasonable estimate of the population density of the WRCs' catchment areas. For the larger WRCs, it may represent an underestimate as WRCs are seldom if ever located in the densest part of their catchment areas. The results for Anglian Water appeared well differentiated. They are set out in the following table.

Table 2: Population density of post code districts where Anglian Water STWs are located, by STW bands



Band	Population density /km²
1	101.2
2	100.7
3	92.6
4	174.5
5	696.7
6	1,223.3

Up to Band 4, the average population density for the WRCs in those bands is below 250/km^2. This analysis has informed our cost modelling. We recognize that the population density in the area served by Anglian Water is amongst the sparsest of the WaSCs. For this reason we have used both the Ofwat population sparsity factor looking at the proportion of population in LSOAs with a sparsity <250/km^2 and the factor looking at the proportion of population in LSOAs with a sparsity <600/km^2 as well.

A series of regional wage data has been collated and distributed by Ofwat, based on ONS and ASHE data. Although this data set is designed for wholesale services, when it has been used previously it has been notably unsuccessful in finding reliable statistical relationships.

Data concerning types of treatment have been collected as part of the Information Requests both in 2016 and 2017.

Similarly, data on sludge disposal routes has been collected in the Information Requests. The problem with the sludge disposal data is that almost all of it goes to farmland. As such, there is very little variability in the data across the 10 companies.

A useful measure of ease of disposal of treated sludge, and indirectly the quality of treated sludge, would be the available land bank for each company. The potential loss of land bank for Anglian Water is a matter of great importance. Its preservation was a key factor driving us to improve the quality of treated sludge. As such, any increase in the size of the land bank would be evidence of improved quality. Unfortunately, while each company will know that figure for its own area, the data have not been collected centrally. In its absence, we have used[1] data from the DEFRA 2016 "Agriculture in the UK" report. Specifically, we have looked at the area of arable land within each appointed area as a proportion of the total identified arable land. This can capture the ease of disposal but not the quality aspect.

To capture quality, we looked at using data from the Biosolids Assurance Scheme (BAS), a scheme promoted by Water UK to set quality standards for treated sludge. Unfortunately as data are only available for the last two years (for three companies) and for the last year (for the other seven), this is inadequate for cost modelling purposes. We also looked at using the achieved price for treated sludge by companies. While this appeared to be a promising approach, the lack of data led us ultimately not to use this potential variable.

The issues surrounding the outputs cost drivers are dealt with in section 4 below.

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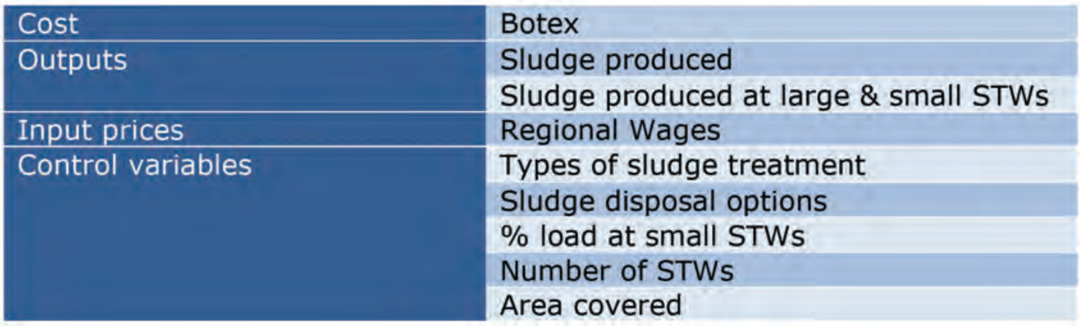
[1] *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/629226/AUK-2016-17jul17.pdf*

2.3. The Network Plus model

Based on the discussion in section 2.1 above, the general form of the Network Plus model is set out in Table 3 below.

Table 3: Network Plus model form



Cost	Botex
Outputs	Sludge produced
	Sludge produced at large & small STWs
Input prices	Regional Wages
Control variables	Types of sludge treatment
	Sludge disposal options
	% load at small STWs
	Number of STWs
	Area covered

Load produced at small WRCs was used in PR14 models and in the work undertaken by the CMA in the Bristol appeal. In both cases, it was defined as the proportion of load treated in bands 1-3 – that is, in WRCs serving up to 2,000 population equivalent (p.e.)

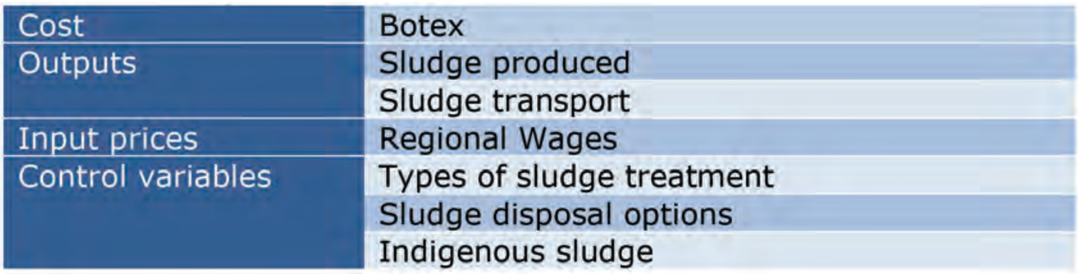
As well as using sludge produced (measured in tons of dry solids, tds) as the output variable, we also looked at taking an approach similar to that in the demographic model and using the proportion of sludge generated by different sized WRCs. This was calculated as being the proportion of load from the relevant WRCs multiplied by the tds for the company.

As set out below, we use a number of measures of area covered as a scale variable for considering sludge transport.

2.4. The Outputs model

Based on the discussion in section 2.1 above, the general form of the Outputs model is set out in Table 4 below.

Table 4: Outputs model form



Cost	Botex
Outputs	Sludge produced
	Sludge transport
Input prices	Regional Wages
Control variables	Types of sludge treatment
	Sludge disposal options
	Indigenous sludge

The Outputs model broadly accords with the integrated cost models reported in our initial cost modelling report in September 2017.

3. Costs to be used

3.1. The data used

The source files for the data used in the Bioresources cost modelling were as follows:

- 20171013 hc Master wholesale waste July 2017
- Company specific labour cost indices
- High density and scarcity indices hc.

We recognize that even now at the time of writing (mid February 2018), the data set has yet to be confirmed and that the key data file (20171013 hc Master wholesale waste July 2017) is still subject to modification. However, given the time constraints imposed on us by the PR19 timetable, we cannot wait until the data set has been finally confirmed to start the cost modelling. It is regrettable but inevitable that Ofwat will have a more accurate data set to work with when it begins its cost modelling. However, given the concerted efforts of the members of the Ofwat Cost Assessment Working Group in highlighting shortcomings within the data, it may be hoped that further changes will be relatively minor.

We will re-run our models after July 2018, when we will have the benefit of both corrected data and 2017-18 data. The impact of these changes will be available to us during the later stages of the price review process.

The costs included in botex were as follows:

- Total operating expenditure (excluding third party services); minus
- Local authority and Cumulo rates; plus
- Maintaining the long term capability of the assets – infra; plus
- Maintaining the long term capability of the assets - non-infra.

Operating costs should be reported net of income companies have earned from appointed activities, such as sales of biosolids and energy generated from sludge gas. We have reported to Ofwat our concerns that companies are not applying a consistent treatment of these revenues.

The costs are all taken from the Regulatory Accounts filed by appointed companies. All costs exclude atypical expenditure as reported by companies.

All costs are rebased in 2012-13 prices.

3.2. Capital enhancement issues

The problems surrounding the use of econometrics for evaluating capital enhancement have been thoroughly rehearsed. While we recognise the desire to achieve robust totex models, the widespread recognition that if there is no prior data relating to particular forecast outputs, it is not feasible to use the same approach as for outputs which have a long track record. This was the starting point for the idea that if some aspects of enhancement do indeed recur, then those could be included in the econometric cost modelling exercise.

Following the discussions of this nature within the Ofwat Cost Assessment Working Group, and in line with the PR19 Draft Methodology Statement of July 2017, we have also explored an alternative version of Botex which we have described as botex plus. This, for the purposes of Bioresources, includes enhancement expenditure on growth.

Considering Tables 5, 6, 7 and 8, a number of factors are apparent.

- Sludge Treatment accounts for nearly all the enhancement capex for Bioresources.
- There is next to no enhancement capex at all for Sludge Transport.
- For Sludge Disposal, all of the growth related enhancement relates to just one company – TMS.
- Within Sludge Treatment, more than half of enhancement capex relates to quality improvements. 36% of Sludge Treatment enhancement capex relates to growth
- Within that 36%, over 90% (£201m out of £218m) relates to just one company, TMS.

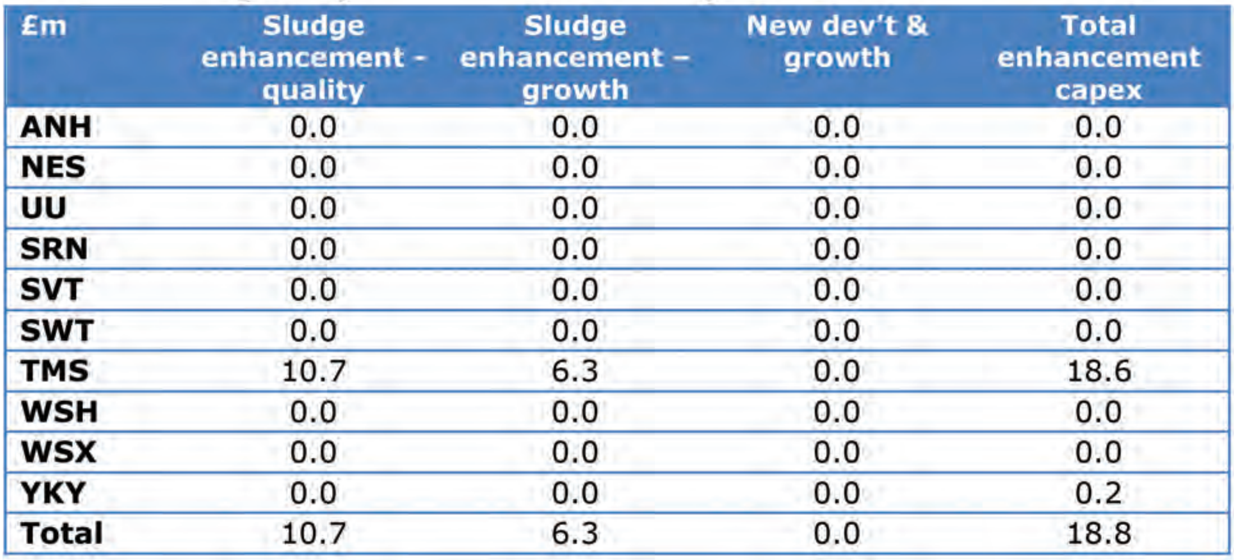
Table 5: Sludge Treatment enhancement capex 2011-12 to 2016-17

£m	Sludge enhancement quality	Sludge enhancement growth	New dev't & growth	Total enhancement capex	Growth/ Total
ANH	84.5	0.4	0.0	85.2	0.5%
NES	0.0	0.0	0.0	0.0	
UU	111.1	0.0	0.0	125.9	0.0%
SRN	0.0	3.7	0.1	6.6	57.5%
SVT	22.3	5.5	0.0	28.3	19.5%
SWT	0.0	0.0	0.0	0.0	0.0%
TMS	86.1	201.3	0.0	321.4	62.6%
WSH	0.4	0.9	0.0	1.9	46.7%
WSX	1.5	6.0	0.0	7.9	76.3%
YKY	30.0	0.2	0.0	33.8	0.6%
Total	336.0	218.0	0.1	610.9	35.7%

Table 6: Sludge Transport enhancement capex 2011-12 to 2016-17

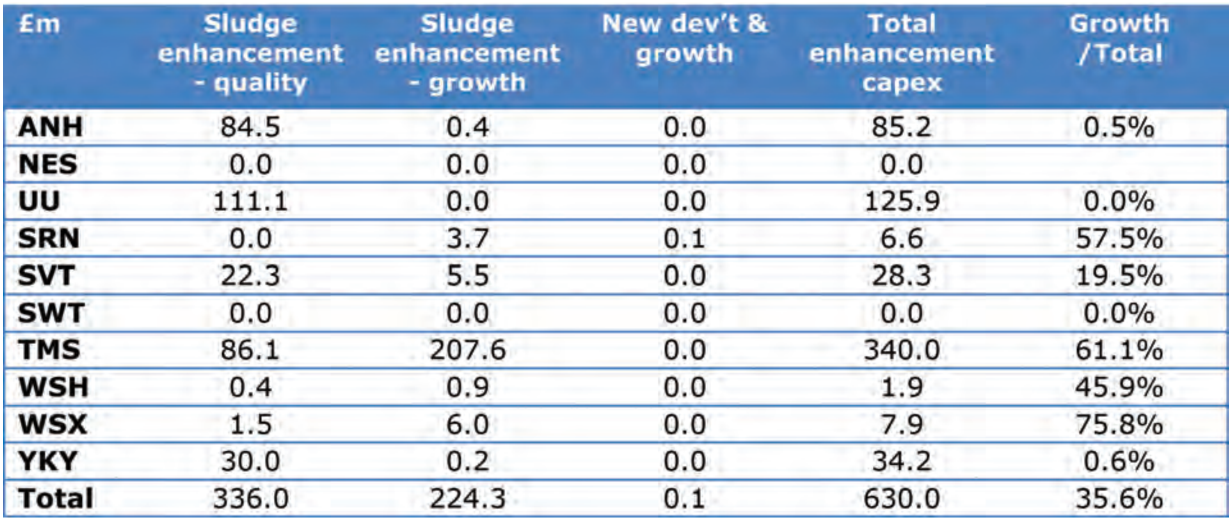
£m	Sludge enhancement - growth	New dev't & growth	Total enhancement capex
ANH	0.0	0.0	0.0
NES	0.0	0.0	0.0
UU	0.0	0.0	0.0
SRN	0.0	0.0	0.0
SVT	0.0	0.0	0.0
SWT	0.0	0.0	0.0
TMS	0.0	0.0	0.0
WSH	0.0	0.0	0.0
WSX	0.0	0.0	0.1
YKY	0.0	0.0	0.2
Total	0.0	0.0	0.3

Table 7: Sludge Disposal enhancement capex 2011-12 to 2016-17



£m	Sludge enhancement - quality	Sludge enhancement – growth	New dev't & growth	Total enhancement capex
ANH	0.0	0.0	0.0	0.0
NES	0.0	0.0	0.0	0.0
UU	0.0	0.0	0.0	0.0
SRN	0.0	0.0	0.0	0.0
SVT	0.0	0.0	0.0	0.0
SWT	0.0	0.0	0.0	0.0
TMS	10.7	6.3	0.0	18.6
WSH	0.0	0.0	0.0	0.0
WSX	0.0	0.0	0.0	0.0
YKY	0.0	0.0	0.0	0.2
Total	10.7	6.3	0.0	18.8

Table 8: Total Bioresources enhancement capex 2011-12 to 2016-17



£m	Sludge enhancement - quality	Sludge enhancement - growth	New dev't & growth	Total enhancement capex	Growth /Total
ANH	84.5	0.4	0.0	85.2	0.5%
NES	0.0	0.0	0.0	0.0	
UU	111.1	0.0	0.0	125.9	0.0%
SRN	0.0	3.7	0.1	6.6	57.5%
SVT	22.3	5.5	0.0	28.3	19.5%
SWT	0.0	0.0	0.0	0.0	0.0%
TMS	86.1	207.6	0.0	340.0	61.1%
WSH	0.4	0.9	0.0	1.9	45.9%
WSX	1.5	6.0	0.0	7.9	75.8%
YKY	30.0	0.2	0.0	34.2	0.6%
Total	336.0	224.3	0.1	630.0	35.6%

The analysis shows that enhancement capex relating to growth is both lumpy and disproportionately relates to just one company –TMS. A decade ago, Anglian would very likely have appeared as a similar outlier. It is very hard to imagine how a cost model could effectively model this level of lumpiness based on, for example, population growth numbers. In order to predict growth expenditure in sludge effectively, one would need to know the current level of headroom in terms of capacity that companies have; the level of risk appetite of the companies; companies' plans for the net trading out of sludge; in addition to forecasts of population growth within the companies' regions.

Only the last of these factors is in the public domain. The implication of the above analysis is that including growth related enhancement capex within botex plus without including a set of cost drivers which are not at present in the public domain (and would be very commercially sensitive and/or hard to define) is likely to result in cost models which perform less well than straightforward botex models. A botex plus model could be expected to lead to TMS being disadvantaged.

Consequently, the conclusion we reached is that we do not propose a botex plus model for sludge, and enhancement costs have to be allowed for by a separate route.

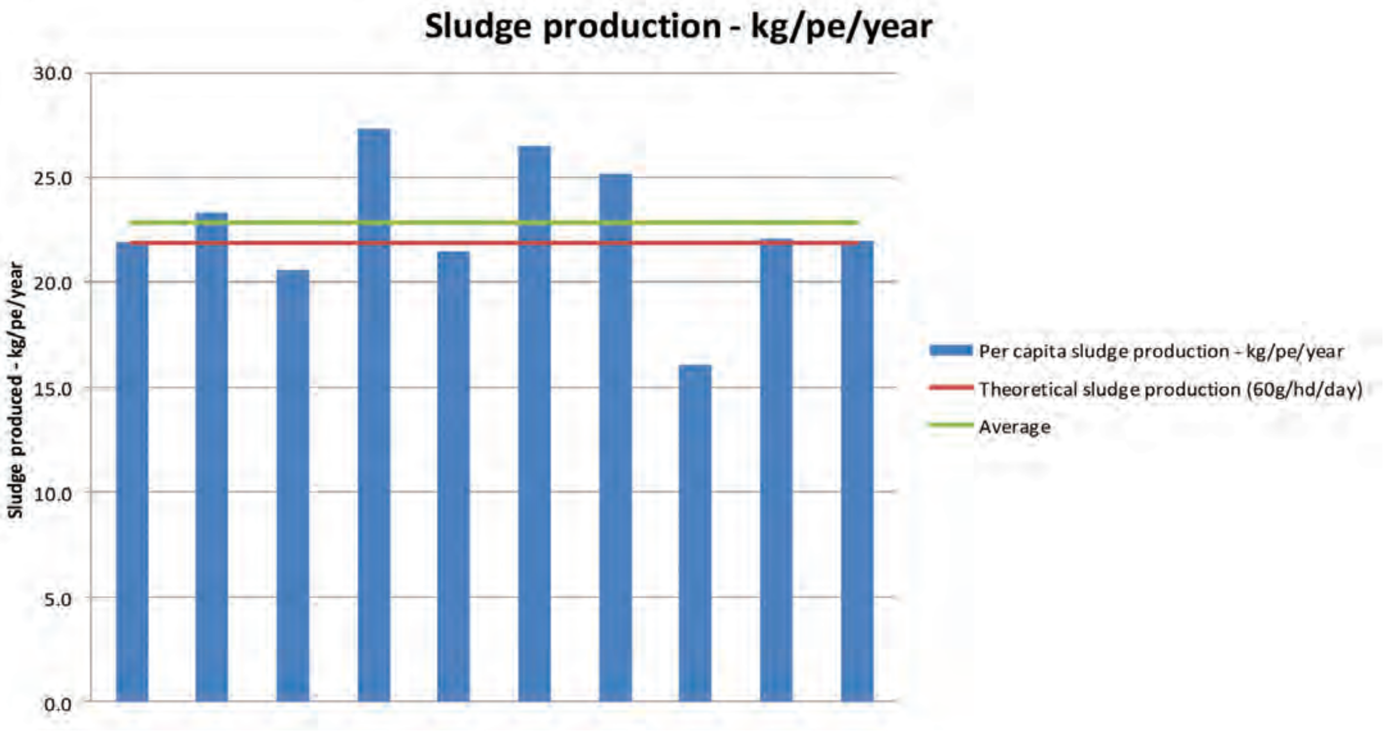
4. Key cost drivers

4.1. Sludge Treated

It was clear from our Phase 1 report that sludge produced is a critical cost driver for Bioresources. As such, we recognize that it is important that the numbers for tons of dry solids (tds) reported by companies to Ofwat are accurate. The blue bars in Figure 1 show the annual sludge production per population equivalent for all 10 WaSCs based on the 2017 Information Return. The green horizontal line shows the weighted average for the companies of 22.9kg/p.e./year. The red line shows 21.9kg/p.e./year, the amount of sludge that would be expected, based on an assumed sludge production of 60g/p.e/day (an assumption incorporated into the Urban Wastewater Treatment Directive). From Figure 1, four companies can be seen to be within 5% of the theoretical quantity of sludge. Four are more than 5% above the theoretical amount and the remaining two are more than 5% below the theoretical amount. Unless these differences in sludge production are justified, there is a risk that conclusions drawn from the modelling results may be inaccurate.

The cost models reported in Section 5 are all based on the reported sludge produced. We suggest that if companies cannot justify why their figures are substantially different from the theoretical numbers, then models should be developed using the theoretical and not the reported numbers.

Figure 1: Actual and theoretical sludge production



Source: 2017 Information Request; ANH analysis

4.2. Sludge Transport

Anglian Water's appointed area is large and has large areas of low population density. As a result, not only has it the largest number of Water Recycling Centres (WRCs), it also has a large number of small WRCs (serving fewer than 10,000 p.e.). As it is not economically viable to dewater sludge at small WRCs so as to produce sludge cake, Anglian Water has to move large volumes of liquid sludge by tankers from the small works to the ten Sludge Treatment Centres (STCs) which are co-located with large WRCs. Other companies with similar demographic characteristics experience the same operational challenges and cost impacts. At the same time, companies serving larger urban centres experience this disadvantage to much lesser degree.

Historically, we have claimed a Special Cost Factor (SCF, at PR19 referred to as a Cost Adjustment) for sludge transport. This was because the opex model for sludge used up to PR09 did not take into account the demographic and geographic factors which lead Anglian Water to transport large quantities of liquid sludge.

The cost models we have developed have been designed deliberately to capture the significant impact on costs of this factor.

4.3. Disposal routes

As can be seen from the 2017 Information Request, nearly all sludge is recycled to land. Where it does not, incineration (very expensive) is the principal alternative. Those companies still incinerating sludge have been moving away from this approach to reduce costs.

A critical business risk for the companies, is the potential loss of the land-bank. In this context, the land-bank is the agricultural land available to companies for disposal of treated sludge. Protection of the land-bank was a key strategic driver for improving our treated sludge quality which has had the ancillary benefit that the company now earns over £2m pa from selling its treated digestate as fertilizer.

While on the face of it, Anglian Water might be thought to be in a fortunate position with regard to land-bank, given the area of arable land within the appointed area, there is nothing inevitable about the availability of this strategic asset: other companies can and do dispose of treated sludge within our appointed area. Moreover, without maintaining the high quality of our treated digestate, farmers could potentially stop buying from Anglian Water.

All of that said, the amount of potential arable land available as land-bank is a relevant potential cost driver. Data for land-bank by company is not in the public domain. There is data from DEFRA on arable land by ONS standard region. We have made use of this to estimate the amount of land per company, based on work done by Ofwat translating standard regions into company areas.

4.4. Regional wages

Ofwat has developed a regional wage series based on SOC2 codes for wholesale based activities. We have taken the data made available by Ofwat for the years up to 2014-15. These have been put into 2102-13 cost base and have been trended forward up to 2016-17 for cost modelling purposes.

The regional wage variable was tried in all of the models but failed to have predictive power. The coefficient was either unrealistic or insignificant or both. As such, it has not been reported in Section 5.

4.5. Quality

We wanted to include a measure of quality for treated sludge. Two possible approaches were investigated.

First, we looked at using the audit data from the Biosolids Assurance Scheme (BAS), an industry initiative instigated by Anglian Water. BAS was conceived as a way to demonstrate to the farming community the quality of the treated digestate. Unfortunately, the BAS audit data are only available for a few companies over the last two years. It proved too limited a data set to act as an effective cost driver.

The second idea was to use the revenue per ton earned as a proxy for the digestate's quality. Unfortunately, only three out of ten companies sell treated sludge. This also was too limited a set to act as an effective cost driver, although one could argue that the failure of the other seven companies to earn revenue from their treated digestate can be read as their inability to demonstrate to farmers the value of their treated digestate.

Reluctantly then, we ended up without a measure of quality in the chosen models.

5. Cost modelling development

We have used STATA v14 in our cost modelling. The outputs shown below in section 5 are the STATA outputs for the various models.

The key to the abbreviations used in section 5 are given in Table 9 below.

Table 9: Key for Section 5 cost models

Abbreviation	Description
A	Appointed area
A_r	Arable land in appointed area as % of total arable land
B_{1-2}	Proportion of load handled by Band 1-2 STWs (p.e.<1,000)
B_{1-3}	Proportion of load handled by Band 1-3 STWs (p.e.<2,000)
B_{1-4}	Proportion of load handled by Band 1-4 STWs (p.e.<10,000)
B_{3-4}	Proportion of load handled by Bands 3 & 4 STWs (1,000<p.e.<10,000)
B_5	Proportion of load handled by Band 5 STWs (10,000<p.e.<25,000)
CDAD	% tds treated by conventional or advanced anaerobic digestion
D	% treated sludge disposed to farmland
I	% sludge produced at co-located STW (Indigenous sludge)
K	Constant
S_2	Ofwat sparsity measure 2: % of population in LSOA with sparsity <600/km^2
S_3	Ofwat sparsity measure 3: % of population in LSOA with sparsity <1,150/km^2
S_A	Sewered area
T	Time Trend
V	Actual total thousand tons dry solid (ttds) produced
V_T	Theoretical total thousand tons dry solid (ttds) produced based on 60g/p.e./day
V_{B1-3}	Ttds generated by Band1-3 STWs
V_{B1-4}	Ttds generated by Band1-4 STWs
V_{B5}	Ttds generated by Band5 STWs
V_{B6}	Ttds generated by Band6 STWs
W_V	Work done by volume in moving liquid sludge

5.1. Demographic model

We developed seven variants of the demographic model described in Section 2.2. The cost drivers in these models are set out in Table 10 below. It can be seen that versions 4, 5 and 6 differ from 1, 2 and 3 only in that they use a different population sparsity measure. Version 7 adds one further control variable to version 3.

The demographic model requires few cost drivers.

We have reported only version 7 as we felt this best captured the demographic factors. All coefficients are significant at 90% and all but one at 95%.

Table 10: Variables in demographic models

1	2	3	4	5	6	7
V	VS_2	VS_2	V	VS_3	VS_3	VS_2
S_2	$V(1-S_2)$	$V(1-S_2)$	S_3	$V(1-S_3)$	$V(1-S_3)$	$V(1-S_2)$
CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD
T	T	T	T	T	T	T
		A			A	A
						S_A/A

Table 11: Demographic v7

Source	**SS**	**df**	**MS**			
Model	20.3684	6	3.39473	Number of obs	=	60
Residual	3.70582	53	0.06992	Prob > F	=	0
Total	24.0742	59	0.40804	R-squared	=	0.8461
				Adj R-squared	=	0.8286
				Root MSE	=	0.26443

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln($V.S_2$)	0.38302	0.17734	2.16	0.035	0.02732	0.73871
Ln($V(1-S_2)$)	0.46186	0.043	10.74	0	0.3756	0.54811
Cdad	-0.99207	0.15972	-6.21	0	-1.31242	-0.67172
Ln(A)	0.48798	0.18872	2.59	0.013	0.10945	0.86651
S_A/A	2.18216	1.29727	1.68	0.098	-0.41984	4.78416
T	0.04598	0.02059	2.23	0.03	0.00468	0.08728
K	-4.71939	1.46067	-3.23	0.002	-7.64912	-1.78966

It should be noted that while the non sparse (V.(1-S) coefficient is higher than the sparse coefficient, as the volume of sparse sludge is significantly lower than the volume of non sparse sludge, the marginal cost of the sparse sludge is significantly higher than that of the non sparse sludge.

5.2. Network Plus model

We developed 11 versions of the Network Plus model described in Section 2.3.

Versions 1, 3, 5 and 7 are variations on a theme. All use the volume of sludge produced as the output, differing by the control variables used to set out the proportion of load in differing groupings of bands of STWs.

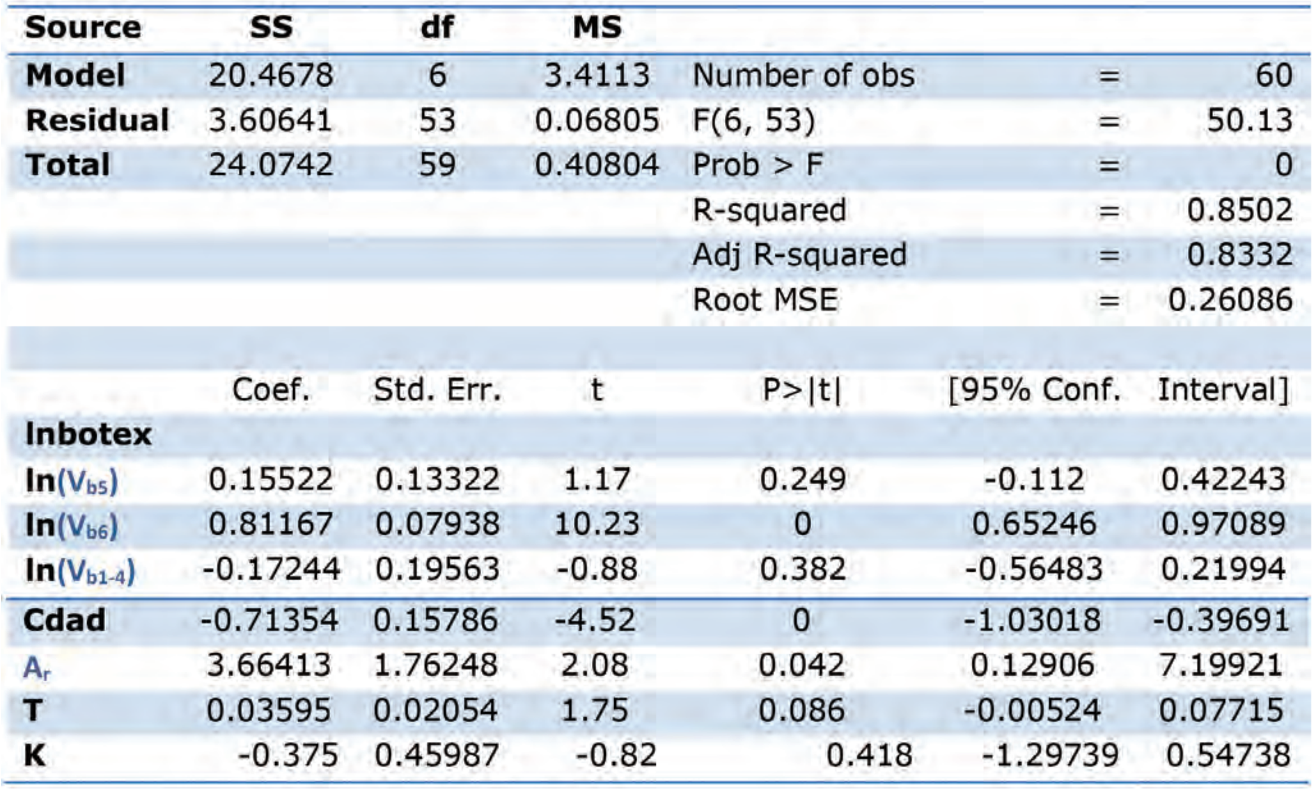
Similarly, versions 2, 4, 6 and 8 are also variations on a theme. All use sludge produced disaggregated to differing groupings of bands of STWs.

Version 9 is a variant on version 2, with the proportion of arable land within the appointed area replacing the proportion of sludge disposed to farmland. Similarly, versions 10 and 11 (the two which we report) are variants on version 4.

Table 12: Variables in Network Plus models

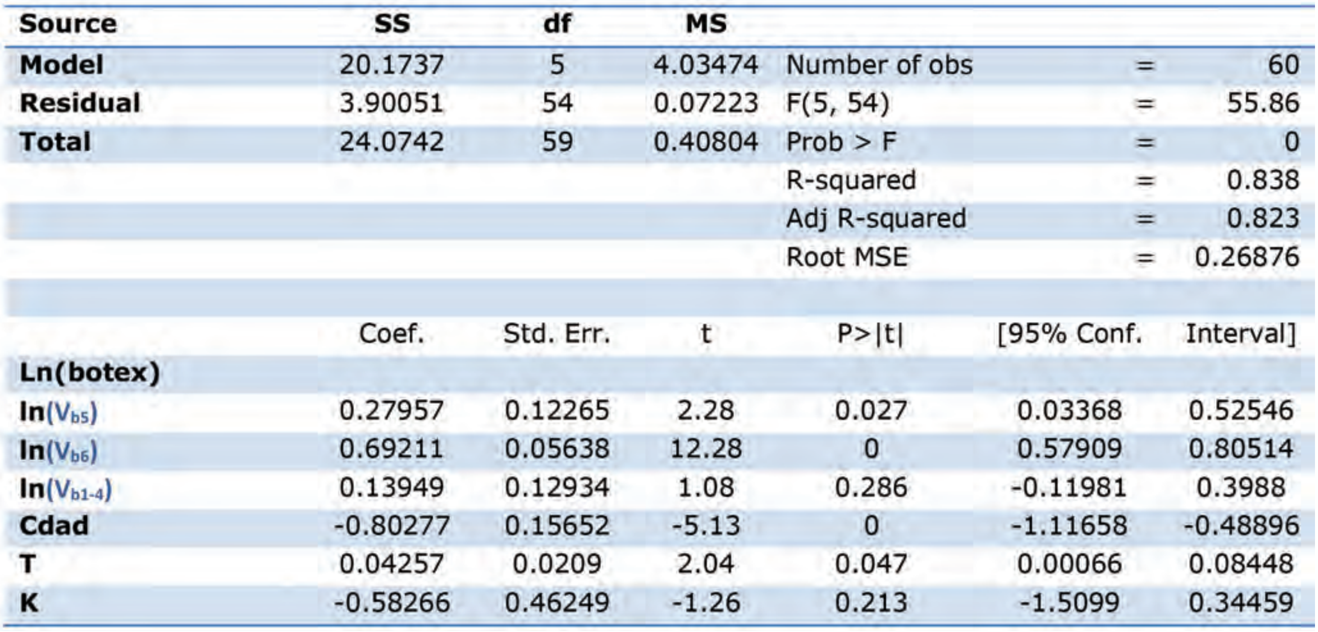
1	2	3	4	5	6	7	8	9	10	11
V	V_{b1-3}	V	V_{b1-4}	V	V_{b1-4}	V	V_{b1-2}	V_{b1-3}	V_{b1-4}	V_{b1-4}
	V_{b4-6}		V_{b5-6}		V_{b5}		V_{b3-4}	V_{b4-6}	V_{b5}	V_{b5}
					V_{b6}		V_{b5-6}		V_{b6}	V_{b6}
B_{1-3}		B_{1-4}		B_{1-4}, B_5		B_{1-2}, B_{3-4}				
CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD
D	D	D	D	D	D	D	D	A_r	A_r	
T	T	T	T	T	T	T	T	T	T	T

Table 13: Network Plus model v10



Source	SS	df	MS			
Model	20.4678	6	3.4113	Number of obs	=	60
Residual	3.60641	53	0.06805	F(6, 53)	=	50.13
Total	24.0742	59	0.40804	Prob > F	=	0
				R-squared	=	0.8502
				Adj R-squared	=	0.8332
				Root MSE	=	0.26086
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnbotex						
ln(V_{b5})	0.15522	0.13322	1.17	0.249	-0.112	0.42243
ln(V_{b6})	0.81167	0.07938	10.23	0	0.65246	0.97089
ln(V_{b1-4})	-0.17244	0.19563	-0.88	0.382	-0.56483	0.21994
Cdad	-0.71354	0.15786	-4.52	0	-1.03018	-0.39691
A_r	3.66413	1.76248	2.08	0.042	0.12906	7.19921
T	0.03595	0.02054	1.75	0.086	-0.00524	0.07715
K	-0.375	0.45987	-0.82	0.418	-1.29739	0.54738

Table 14: Network Plus model v11

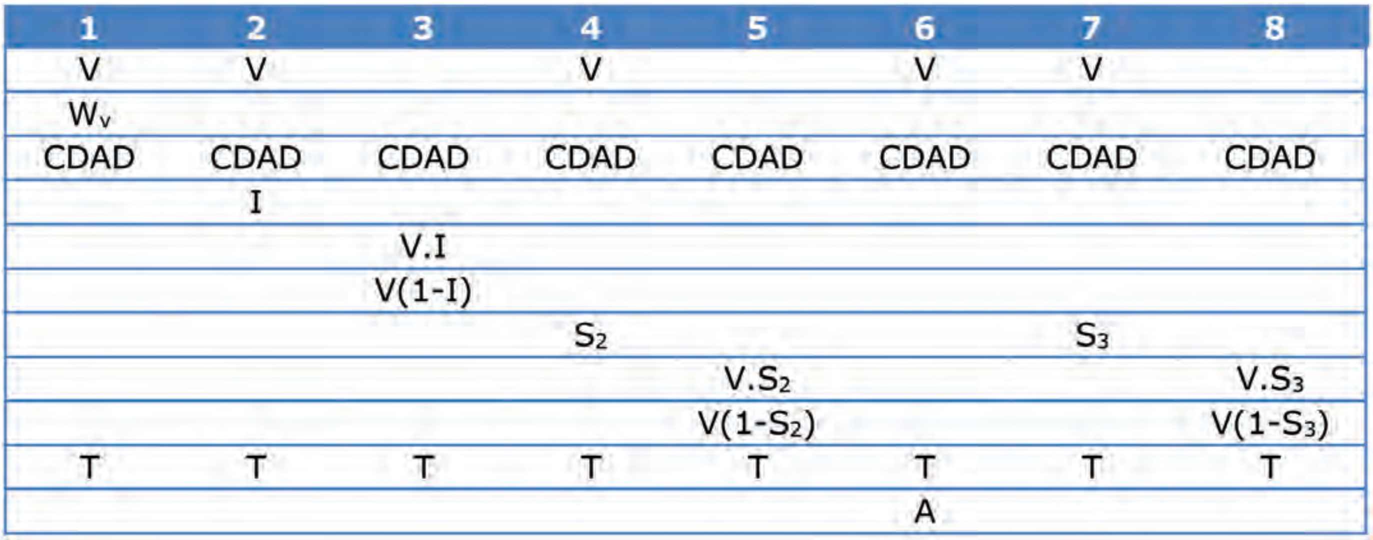


Source	SS	df	MS			
Model	20.1737	5	4.03474	Number of obs	=	60
Residual	3.90051	54	0.07223	F(5, 54)	=	55.86
Total	24.0742	59	0.40804	Prob > F	=	0
				R-squared	=	0.838
				Adj R-squared	=	0.823
				Root MSE	=	0.26876
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex)						
ln(V_{b5})	0.27957	0.12265	2.28	0.027	0.03368	0.52546
ln(V_{b6})	0.69211	0.05638	12.28	0	0.57909	0.80514
ln(V_{b1-4})	0.13949	0.12934	1.08	0.286	-0.11981	0.3988
Cdad	-0.80277	0.15652	-5.13	0	-1.11658	-0.48896
T	0.04257	0.0209	2.04	0.047	0.00066	0.08448
K	-0.58266	0.46249	-1.26	0.213	-1.5099	0.34459

5.3. Outputs model

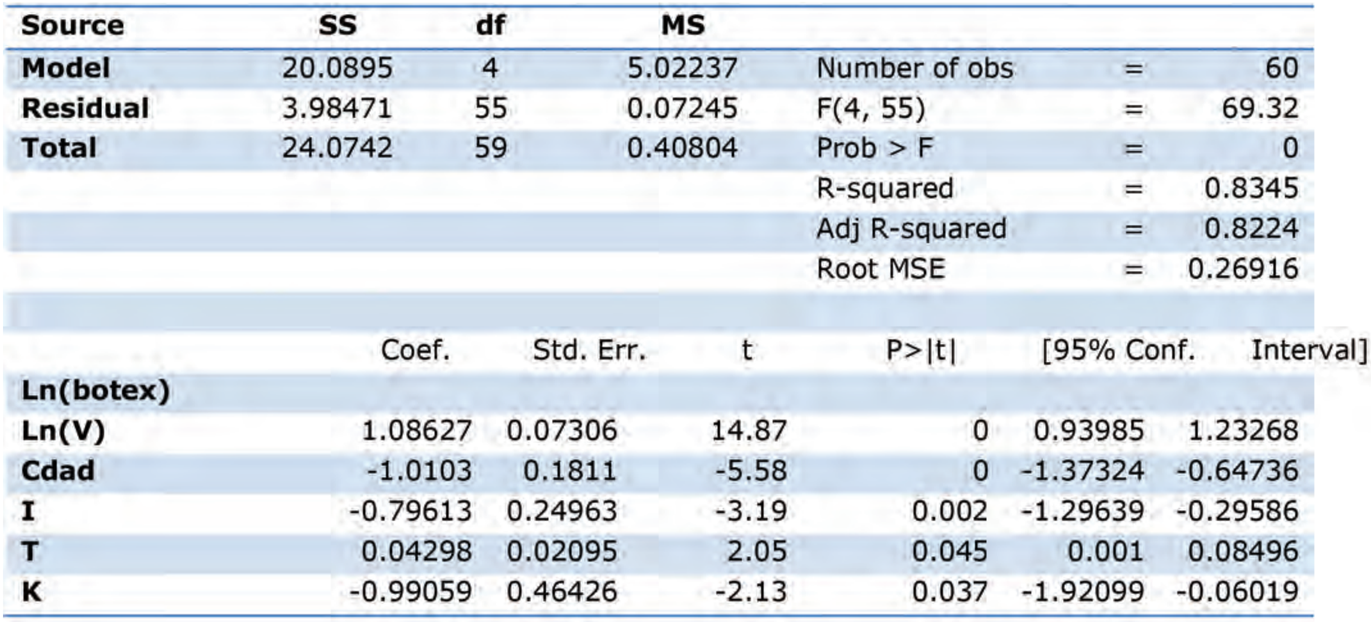
We developed eight versions of the Outputs model described in Section 2.4. Version 1 uses the direct measure of work done moving liquid sludge. Versions 2, 4, 6 and 7 each use a different control variable to address the size and dispersion of population. Versions 3, 5 and 8 are similarly variants on the same theme of disaggregating volume. The three most robust variants of the outputs model, versions 2, 7 and 8, are reported below.

Table 15: Variables in Output models



1	2	3	4	5	6	7	8
V	V		V		V	V	
W_v							
CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD	CDAD
	I						
		V.I					
		V(1-I)					
			S_2			S_3	
				$V.S_2$			$V.S_3$
				$V(1-S_2)$			$V(1-S_3)$
T	T	T	T	T	T	T	T
					A		

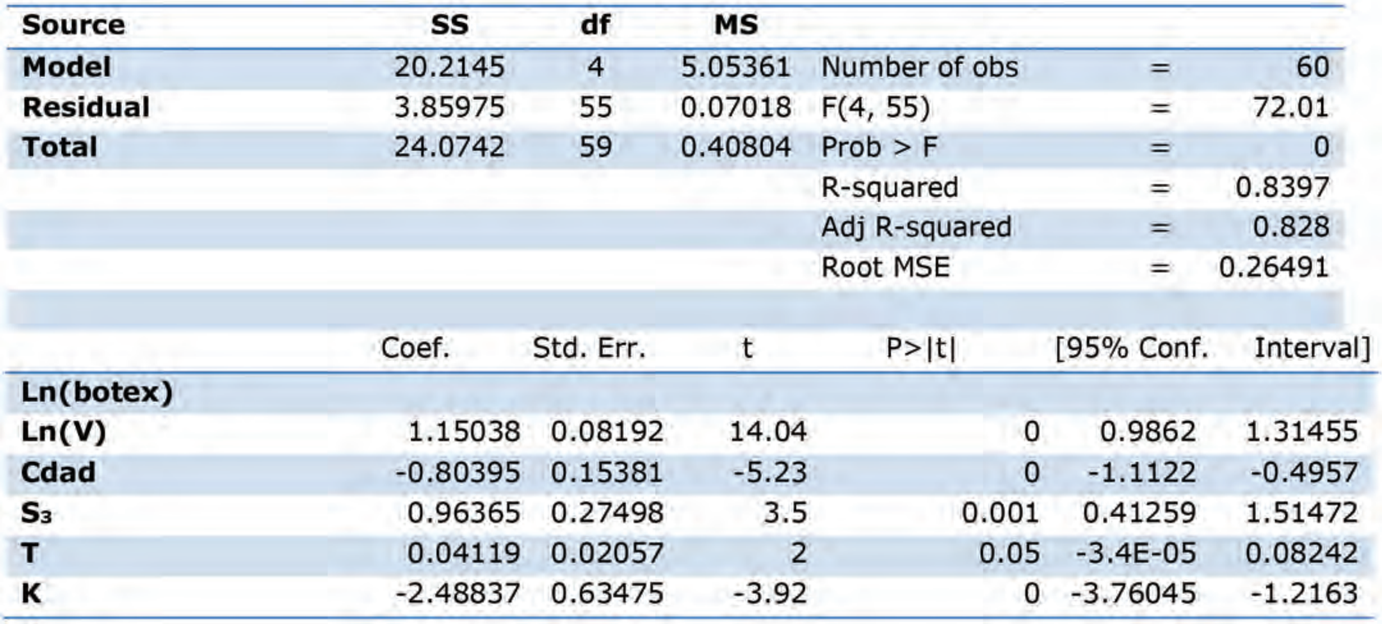
Table 16: Outputs model v2



Source	SS	df	MS			
Model	20.0895	4	5.02237	Number of obs	=	60
Residual	3.98471	55	0.07245	F(4, 55)	=	69.32
Total	24.0742	59	0.40804	Prob > F	=	0
				R-squared	=	0.8345
				Adj R-squared	=	0.8224
				Root MSE	=	0.26916

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex)						
Ln(V)	1.08627	0.07306	14.87	0	0.93985	1.23268
Cdad	-1.0103	0.1811	-5.58	0	-1.37324	-0.64736
I	-0.79613	0.24963	-3.19	0.002	-1.29639	-0.29586
T	0.04298	0.02095	2.05	0.045	0.001	0.08496
K	-0.99059	0.46426	-2.13	0.037	-1.92099	-0.06019

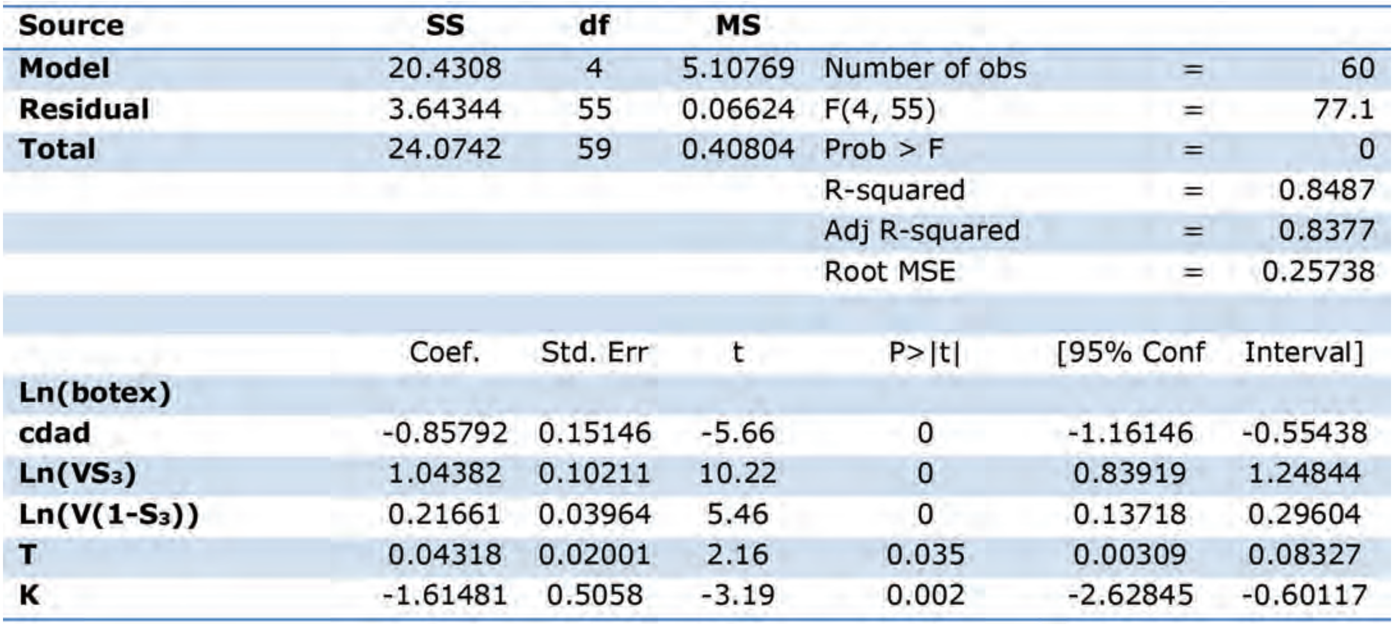
Table 17: Outputs model v7



Source	SS	df	MS			
Model	20.2145	4	5.05361	Number of obs	=	60
Residual	3.85975	55	0.07018	F(4, 55)	=	72.01
Total	24.0742	59	0.40804	Prob > F	=	0
				R-squared	=	0.8397
				Adj R-squared	=	0.828
				Root MSE	=	0.26491

	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(botex)						
Ln(V)	1.15038	0.08192	14.04	0	0.9862	1.31455
Cdad	-0.80395	0.15381	-5.23	0	-1.1122	-0.4957
S_3	0.96365	0.27498	3.5	0.001	0.41259	1.51472
T	0.04119	0.02057	2	0.05	-3.4E-05	0.08242
K	-2.48837	0.63475	-3.92	0	-3.76045	-1.2163

18: Outputs model v8



Source	SS	df	MS			
Model	20.4308	4	5.10769	Number of obs	=	60
Residual	3.64344	55	0.06624	F(4, 55)	=	77.1
Total	24.0742	59	0.40804	Prob > F	=	0
				R-squared	=	0.8487
				Adj R-squared	=	0.8377
				Root MSE	=	0.25738

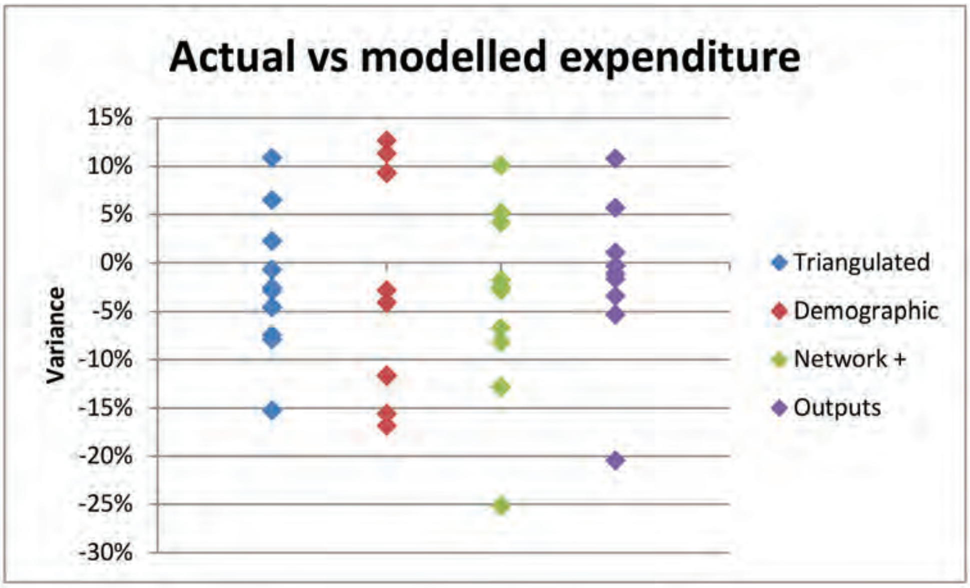
	Coef.	Std. Err	t	P>|t|	[95% Conf	Interval]
Ln(botex)						
cdad	-0.85792	0.15146	-5.66	0	-1.16146	-0.55438
Ln(VS_3)	1.04382	0.10211	10.22	0	0.83919	1.24844
Ln(V(1-S_3))	0.21661	0.03964	5.46	0	0.13718	0.29604
T	0.04318	0.02001	2.16	0.035	0.00309	0.08327
K	-1.61481	0.5058	-3.19	0.002	-2.62845	-0.60117

5.4. Results

We have calculated the expected value produced by each selected version for the ten companies and triangulated the values to produce a single modelled cost. The variances between modelled and actual costs are shown below as the Triangulated results (the blue markers in Figure 2 below). The single chosen version of the demographic model is shown below with the red markers. The two versions of the Network Plus models were triangulated and reported in the green markers in Figure 2 below. Finally, the three chosen versions of the Outputs models were triangulated and shown in the purple markers below.

It can be seen that the variability of the Triangulated results, ranging from -15% to 11%, is smaller than any one of the three separate models (Demographic: -17% to +13%; Network Plus: -25% to +10%; Outputs: -20% to +11%). It is also a better looking result than that published as our Phase 1 Integrated Bioresources result.

Figure 2: Variability of actual vs modelled Bioresources costs



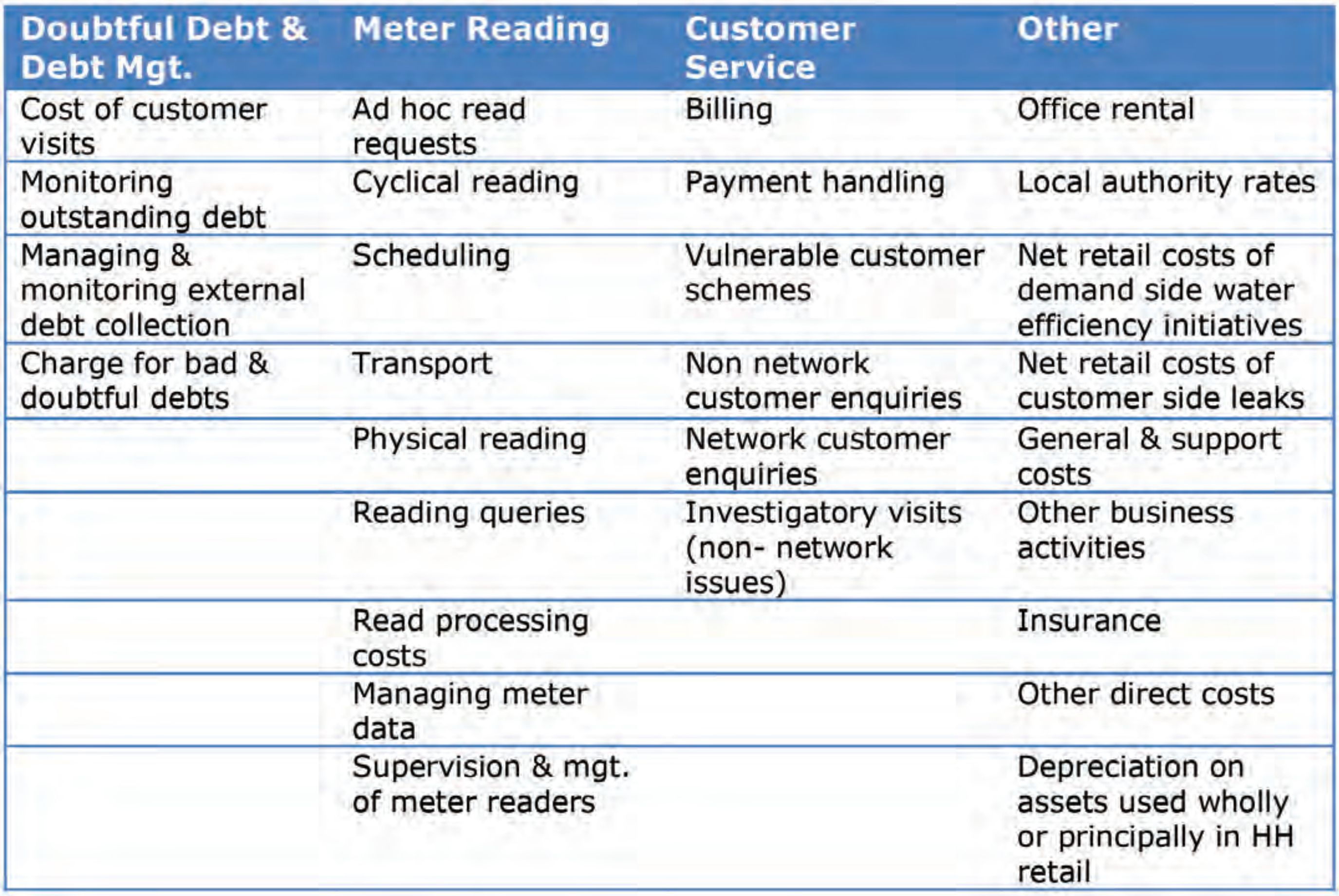
Source: Anglian Water

Annex 5 - Retail

1. Models to be created

At the outset, it would be useful to review what costs are included in Retail. This is set out in Table 1 below.

Table 1: Constituent costs in Household 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

We have developed three Retail models. These are:

1. An integrated model, covering all categories of Retail costs (The **Integrated model**)
2. A model which covers only doubtful debt and debt management costs (The **DDDM model**), and
3. A model covering the other elements of Retail botex, namely customer service, meter reading and other Retail services (**The Other Retail model**).

The reasons for this choice are as follows:

a) Ofwat, in the Draft Methodology document for PR19 published in July 2017, indicated that it was minded to model at this level of granularity. This was confirmed in the December 2017 Methodology Statement.

b) In Phase 1, we developed separate models for

  a. DDDM
  b. Customer service
  c. Meter reading, and
  d. All other Retail costs.

  We identified significant problems with these very granular models. In particular, cost allocation is a problem.

c) If one were to model customer service, meter reading and the other non debt related activities separately, then there are problems which flow from the small size of metering. There are also possible cost interactions between these activities (e.g. poor meter reading might result in higher customer service costs).

d) Other Retail does not have an output associated with it . Essentially it is just a catch-all category for all other costs.

We note a significant issue in that the Other Retail services cost catch-all includes cost categories that are also likely to be borne by the doubtful debt and debt management function, but which are not allocated to it, suggesting a further cost allocation issue that may result in biases from disaggregated modelling. For example, all Retail property rental charges are included in Other costs, while the debt management operation bears no rental cost for the office space for the significant numbers of staff engaged in this activity. This suggests a considerable issue with the cost definition categories mandated in Ofwat's accounting guidelines for Retail, as they are not based on meaningfully defined Retail outputs. We therefore propose for consideration the removal of the Other Retail costs categories and the appropriate reallocation of these costs to the DDDM, customer service, and meter reading categories, which do have identifiable outputs associated with them. As this is not feasible for current purposes, we have proceeded with the existing cost data. It may be worth considering for future revisions of the RAGs.

We also note that while meter reading can be seen as a clearly defined activity with costs associated to it, we also see it as a choice being driven by companies: Ultimately it is a characteristic which influences the billing costs of customers, which companies choose to pursue or not, based on their desire to achieve strategic benefits such as reducing water demand. We would note that that this decision is likely to result in a further cost interaction, and a logical desire to reduce the overall cost of Water services, as firms set the increased recurring cost of metered billing against larger long term cost benefits in Network Plus and Water Resources.

While we have concerns with regard to the ability meaningfully to separate the overall cost of debt management from Other Retail costs with the data available, we clearly support the need for Ofwat to ensure that companies are minimizing the costs imposed on other customers by customers who do not pay their bills. However, as with efforts to reduce shoplifting, there is a cost benefit trade off that must be allowed for, as firms should strive to reduce doubtful debt charges up to the point where the cost of doing so does not exceed the benefit. Our models therefore aim to capture this important tradeoff.

2. The production processes for Retail

We have considered the activities of Retail services, and believe that billing, customer interaction (including metering) and debt management appear to be the key customer service facing activities carried out. Our analysis is based on consultation with Retail managers within Anglian Water and also takes into account other work being carried out elsewhere in the sector. In the following sections we note the issues and characteristics that influence our modelling.

2.1. Doubtful Debt and Debt Management (DDDM)

This is clearly a major part of the Retail service, accounting as it does for 45% of total Retail costs.

We have found it helpful to think that DDDM costs are driven by customers who can be broadly thought of as being made up of "can't payers" and "won't payers". We take as our starting point that "can't pay" debt is driven by the level of deprivation suffered by customers. The work undertaken by United Utilities in conjunction with Reckon and Equifax in quantifying regional values for deprivation has been invaluable in developing this element of the cost model. Debt management is therefore principally concerned with minimizing the "won't pay" element. It is true that the two categories are not as clearly defined as we set out above: can a non payer with a pay TV subscription be correctly described as a "can't payer"? It may well be that transience is a significant factor for "won't pay". However, we have not been able to test this as we were not able to find a suitably robust national data set for transience.

In Ofwat's earlier work, the key cost driver used for DDDM was total revenue. We have used Average Bill Size and Total number of customers instead of total revenue, as they are closely related:

Average Bill Size = Total Revenue / Customers or, alternatively,

Total Revenue = Average Bill Size x Customers.

Although this appears to go against our preference for simplicity over complexity, there are two reasons why we have taken this approach. Firstly, at a household level, it is more straightforward to think of doubtful debt being driven by the size of the bill; customer numbers merely acts as the scalar. Secondly, there is an issue with having total revenue in the integrated model, which is that our approach in this phase of our work is to ensure that the cost drivers in disaggregated models are all represented in the integrated model. When total revenue is used alongside customer numbers (which are a key driver for Other Retail costs), there is a major issue of collinearity. Using average bill size neatly gets around this problem.

The initial Ofwat work earlier in the year also pointed to the impact deprivation has upon DDDM. This is a key driver of the "can't pay" element of DDDM. As mentioned earlier, we have relied on the UU/Reckon/Equifax work. Of the 27 measures reported, it is not immediately obvious which measure or measures should be used for cost modelling purposes. This, presumably, is why they were all reported. Our starting point is that the median measures are too broad and the 99th percentile is too narrow (doubtful debt relates to more than 1% of customers). However, we have no strong view as to whether the 95%, the 90th or the 80th percentile is the correct measure. Our choice criterion was, having developed a robust cost model for DDDM, to test that model with all of the options. This led us to focus on the 80th percentile of the IMD measure, which uses the bill size as a weight in aggregating data from the LSOAs as this had the most positive impact on the quality of the model.

In our work, we noticed that when a time trend for DDDM was included, it invariably had a negative coefficient. Our suspicion was that this was picking up the fact that in general doubtful debts have decreased over the five modelled years as the economy has improved. Ideally, we would have liked to use a measure of regional economic growth, but believe that regional unemployment rate would act as a reasonable proxy for regional economic trends. Consequently, despite the lack of impact shown by regional unemployment rate in the earlier Ofwat work, we decided to include the regional unemployment rate as a potential cost factor for DDDM.

Assuming that deprivation (and the unemployment rate) reasonably control for the "can't pay" element of DDDM, then the variability seen in DDDM costs is driven by "won't payers". Anecdotally, it appears that some companies are unwilling to use debt management robustly for fear of damaging their Quality of Service scores, thereby highlighting another important element in the cost benefit trade-off decision that firms make when deciding their optimal level of debt management. While consideration of the relative size of doubtful debt charges and the incentives/penalties associated with SIM might suggest this to be a questionable strategy, *de minimis* it indicates that there is a range of opinion between companies on how firmly to implement debt management techniques.

As mentioned in section 4.7, regional wages can be expected to have an impact on debt management costs, which account for ~20% of DDDM costs. As the nature of debt management activities requires debt management staff to be largely based within companies' licensed areas, it would seem sensible to include regional wages in the DDDM model.

A possible alternative approach, that we discussed extensively with our academic advisors, to DDDM cost modelling would be to require companies to demonstrate that they are maximizing their realized revenues while taking into account the trade-off between the benefit of increased debt management activities relative to its cost. We feel that by taking such an approach in the future would move us away from relying on the accounting assumptions surrounding doubtful debt provisions as a major part of Retail cost assessment. Moreover, such an approach might improve incentives by allowing managers rather than regulators to manage this trade-off

Given Ofwat's stated approach to Retail modelling, we decided not to pursue this approach for PR19.

2.2. Other Retail costs

The key services delivered within the Other Retail model are customer services (from a staffing perspective this is mainly the call centre function but it also encompasses the other elements set out in Table 1 above), metering and billing. Leaving aside the issue of cost allocation which was mentioned above, what are the key characteristics of these functions?

From the point of view of customer billing, the key distinction is between metered and unmetered customers. It should be remembered that in both the case of metered and unmetered customers, it is the water element of the bill which drives the wastewater element. Essentially, metering and billing are functions of the water service, for the following reasons:

- By and large, all customers receiving a waste water service also receive a water service whereas around 10 per cent of water customers make private arrangements for wastewater disposal
- For metered customers, the wastewater bill is driven by water usage, being based on a fixed percentage of the measured water consumption
- In terms of billing, more than 75% of wastewater bills are raised by the WaSC service provider.

In applying this to the cost models, it is therefore necessary to control for the proportion of customers that are wastewater customers. We have addressed this in two separate ways, both of which we consider valid. In the first, we take wastewater customer numbers as a proportion of total customers (defined as (B+C)/(A+B+C))[1]. In the other, we disaggregate the wastewater proportion into those customers which are billed by the WaSC (C/(A+B+C), what we refer to as 'own billed') and those service recipients who are customers of (and usually billed by) a WoC (B/(A+B+C), 'other billed'). We recognize that there are cases where a WaSC may bill the WoC customers directly rather than pay the WoC to issue the bills, but in both cases, the cost causation is the same.

Moreover, customer service calls, and therefore costs, increase with both:

i) Meter penetration (more billing contacts); and

ii) Switching from unmetered to metered (companies increasing metering can be expected to have more customer service functions than those with a stable level of metering as customers are more likely to query a bill when moving from unmetered to metered. Moreover, the process of switching to a meter in itself requires customer service interaction).

As set out in section 4.7, regional wages can be expected to have a significant impact upon Retail costs, given the high proportion of staff costs within overall Retail botex and the factors which limit options for locating those staff outside companies' licensed areas.

Customer Service contacts are also likely to increase with:

- Quality of Service (QoS) and performance in both the water and wastewater networks. As we discuss in section 4.6, QoS (for both Wholesale and Retail) can reasonably be expected to be a driver of Retail costs. QoS has been included in our cost modelling of Other Retail costs.
- Increased household transiency, as for a given population more moves will occur, and hence more customer service interaction. We have not tried to address transiency as we have not found a suitably robust data set for transiency.

2.3. Models to be tested

On the basis of section 2.1 above, DDDM is expected to be a function of:

- Average bill size
- Customer numbers
- Deprivation
- Regional unemployment
- Regional Wages.

On the basis of section 2.2 above, Other Retail costs are expected to be a function of:

- The number of metered customers
- The number of unmetered customers
- The proportion of customers which take a wastewater service
- Regional Wages
- Quality of Service.

If our cost models for DDDM and Other Retail costs have been properly specified, then the Integrated model needs to be driven by all of the cost drivers which drive the two components of the total Household Retail costs. Consequently, the Integrated model is expected to be a function of:

- The number of metered customers
- The number of unmetered customers
- Average bill size

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[1] *Using the terminology set out in Section 4.1*

- The proportion of customers which take a wastewater service
- Regional Wages
- Quality of Service
- Deprivation
- Regional unemployment.

3. Costs to be used

There was no Information Request for Retail in 2016. Instead, for the analysis it shared in March 2017, Ofwat collated data from:

- Annual Performance Reports (APRs),
- The Industry Performance Review and Regulatory account data which preceded the APRs (The Water UK 'Four Pack')
- PR14 data submissions.

Unlike the Wholesale analysis undertaken at PR14 and the data collected in the PR19 Information Requests, the cost data are all in costs of the day and not in a RPI deflated (2012-13) cost base.

The 2017 Information Request collected data for 2016-17 only.

We have followed the existing approach and base our analysis on the updated data file from Ofwat, with costs in prices of the day. In doing so we do not accept that there are no inflationary pressures in Retail. In using cost models for cost forecasting, separate allowances need to be made for the impact of future input price changes. Moreover, these conclusions are supported by our estimation of a statistically significant positive time trend in our below reported integrated Retail cost modelling.

In all of the Wholesale cost modelling which we have undertaken, we have followed the approach taken by Ofwat at PR14 and excluded local authority rates from the cost models. We have not done this for Retail on two grounds:

i) Immateriality. For 2014-15, in aggregate, those costs represented 0.6% of total Household Retail opex.

ii) For 2015-16 and 2016-17, we do not have local authority rates split out of Household Retail costs.

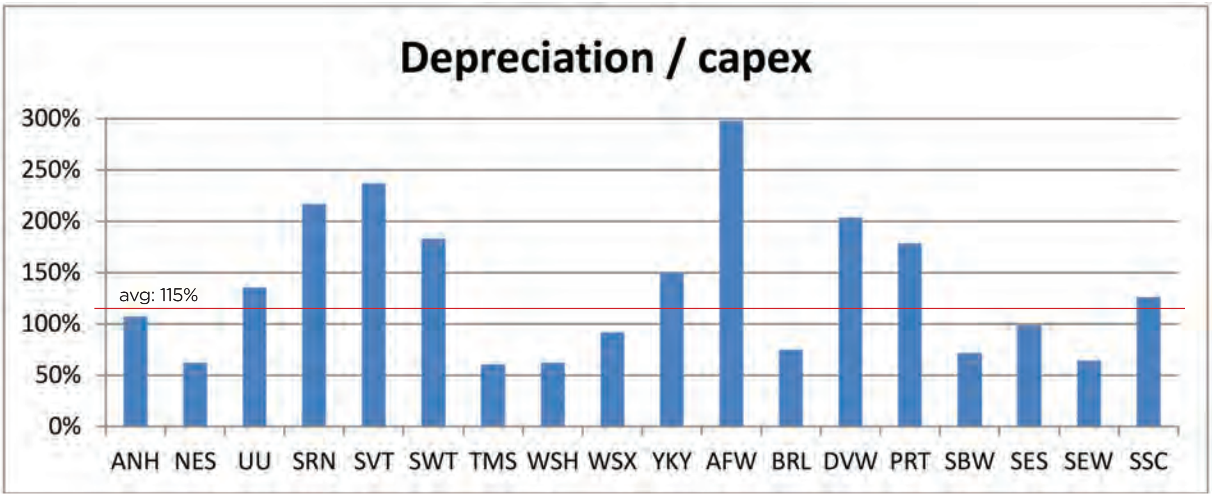
Unlike the Wholesale cost modelling work done at PR14, and in Phase 1 of this work, Retail botex was defined by Ofwat in its initial modelling work as opex + depreciation rather than opex + capital maintenance. As Retail is considered by Ofwat not to involve any enhancement capex, by definition all capital expenditure for Retail is maintenance capex. The APR captures three elements of Retail capex:

1. Additional capex shown in section 3A of Table 2D in the APR
2. Demand-side water efficiency - net Retail expenditure shown in section B of Table 4F in the APR
3. Customer-side leak repairs - net Retail expenditure shown in section B of Table 4F in the APR

To align the approach taken in cost modelling Retail with that for Wholesale, we have chosen to use these capex numbers in place of depreciation in our cost modelling of Retail. The key reason is set out in the following graph of cumulative capex against cumulative depreciation for the five years to 2017.

Some companies have provided data indicating significantly more in depreciation charges than has been spent on capex. Others have a significantly higher capex total relative to depreciation charges. It might be thought that the above table suggests that capex is not a good proxy for depreciation and thus the only reason for using capex is for consistency with the Wholesale approach. We look at the problem the other way around: depreciation here is not a good proxy for capex. Cash flow is spent on assets not on depreciation, which is actually an accounting charge and not an activity resulting in cash flow. **So as to be consistent with the Wholesale cost modelling approach, it would therefore be appropriate to to focus on capex rather than depreciation.**

Figure 1: Ratio of depreciation to capex for Household Retail



4. Key cost drivers

4.1. Customer numbers to be used

From Phase 1 of our analysis, we can see that customer numbers are a key driver of costs. Hence, it is very important to identify exactly what numbers should be used.

For the purpose of subsequent consideration, let us refer to:

- Water only customers as A
- Wastewater only customers as B
- Dual customers as C.

These numbers were reported in Pack C of the Industry Performance Data-share (organized by Water UK) up to 2016 and in Table 2F of the Annual Performance Report in 2016 and 2017.

In Phase 1 of our work, we defined customers as A+B+C. This followed the approach taken by Ofwat earlier in the year in its initial work on the subject. For DDDM, the important figure is the number of customers who are issued with bills. So for DDDM, A+B+C would seem to be sensible.

As set out in section 2.2 above, for the Retail costs that are not DDDM (that is to say the Other Retail costs), the first consideration is the split between metered and unmetered customers. This can be written:

- For unmetered customers as: $A_{un} + B_{un} + C_{un}$
- Metered customers as: $A_{met} + B_{met} + C_{met}$

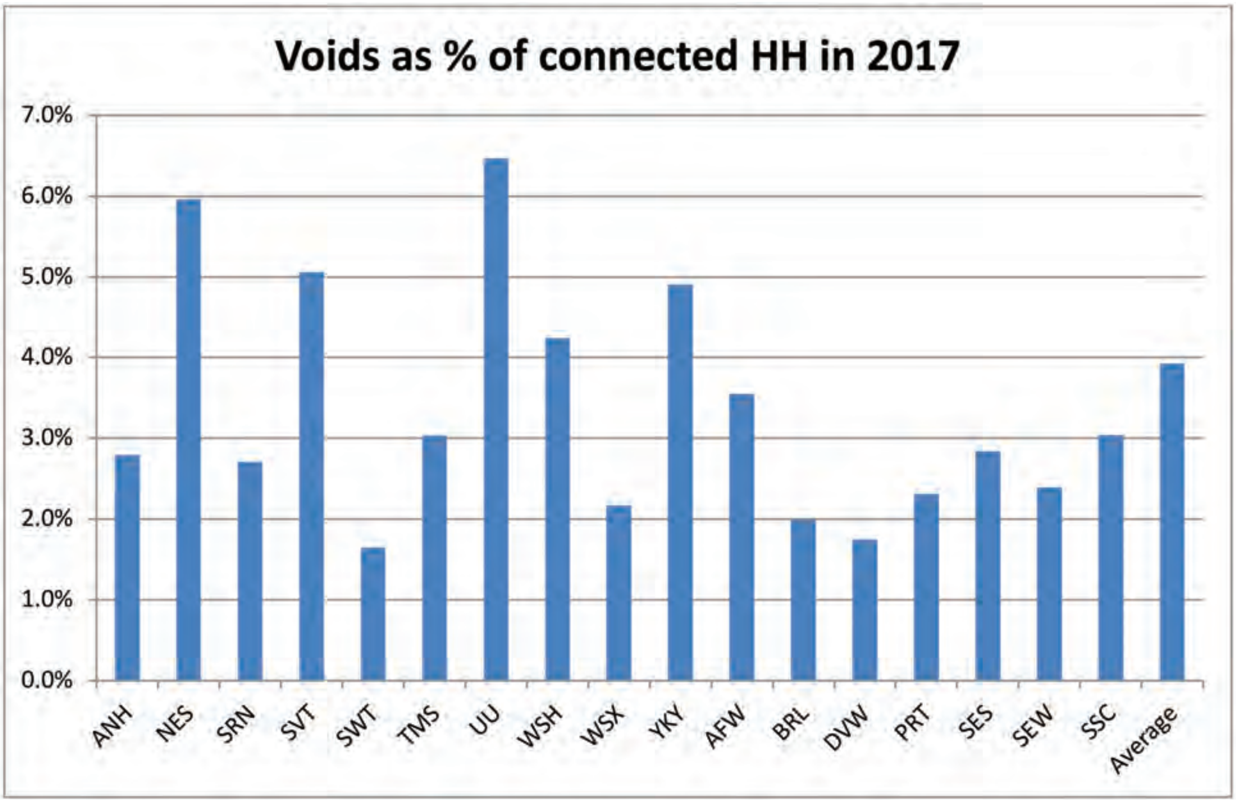
As $A_{met} + A_{un} = A$ (and equally for B and C), this equates to A+B+C as well.

It can be seen that taking this approach avoids the need to assume or compute a factor for the economy of scope between water and wastewater services, as an appropriate specification of these output variables should capture the difference in service costs associated with dual customers. We recognize that there is a potential issue in that WoCs generally bill wastewater services to their customers on behalf of WaSCs. While WaSCs pay WoCs for this service, there is clearly a loss of direct control over the quality of the billing, and a more complex relationship between customer services and its production, than if Retail services were directly produced by the firm providing Network Plus services. It should be borne in mind that the decision by a WaSC to ask the WoC to bill its wastewater customers is because it believes this to be the most efficient means of discharging the function. It is not mandatory and exceptions exist. Under current circumstances, we unfortunately do not believe it is feasible to control for these considerations.

4.2. Voids

There is a substantial variation between companies in the proportion of voids they report that is not easily explained. The ONS national average figure for voids as a proportion of the total number of households across England in 2017 is 2.2%[2]. Figure 2 shows the proportions reported by all appointed companies in Table 4A of the APR.

Figure 2: Voids as a proportion of connected Households



Source: Anglian Water Source: 2017 APR data-share, as updated. Anglian Water analysis

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[2] ONS Table 615 Vacant dwellings by local authority district: England, from 2004

While the proportion of void properties can be expected to be higher for Northumbrian and UU (from the ONS data, the figure for Middlesbrough is 4.4%; that for Merseyside is 4.0%), there appear to be some significant outliers.

A possible reason for over-reporting voids is that doing so enables reduction in the level of doubtful debt reported and enables companies to recover uncollected revenue from the customers of occupied properties through the Revenue Correction Mechanism.

If the number of billed customers is used as a cost driver, rather than the number of connected properties, this will have the effect of excluding voids from the cost calculation. The higher the voids figure, the lower the Retail costs should be, given the strong positive relationship between total revenue, number of households and Retail costs. Using billed customers also provides a material disincentive for companies to over-report voids.

As Retail costs are driven by the number of customer bills and not the number of connected properties, the billed customer numbers should be used in cost modelling. The customer numbers, disaggregated by service, are taken from Table 2F in the APR.

4.3. Deprivation

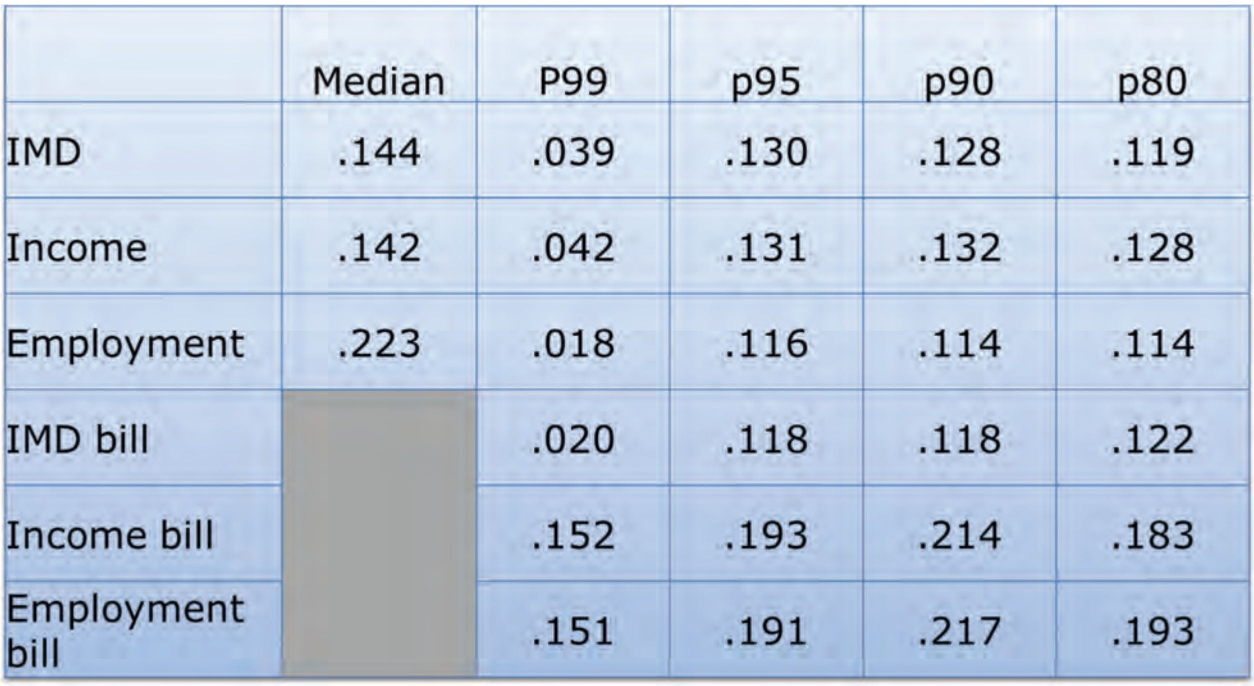
In Ofwat's initial work on Retail, which was put into the public domain in March 2017, the ONS Index of Multiple Deprivation (IMD) was used in its model for doubtful debt and debt management. The coefficient was significant, suggesting that IMD is helpful in explaining doubtful debt charge costs for Retail.

In our recreation of Ofwat's Retail cost modelling in Phase 1, we also modelled using IMD. While Ofwat only used one year's data, we extended that to four years by interpolating between the most recent IMD and its predecessor. We too found a strong link between IMD and bad debt and debt management cost.

United Utilities, working with data from Equifax and with Reckon, has put into the public domain a set of measures for deprivation. These data are at the company level though developed using very granular (LSOA level) data over six years to 2017. There are in total 27 different measures of deprivation based on employment levels, income levels and an Index of Multiple Deprivation.

The R^2 for relationship between total Retail botex and the various deprivation measures is shown below in Table 2. In the table, P99 is the 99th percentile measure – that is to say the lowest 1% by the various measures (deprivation, income or employment). Similarly, P95, P90 and P80 are the 95th, 90th and 80th percentiles.

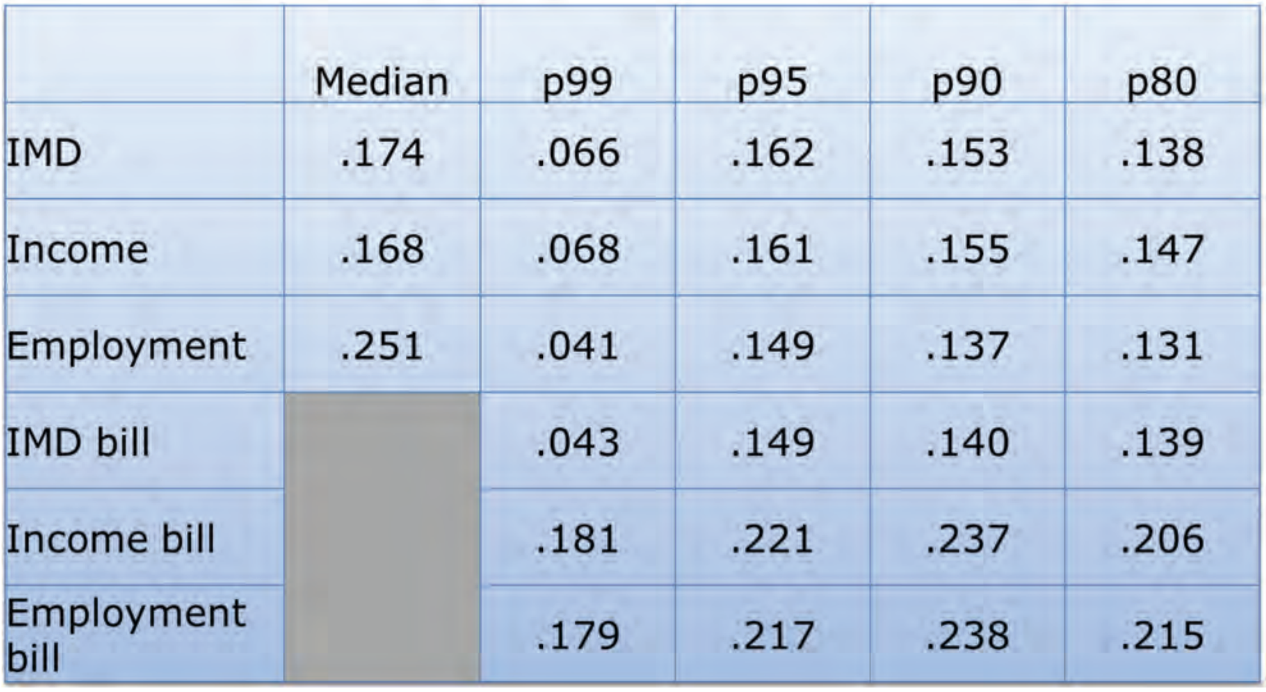
Table 2: Total Retail Botex to deprivation correlations



	Median	P99	p95	p90	p80
IMD	.144	.039	.130	.128	.119
Income	.142	.042	.131	.132	.128
Employment	.223	.018	.116	.114	.114
IMD bill		.020	.118	.118	.122
Income bill		.152	.193	.214	.183
Employment bill		.151	.191	.217	.193

The same table for the relationship between doubtful debt and debt management cost and measures of deprivation is shown below in Table 3.

Table 3: DDDM Botex to deprivation correlations



	Median	p99	p95	p90	p80
IMD	.174	.066	.162	.153	.138
Income	.168	.068	.161	.155	.147
Employment	.251	.041	.149	.137	.131
IMD bill		.043	.149	.140	.139
Income bill		.181	.221	.237	.206
Employment bill		.179	.217	.238	.215

In Tables 2 and 3, the first three rows concatenate the LSOA data using household numbers. The bottom three rows concatenate using the product of household numbers and bills per households (i.e. total revenue per category).

To begin with, we used two measures from the above tables which had high correlations. Once we had determined robust model formulations, we then reworked the chosen models with each of the 27 measures in order to determine which measure had the most significant impact on the estimated models.

4.4. Meter reading

We have chosen not to pursue the development of a separate meter reading cost model, as ultimately discussion with our managers and academic advisors has led us to emphasize that meter reading costs represent the additional cost associated with a type of billing, and that this type of billing has associated higher costs of billing and customer service associated with it.

Meter reading costs only represent around 5% of Retail costs. However, from discussions with our customer service and billing managers, the level of meter penetration is clearly considered to be a major factor driving customer contacts and hence customer service costs. The logic is that unmetered customers know with certainty what their bills will be. By comparison, metered customers' bills are likely to be more volatile (and may occasionally be mis-billed), providing impetus for customer contacts. It is for this reason that we took the view that the metered / unmetered split is a key driver of cost in our cost model for the Other Retail costs.

From the point of view of tariff derivation, the cost of Retail service for metered customers is seen as everywhere and always higher than that for unmetered customers. This understanding has been accepted within the water industry for some time. Anglian Water had a Special Cost Factor (SCF) up to PR09 to take account of additional costs incurred as a result of having a significantly higher metering penetration than the industry as a whole. This view that meter penetration drives Retail costs has been accepted by all parties in the industry for at least a decade.

The number of metered and unmetered customers is included in Table 2F of the APR.

As discussed in section 2 above, we included metered customer numbers as a cost driver in our cost modelling.

4.5. Average bill size

This was identified in the work undertaken by Ofwat earlier in 2017 as being a significant cost driver for the Integrated model.

Average bill size is the quotient of total revenue divided by total customer numbers. A logarithmic model, with customers and average bill size as the cost drivers $\ln(botex) = a\ln(C) + b\ln(R/C) + c$, can be rewritten as

$$\ln(botex) = (a-b)\ln(C) + b\ln(R) + c.$$

So if $a \approx b$ (as appears to be the case), then Revenue remains the dominant cost driver.

Putting average bill size into a cost model which contains customer numbers leads to a similar result to using Revenue alone, while avoiding the problem of collinearity.

4.6. Quality of Service

There are a number of possible links between Quality of Service and overall Retail botex.

Customer service calls tend to be driven by necessity (e.g. moving house), by dissatisfaction with Retail service (e.g. billing errors) or by Network Plus service quality (e.g. sewer flooding or poor water quality). Moreover, the absence of factors causing dissatisfaction does not lead to customer service calls praising the company. This trite observation does have a significant implication: that increased quality of Retail and Network Plus service may be expected to lead to reduced customer contacts. The Service Incentive Mechanism (SIM) is a quality of service measure that covers both Network Plus and Retail.

It is possible that an appointed company, appropriately responding to the incentives set it by Ofwat at PR14, may view performing well in terms of the Service Incentive Mechanism (SIM) to be more important than taking a robust approach to debt management. Moreover, there is anecdotal evidence to this effect.

We therefore felt it was sensible to consider QoS as a potential driver of cost. We considered both SIM (as it takes account of Network Plus driven quality as well as that for Retail) and also the number of billing complaints reported by CCW Water in its Water Matters publication as a measure of quality of service. (The Water Matters series focus more specifically on the Retail service).

4.7. Regional Wages

The share of Retail costs represented by staff costs is high. For Anglian Water, Retail staff costs amount to ~£20m or ~30% of Retail costs. These costs fall principally on Other Retail costs. As these account for 55% of total Retail costs, staff costs account for around half of our Other Retail costs. Given this, it is hard to avoid the conclusion that wage costs are a relevant cost factor for household Retail costs.

That said, apart from meter reading and debt collection, which together account for around 15% of Retail costs, Retail functions are not location specific. There is no particular reason why customer service functions even need to be provided within the appointed company's own region. This may be an argument for not using a regional wage measure based on the appointed company's geographic region. Nevertheless, whether due to regional chauvinism, customer preference or some other reason, water companies have tended to keep call centres within their regions, usually in (relatively) low wage cost areas, although some back office services may be out of area . However, the bulk of Retail employment does appear to take place within the operating region of the company. This may be an argument for focusing on a regional wage measure which looks at the lowest cost area within each region.

Another complicating factor in using the Ofwat defined regional wage series is that this series is based on a range of occupations which is more suited to the Wholesale operations of appointed companies.

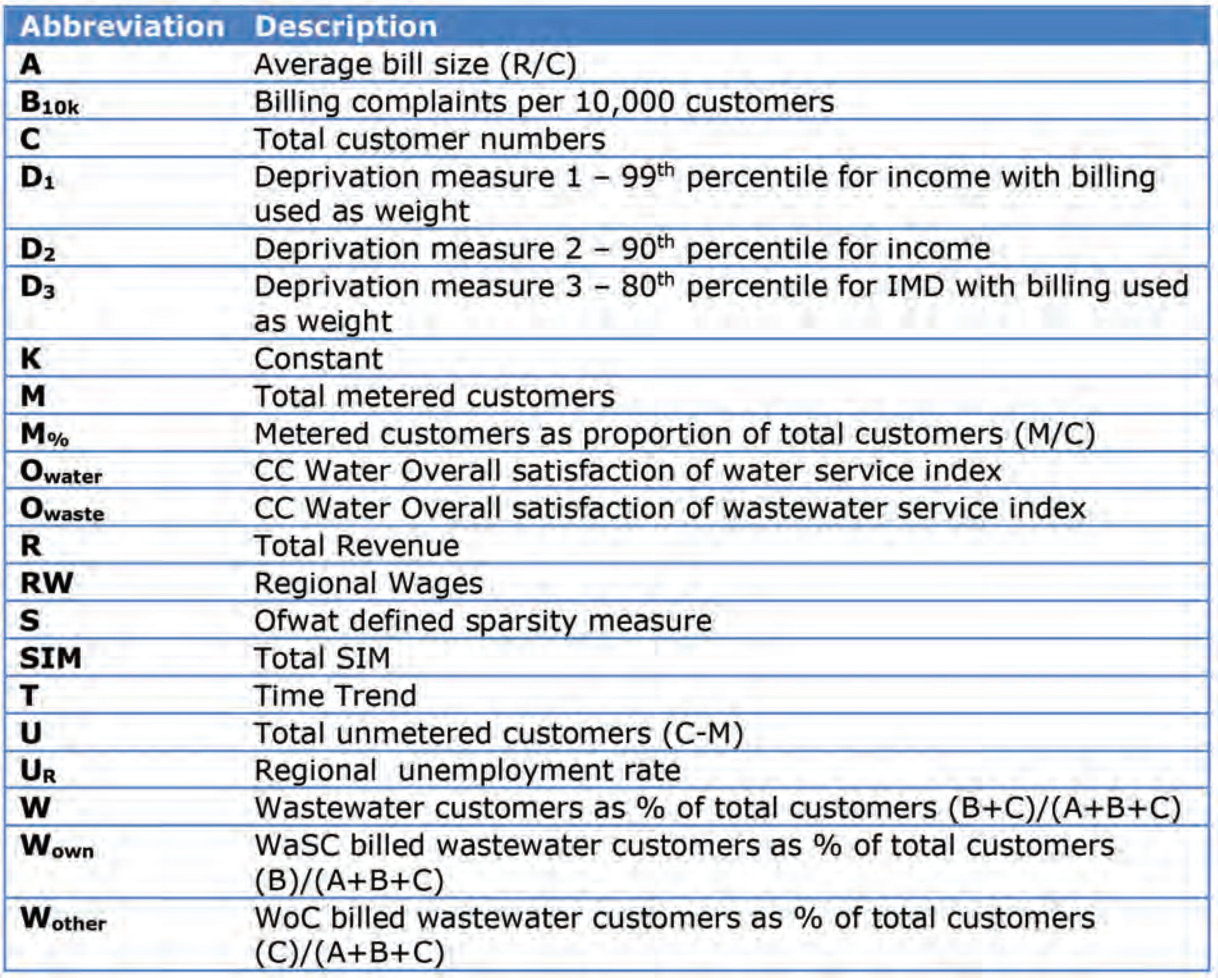
Phase 1 failed to find a strong econometric relationship between regional wages and Retail costs. **In Phase 2, we tried again. We used the Ofwat regional wage series, despite the fact that this series was designed for Wholesale occupations. Again, we found regional wages did not perform well in the Retail models.**

In future developments we would want to use a modified Retail series to address the above issues. This would require developing a Retail regional wage function which focuses on SOC codes 72 (Customer service occupations) and 41 (administrative occupations). It would not look at the weighted average wage rate within the appointed companies' areas but instead look at the rate in the lowest cost region of each company. For most WoCs, this would make no difference to the whole area, given most are geographically small. However, for WaSCs, this would tend to reflect reality. However, on past experience, we do not have high hopes that such a targeted regional wage series for Retail would fare much better.

5. Cost modelling development

The key to the abbreviations used in section 5 are given in Table 4 below. Deprivation measures D1 and D2, which displayed the highest correlations in section 4.3, were used initially in the Integrated and DDM models. Once we had determined the best performing version of the Integrated and DDDM models, then all 27 of the measures were tried sequentially in the preferred model and the measure which generated the strongest adjusted R^2 was picked. This turned out to be the IMD80th percentile with the bill size used as a weight in aggregating the results from the individual LSOAs. This measure, referred to as D3 below, was then used in a final version of each of the relevant models.

Table 4 Key for Section 5 cost models



Abbreviation	Description
A	Average bill size (R/C)
B_{10k}	Billing complaints per 10,000 customers
C	Total customer numbers
D_1	Deprivation measure 1 – 99th percentile for income with billing used as weight
D_2	Deprivation measure 2 – 90th percentile for income
D_3	Deprivation measure 3 – 80th percentile for IMD with billing used as weight
K	Constant
M	Total metered customers
$M_{\%}$	Metered customers as proportion of total customers (M/C)
O_{water}	CC Water Overall satisfaction of water service index
O_{waste}	CC Water Overall satisfaction of wastewater service index
R	Total Revenue
RW	Regional Wages
S	Ofwat defined sparsity measure
SIM	Total SIM
T	Time Trend
U	Total unmetered customers (C-M)
U_R	Regional unemployment rate
W	Wastewater customers as % of total customers (B+C)/(A+B+C)
W_{own}	WaSC billed wastewater customers as % of total customers (B)/(A+B+C)
W_{other}	WoC billed wastewater customers as % of total customers (C)/(A+B+C)

5.1. Integrated models

We developed 11 versions of the Integrated model. As explained in Section 2.3, the cost drivers used in the Integrated model are those used in the disaggregated DDDM and Other Retail cost models.

Table 5 below sets out the cost drivers used in each version. The first two model variants hark back to the work we reported in our initial cost modelling report dated September 2017. The subsequent eight variants are based on the ideas set out in section 2. The abbreviations used are set out in Table 4 above.

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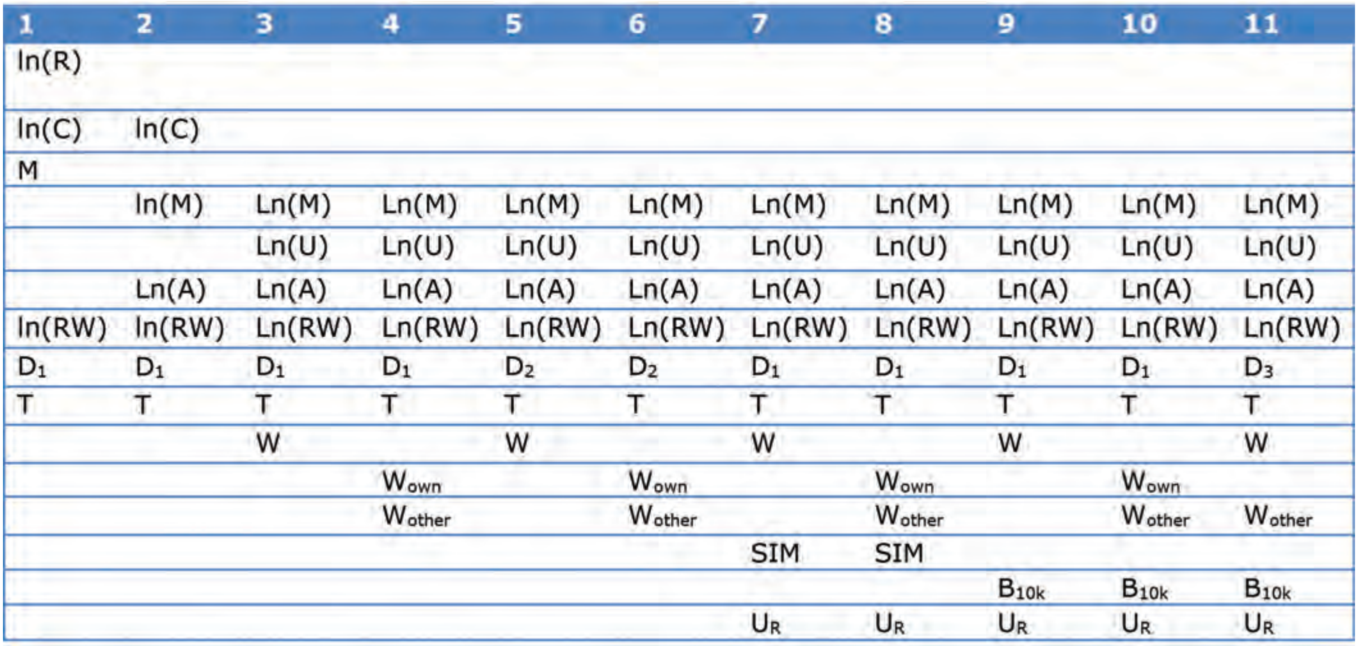
Table 5: Variables in Integrated models



1	2	3	4	5	6	7	8	9	10	11
ln(R)										
ln(C)	ln(C)									
M										
	ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)
		Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)
	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)
ln(RW)	ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)
D_1	D_1	D_1	D_1	D_2	D_2	D_1	D_1	D_1	D_1	D_3
T	T	T	T	T	T	T	T	T	T	T
		W		W		W		W		W
			W_{own}		W_{own}		W_{own}		W_{own}	
			W_{other}		W_{other}		W_{other}		W_{other}	W_{other}
						SIM	SIM			
								B_{10k}	B_{10k}	B_{10k}
						U_R	U_R	U_R	U_R	U_R

The starting point for the Integrated models was Integrated v1, which followed the Ofwat format from earlier this year.

This was highly collinear in total revenue (R) and customer numbers (C).

To address the issue of collinearity, we replaced revenue with average bill size in Integrated v2.

We then moved to what proved to be a superior formulation in Integrated v3, splitting customers into the total number of metered (M) and unmetered (U) customers and using average bill size in place of total revenue. Wastewater service was controlled for though W, wastewater customers as a proportion of total water and wastewater customers.

A regional wage variable was also included and is significant, if rather large, given the proportion of total Retail botex represented by employment costs. The coefficient on metered customers is higher than that for unmetered (which matches *a priori* expectations).

Integrated version 4 is a variant on version 3, with the proportion of wastewater customers disaggregated into ‘own billed’ (by the WaSCs) and ‘other billed’ (by WoCs).

The regional wage coefficient is undoubtedly now too high. The coefficient for own billed wastewater customers is significant and positive which looks credible. However, that for other (WoC) billed customers is not significant and negative. While a lower coefficient for WoC billed customers is conceivable, a negative coefficient seems far-fetched.

Versions 5 and 6 re-ran versions 3 and 4 but using an alternative deprivation measure. The results were marginally less good than those for 3 and 4 and the measure in 3 and 4 was used in all subsequent versions.

Versions 7 and 8 are also variants on versions 3 and 4, adding in two new cost drivers – regional unemployment (U) and the SIM score (SIM).

Similarly, versions 9 and 10 are also variants on versions 3 and 4, also adding in two new cost drivers: regional unemployment (U) and this time using the CCW Water Matters measure of billing complaints per 10,000 customers (Billing10k) instead of SIM. **Although SIM might from a theoretical point of view be considered the preferable measure of QoS, of the two measures, Billing complaints per 10,000 customers performed marginally better. When both measures were included, the Billing10k coefficient was strongly significant and the SIM coefficient was insignificant.**

For this reason, we prefer v10.

Version 9 above shows a similar pattern to version 3. U is strongly significant with a high positive coefficient, suggesting a strong link to unemployment through doubtful debts. The coefficient of bill10k suggests that costs rise as QoS falls (SIM showed a similar pattern in versions 7 and 8): virtue apparently is not only its own reward but is cost beneficial too.

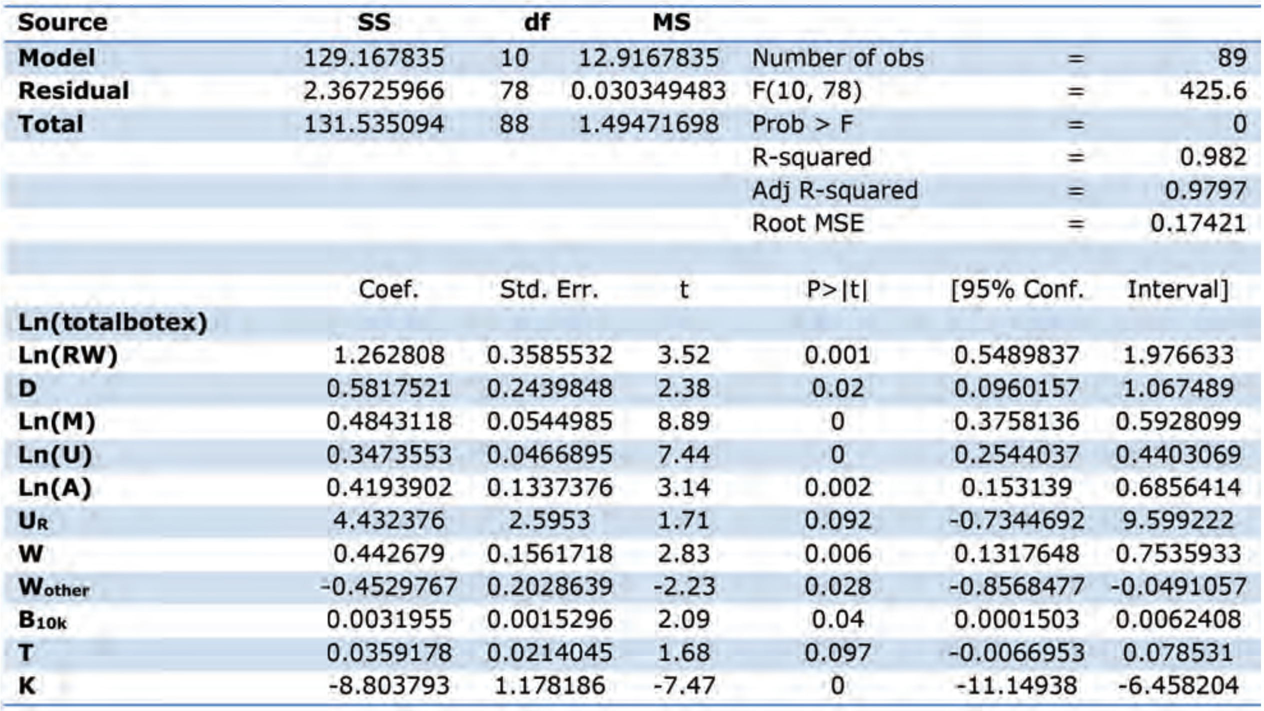
Likewise, version 10 is similar to version 4 except that the coefficient for WoC billing is positive (albeit still insignificant). The coefficient on regional wages is still looks to be high.

Having focused upon v10, we then retried this version with each of the deprivation measures sequentially, looking for the version which performed the best. The best result came with the IMD bill measure at the 80th percentile. This is now reported as v11. V11 contains one further change from v10. Instead of showing the proportion of own billed and other billed wastewater customers, we show the overall proportion of wastewater customers and the proportion of WoC customers. In this formulation, both coefficients are significant. This is saying that for the average WaSC there is a positive cost associated with having wastewater customers even if billing them via a WoC reduces its costs.

Version 11 is the version which we focus on as being the most robust.

Table 6: Integrated v11

. reg ln(totalbotex) ln(RW) D ln(M) ln(U) ln(A) U_R W W_{other} B_{10k} T



Source	SS	df	MS			
Model	129.167835	10	12.9167835	Number of obs	=	89
Residual	2.36725966	78	0.030349483	F(10, 78)	=	425.6
Total	131.535094	88	1.49471698	Prob > F	=	0
				R-squared	=	0.982
				Adj R-squared	=	0.9797
				Root MSE	=	0.17421

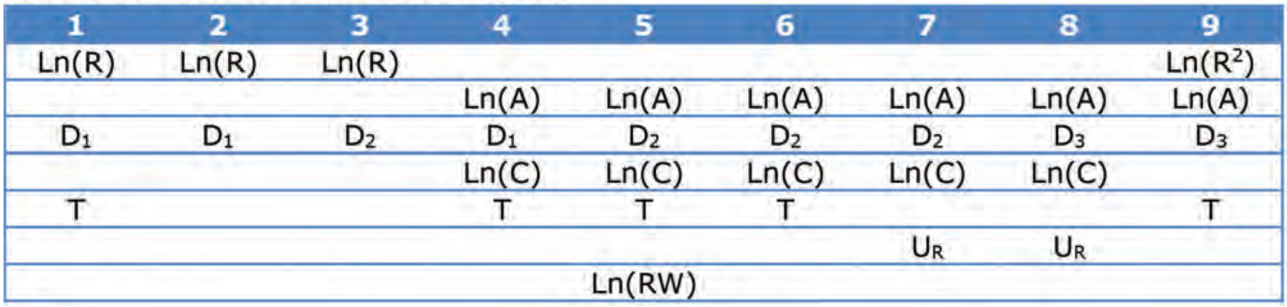
	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ln(totalbotex)						
Ln(RW)	1.262808	0.3585532	3.52	0.001	0.5489837	1.976633
D	0.5817521	0.2439848	2.38	0.02	0.0960157	1.067489
Ln(M)	0.4843118	0.0544985	8.89	0	0.3758136	0.5928099
Ln(U)	0.3473553	0.0466895	7.44	0	0.2544037	0.4403069
Ln(A)	0.4193902	0.1337376	3.14	0.002	0.153139	0.6856414
U_R	4.432376	2.5953	1.71	0.092	-0.7344692	9.599222
W	0.442679	0.1561718	2.83	0.006	0.1317648	0.7535933
W_{other}	-0.4529767	0.2028639	-2.23	0.028	-0.8568477	-0.0491057
B_{10k}	0.0031955	0.0015296	2.09	0.04	0.0001503	0.0062408
T	0.0359178	0.0214045	1.68	0.097	-0.0066953	0.078531
K	-8.803793	1.178186	-7.47	0	-11.14938	-6.458204

5.2. DDDM models

We developed nine versions of the DDDM model.

Table 7 below sets out the cost drivers used in each version and are based on the modelling ideas set out in section 2. The abbreviations used are set out in Table 4 above.

Table 7: Variables in DDDM models



1	2	3	4	5	6	7	8	9
Ln(R)	Ln(R)	Ln(R)						Ln(R^2)
			Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)	Ln(A)
D_1	D_1	D_2	D_1	D_2	D_2	D_2	D_3	D_3
			Ln(C)	Ln(C)	Ln(C)	Ln(C)	Ln(C)	
T			T	T	T			T
						U_R	U_R	
Ln(RW)								

The starting point for the debt model development was the Ofwat model form from earlier in the year, which had total revenue (R) as the key cost driver, with an added time trend.

Version 1 used the deprivation measure which had the highest correlation to botex. This was the 99th percentile for income, with the results per LSOA aggregated using a weighting which takes bill size into account. As mentioned in section 4.3, we resolved to try the other deprivation measures to find the optimal measure once the optimal model form has been identified. For now, this measure and the measure which also showed a (relatively) high level of correlation to botex were used.

Version 2 dropped the time trend as the coefficient was insignificant. Version 3 replaced the deprivation measure used in version 1 with the second deprivation measure (the unweighted 90th percentile for income). Both versions 2 and 3 gave very similar results to version 1.

Version 4 replaced total revenue with average bill size and the number of customers (C). This can be seen to give a very similar result to version 1.

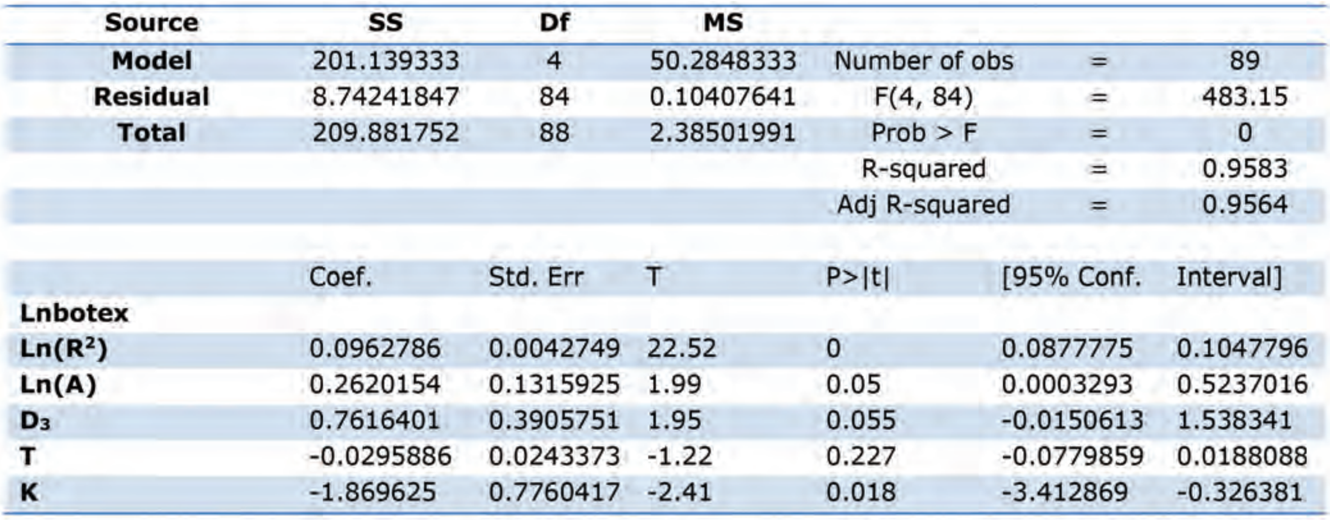
Versions 5 and 6 are variants on version 4, looking at using the 90th income percentile instead of the weighted 99th income percentile. Version 4 also introduces the regional wage variable. Neither version improved on version 4.

Version 7 replaced the time trend in version 4 with regional unemployment. Regional unemployment did not perform well in the earlier Ofwat work – and indeed does not display a significant coefficient here either. Unfortunately, the coefficients on A (i.e. R/C) and C suggest that the coefficient on C is effectively zero which seems improbable. Having reworked the approach in a translog form, and after removing insignificant terms, the form shown in version 9 emerged as a strong, credible form. It also replaced the 90th percentile deprivation measure with the 80th and we therefore settled on using this as our deprivation variable.

Version 9 is the version which we focus on as being the most robust.

Table 8: DDDM v9

. reg lnbotex ln(R^2) ln(A) D_3 T



Source	SS	Df	MS			
Model	201.139333	4	50.2848333	Number of obs	=	89
Residual	8.74241847	84	0.10407641	F(4, 84)	=	483.15
Total	209.881752	88	2.38501991	Prob > F	=	0
				R-squared	=	0.9583
				Adj R-squared	=	0.9564

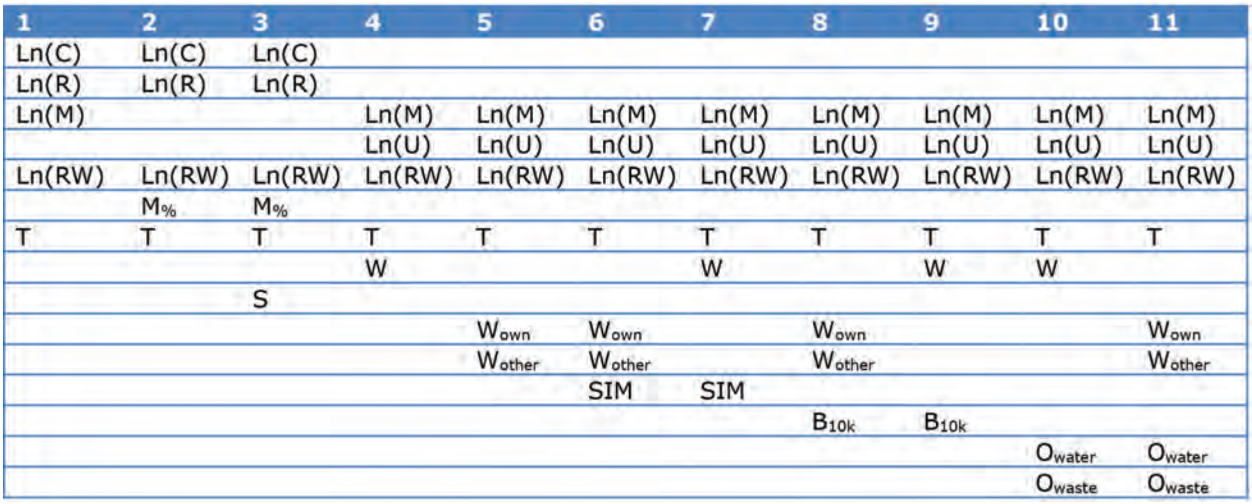
	Coef.	Std. Err	T	P>|t|	[95% Conf.	Interval]
Lnbotex						
Ln(R^2)	0.0962786	0.0042749	22.52	0	0.0877775	0.1047796
Ln(A)	0.2620154	0.1315925	1.99	0.05	0.0003293	0.5237016
D_3	0.7616401	0.3905751	1.95	0.055	-0.0150613	1.538341
T	-0.0295886	0.0243373	-1.22	0.227	-0.0779859	0.0188088
K	-1.869625	0.7760417	-2.41	0.018	-3.412869	-0.326381

5.3. Models of Other Retail costs

We developed 11 versions of the Other Retail model.

Table 9 below sets out the cost drivers used in each version and are based on the ideas set out in section 2. The abbreviations used are set out in Table 4 above.

Table 9: Variables in Other Retail models



1	2	3	4	5	6	7	8	9	10	11
Ln(C)	Ln(C)	Ln(C)								
Ln(R)	Ln(R)	Ln(R)								
Ln(M)			Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)	Ln(M)
			Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)	Ln(U)
Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)	Ln(RW)
	$M_{\%}$	$M_{\%}$								
T	T	T	T	T	T	T	T	T	T	T
			W			W		W	W	
		S								
				W_{own}	W_{own}		W_{own}			W_{own}
				W_{other}	W_{other}		W_{other}			W_{other}
					SIM	SIM				
							B_{10k}	B_{10k}		
									O_{water}	O_{water}
									O_{waste}	O_{waste}

The starting point for the Other Retail cost modelling was Version 1 below. This had customer numbers, total revenue, the number of metered customers, regional wages and time trend as cost drivers.

Version 2 replaced the number of metered customers with metered customers as a percentage of total customers. This made no difference – the coefficient on the metering variable remained insignificant. Version 3 tried adding in population sparsity to version 2. The coefficient was barely significant and sparsity was dropped for subsequent versions.

Version 4 took a different approach to the initial three versions, splitting customers into metered (M) and unmetered (U), with account taken of the proportion of wastewater customers (W). For the reasons set out in our discussion of Integrated version 3, we prefer this form.

Version 5 replaces S with two alternative cost drivers – the proportion of own billed wastewater customers and the proportion of other billed wastewater customers.

Swapping the wastewater control variables increases the adjusted R^2 in Version 5, although the coefficient on regional wages moves to an improbably high level.

Versions 6 and 7; 8 and 9; and 10 and 11 are all variants on versions 4 and 5, adding in alternative Quality of Service (QoS) measures. In versions 6 and 7, SIM is included. In versions 8 and 9, the Consumer Council for Water's (CCW) Water Matters index for billing complaints per 10,000 customers was used. In versions 10 and 11, the CCW's measures of overall water and wastewater service satisfaction were used.

The CCW satisfaction measures perform poorly. Versions 10 and 11 have the lowest R^2 of all the models tried. These were thus discounted. The SIM models performed better than the billing complaints per 10,000 customers versions and these were used.

Below we show the results of the SIM versions which we went on to focus on as being the most robust:

Table 10: Other Retail v 6

Source	**SS**	**Df**	**MS**			
Model	99.70993	7	14.24428	Number of obs	=	89
Residual	2.838596	81	0.035044	F(7, 81)	=	406.46
Total	102.5485	88	1.165324	Prob > F	=	0
				R-squared	=	0.9723
				Adj R-squared	=	0.9699
				Root MSE	=	0.1872

	Coef.	Std. Err.	T	P>|t|	[95% Conf.	Interval]
Lnotherbotex						
Ln(M)	0.548931	0.043616	12.59	0	0.46215	0.635713
Ln(U)	0.338622	0.035454	9.55	0	0.26808	0.409165
W_{own}	0.50546	0.096622	5.23	0	0.313213	0.697706
W_{other}	-0.30118	0.140263	-2.15	0.035	-0.58026	-0.0221
Ln(RW)	1.044556	0.415293	2.52	0.014	0.218254	1.870858
SIM	-0.00681	0.004716	-1.44	0.152	-0.0162	0.002569
T	0.017667	0.016666	1.06	0.292	-0.01549	0.050826
K	-5.39536	1.208827	-4.46	0	-7.80055	-2.99018

Table 11: Other Retail v 7

Source	**SS**	**Df**	**MS**			
Model	98.9048697	6	16.484145	Number of obs	=	89
Residual	3.64366104	82	0.044434891	F(6, 82)	=	370.97
Total	102.548531	88	1.16532421	Prob > F	=	0
				R-squared	=	0.9645
				Adj R-squared	=	0.9619
				Root MSE	=	0.2108

	Coef.	Std. Err.	T	P>|t|	[95% Conf.	Interval]
lnotherbotex						
Ln(M)	0.5213738	0.0486843	10.71	0	0.4245252	0.6182224
Ln(U)	0.3821722	0.0385893	9.9	0	0.3054058	0.4589387
S	0.2493496	0.0906479	2.75	0.007	0.0690221	0.4296771
Ln(RW)	0.1367634	0.4161701	0.33	0.743	-0.6911315	0.9646584
SIM	-0.0121796	0.0051589	-2.36	0.021	-0.0224422	-0.001917
T	0.0326991	0.018431	1.77	0.08	-0.003966	0.0693642
K	-2.874686	1.225613	-2.35	0.021	-5.312822	-0.4365502

Overall results

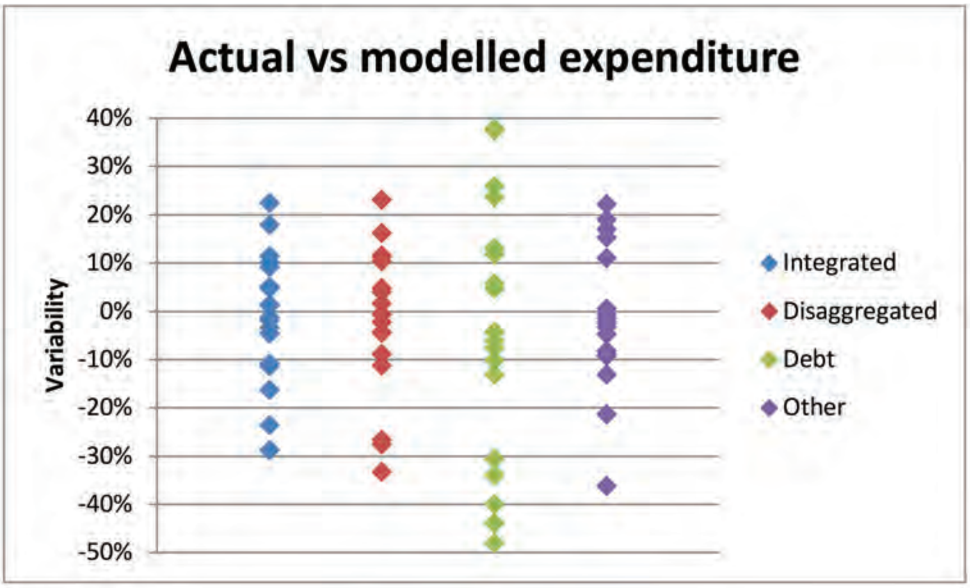
We have calculated the expected value produced by each of the preferred versions for the eighteen companies. Comparing companies' actual costs with their modelled costs over the modelled period allows us to calculate the percentage variance and these data are graphed in Figure 3 below.

The blue markers in Figure 3 below show the results of the chosen Integrated Retail model. The single chosen DDDM model is shown below with the green markers. The two Other Retail cost models were triangulated and reported in the purple markers in Figure 3 below. Finally, the result of adding the DDDM and Other Retail models to create a summed disaggregated model is shown with the red markers below.

It can be seen that the variability of the Integrated results, ranging from -29% to +22%, is smaller than either of the two separate subsidiary models (DDDM: -48% to +38%; Other Retail: -36% to +22%). However, much of the variability displayed by the separate DDDM and Other Retail is eliminated on consolidation into the disaggregated model (red markers), whose variances (-33% to +23%) are very similar to those for the integrated model. The company specific results are also very similar as can be seen from Figure 4.

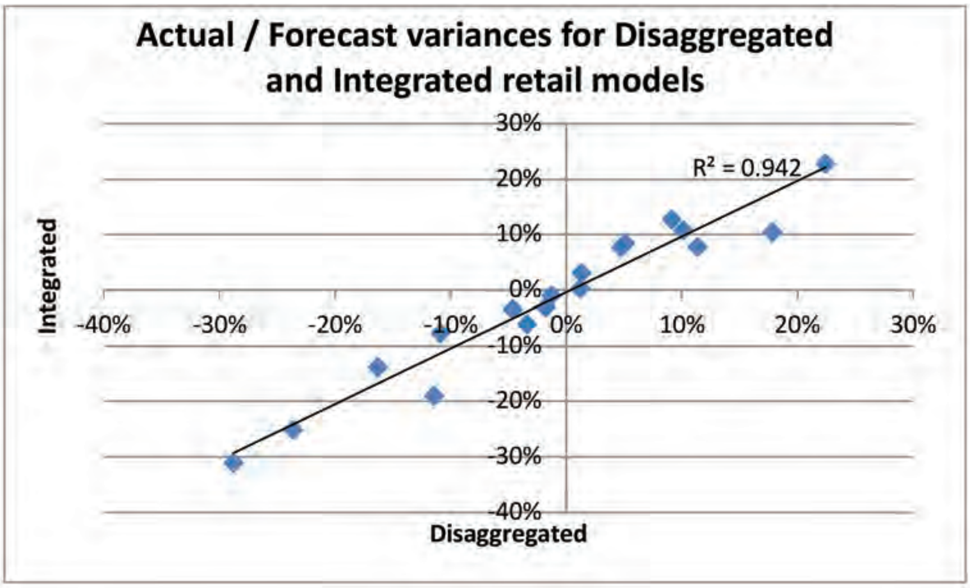
In terms of the variability, these results are overall very similar to those reported in our Phase 1 report in October 2017, with a marginal reduction in variability shown as a result of the new data and new model forms. Overall, despite the new model forms and the new data, what stands out is the continuity with the earlier results.

Figure 3: Variability of actual vs modelled Retail costs



Source: Anglian Water analysis

Figure 4: Variability of actual vs modelled Retail costs – Integrated v Disaggregated



Source: Anglian Water analysis