PR19 Assurance Support

Severn Trent Water

Wastewater Treatment Cost drivers

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Executive Summary

This report sets out to improve wastewater cost modelling by contributing to the development of an expenditure assessment system that has an appropriate balance between modelled outcomes and post-modelling adjustments (special factors).

Our work builds on the issues raised by Arup and Vivid Economics (AVE) at Ofwat's January 2017 Costs Assessment Working Group(CAWG). We address concerns that some of the shortcomings of the PR14 modelling related to poorly specified models. We adopted a risk-based approach and have focused on how we can make material improvements to the cost assessment modelling by obtaining and using data that is more relevant and of higher quality than that used until now.

Our approach was to consider the exogenous factors that could be leading to material differences (at the company level) in wastewater unit costs. We looked at the 7 of the 8 areas identified by AVE in January 2017 (model form was outside of project scope) and identified another 4 potentially material areas. We have challenged these on materiality, on their exogenous nature, the likely availability of modelling-quality data for use at the next periodic review. We have also considered collinearity – several of the factors are attempting to describe the same thing – usually the distribution of households across a company's area.

Figure E1 provides a summary of our conclusions in each case.

Figure E 1 Wastewater treatment expenditure issues

Economies of scale (Section 2)

- AVE headline – economies of scale at works level are most important
- Jacobs – considered in detail. Observed economies of scale relate to the mix of load and works
- Looking for an explanatory variable that describes the distribution of households across the company area

Drainage (Section 4.3)

- AVE – identified as a network and pumping cost driver
- Jacobs – poor data on this issue and may not be wholly exogenous
- Consider unlikely to be a modelling factor but some companies could develop as a special factor

Treatment quality (Section 3)

- AVE – Consents drive costs
- Jacobs - we would expect to see a relationship between expenditure and consents. However, industry data poor - we used Severn Trent data to identify issues and develop special factor methodology
- An area where more work would be beneficial

Sludge modelling

- AVE – new models needed
- Jacobs scope – Not considered in detail (but we agree)

Regional wage (Section 2.6)

- AVE - better data or an alternative measure will improve models
- Jacobs – identified better data sources and prposed approach based on ONS data
- No real evidence that variations in labour costs lead to a material impact on costs

Density (Section 2.5)

- AVE – suggested company level density factor misses asset level cost factors
- Jacobs scope - Critique statement and propose alternative density approaches
- Density measures may help explain expenditure variance arising - but there are collinearity risks

Load measurement (Section 3.7)

- AVE - need to improve data consistency and accuracy.
- Jacobs - support the need for improved data. Some scope to develop data from EA/consents sources.
- We consider data quality unlikely to be sufficiently improved before PR19

Data quality

- Potentially the biggest impact on model outcomes
- Industry data share contains errors and inconsistencies that impeded model development
- Needs commitment and investment from companies and the regulator now - models developed using poor data will themesleves be poor

Network characteristics

- There is a trade-off between works size to access and network length.
- Network design (combined vs separate systems) and private sewer assumptions may reduce the effectiveness of network length statistics
- Network costs provide a natural buffer to treatment economies of scale.

Security

- Possibly an issue related to the sensitivity of locations and to scale (lots of small works more difficult to protect)
- May just be a socio-geographic proxy with a collinearity risk

Regional consent variance (4.2.2)

- New issue raised by Jacobs
- Potential for variation in consenting across regions

As can be seen in our assessment, in some instances we accepted the suggestion that an improved factor could add clarity (such as load measurement), but concluded that the sector would struggle to produce and test the necessary data within the available time frame. Therefore, we focused on matters that could improve the PR19 expenditure assessment. Based on our assessment we consider that the most benefit will accrue from working on the following three factors:

- Economies of scale – we need to understand how to take account the impact of company operating environments on reported expenditure. Average unit costs appear to reflect opportunities to take account of the scale economies associated with increasing works size. We do not accept the AVE conclusion that factors around small treatment works can reliably explain variations in company unit costs. We discuss this in section 2.

- The impact of consents on costs – works level data on costs is not published for all companies and works, we think that the observed variation in the consents must have a material impact on expenditure. We have examined Severn Trent Water's discharge consent and treatment complexity data. The analysis gives potential support for related costs to be include as a moel driver or a special factor. We discuss this in section 3.

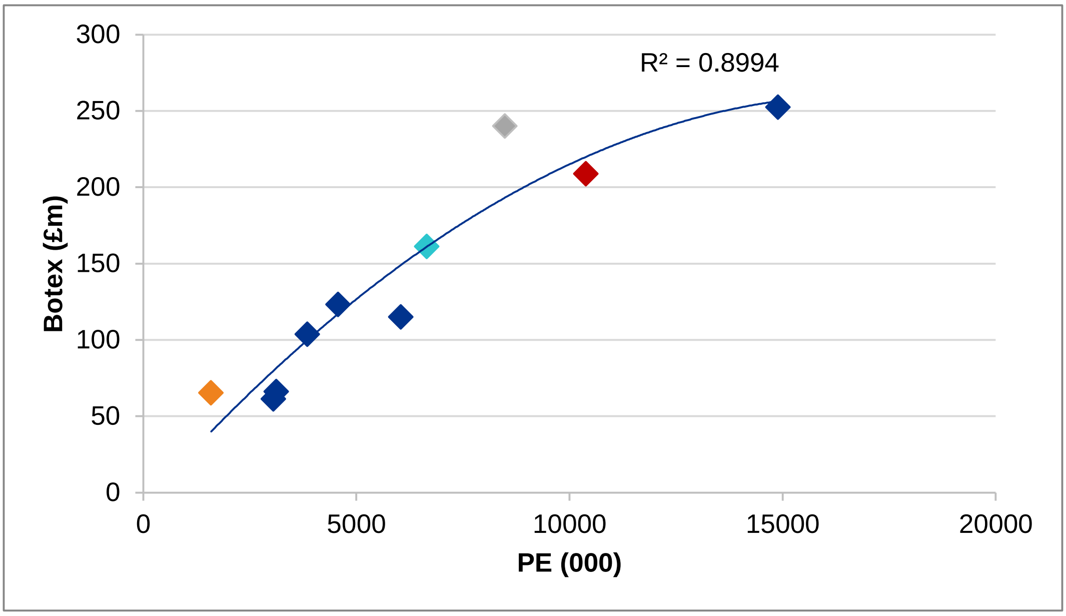
- Improved data quality – we examined the industry data assets for PR14 and the 2016 data share – in the latter we found anomalies and inconsistencies that would have a material impact on modelling outcomes. We provided examples of issues throughout the report.

In section 4 we consider the remaining findings of AVE's January 2017 presentation to Ofwat's Cost Assessment Working Group (CAWG).

E1 Economies of scale

We observed evidence of apparent economies of scale at the company level (for opex, botex and totex) in the wastewater treatment function – these were partly offset when reported expenditure for network and treatment was considered together (against load). We looked at treatment opex, botex, totex, and power opex, we also considered network plus treatment botex. We found that there was always a strong relationship between load and expenditure at the whole-company level. Figure E2 shows 2011-16 average wastewater treatment botex plotted against Population Equivalent.

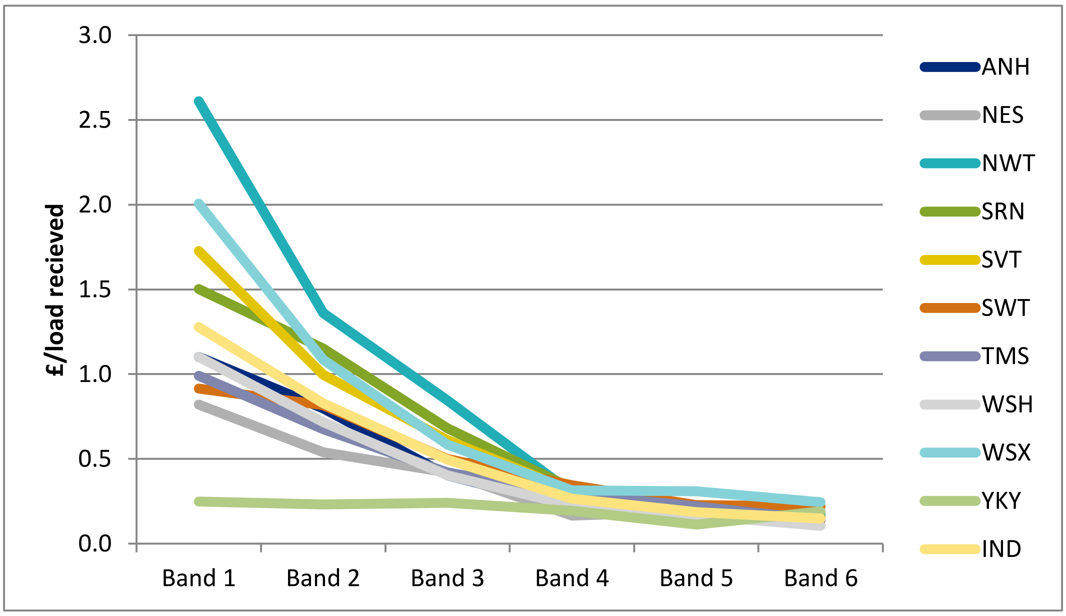
Figure E2: 2011-16 average treatment botex vs population equivalent



The figure shows a strong link between load and expenditure with a typical economy of scale form. There is some divergence – SWT (orange) and UU (grey) showing markedly higher than trend unit expenditure, and SVT (red) showing lower unit expenditure.

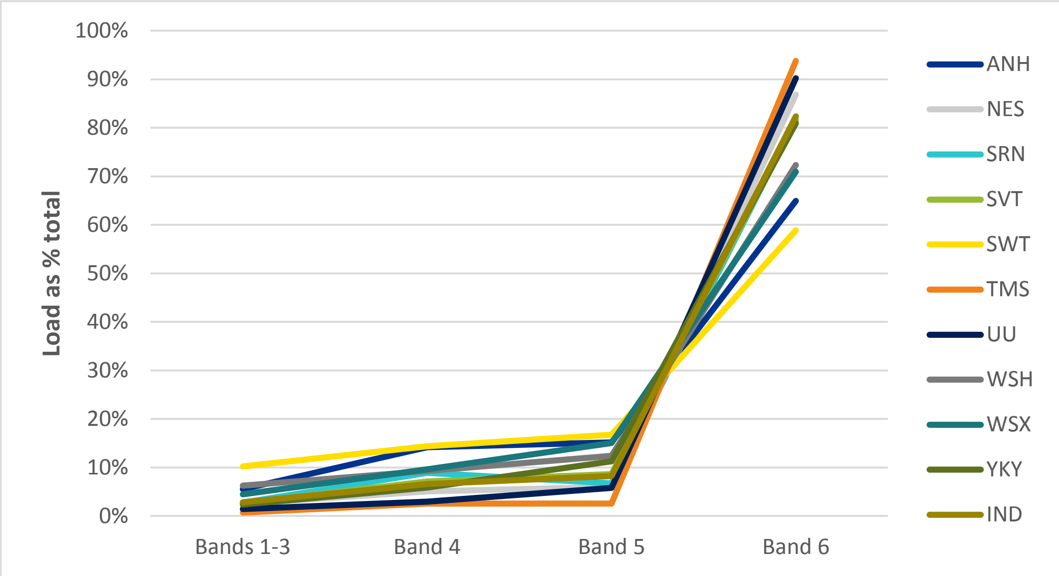
There are clear economies of scale at the works level – unit costs of treatment are much higher at small works. We also noted that there was a wide variation in unit costs at the small works level between companies.

Figure E3 Unit direct cost by band



We note that he total load received by works size shows that all companies treat most load received is at larger works as demonstrated in Figure E4.

Figure E4 Load received by works size as % total



We agree with AVE that economies of scale are asset related – but we find that the company costs (and these are the modelled costs) relate to the entire asset profile. The most important contributor to the industry cost curve is the opportunity to operate very large works. We found that it was the whole load profile, not just the load received at small works that determined company cost variances. We noted that TMS has a special and unique impact on the trend lines in nearly every analysis. We think this is because it serves an urban area that has no comparators in England and Wales.

E2 Wastewater treatment cost drivers

It seems self-evident that the more complex levels of treatment associated with the most demanding consents will lead to higher than average unit costs of treatment. To investigate we adopted a hypothesis based review of SVT's wastewater treatment costs. We established six hypotheses and tested each using evidence from the industry data share and SVT's data on consents and costs.

At the industry level, the shared data on consents does not lend itself to analysis – while there is expenditure data (direct costs) for each works band, the consents descriptions are not true metrics and using them in comparative analysis leads to counter-intuitive results.

However, using shared data on costs and expenditure in combination with explanatory data from the EA consents database begins to highlight the relationship (and show that costs may be higher for more demanding consents). With more work, it may be possible to develop a model factor for each company (in England) relating to the cost implications of ammonia consents.

Table E-1 summarises our hypotheses and the key findings in each case.

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Hypothesis & theory	Findings	Deep Dive Analysis
Works with ammonia consents will have greater unit costs. *More oxygen, more power. More complicated biological matter, more civils assets.*	**Supported in part** • Evidence of increased costs across Bands 3, 4 and 5. • Little evidence in Bands 1 and 2 given other factors. • Difficult to see in Band 6 due to lack of BOD only sites for SVT dataset. • Industry dataset shows strong correlation.	When process type is taken into account, we see higher unit costs for works with ammonia standards than those without particularly in Bands 5 and 6 sites. The prevalence of ammonia consents in the higher bands (e.g. 3, 4, 5, 6) allows for only limited comparison of costs with and without ammonia consents.
Unit cost to treat per load removed is a better indicator of cost than discharge standard or population served. *Load removed considers size of the catchment (load coming in) and size of the receiving water (load going out), whereas consent tightness considers only load out.*	**Supported in part** - across SVT data, load removed offers best correlation in Bands 4, 5 and 6 compared with numerical consent details or PE served (incoming load). Marginal improvement for PE versus load removed given SVT stringent consents Within Band 6 reasonable correlation across industry dataset with load incoming or removed. Cost driver within varying ammonia consents unclear in SVT dataset.	Within bands, comparing like process types we see the impact of consent tightness more clearly but load removed (for stringent ammonia standards) or load incoming offers an improved correlation and potential driver.

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Hypothesis & theory	Findings	Deep Dive Analysis
Costs are driven by actual performance rather than consented performance. *Companies have varying consent risk tolerances – some may require 33% of the 95%ile ammonia standard to be met on average; others 40%, others 50% - for example. Actual sites may outperform their consents due to process type or operator inputs.*	**Not supported** - given the high degree of performance required of SVT assets and the small incremental additional cost for incremental treatment this is not evident from SVT dataset. It is not considered significant for SVT across majority of assets. At industry level it is probably not of significance relative to other drivers.	Not supported due to high levels of compliance required and very high degree of compliance achieved well in excess of SVT asset standards for consents. Evidence of outperforming of some assets with less stringent consents in smaller bands – e.g. Band 3 and below. We would expect this with limited scope for process control at smaller size.
Smaller works will have higher unit costs to remove ammonia and BOD. *Due to economies of scale, catchment characteristics and peaking, types of processes and complexity of control.*	**Supported**. Differential drops away in SVT significantly beyond Band 1 and costs continue to decrease through bands. Not considered of consequence in terms of where most load is being treated Supported by industry dataset; differential drops away >2000PE.	Supported by deep dive analysis. Deep dive analysis shows in some cases significant variation in opex and particularly in chemical and manpower costs which would not be expected within bands and similar process types.
Costs to treat ammonia <5 mg/l will affect smaller works (perhaps <1000 PE) more significantly than larger works.	The data supports an increased unit cost to treat for smaller works but this is most pronounced for Band 1 (for the limited sites with ammonia consents).	Deep dive analysis does not offer further support though shows the high degree of variability within lower Bands 1, 2 and 3 which cannot be correlated with load

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Hypothesis & theory	Findings	Deep Dive Analysis
Smaller works will have fixed film processes like SAFs and no ASP to upgrade. Existing rock media filtration may not be fit for enhanced ammonia standards.	SVT achieve a high degree of performance from an efficient asset type (RBC, filters) at lower bands. This is not the case for other WaSCs which may be more disadvantaged in the low bands though overall, loads are not consequential in terms of overall cost to treat.	removed or incoming or consent requirements.
Treatment costs will be impacted by the presence of phosphorous consent. *Additional chemicals are required to remove phosphorous and therefore higher operational costs are anticipated.*	SVT have such a high degree of P compliance required that this cannot be supported by the data; so limited are the sites without P consents. This would be expected to be significantly different for other WaSCs.	Most sites have a P consent. The smaller sites are less likely to have P consents - we see high variability and little correlation between size or load removed and costs. We cannot see the impact of P consents but in terms of costs this is unlikely to be of consequence.

Table E-1 Wastewater treatment cost drivers summary

E3 Recommendations

We have recommendations in three general areas:

E3.1 Expenditure modelling

It is clear to us that observed unit expenditure is materially influenced by each company's socio-geographic environment – principally the scope to develop and operate very large works which have very low unit costs of treatment. We also note that rurality issues may have a material impact on company unit costs. If these factors are to be considered in the modelling process (rather than as post-modelling adjustments) we recommend the development of a modelling factor that can describe the works size profile across the whole range of works for each company.

The PR14 models already contain several variables which attempt to address (wholly or partly) the economy of scale challenge (these include population and property density, network length and regional wages). We are concerned that this brings a risk of errors relating to collinearity. We noted that considering network expenditure together with treatment expenditure improved the general relationship between load and expenditure. We suggest that a single model may address legacy and other issues (such as the trade-off between closing small works and pumping wastewater elsewhere).

We observed that reported wastewater treatment expenditure demonstrated increasing divergence as companies appeared to respond to new incentives. This could lead to decreasing model performance – and ultimately cause some models to fail. It could be worth stress testing the models by developing some challenging scenarios that reflect continued expenditure divergence.

E3.2 The impact of consents on costs

Like AVE, we are concerned that there is a generally poor understanding of the impact of demanding consents on company costs. The reported and published data is not in a format that allows us to investigate this in a comparative way. However, our work has identified additional data sources (the EA consents database and SVT's internal data on costs for each works). We think that further analysis on the impact of demanding consents, especially for ammonia, would be worthwhile.

SVT's internal data on treatment costs could provide important evidence on the impacts consents on costs. However, we found some unexplained variations in local manpower, power and chemical cost variations that limited our ability to draw conclusions. We recommend that SVT should work to improve its data on wastewater costs and continue to improve its understanding of how changes in the consents regime affects its expenditure.

E3.3 Data quality

The periodic review modelling regime depends wholly on the data provided by each company. We were concerned that the most recent data we used (from the 2016 data share) had some anomalies. If it was used without improvement to develop models it is likely that these would produce sub-optimal results. Accordingly, we recommend that the companies and Ofwat support additional investment aimed at improving the current industry data share, including agreeing and publishing clear treatment complexity line definitions, auditing data returns and carrying out independent reviews and sense checks.

1 Introduction

This report provides a summary of work undertaken by Jacobs for Severn Trent Water investigating wastewater treatment cost drivers.

The purpose of the work is to support the development of existing and future Severn Trent Water (SVT) costing tools and metrics through two discrete packages of work:

- Economies of scale in the wastewater treatment domain– including analysis of issues raised by AVE in their January 2017 paper to the Ofwat CAWG.
- Wastewater treatment cost drivers - a commentary with supporting evidence on the extent to which discharge consents and load removed drive SVT wastewater operational costs. We make recommendations for SVT on how available industry wide data could be best used to represent identified relationships.

The work was undertaken in March 2017 with scope as set out in the Proposal document *PR19 Technical and Economic Analysis,* February 2017 and 17 February email confirmation from Rob Holdway, Severn Trent Water.

This report provides a methodology for the work, analysis, results and recommendations for future work. It is divided into 4 sections with supporting annexes.

- Section 2 considers Economies of scale – we need to understand how to take account the impact of company operating environments on reported expenditure. Average unit costs appear to reflect opportunities to take account of the scale economies associated with increasing works size. We do not accept the AVE conclusion that factors around small treatment works can reliably explain variations in company unit costs.
- Section 3 investigates the impact of consents on costs – while industry-wide data on costs and discharge consents is not available, we think that the observed variation in the consents must have a material impact on expenditure. We have examined Severn Trent Water's data and identified data on costs and explanatory factors that could be used to develop a methodology and model for special factor claims.
- In section 4 we consider the remaining issues identified by AVE or in our initial audit.
- Throughout the report we comment on matters relating to data quality – we examined the industry data assets for PR14 and the 2016 data share – in the latter we found anomalies and inconsistencies that would have a material impact on modelling outcomes. We provided examples of issues throughout the report.

2 Economies of scale in the wastewater treatment domain

Findings

- Company unit costs (expenditure vs load or PE) of wastewater treatment decrease with company size for all measures of expenditure. The decrease is less marked when treatment costs are considered with network costs.
- At the works level unit costs are highest (and most variable) at the smallest works
- For all companies, most load is treated at large works – but each company has a unique profile of works by size. Data analysis of costs by size is hindered by the currently defined treatment works size bands.
- While load received is the major cost determining factor, the unique load-received profile – reflecting its socio-geographic environment - has a major impact on its unit costs. We recommend work to develop a modelling factor that reflects this.
- It is possible to assess the impact of higher incidence of particular sizes of works and make an assessment of a ‘special’ factor.
- It is possible to improve on the current measure of density but this seems to be explaining the same things as the works size profile.
- Regional wage levels could have a material impact on expenditure. But this is a very complex area and we do not recommend that it should be included as a factor in the models.

2.1 Overview commentary

Severn Trent Water asked us to review and consider aspects of Ofwat’s wastewater cost modelling and provide advice to facilitate their preparations for the 2019 periodic review (PR19).

SVT asked us for:

- A quantified assessment of the extent to which Severn Trent Assets/region support or disprove the conclusions from the AVE presentation made to Ofwat’s costs assessment working group (CAWG) on 24 January 2017. This would include:
    - Discharge tightness
    - Load removed
    - Sewage Treatment Works (STW) size

We were also asked to

- Review other drivers identified but not quantified by AVE (including surface water drainage):
    - Describe the relevance and fit with Severn Trent circumstances (with quantification where possible).
    - Explore variance across industry
    - Explore availability of modelling data (Ofwat data, proxies within Ofwat data, independent external data)

We begin by outlining the regulatory context to the AVE work and then summarising their presentation. We then consider how unit costs vary with works size (sub-section 2.3). In sub-section 2.4 we look at the relationship between load and expenditure. We examine the density factor used in the wastewater models in 2.5 and the regional wage factor in 2.7.

2.2 Regulatory context

Ofwat developed a new set of models for the 2014 price review (PR14) to allow it to assess wastewater costs. It was unable to produce a true totex[1] model for wastewater and used a suite of five econometric models covering the sewerage domain. The PR14 sewage treatment models also included sewage sludge. We understand that Ofwat intends make the sludge business more contestable for PR19; this is likely to mean that Ofwat will have to undertake further development work on its sewage treatment and overall sewerage models (although the models used no sludge specific factors apart from costs). Companies have recently provided Ofwat with a comprehensive data submission to support the development work.

The models relating to wastewater treatment used a range of drivers and explanatory variables:

- Botex (opex plus base capex)
- Density
- Load
- Regional wages
- Proportion treated in bands 1-3
- Time trend

There was no formal review of the wastewater cost assessment models after their use in the price review. In the final stages of PR14 Ofwat noticed that its models did not react well to the new data that became available after draft determinations. Subsequently companies have noted that the key indicator statistics around the models were declining with time. Both the companies and Ofwat have started to think about the PR19 cost assessment mechanisms. Companies including Severn Trent are now working with the regulator as part of the cost assessment working group on the development of models for PR19.

2.2.1 Approach

We looked at the issues around wastewater cost assessment from the company and industry level. We consider costs and outputs at company level with the aim of identifying key issues and trends. We have used cost and output data from the PR14 data set and the 2016 data submission to Ofwat. These allow us to undertake some analysis at the sub-company (treatment works size) level.

We investigate:

- Industry costs (opex, botex and totex) and comparing them to the outputs (load received at works or population equivalent (PE) served).
- Issues around treatment works size and economies of scale
- How to reflect the socio-geographic environment through a coherent density metric.
- Appropriate sources of data on regional wages
- The potential impact of sewer infiltration and changes in surface water drainage on wastewater treatment costs
- The use of ‘load removed’ as opposed to ‘load received’ as a key output metric.

[1] Totex = operating expenditure + capital maintenance expenditure + capital enhancement expenditure

2.3 Size of treatment works

Findings

- Unit costs of treatment increase as works decrease in size.
- Wide range of unit costs in the smallest bands in unit costs.
- For all companies, most load is treated at large works.
- Each company has a unique profile of works sizes.
- It is possible to assess for each company how its reported expenditure is impacted by having a greater exposure to a band type than the average and this could be used to develop special factors.
- Currently defined treatment works size bands can confuse analysis.
- Observed company treatment costs almost entirely reflect the load and costs for larger works. Small works have little general impact on the unit cost trend line.

Ofwat currently classifies wastewater treatment works using a system based on 6 bands. Table 2-1 below summarises these.

Table 2-1 : Wastewater works size bands

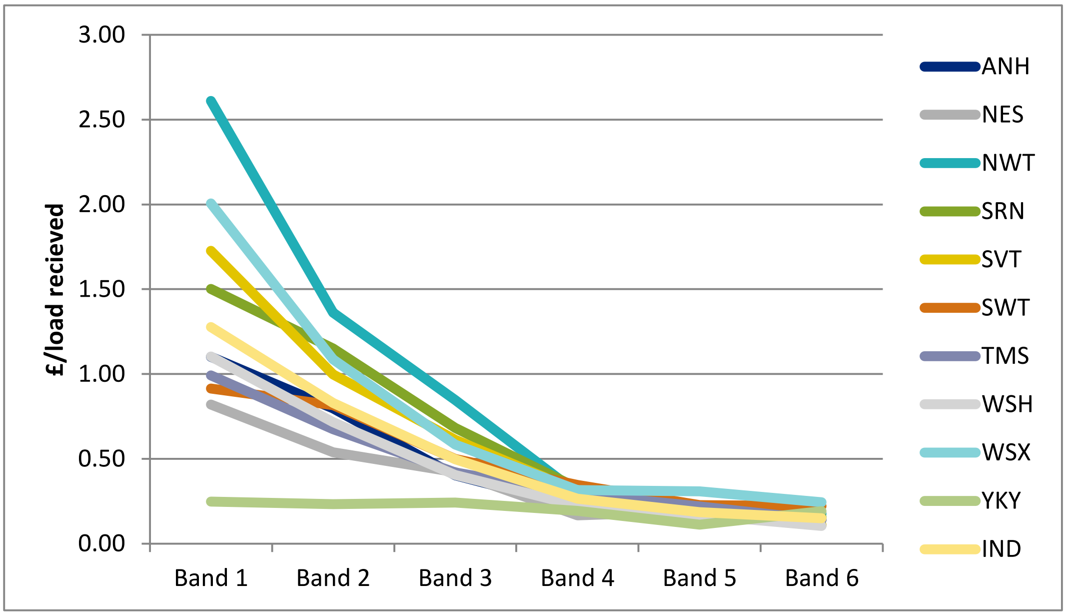
		Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
Range	PE	0-250	250-500	500-2000	2000-10000	10000-25000	>25000
	BOD (kg/day)	0-15	15-30	30-120	120-600	600-1500	>1500
Band Size	PE	250	250	1500	8000	15000	unlimited
	BOD (kg/day)	15	15	90	480	900	

The 2016 data share includes information about treatment works across the size range. At the band level, we have data on the number of works, and the load and treatment types in the bands. We also have some cost data. However, the costs declared are categorised as ‘direct costs’ – these are quite close to (but not the same as) operating expenditure. We understand that the data is audited, although we have observed some significant anomalies. These may be due to different interpretations of the existing line definition of what is included as ‘direct costs’. The existing reporting requirements mean that whilst we have direct costs for each band, we only have general and support costs (a material component of treatment costs) in aggregate for bands 1-5 and band 6 only. If we had similarly defined data for each band it may be possible to make further observations about economies of scale and efficiency. Nevertheless, they are all we have at band level and they do help us imagine what, with a little more effort, we could achieve.

2.3.1 Unit direct costs by band

It would be helpful to undertake a robust analysis of unit costs by band. Figure 2.1 below plots direct costs against load received for each band. (The costs in bands 1-5 are underestimates because they do not include general and support costs which are not reported individually for all bands). However, we can see that unit direct costs decrease quickly as the size as the size of the works increases.

Figure 2.1: Unit direct costs 2015-16 by band



The chart shows that:

- Average unit costs for each band decline as the size of works increases – the industry unit direct cost for band 1 is more than 10 times that of the industry band 6 figure.
- Company unit costs vary widely - but they decline on a consistent basis.
- While rapid decreases in costs have almost disappeared by band 4 there are still visible decreases in unit costs into band 6.
- There are economies of scale at treatment works level – but these seem to decline after 2000 PE (in band 4).

To understand the impact of this analysis at company level we have considered the distribution of the work done – the wastewater treated – by band. Table 2-2 below shows load removed (% total load received) for each band for each company.

Table 2-2 : % Load received at works by band

% load received by band

	Band 1	Band 2	Band 3	Bands 1-3	Band 4	Band 5	Band 6
ANH	0.6%	0.7%	4.2%	**5.5%**	14%	15%	**65%**
NES	0.6%	0.3%	1.6%	2.6%	7%	5%	85%

% load received by band							
NWT	0.3%	0.3%	0.8%	1.5%	3%	6%	90%
SRN	0.2%	0.3%	2.2%	2.6%	8%	7%	82%
SVT	0.4%	0.4%	1.7%	2.4%	7%	8%	83%
SWT	1.7%	1.9%	7.1%	**10.6%**	16%	15%	**58%**
TMS	0.0%	0.1%	0.5%	0.7%	2%	3%	95%
WSH	1.2%	1.2%	3.7%	**6.1%**	9%	12%	73%
WSX	0.3%	0.4%	3.7%	4.4%	9%	13%	73%
YKY	0.5%	0.4%	1.5%	2.4%	6%	12%	79%
IND	0.4%	0.4%	1.9%	2.8%	6%	8%	83%

There are other ways of using the data on loads and direct costs (remembering that this is not the best quality data).

2.3.2 Average load analysis

If we take a view that the variation in load by band is entirely exogenous – so differences from the average load for each band are outside the control of a company – we can calculate the theoretical impact of the real load profile on company costs. To do this we need good information on loads and costs for each band. The load data we have is good, but the costs data is not up to deterministic standard. However, we can show some illustrative results. Table 2-3 shows the results (negative numbers in brackets).

Table 2-3 Costs assuming industry average loads and company unit costs

	Load (difference to average)			Incremental costs (£m)				
	Bands 1-3	Bands 4-5	Band 6	Bands 1-3	Bands 4-5	Band 6	Total difference	% difference
ANH	11,533	61,200	(72,734)	6,096	11,417	(10,271)	7,242	9.9%
NES	(382)	(4,375)	4,758	(203)	(772)	510	(464)	-2.1%
NWT	(6,884)	(29,391)	36,275	(9,324)	(6,256)	6,369	(9,211)	-8.9%
SRN	(324)	1,167	(843)	(258)	320	(131)	(69)	-0.1%
SVT	(2,052)	2,950	(898)	(1,714)	736	(98)	(1,077)	-1.2%
SWT	8,340	18,034	(26,375)	5,185	5,200	(5,827)	4,557	15.1%
TMS	(20,197)	(94,345)	114,542	(10,173)	(23,968)	16,137	(18,004)	-12.5%
WSH	8,327	15,426	(23,753)	4,991	2,957	(2,470)	5,477	14.4%
WSX	3,120	15,796	(18,915)	2,293	4,910	(4,613)	2,590	4.8%
YKY	(1,481)	13,539	(12,058)	(358)	1,881	(2,293)	(770)	-1.2%

In the table, a positive number shows the additional cost borne by the company because it has more than average load in a band category. So, for ANH, its higher than average load in bands 1-3 means it direct costs are £6.096m higher, in bands 4-5 they are £11.417m higher, but in band 6 they are £10.271m lower. The total impact of its load profile is £7.242m (9.9% of total direct costs).

We can see that both NWT (UU) and TMS have a major direct-costs benefit from their load profile while SVT, WSH and ANH have higher costs.

The analysis is not perfect – it uses direct costs data which is not well-defined. But it does show the importance of whole load profile as a cost determining factor.

2.3.3 Average cost analysis

Another way of looking at the direct costs data is to consider what a company's costs would be if it could treat its own load profile at the industry average cost (or its own costs, whichever is lower).

Table 2-4 Costs assuming average direct costs (where lower than actual costs)

WaSC	Unit costs			Total costs at lowest of average or own			Report-ed direct £	Ave.or lower £	Differen-ce (£m)	Differe-nce %
	1-3	4-5	Band 6	Bands 1-3	Bands 4-5	Band 6				
ANH	0.53	0.19	0.11	12,199	22,696	28,706	63,601	63,601		
NES	0.53	0.18	0.08	2,421	3,801	12,023	18,246	18,246		
NWT	1.35	0.21	0.13	5,052	9,945	52,589	83,602	67,586	16016	19.2%
SRN	0.80	0.27	0.13	4,892	9,214	25,728	48,228	39,834	8393	17.4%
SVT	0.84	0.25	0.09	10,167	20,863	48,351	84,732	79,381	5351	6.3%
SWT	0.62	0.29	0.17	7,009	7,387	6,853	27,332	21,248	6083	22.3%
TMS	0.50	0.25	0.12	3,304	10,125	102,142	127,360	115,570	11790	9%
WSH	0.41	0.27	0.15	6,239	11,384	20,335	47,620	37,958	9662	20%
WSX	1.07	0.22	0.10	5,607	9,865	13,752	32,733	29,224	3509	10.7%
YKY	0.24	0.14	0.05	2,078	9,219	13,578	24,874	24,874		
IND	0.66	0.22	0.11	58,969	114,497	324,056	558,327	497522	60806	11%

This is a basic form of efficiency analysis – using a makeshift average cost based target. The figures in the difference column show how much the company could reduce its total direct costs by if it reduced its unit costs to the average for each band.

2.3.4 Conclusions on the use of sub-company data

We have used the band-level direct costs data to investigate industry expenditure trends and patterns. We have shown that unit costs fall as works size increase – and noted that the decrease in unit cost is most dramatic in the band up to works of around 2000PE.

We used the direct cost data to investigate the impact of unit costs across the whole size range of works. By making assumptions about the load received and the average load in each band to calculate the implications of having a non-average load pattern. We found that the company impact depended on the differences in all treatment bands (not just the small ones).

By assuming that companies could address higher than average unit costs, we were able to identify companies where high unit costs were leading to above average company costs. Once again, the analysis showed that it was important to consider the treatment profile if we were to obtain useful results.

However, both analytical approaches suffered from the very variable band level data included in the 2016 data-share. Therefore, we consider that there is an opportunity for the sector to work together to improve the definitions of the reporting categories, and review historic reported data, which will enable both companies and the regulator to obtain very useful insight.

2.3.5 Economies of scale

We see two broad types of economies of scale in the wastewater treatment data:

- at the treatment works level where unit costs reduce rapidly up to the 2000 PE level.
- at the company level where average costs reduce more quickly as company size increases.

We think it is important to identify factors that can explain economies of scale at the level of regulatory disaggregation. While these will derive from asset level factors (which themselves reflect environmental factors and management decisions) it is the cumulative result that is important in the regulatory decision making process.

We know that load removed is the most significant scaling factor in the wastewater treatment area, but we observe consistent cost variation by company and over time, that suggests there are other factors driving observed costs.

We have already identified and discussed the economies of scale that exist in the small works area. For works up to 2000 PE there is a rapid decline in average costs as size increases. Average costs carry on decreasing across the size range right up to the very largest works – but not at the initial rate. However, total costs do seem to fall more quickly as companies become very large – because so much wastewater is treated that even marginal unit cost reductions deliver very meaningful overall gains.

We have noticed the classic imprint of economies of scale on the trend lines for industry level costs. We should exercise some caution here – the reported expenditure of the three very large companies is not wholly stable and we can often induce a linear relationship by treating TMS as an outlier. But underneath this we can see that companies which might be expected to suffer from the burden of rurality (such as WSX, NES and WSH) deliver unit costs that are close to average - possibly because they have taken advantage of opportunities to build and operate very large works.

2.3.6 Load removed in bands 1-3

At the last price review Ofwat used factors to account for population density, regional wage differences and ‘economies of scale’.

For PR14 Ofwat used the proportion of load removed at works in bands 1-3 ‘to capture economies of scale in the treatment facility’. It (or its advisors CEPA) also suggested that population density can identify economies of scale as ‘more dense areas can take advantage of treatment economies of scale’. Ofwat does not appear to have considered options on the form of its scale factors.
In in its January 2017 presentation AVE recommended that ‘% of total load removed in bands 1-3’ should be used to explain economies of scale.

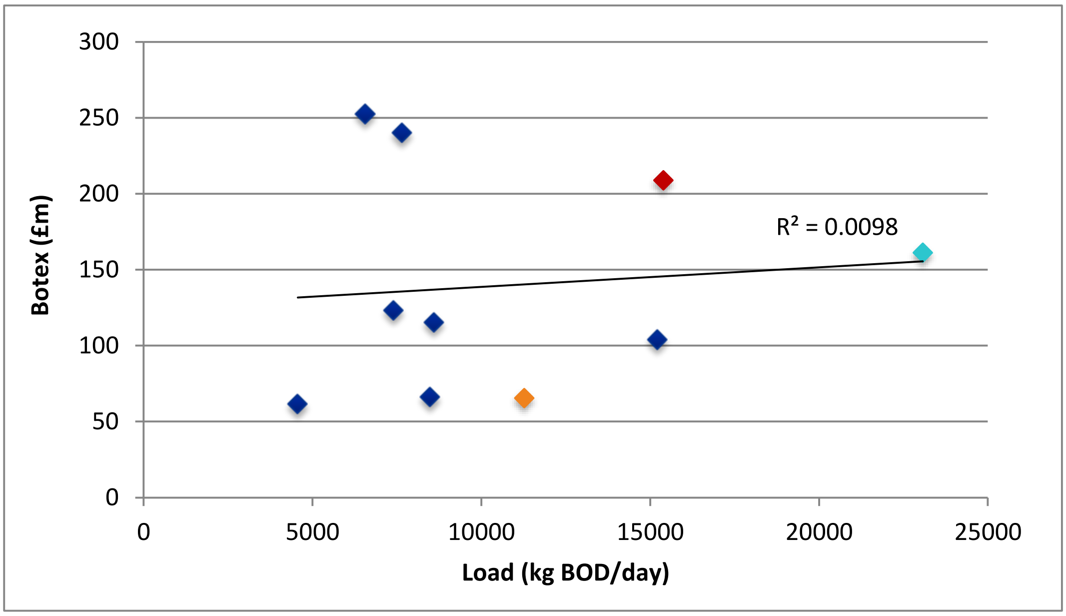
It is an attractive recommendation – some of the companies with relatively high loads in the smaller bands do show consistently higher than average wastewater treatment expenditure. But some do not.

The two companies (SWT and ANH) showing higher than expected average opex have high levels of load received at works in bands 1-3, but so does WSH which showed no divergence

- ANH shows no divergence at the botex level
- While SWT and ANH have proportionally high loads in bands 1-3, their unit costs are lower than average and the proportion of total costs is relatively small.
- SWT and ANH have the lowest load in band 6 – where unit costs can be very low.

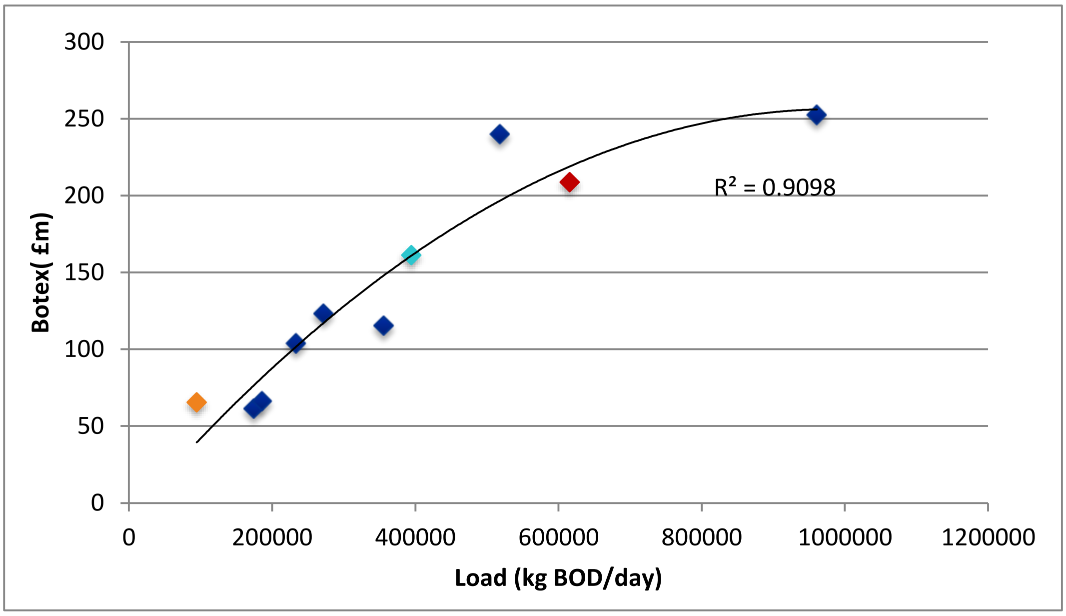
If the load received in bands 1-3 is an important general factor in explaining overall wastewater costs we would expect this to see a relationship between it and total costs. Figure 2.2 plots load received (BOD) in bands 1-3 against botex for the 2007-13 period (SWT in orange, ANH turquoise, SVT red).

Figure 2.2: 2011-16 average company treatment botex vs 2016 load in bands 1-3



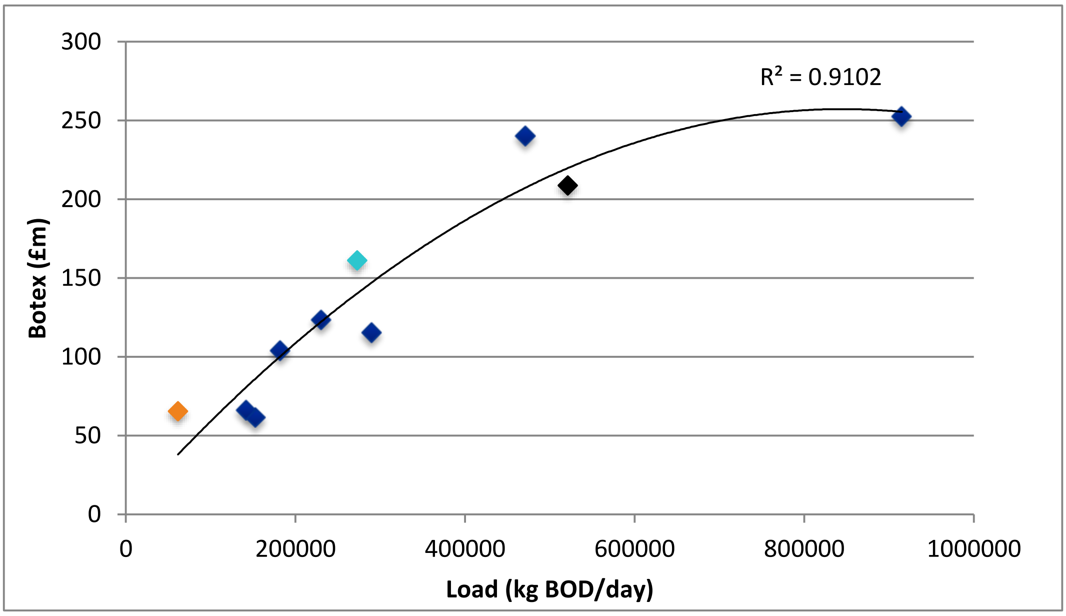
But we see a poor relationship. This is partly because the load in bands 1-3 is relatively small but also because reported small works unit costs seem very variable. If we look at this from the other end – so consider a plot of load in bands 4-6 against botex.

Figure 2.3: 20011-16 average company treatment botex vs 2016 load in bands 4-6



We can see that the cost curve is already well formed without the load data for bands 1-3.

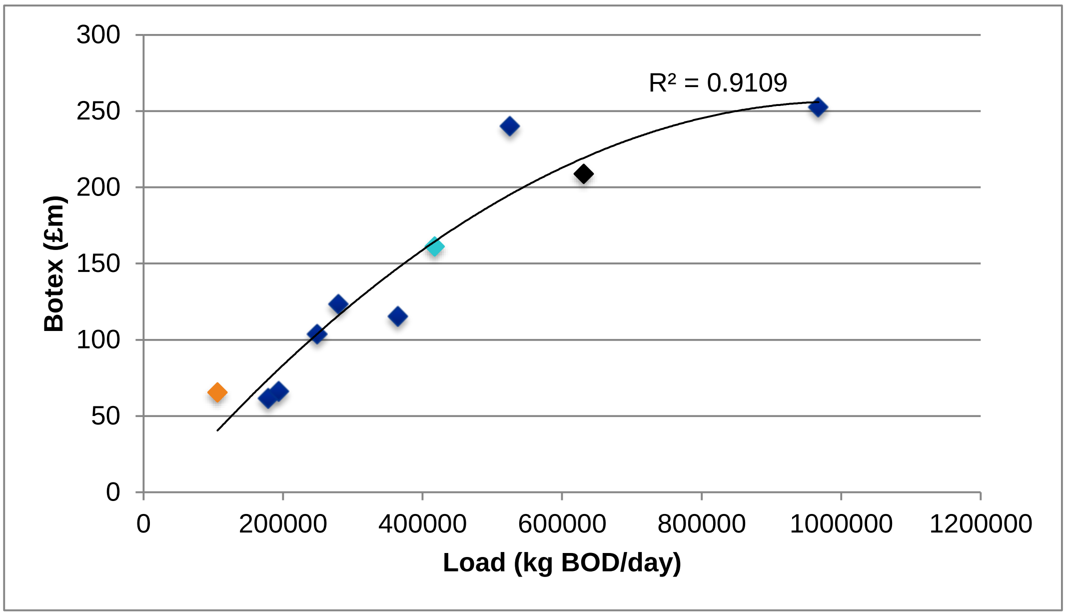
Figure 2.4: 2011-16 average company treatment botex vs 2016 load in band 6



This shows an even stronger relationship between total botex and the load in band 6 that we saw in the previous analysis where we used the load in bands 4-6.

Figure 2-5 shows average 2011-16 costs plotted with 2016 botex.

Figure 2.5: 2011-16 average company treatment botex vs 2016 total load



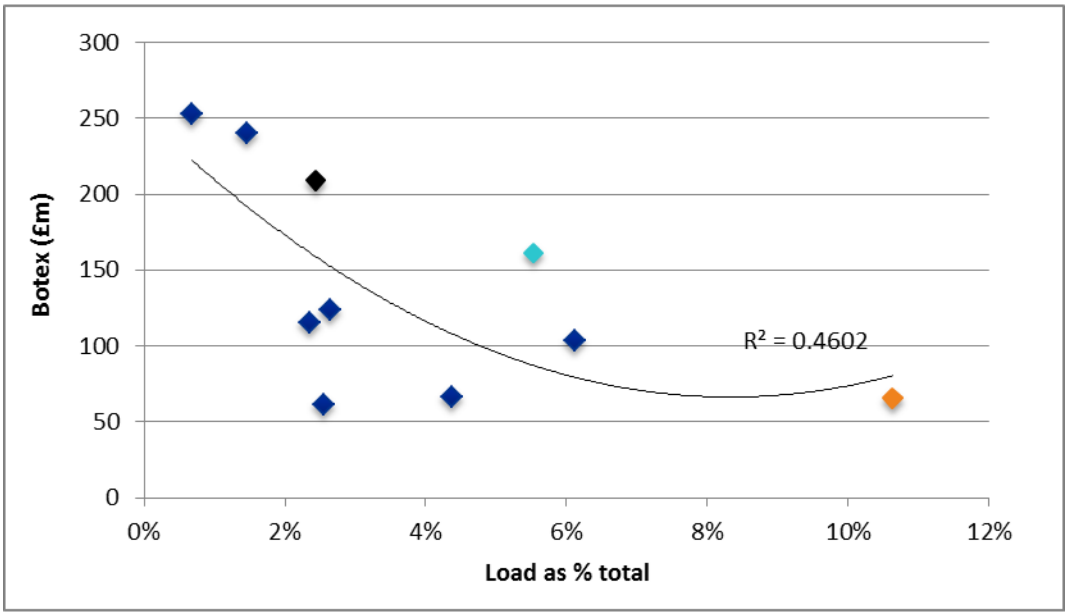
The relationship is slightly better than band 6 on its own (Figure 2-4) but not by much.

What do the four charts tell us?

- The load removed in bands 1-3 does not seem to be a strong explainer of industry costs. But given the small proportion of load removed by these very small works and the significant unexplained variation in unit costs at that level this is what we should expect.
- Even for SWT the load removed in bands 1-3 does not look to be a good explainer of its variance (the distance from the trend line is similar in the all bands and the bands 4-6 plot).
- It may be that using some sort of transformation of load in bands 1-3 could provide a factor to address the SVT variance.
- While total load is the best single variable for explaining observed wastewater treatment costs, the load in band 6 alone produces almost as strong a relationship with company botex.

However, AVE has proposed the use the **percentage** of a company's load in bands 1-3 rather than the **total** load. We have considered this – the chart below plots unit botex against the %average bands 1-3 load to total load.

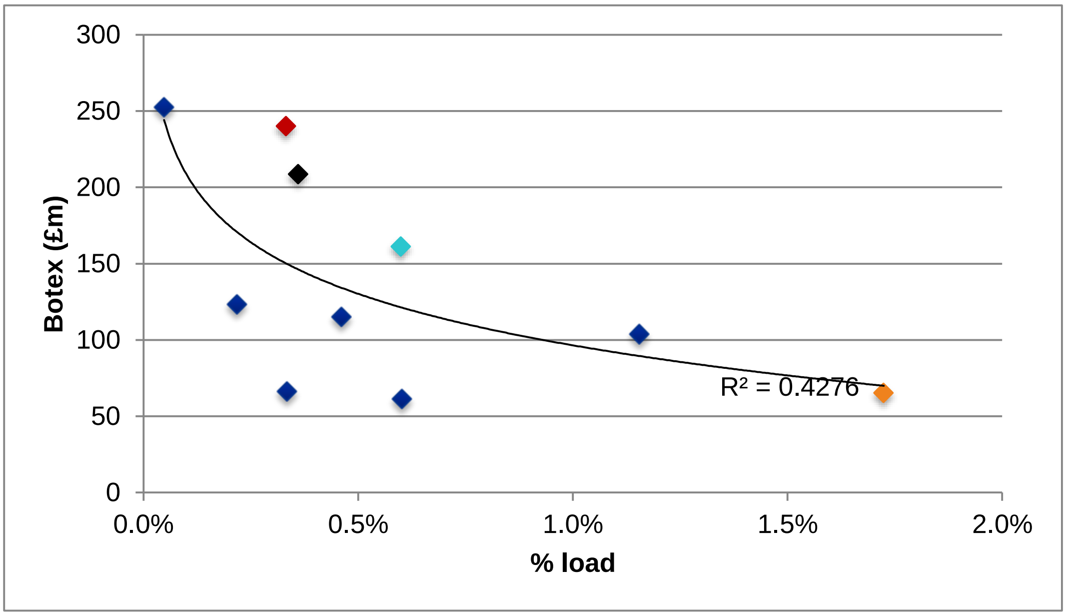
Figure 2.6: 20011-16 average treatment botex vs % load in bands 1-3



The results are interesting – a much stronger R^2 value than we saw when plotting load against botex (Figure 2.2) and clearly an initially attractive result if we were looking to find a factor to explain the observed economies of scale.

The immediate (and important) question is why this is so different to what we saw in 2.2. It is different because the apparently simple change from absolute to % load is a highly material data transformation. It makes the smaller loads much more significant. We can demonstrate this by looking at % in band 1 vs botex.

Figure 2.7: 2011-16 average treatment botex vs % load in band 1



We see a relationship like that in figure 2-6 with a reasonable R^2 value. But does this mean that we could seriously think that the % of load removed at band 1 works is an important explainer of costs on its own merit (i.e. because the costs are higher - not that it shows something else)?

We have already shown that it is possible to calculate the theoretical cost of treating more than the average amount of load at smaller works. We also found that some companies with more load in the smaller size bands had higher than average treatment costs in other bands.

We think it is inappropriate to use a modelling factor that is derived from a single small part of the cost profile when it is evident that it is the whole profile that is important in determining company level costs. Accordingly, we can see no reason to suggest that the %load removed in bands 1-3 is a reasonable factor for explaining the observed company level economies of scale for reasons related to the costs at those works.

2.3.7 Load removed at large works

From 58% (SWT) to 95% (TMS) of load is treated at the largest works – those in band 6. The charts reviewed earlier suggest that average costs fall as companies get bigger - because bigger companies treat proportionally more waste water at very large works.

We saw in figure 2.4 how important the load removed in band 6 was in determining the shape of the cost/load curve. And we can see how TMS is influencing the curve and suggesting where the economies of scale are located. The problem with any analysis of band 6 costs is that the band is very wide – too wide – and we do not have expenditure information at the band level. But we do know that TMS has larger works serving a bigger urban area than any other company.

Looking at treatment costs alone may be misleading. When we added network costs to our analysis there was a visible (but not total) straightening of the trend line. This suggest that some of the benefits from treating waste water at very large works may be offset by higher network costs.

2.4 Wastewater treatment expenditure

Findings

- Company unit costs (expenditure vs load or PE) of wastewater treatment decrease with company size for all measures of expenditure. The decrease is less marked when treatment costs are considered with network costs.
- There is always a very strong correlation between load (or PE) and expenditure.
- Most recent data shows increasing divergence – mostly arises from capital maintenance expenditure.
- Using network and treatment costs straightens the line of best fit – probably an indication of trade-offs between keeping the network length low and consolidating works to get the scale benefits.

We have used two sources of data for our initial analysis of the relationship between observed costs of treatment and the scaling variables (principally load received at works and the related population equivalent[2]):

[2] Load incoming or received and PE are essentially the same thing – PE is calculated from BOD using the assumption that 60g of BOD is equivalent to one PE or equivalent nutrient (ammonia, phosphorus) per capita

- The PR14 data summary file – costs (in 2013 prices) for the 2007-14 period. Sludge related costs are not separated out in this data set and the dataset does not include any capital enhancement costs.
- The 2016 Ofwat data collection – includes a full expenditure by purpose analysis of all costs from 2011-12 to 2015-16 (including capital enhancement) and some costs relating to works size.

2.4.1 Company level costs

We began by investigating the reported treatment expenditure for each company for each year of available data and for the average of the two data periods. For each data set we produced a scatter plot and trend line for each year, and for the period average, for opex and botex (opex plus base capex). Each chart contains 10 points (one for each company) and plots costs (on the vertical axis) against load. We have also included a simple regression trend line using the form that produces the strongest R^2 coefficient. This is most often a polynomial expression. We also have considered our conclusions in the context of sewerage network costs.

The 2016 dataset includes metrics on treatment costs (direct costs – local opex plus some maintenance) at the works band level. However, there are issues with the data that seem to relate variations in how companies have interpreted the data definitions guidance.

We start by looking at all costs with a view that the only necessary scaling factor was the load received at works. We have then sought to understand the factors that could be behind observed variation. While a perfect approach would be to list all the factors that could influence costs, to obtain and test data, and to use the most significant metrics to build a model, this is not practical or achievable or within the scope of this study.

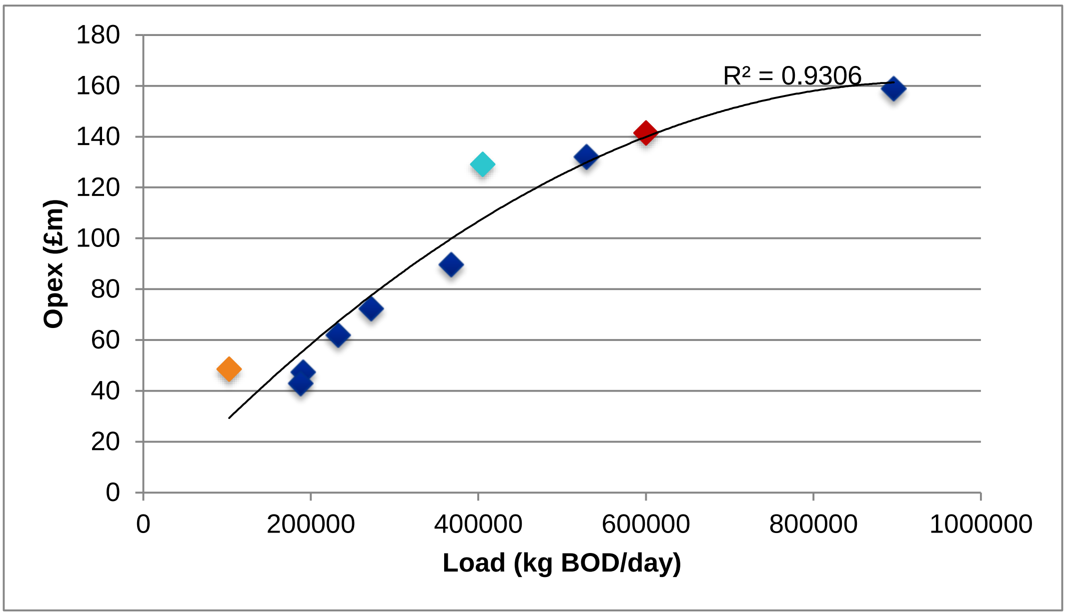
2.4.2 PR14 data

Figure 2-8 shows average opex for the 2007-14 period against load received at works[3]. There is a visual relationship and the trend line has a strong coefficient. We notice that two data points are above the line indicating that the companies concerned (South West (SWT) and Anglian (ANH) – in orange and turquoise respectively) have higher costs than the trend. Severn Trent (SVT - in red) is the second point from the right and is positioned on the line.

loadings. Load treated or removed subtracts the load outgoing in final effluent dependent on the works license.

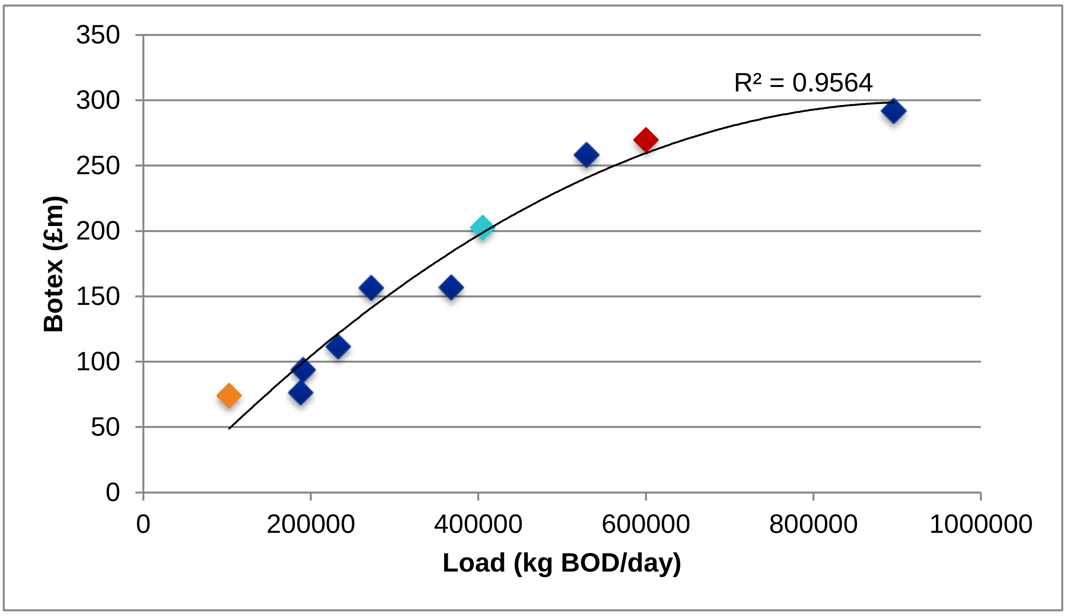
[3] Charts for individual years are at Appendix B.

Figure 2-8 2007-14 average treatment opex vs load



The next Figure shows average 2007-14 botex plotted against load[4].

Figure 2.9 2007-14 average treatment botex vs load



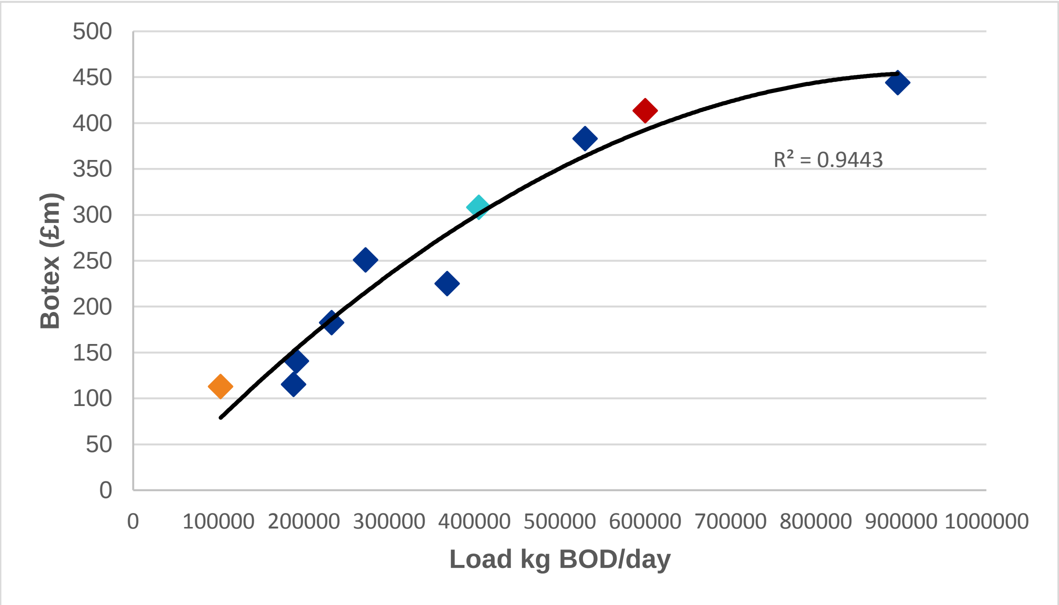
We see that SWT remains above the trend line while ANH has, with the inclusion of capital maintenance costs, moved onto the line. The ANH movement is interesting. The opex analysis had identified SWT and ANH as companies with higher costs – it was tempting to suggest that this related

[4] Charts for individual years are at Appendix B

to rurality issues. But the movement back to the average cost line with the inclusion of base capex costs suggests that ANH's capital maintenance costs are much lower than average.

Finally, for the 2014 data figure 2.10 shows the sum of network and treatment botex against load.

Figure 2.10 Average 2007-14 botex (network plus treatment) vs load



The 2014 data identifies the following issues:

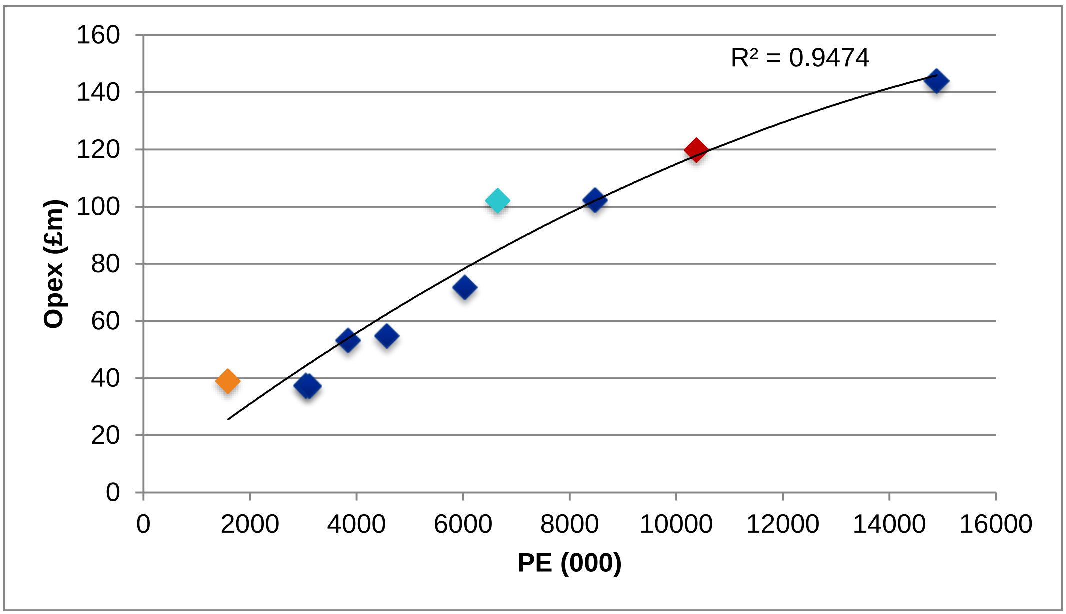
- The shape of the trend line suggests economies of scale at the company level – there is a clear flattening of the trend line as the load increases. However, the shape of the curve is mostly due to the impact of the TMS data. If we exclude TMS from the analysis we see a strong linear relationship. If we exclude SWT, the R^2 increases but the trend line stays the same.
- SWT's divergence is sensitive to the inclusion of TMS in the analysis. With TMS included, SWT's average treatment botex is around 45% higher than predicted by the trend line. Without TMS the difference is 20%.
- Observed variance from the trend line could be due to cost allocation issues, data issues and/or inefficiency.

2.4.3 2016 data

The next three charts show 2016 cost data plotted against population equivalent (PE). While the 2014 cost data included sludge related costs, this data set excludes them. The first chart shows opex[5].

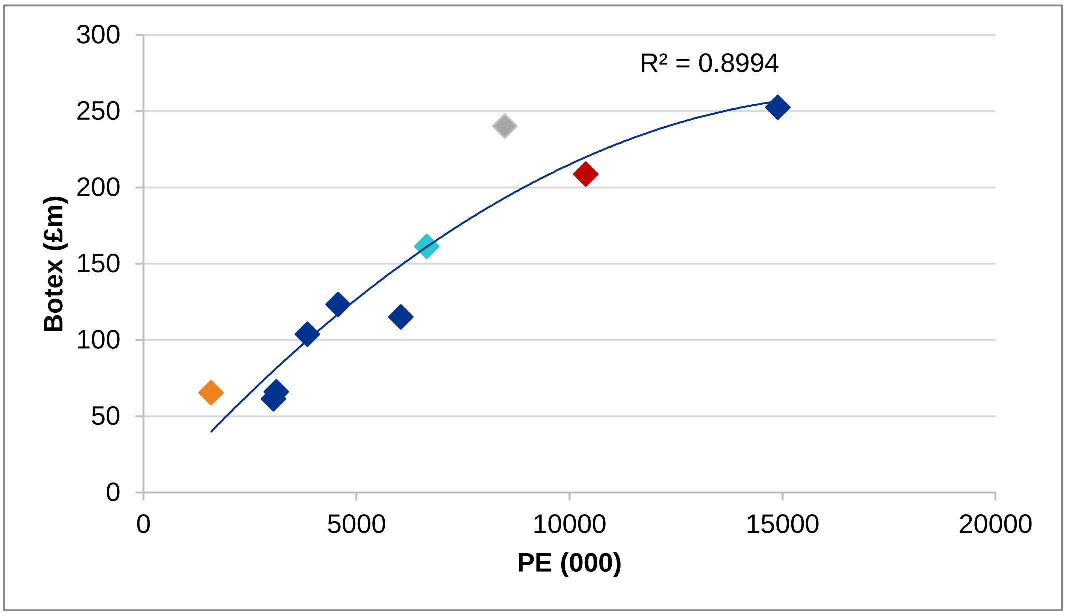
[5] Annual plots at Appendix B

Figure 2.11: 2011-16 average treatment opex vs PE



Again, as we saw with the 2014 data SWT and ANH show above the trend line.

Figure 2.12: 2011-16 Average treatment botex vs PE

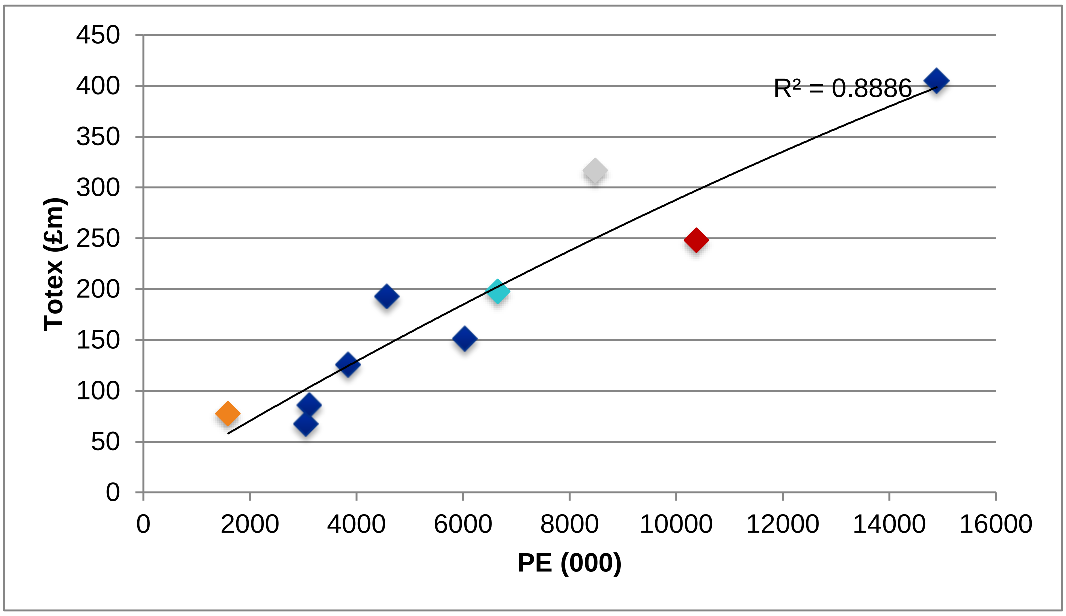


SWT remains persistently above the trend line while ANH has moved below. We also see both SVT and United Utilities (UU – third from the right - grey) diverging from the line. The divergence process is clearer on the annual charts in Appendix C.

Figure 2.13 shows load against totex[6].

[6] Annual plots at Appendix B

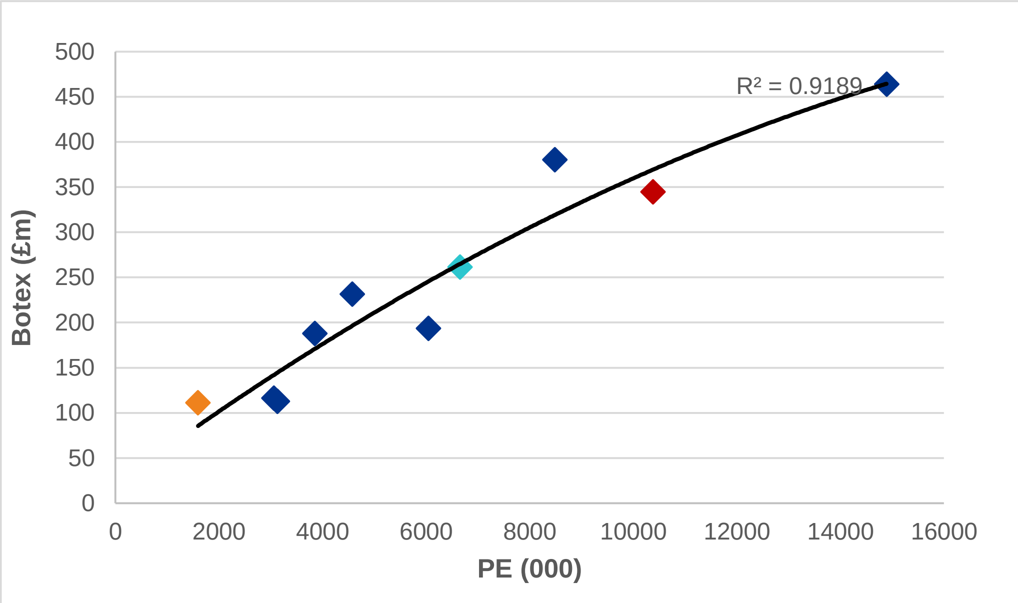
Figure 2.13: 2011-16 average treatment totex vs PE



The totex plot shows a more scattered distribution - this is probably because capital enhancement expenditure varies extensively between companies and over time. SWT is above the line and ANH remains on the trend line. The SVT and UU divergence remains.

Finally, Figure 2.14 shows the network plus treatment costs analysis. The 2016 data provides a similar picture to that seen with the 2014 data. However, R^2s are generally weaker – possibly reflecting more variety in approaches to asset management.

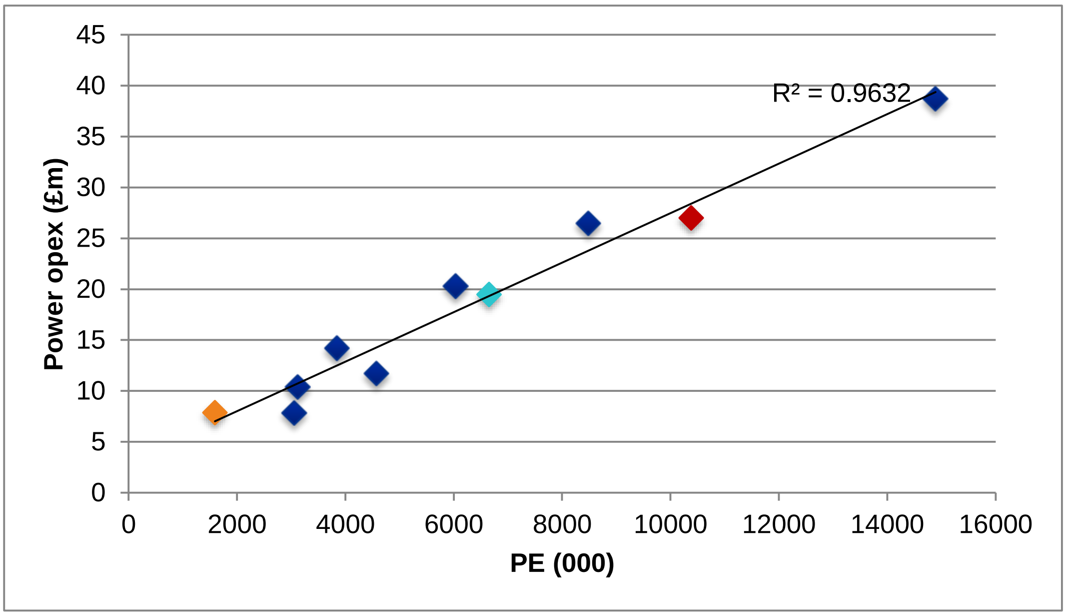
Figure 2.14 2011-16 Average network + treatment costs vs PE



2.4.4 Power costs

Power costs made up 28% of reported 2016 wastewater operating expenditure. We plotted power expenditure (average of 2011-16) against PE. We see a very strong linear relationship.

Figure 2.15: 2011-16 Power opex vs PE



This is probably what we would expect - power is very closely related to load (primarily aeration costs to treat load and pumping costs to convey it). From this we can be better satisfied that the observed opex and botex economies of scale relate to the reductions in manpower that come with scaling up.

However, the power cost data used in the chart is a combination of two components - the unit price paid and the amount used.

- Companies devote significant management time to buying power at good rates. But power prices can change quite quickly and even the best energy procurement teams can be caught out and can end up paying significantly more than other wastewater service companies for much of a price review period.

- Our review of the works-level costs (which at a comparative level eliminates the power buying effect) does not much support the company level observations. This could suggest cost allocation issues at the works level. It would be interesting to consider the actual power usage (in kWh) across the company and the industry.

The table below shows key metrics for reported power opex for the 2011-16 period.

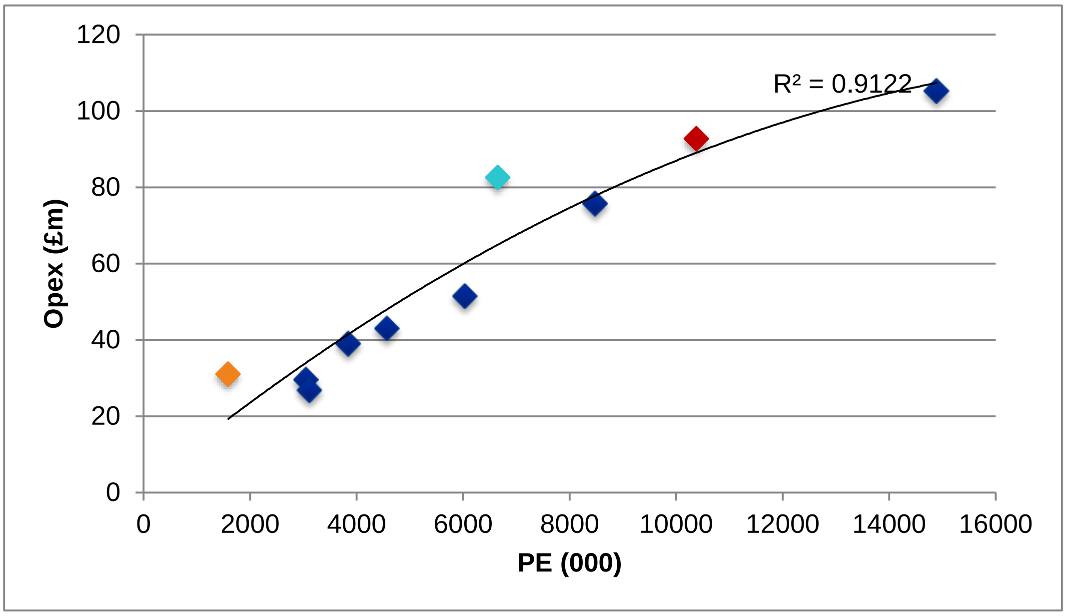
Table 2-5: Reported wastewater treatment power opex

Company	Unit power costs (expenditure/load)	2011-16 power opex as % opex	Increase in power costs 2011-16
ANH	0.29	19%	54%
NES	0.26	21%	21%
NWT	0.31	26%	107%
SRN	0.26	21%	35%
SVT	0.26	23%	21%
SWT	0.49	20%	17%
TMS	0.26	27%	96%
WSH	0.37	27%	63%
WSX	0.33	28%	22%
YKY	0.34	28%	47%

Table 2-5 is informative. The unit costs (column 2) show the imprint of size and rurality. It seems that unit power costs are higher for the more rural companies. But there is more uniformity around the percentage of reported opex that is attributed to power costs – and no rurality issues (this is what we see in figure 2.6). But it is the change in power costs (column 4) that is notable. This probably relates to power purchasing where ‘hedging’ is important.

So, it is interesting to look at treatment opex with power costs removed.

Figure 2.16: 2011-16 average opex minus power vs PE



Again, we see a polynomial curve (suggesting economies of scale) with SWT and ANH showing higher than expected reported operating costs.

2.4.5 Issues arising from this analysis

Looking at both the 2014 and 2016 data sets has been instructive. While the reported data reflects changing regulatory (the move to a deregulated sludge market) and company (the new price control period) priorities, there is consistency:

- Reported expenditure shows a very strong relationship to load received at treatment works for all companies.
- There is evidence of economies of scale – or at least evidence that it is possible to show lower average expenditure when providing service to very large urban environments.
- Some of the economies of scale seen in the treatment function seem to be offset by the inclusion of network botex in the analysis. There may be some operational justification for this – while larger works may offer lower treatment costs, they could lead to additional network costs. The classic aggregation approach is to close a small works, replace it with a pumping station and a rising main to a more efficient works – net result lower treatment costs and higher network costs – but no additional outputs.
- Both SWT and ANH show consistent divergence from the opex trend line. While both companies have characteristics relating to rural or less urban character, other similar companies – notably Dwr Cymru (WSH) and Wessex (WSX), show no divergence. When we bring capital maintenance expenditure into play the ANH divergence reduces. This could mean that ANH's cost allocation between opex and capital maintenance is not aligned with the rest of the industry - or that it prefers opex based solutions to maintenance issues – or something else entirely. Only one company - SWT - shows consistently (i.e. for opex, botex

and total expenditure) higher than trend average unit expenditure. SWT has a range of unique operating circumstances that may contribute to this.

- Companies have developed and enacted business strategies that have resulted in visible divergence from the trend lines (and contributed to weakening R^2s). Both SVT and UUW have started to move away from the trend line – SVT's capital maintenance spend has reduced while UUW have increased their spend in this area (see Figure 3.1). Operationally there is not a problem with this behaviour – capital maintenance expenditure is much less even than operating expenditure. However, there are two regulatory issues:
  - the divergence could further weaken the model coefficients.
  - the predicted and allowed expenditure might not be appropriate for the future. It may be prudent to develop a good understanding of the issues.
- Power costs appear to have a strong linear relationship to the main scale/size driver. This is consistent with our understanding of the wastewater treatment function – power usage largely relates to moving and treating wastewater volumes and loads. Our analysis also suggests that observed company level economies of scale derive from being able to design and operate works with lower rates of manpower usage (a key driver of opex efficiency since 1989). Size of works is discussed further below.

2.5 Density

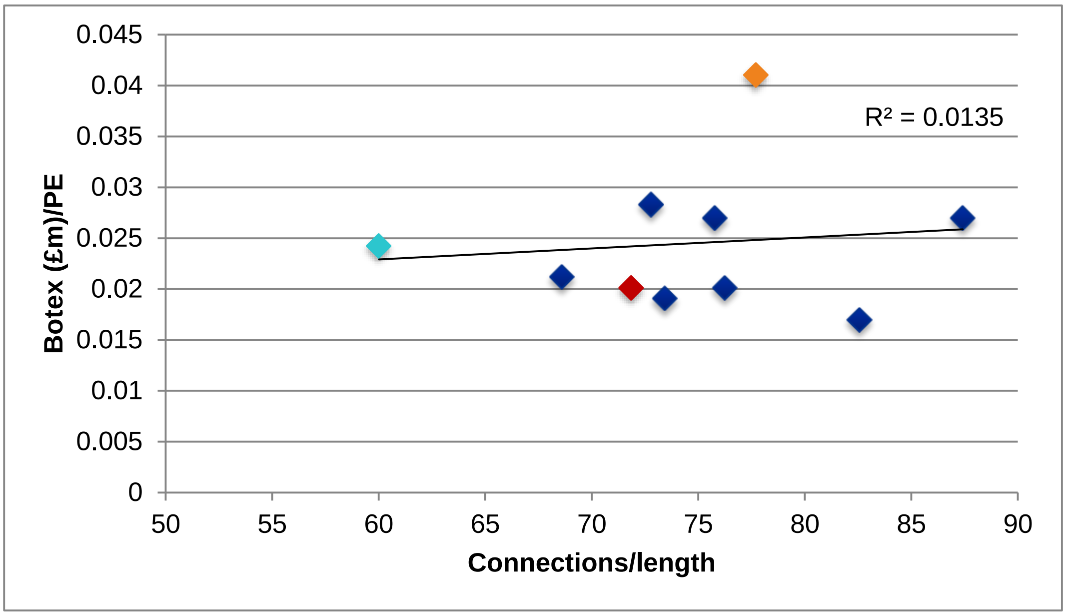
Findings

- PR14 density measure used at PR14 not really coherent – based on network length which is a poor-quality metric (because it reflects legacy issues such as the incidence of combined sewers and assumptions such as those around private sewers).
- We have developed two additional measures of population density.
- Density is another way of addressing differences in the number of very large works – both seek to identify large urban areas.
- Using a density measure and a scale factor risks multi-collinearity problems.

Ofwat uses a measure of 'density' in several of its wastewater models. The CEPA report suggests that this may be to address economies of scale. For PR14 Ofwat defined density as sewerage connections divided by length of main. It's more recent work it uses a 'high density' measure – we understand this to be based on a spatial analysis of the distribution of urban areas in England and Wales.

We have reviewed Ofwat's PR14 density factor. We can understand that the measure has the advantage of being able to be calculated from company data, however, the resulting metric (the first data column in table 2.6) is somewhat difficult to interpret. The chart below shows unit botex plotted against PR14 density.

Figure 2.17: 2011-16 botex vs PR14 density



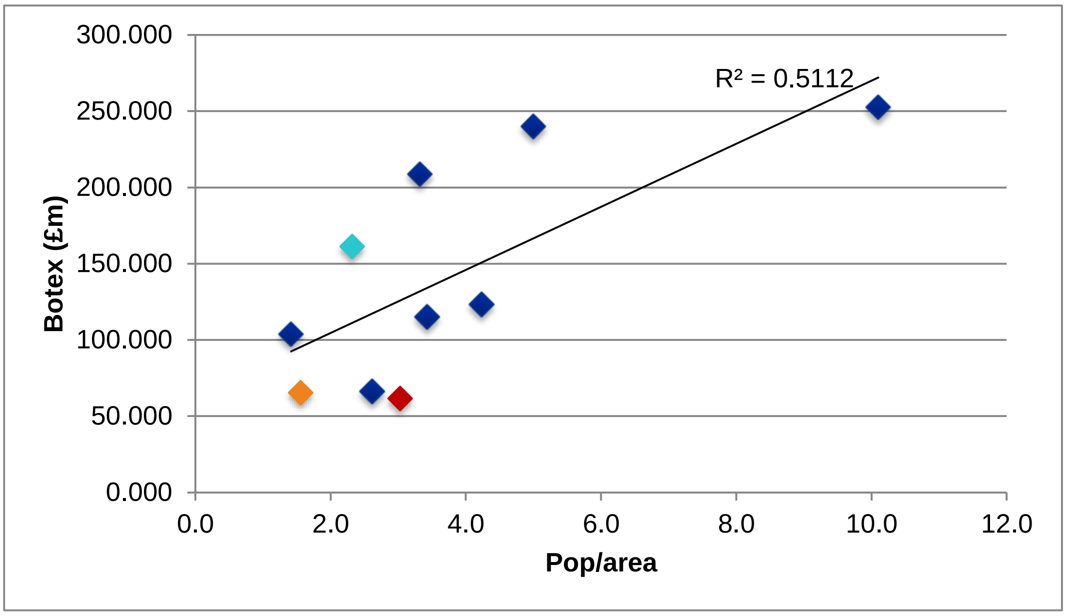
To assist with our analysis, we have considered 3 more measures of density. One is a more traditional measure of density based on local authority population and land area data. Two others consider the incidence or larger urban settlements. Table 2.6 includes these alongside Ofwat's PR14 measure.

Table 2-6: Density measures

Company	PR14 measure	Pop/area	Pop in cities >200000	Count of cities >200000
ANH	60.01	2.3	0	0
NES	76.24	3.0	777,567	3
NWT	72.79	5.0	3,939,839	14
SRN	87.42	4.2	214,859	1
SVT	71.85	3.3	3,505,473	10
SWT	77.71	1.6	255,826	1
TMS	82.57	10.1	7,074,265	1
WSH	75.78	1.4	785,337	3
WSX	68.60	2.6	634,762	2
YKY	73.43	3.4	3,152,559	8

Ofwat's measure gives ANH the least density and SRN the most; SWT is the third most dense. Our measure of density for each company is more intuitive. The chart below plots botex against the population/area measure.

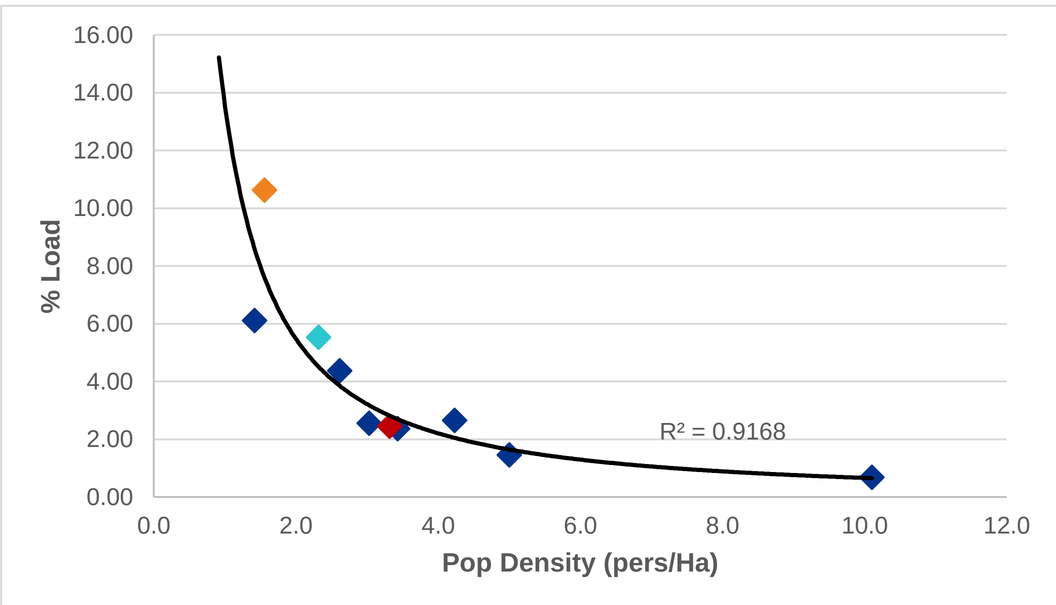
Figure 2.18: 2011-16 total botex vs population density



While the results are not perfect, they do show some sort of relationship between unit costs and density. This measure may give undue weight to areas without a sewerage service; however, it is consistent with what we know about rural companies – the four companies with the lowest population density are the four with most load received in band 1-3 works.

We noticed that there was some similarity between this measure and the %load removed at works in bands 1-3. Accordingly, we plotted the two together, Figure 2.19 shows the results.

Figure 2.19: % Works in bands 1-3 vs population density



We think this explains why the % load removed in bands 1-3 works in the models – it does an excellent job of approximating population density (albeit inversely).

We understand that Ofwat has developed a new density measure based on the incidence of large settlements. We have done the same. We observe that counting urban areas has the problem that it does not take proper account of London. The population in larger cities seems preferable.

2.6 Regional wage factor

Findings

- Variations in regional wages could have a material impact on unit expenditure.
- Even using exogenous data it is very difficult to understand what a company is paying in wages and why its unit costs are different to the average
- We would not support the use of a wages factor in the models – it could be a special factor.

Ofwat used a regional wage factor in all its wastewater models. Because it has been excluded from the public version of the PR14 modelling data set we cannot assess its validity.

The table below is taken from the Office of National Statistics (ONS) publication the Annual Survey of Hours and Earnings (ASHE). It contains recent and validated data on regional earnings for a range of occupations including sewerage plant operatives[7].

Table 2-7: Water and sewerage wages

Weekly pay - Gross (£) – Water and Sewerage plant operatives: United Kingdom, 2016						
		Number	Mean	Annual	Median	Annual
North East	8126	x	566.2	15.6	571.1	15.6
North West	8126	x	369.6	-13.8	419.1	2.1
Yorkshire and The Humber	8126	..				
East Midlands	8126	x	448.7		488.8	-8.3
West Midlands	8126	x	625.9	1.8	628.8	0.0
East	8126	x	616.8	8.7	646.1	10.5
London	8126	x	x		519.4	
South East	8126	x	520.4	-13.9	542.1	-12.5
South West	8126	x	552.4	19.3	546.4	7.9
Wales	8126	..				

[7] https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/regionbyoccupation4digitsoc2010ashetable15

Water and sewerage plant operatives	**8126**	**10**	**528.7**	**4.2**	**539.0**	**1.2**

The small sample size means that the table is incomplete and some numbers (those in green) are considered unreliable. Nevertheless, the median industry figure (£539.0) is considered accurate.

In order to produce a complete dataset, we looked at national figures on earnings.

Table 2-8: Median weekly earnings by region

Median full-time gross weekly earnings and percentage change from previous year, by region, UK, April 2016			
	Median Full-time gross weekly earnings (£)	**Change from 2015 (%)**	**Company**
North East	494.0	0.7	NES
North West	503.2	3.0	NWT
Yorkshire and The Humber	498.3	2.5	YKY
East Midlands	483.2	0.9	SVT
West Midlands	510.2	3.7	SVT
East	528.8	2.3	ANH
London	670.8	1.7	TMS
South East	566.0	2.5	SRN
South West	505.0	2.6	SWT/WSX
Wales	492.4	2.9	WSH
UK	538.7	2.2	

Source: Annual Survey of Hours and Earnings (ASHE) - Office for National Statistics

We can see that the UK median gross weekly wage is £538.70; this is very close to the median figure for water and sewerage plant operatives. We might consider that it would be reasonable to suggest that the models should use the whole earning figures.

However, there is one clear anomaly – London. The median figure is skewed because of the generally higher level of wages in London. The occupation specific figure is £519.4 – but ONS do comment that this figure is only 'acceptable' (one above unacceptable). Nevertheless, it should be possible to produce a judicious figure for London (which TMS could challenge with payroll data if it wished).

2.7 Discussion

We have considered at the issue of economies of scale and how to take account of these when using a modelling approach to determine allowed costs. AVE decided that asset level measures were key to taking account of the economies they observed. They recommended % load removed in bands 1-3 be used as they key metric.

We accept that costs fall quickly as works size increases but we do not find that it is the costs around the small assets that is important, rather the opportunity to build and operate very large works. This was clearly shown in plots of company costs against company load. We looked more closely at the relationship between power costs and load. We saw a very strong linear relationship suggesting that economies of scale were derived from non-power operating costs.

We assessed the potential monetary impact of higher than average incidence of small works, but we also found that companies who would benefit from such an adjustment/factor could also be due a negative adjustment for hypothetical poorer performance in the large works area.

We recommend work to develop a modelling factor that can describe the load distribution profile for each company (this would be easier if the works size bands were re-defined on a more coherent scale – perhaps with additional bands at the highest end or were reported un-banded).

3 Wastewater Treatment Cost Drivers

Findings

- Ammonia load removed has potential as a model factor in cost models. EA consents database could help develop this.
- Correlation between load (whether incoming or removed) and operational costs is poor across the lower treatment band sizes. It improves as we increase through bands in our analysis of SVT data. Load removed shows a better relationship to power opex than to total opex.
- SWT data at the works level shows unexplained (but not unexplainable) variability in manpower costs regardless of works size, treatment type or consent. We also see significant variability in chemical costs per PE which we would not expect particularly when all other site factors appear otherwise equal
- In high level and deep dive SVT dataset, we clearly see the economies of scale in treatment and reduced load variability. Our analysis suggests that further economies of scale are perhaps more evident beyond approximately 150,000 PE.
- The industry dataset via EA database could provide information industry wide to further develop considerations around ammonia drivers.

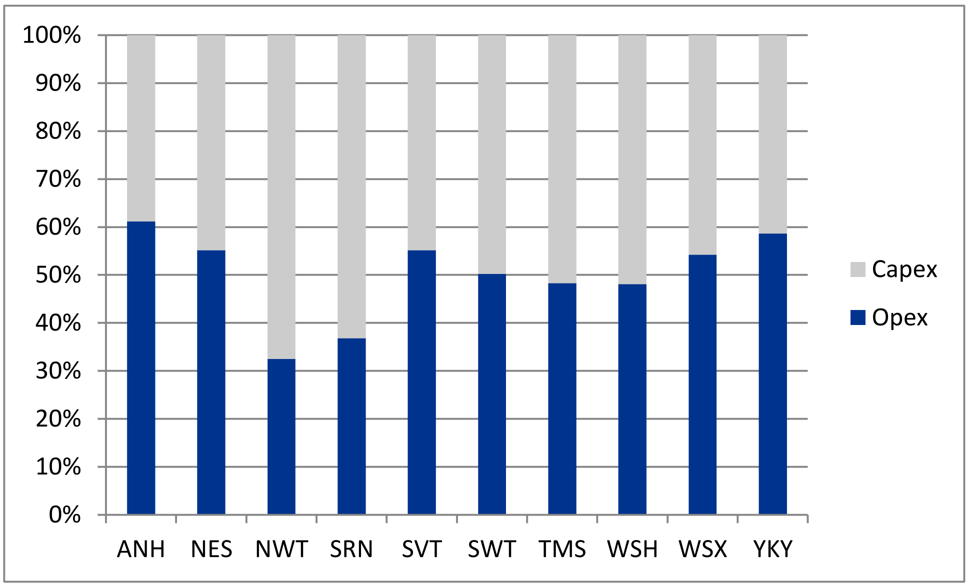
This section provides an investigation and analysis of wastewater cost drivers with a focus on SVT datasets. It provides industry overview and technical background to the hypotheses which we have developed and investigated as part of this work. It draws conclusions from the SVT analysis and investigates potential industry data sources which could offer the basis for similar analysis and investigation. Ultimately, we would like to have identified evidence to support the development of a factor that will allow the cost assessment models to take account of the additional costs arising from higher incidence of very demanding consents. If this is not possible then we would hope to set out a methodology for developing a case for a post-modelling cost adjustment.

3.1 Introduction

During 2015-2016, the 10 water and sewage supply companies spent over £1.7 billion[8] on the provision of wastewater treatment services to their customers. Figure 3.1 shows the split across the 10 WaSCs.

[8] 2015-2016 Totex summary £1.732b from *Master waste hc20161221*

Figure 3.1: Capex/opex split of 2015-2016



3.2 Wastewater treatment - technical overview

Findings

- Wastewater treatment solutions take account of consents, process options, historic and geographic considerations.
- We discuss operational cost considerations and make comparisons to provide context for hypotheses development and testing on the SVT and industry datasets.

3.2.1 Sewage treatment flows and loads

Primarily, sewage treatment is the removal of organic matter, characterised as BOD, and nutrients – nitrogen and phosphorus. In the UK, primarily nitrogen removal equates to ammonia removal. In the following sections, we discuss treatment types and cost considerations with reference to the primary constituents – BOD, ammonia and phosphorus.

STWs treat an incoming load (population equivalent (PE)) which is measured as a PE load where a 1 PE load per person and is equal to the organic loading of 60g biochemical oxygen demand (BOD) per day. Other pollutants in sewage include nutrients, ammonia (NH3) and phosphorus (P). This sewage load is transmitted in a per capita consumption flow per person (PCC) which is part of the incoming Dry Weather Flow (DWF).

Failure to comply with consents leads to fines driven by potential for EU Interactions.

Treatment is provided to an effluent consent which stipulates an allowable discharge load of a range of quality parameters to the receiving water where final effluent from the STW is discharged. Typically, consented quality parameters include BOD, key nutrients which can impact on fresh and estuarine ecosystems - ammoniacal nitrogen or ammonia and phosphorus and total suspended solids. Other constituents which may be of concern to environmental ecosystems such as metals, heavy metals or synthetic substances may also form part of the consented loads.

The required quality compliance is based on water quality modelling undertaken by Environment Agency (EA) and wastewater companies based on required background water quality status under the EU Water Framework Directive (WFD) and subsidiary regulations or based on the EU Urban Wastewater Treatment Directive which requires minimum levels of treatment to remove BOD, Chemical Oxygen Demand (COD), and nutrients total Nitrogen and Phosphorus. Different discharge levels will be specified within and across river basin catchments to reflect water quality drivers (especially for rural and diffuse pollution) and the characteristics of the receiving watercourse. Ammonia consents are assessed under the WFD and are not prescribed numerical values. Untreated sewage may have on average 30-60mg/l inlet ammonia concentration (depending on per capita flows, catchment characteristics trade and infiltration). Ammonia consents, where applied, range from very stringent 1mg/l to relaxed >30mg/l standards[9]. BOD and total suspended solids (TSS) standards are also often prescribed under the WFD as more stringent values than the UWWTD requirements. Depending on upstream process type, the inclusion of a BOD or TSS standard of less than 25mg/l may necessitate tertiary solids removal processes to remove residual BOD and TSS present in solids carried over from upstream treatment to final effluent.

The allowable discharge load specified in the consent is defined by a DWF and a quality standard in mg/l concentration with lower and upper tier levels typically applied. Total phosphorus standards typically require annual average compliance; other BOD, ammonia and TSS standards typically 95%ile compliance. To ensure 95% of samples comply with the consented limit; water companies typically specify a required percentage as an operational set point for compliance. SVT set this at 50% of the 95%Ile compliance lower tier value. For annual average phosphorous compliance, SVT's standards are less clear but good practice would be an operational target of 80% of the annual average.

Individual company risk tolerances can lead to greater treatment costs but will offset the risk of asset quality failures.

Sewage flows incoming to a works vary. DWF to the treatment works, measured by the Q90 or 10th percentile flow from daily flow recordings is made up of the per capita flow per PE, any trade effluent discharged by licensed traders (E), non-domestic and other commercial flows (counted for within PG) and infiltration (I). The DWF formula is expressed as DWF = PG + I + E.

Increased infiltration will lead to increased treatment capex and pumping opex.

Infiltration (unintended water entering the sewerage system) is commonly present in sewage flows. The rate of infiltration will differ based on climate, rainfall patterns and soil/ground characteristics as well as the condition of pipework and fittings. Whilst it may vary throughout the seasons in response to climate, infiltration occurs slowly and constantly.

Capital maintenance to seal pipes and fittings reduces infiltration. Infiltration increases works inflows and dilutes the incoming sewage. This can have

[9] Within EA Consents Database 2015 (available from www.data.gov.uk ammonia standards of, generally, up to 30mg/l occur in E&W WaSCs with a few exceptional even more relaxed standards.

disadvantages as larger capital civil structures are needed and, where pumped, more flow is required to be pumped.

Increased infiltration may reduce process costs - when we consider ammonia removal, increased infiltration dilutes incoming sewage which can improve the operation of nitrifying biological processes which require minimum wetting rates. If we have two sites with the same ammonia consent as concentration but varying levels of infiltration, the site with more infiltration will have less ammonia load to remove to achieve the same concentration. Ammonia consents should be fixed based on an allowable load but in reality, the same numerical standards appear to be widely used.

DWF will vary depending on the size of catchment and degree of infiltration but will exhibit a diurnal profile typically characterised by a morning and evening peak and low overnight flows – reflective of population activities throughout the day.

Larger DWF and FtFT flows require larger capex and opex

A corresponding diurnal load profile of contaminants (BOD, ammonia, phosphorus) is also apparent which will be similar though not identical to the flow profile. These flow and load profiles are accommodated at works design. Typically, a STW is sized to take a 'flow to full treatment' (FtFT or FFT) value which is set as an industry standard at a multiple of incoming components (3PG + I + 3E) figure which would be expected to be sufficiently higher than the peak DWF of any catchment to ensure that all sewage receives adequate treatment.

The daily load profile is also an important for design factor especially for aeration plant for BOD and ammonia removal. Whilst typical 'peaking factors' may be adopted by WaSCs for design, generally, flow and loads data is used to estimate load peaking factors for ammonia, BOD and (for design of chemical dosing) Phosphorus.

Large sewerage networks will typically have more 'smoothed' flow and load profile which offers a more uniform flow and load to treat. Smaller catchments may have higher peaking factors - these may need to be addressed in works design.

Sewerage networks that accept both storm water and sewage flows are termed 'combined'. While newer developments separate the two flows, combined systems remain in widespread use. Wet weather flow has a rapid response to rainfall and, because it is contaminated with sewage flow, requires some degree of treatment. For this reason, wet weather sewage flows although not requiring full treatment may require storm settlement and/or fine screening before they can be discharged. The contents of storm settlement tanks are returned to the treatment process for treatment as FtFT Catchments with more inflow through combined pipework will incur cost to capture, return, screen and discharge these storm flows.

Combined catchments will require additional infrastructure and will likely have higher treatment costs.

3.2.2 Treatment types and efficacy

Current discharge consents will typically require some 97% of the BOD load[10] to be removed and where ammonia standards exist, typically >80% ammonia removal and commonly >95%. To avoid adversely impacting receiving water quality, load is 'removed' by wastewater treatment processes which comprise primary, secondary and tertiary treatment processes.

[10] Based on SVT per capita loads and flows: 60g of BOD in 135L being reduced to the UWWTD standard of 25mg/l BOD on a 95%ile basis.

For BOD and ammonia, load is removed through a secondary biological treatment process called oxidation. This requires microbial ‘biomass’ and the addition of oxygen through aeration processes. The biomass is found naturally in sewage and the oxygen required may be natural aeration to the atmosphere or ‘forced’ where blowers and fine bubble diffused aeration (FBDA) systems or surface rotor aerators and motors (surface aerators) are used. Whilst carbonaceous treatment or oxidation is generally used to describe BOD ‘removal’ or oxidation of organic compounds to carbon dioxide and water, nitrification is the term used to describe the chemical process by which ammonia is oxidised (to another form of Nitrogen - nitrate). Nitrification to remove ammonia will only occur after BOD oxidation has taken place (it occurs preferentially to oxidation of ammonia).

A requirement for nitrification increases both capex and opex costs.

Nitrification requires more oxygen than BOD removal. It also requires more biomass and different types of microorganisms which are slower growing and more sensitive to external factors (residual oxygen, temperature) than carbonaceous microorganisms. This means more civils structures – tanks to treat (basins) and separate (final settlement tanks or clarifiers). Significant pumping of Returned Activated Sludge (RAS) is required in Activated Sludge Process (ASP) treatment to return the separated biomass from the final effluent which is discharged or passes to tertiary treatment processes.

This results in some 30-50% more power being required for a nitrifying (ammonia removal) system than a carbonaceous (BOD removal) system[11].

This will vary most significantly due to the type of mechanical plant used for aeration and its standard aeration efficiency as well as site specific parameters.

A Phosphorus consent will require increased capex and opex costs.

Phosphorus load is removed either biologically by different microorganisms (without the requirement for oxygen) or, as is most common in the UK, through chemical precipitation using Ferric Sulphate or Iron salts. This increases treatment costs including those for sludge treatment and associated chemicals, power and manpower.

Historically, discharge consents evolved from much more relaxed forms of wastewater treatment and treatment processes have similarly evolved to respond both to modern environmental legislation but also to changing land availability, social factors and technology development.

A further treatment consideration which is of relevance (though not to SVT) is disinfection which may be required for discharge to bathing water beaches. This enables bacteria kill to levels deemed acceptable for human bathing and requires to be operated within the designed ‘Bathing season’ which comprises the summer months of each year. Disinfection is undertaken with UV and is only required during the bathing season.

3.2.3 Process type selection

Companies use process selection matrices to identify technological and cost solutions for their assets. SVT uses the DM0201-01 PROCESS SELECTION CRITERIA - SEWAGE TREATMENT[12] Design Guide.

There are two types of biological treatment processes which remove BOD and Ammonia which all treatment processes can be classified into (noting that some may be hybrids of the two). These are:

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[11] Based on our calculations and experience across a range of ASP plants in day to day design and in looking at energy efficiency opportunities. Given variability in aeration plant, quoting a range makes sense here.

[12] DM0201-01 v2.3 last updated August 2016

- **Attached growth** or fixed film processes – where biomass providing the treatment grows attached to media. Examples of fixed film processes include reed beds, Submerged Aerated Filters (SAF), Rotating Biological Contactors (RBC), biological percolating filters (stone media or plastic media), and Biologically Aerated Flooded Filters (BAFF).

- **Suspended growth processes –** where biomass providing the treatment is suspended in a 'mixed liquor' and must be separated and returned to the treatment vessel. Examples of fixed film processes include oxidation ditches and activated sludge plants.

The most common mechanism for phosphorus removal is **chemical precipitation** by addition of Ferric Sulphate and removal of the resulting chemical sludge through solids settlement (in primary settlement tanks) or solids filtration (using modular sand filters or other tertiary solids removal processes).

Removal of BOD is typically termed secondary treatment to a standard of around 10-25mg/l BOD, process depending[13]. For standards below this, a tertiary solids removal process may also be required to remove residual BOD in solids carrying over in effluent from the secondary process. Removal of ammonia if within an existing secondary process in parallel to BOD removal may also be undertaken in secondary treatment.

Removal of TSS to values of <15-25mg/l, process depending, will also often require a tertiary solids removal process.

If the existing secondary treatment plant has not historically had capacity to be upgraded to achieve ammonia removal then a Tertiary Ammonia Removal (TAR) stage may be retrofitted which may include a fixed film process (like biological filters or BAFF).

3.2.4 Type of process and size of works

Process selection matrices are also used to assess preferred process types for upgrades or new treatment works designs based on the PE size of treatment works.

These are likely to be based upon factors such as:

- Required treatment efficacy to meet final effluent consents – e.g. a biofilter would not typically be used to meet an advanced consent which required 1mg/l ammonia and/or 10mg/l BOD to be achieved.

- Existing site processes and enhancement/optimisation opportunities – increasingly larger works with biofilters will have ASP also as upgrades over the past decade or more have seen the preferred less space intensive ASP go in to augment existing processes whilst residual assets are 'sweated'.

- Cost effectiveness of treatment for the given size of load – based on capital and operational costs.

- Complexity of treatment for the given size of load and site constraints – a complex treatment process with significant instrumentation requiring close attention, calibration and optimisation is unlikely to be suitable for a remote site which is only visited once per week by Operations staff.

[13] An activated sludge process will meet a lower BOD standard than an attached growth process due to the nature of solids present and treatment characteristics.

- The footprint of processes and site constraints – the larger the load the more land take required which is likely to be challenging in urban areas even if costs may be lower than a lower footprint solution. Some remote sites may make modular treatment solutions (e.g. package plants) most appropriate from a constructability perspective.

Consideration of the above (and other) factors means that fixed film processes are utilised for smaller loads of <10,000PE and consents which do not require <3mg/l ammonia or <10mg/l BOD or <15mg/l TSS. Fixed film (biofilters) or suspended growth (ASP) processes may be specified for loads of >10,000PE up to 50,000PE (as at SVT) – the process selected depending on site factors and consent requirements. For >50,000PE (or in some WaSCs >10,000PE) activated sludge processes would be specified alone).

More modular type treatment plants are likely to be utilised for plants up to 2,000PE. These allow off site construction in some cases and easy augmentation and redundancy. Typically attached growth such as SAF or RBC, these can also be suspended growth by exception (e.g. Oxibox type technology). They do not offer much if any process control and as a result are less efficient from an operational cost perspective than larger scale plants.

Typically, smaller STWs of up to a few thousand PE will suffer from higher catchment peaking factors given the shorter sewerage networks lengths which results in less time based ‘smoothing’ of otherwise diurnal load profiles for a domestic catchment. **Peaking factors for design of aeration systems are likely to be higher for smaller works and when this is combined with the general lack of process control (for example of aeration) this will lead to higher operational power costs relative to a larger treatment works.** For works receiving loads of 2,000 – 10,0000PE the attached growth processes are likely to be biological filters or oxidation ditches.

Table 3-1 provides a summary of typical processes used to meet typical standards set in the present regulatory framework. The processes highlighted in green are options which would typically offer lower **operational cost** solutions, those in red higher cost solutions. The reasons for this are covered above in Section 3.2.2; existing site constraints and processes may often dictate process treatment solutions. The cost impact of process types is further considered in Sections 3.3 and 3.3.1.

Table 3-1: Typical treatment processes considered for varying consents

Treatment Works Size	Basic Consent 20 mg/l BOD5	Enhanced Consent 20 mg/l BOD5, >/= 5 mg/l NH3-N	Advanced Consent 10 mg/l BOD5 >/= 5 mg/l NH3-N 1 - 2 mg/l P
Small (up to 2,000 PE) **Size band 1-3**	Rotating biological contactor Submerged aerated filter Biological filter **Crude oxidation process (SVT)** **Reed bed incl. aerated (SVT)**	Rotating biological contactor Submerged aerated filter **(SVT – 1500PE – 2000PE range only)** Biological filter **Crude oxidation process (SVT)** **Reed bed incl. aerated (SVT – only to 5mg/l ammonia not below)**	As Enhanced + chemical dosing and tertiary solids removal

Treatment Works Size	Basic Consent 20 mg/l BOD5	Enhanced Consent 20 mg/l BOD5, >/= 5 mg/l NH3-N	Advanced Consent 10 mg/l BOD5 >/= 5 mg/l NH3-N 1 - 2 mg/l P
Small-medium (2,000-10,000 PE) **Size band 4**	Biological filter Oxidation ditch	Biological filter Oxidation ditch	As Enhanced + chemical dosing and tertiary solids removal
Medium (10,000 PE-50,000) **Size band 5 – 6 (<25,000PE)**	Activated sludge (Carbonaceous) trickling filters	Activated sludge Nitrifying trickling filters (typically down to 3mg/l standard only) Tertiary high rate nitrifying process (e.g. Nitrifying trickling filter NTF typically down to 3mg/l standard only)	As Enhanced + chemical dosing and tertiary solids removal
Large (50,000 PE) **Size band 6**	Carbonaceous ASP Existing works + tertiary process	Nitrifying ASP Existing works + tertiary process	As Enhanced + chemical dosing and tertiary solids removal Existing works + tertiary process

3.2.5 Types of aeration

Fixed film processes may be naturally aerated or mechanically aerated. The operational power cost of mechanical systems is significantly more (>10 times) than naturally aerated systems. An example of this is a comparison of an RBC – with a SAF. Both are specified as potential process types to be selected under the small works (<2,000PE) process selection matrix. A RBC although mechanically driven uses no mechanical aeration and relies on atmospheric air whilst rotating out of the treatment basin to meet the aeration demand required by microorganisms growing on the contactors). The capital costs of RBC systems are typically higher but due to the increased operational power cost, a whole life cost analysis would give preference to RBCs.

Suspended growth processes are always mechanically aerated but different types of aeration have historically been utilised. Modern design would typically see FBDA installed in newly designed systems but this may not always be practicable for shallower basins or maintenance reasons and in some cases surface aerators continue to be used. Although higher in capital cost, FBDA systems have operational power costs **50% lower than for surface aerated systems.**

Often FBDA is retrofitted to increase capacity within an existing secondary treatment activated sludge plant. A new ASP with 6m depth compared with retrofitted 4m depth tank will require less aeration and 10% lower operational power – which means that new build sites in this respect have an inherent operational cost advantage over retrofitted sites.

The control of aeration is also a significant factor. Aeration systems are designed to deliver a minimum air demand to the living biomass which is a function of incoming load. Because loads vary diurnally throughout a day, on weekends and across the year, the oxygen demand also varies and aeration control is utilised in modern plants which allows a residual dissolved oxygen (DO) to be maintained by varying the amount of air provided by blowers and aerators. Historically, more crude forms of control were used or no control and WaSCs commonly have such systems still in operation.

A **30% saving** in operational power cost is achievable by introducing active DO control[14] to an existing surface aerated site. At existing sites, set point changes alone can be used to effect significant >10% savings in aeration power demand. Whilst typically nitrification residual DO levels were specified at 2mg/l and carbonaceous at 1mg/l, evidence in the UK and globally shows effective nitrification can be achieved at lower DO concentration (e.g. 1.8mg/l) and carbonaceous at residual DO levels down to 0.5mg/l when set points are challenged.

Further savings of up to 40%[15] are achievable by introducing real time control (RTC) or other (e.g. ammonia) controls to existing FBDA systems. Such RTC and ammonia systems are being investigated but not widely used in the UK.

3.3 Operational costs in wastewater treatment

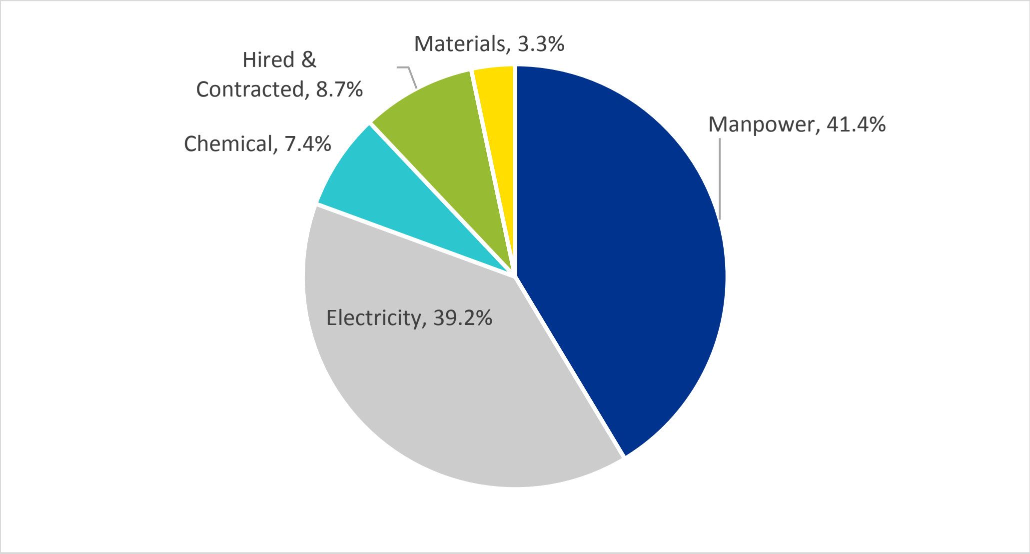
Findings

- The material elements of wastewater treatment opex are power, consumables including chemicals, materials and labour.
- Different treatment types – whether specified for different consents or due to historical development of the site - have different operational costs.
- Each company will have options as to how it allocates costs and procures energy (for example). There may be local cost differences around wages and materials.

[14] Jacobs (2017)
[15] UKWIR (2010) Report Ref No 10/CL/11/3

Figure 3.2 shows how SVT's local operating costs are divided between the key cost categories. This shows the significance of site power and resource usage (manpower) in terms of site operational costs, each worth around 40% of SVT local opex.

Figure 3.2: Local operating cost split across Bands 1 – 6 SVT 2014- 2015 dataset



Assuming sludge related treatment stages (e.g. polymer dosing) are excluded from chemical costs, chemicals are not widely used in wastewater treatment processes and chemical costs themselves generally would not be expected to comprise a significant proportion of total operational cost (approx. <5%). When used, chemical costs would be expected to be linearly proportional to the incoming works load (PE or expressed as a load of Phosphorus).

Manpower costs are a significant portion of site operational costs based on the SVT dataset. Whilst literature offers plenty of commentary on operational power demands for different process and consent types, operational manpower is more challenging to assess, particularly in the rapidly changing automation environment. Generally, processes with more mechanical plant and automation should require less operator input beyond daily equipment checks (though would be expected to require more capital maintenance). Assets which require manual operation – e.g. desludging or regular rodding/maintenance of day to day filter operation would be expected to require more manpower cost.

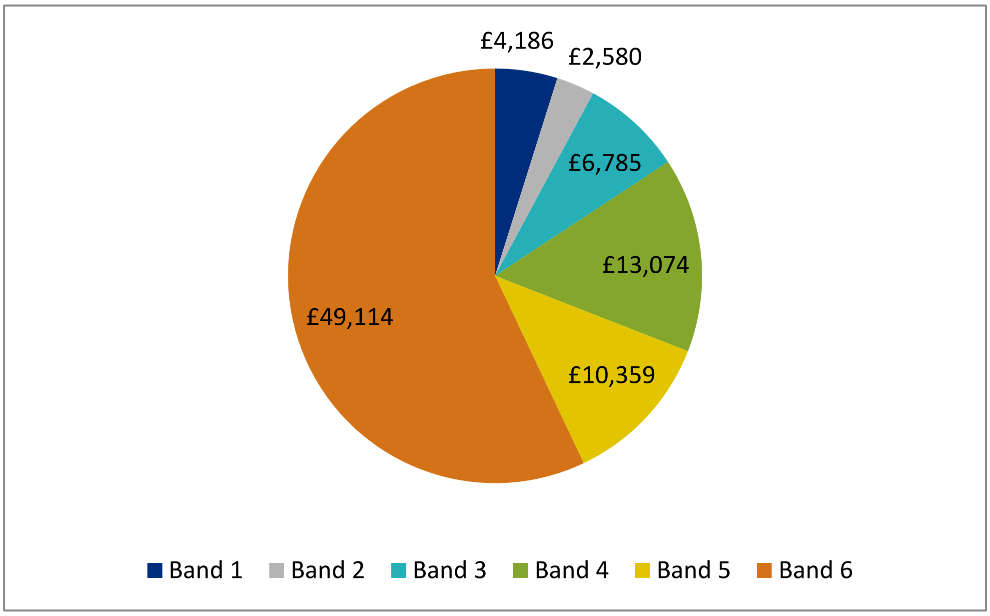
Resources are required to both operate and maintain the STW asset. The allocation of resource to operational versus maintenance related tasks is not clear and unlikely to be approached the same by all companies. The extent of resourcing required to operate and maintain a site will depend on the type, condition and complexity of existing treatment processes, site and catchment specific constraints as well as the culture of the company and other factors. For two similar sites in terms of process plant and consent levels, it might be expected that manpower costs may be similar but that regional factors may still be present. For higher energy processes with more operational plant and equipment it would be expected that manpower effort would be increased over a simple treatment system with few moving parts.

Whilst indicative resource usage could be estimated based on the type of treatment processes or perhaps modern equivalent asset value (MEAV) this is more challenging than prediction of power and chemical usage and subject to more extenuating factors including regional wages, workforce.

Operational power costs are easy to quantify reliably, as a product of electricity usage and tariff and, comprising 40% of the SVT local operating cost on average across all bands, are worth focus on in consideration of wastewater cost drivers. SVT costs, reported as Direct costs in *Master waste hc 20161221*, are shown by works size band in

Figure 3.3 below.

Figure 3.3: SVT 2015-2016 Direct costs (£000)

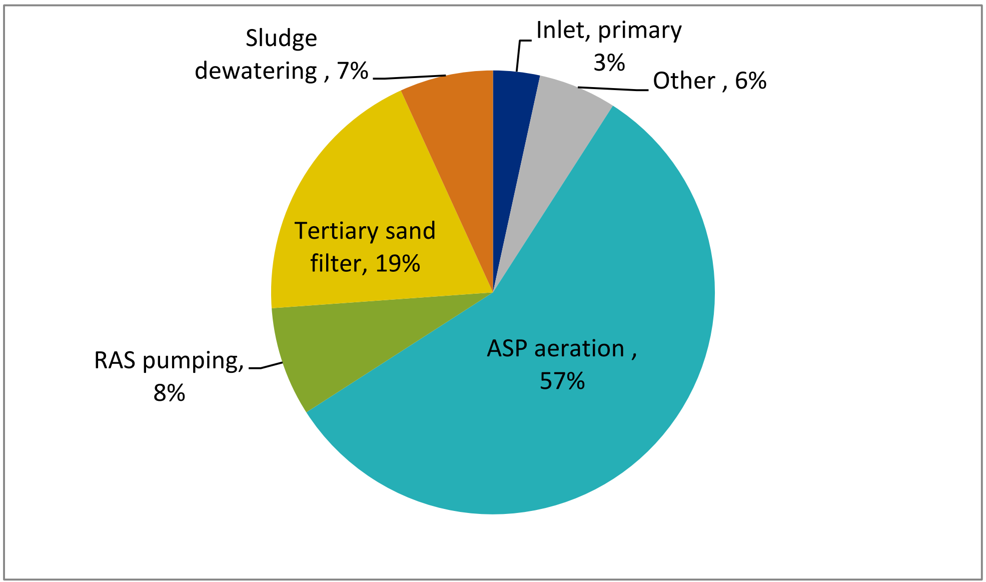


3.3.1 Operational power costs

Broadly, significant operational power cost differences exist between different process types which may be selected within treatment size bands. Power costs are influenced by energy tariffs. Although these should be uniform across SVT datasets, when considering industry data, power usage is a better metric for comparisons.

An indicative split of operational power cost for a nitrifying activated sludge treatment works with tertiary treatment sand filter which requires interstage pumping is shown below. This includes sludge dewatering only.

Figure 3.3: Indicative large nitrifying ASP operational power cost



Key operational power costs are associated with aeration required for treatment of BOD and ammonia, for tertiary treatment and for interstage and RAS pumping. Where downstream tertiary treatment processes are retrospectively added to an existing hydraulic gradient at an existing STW, pumping of FtFT is required. Even for original gravity based treatment, return and recycle pumping is typically required and is required for ammonia removal. UV treatment could make up 10-15% of site power costs or some 5-8% of total site opex assuming power comprises approximately 40% of local opex as per the SVT dataset.

We have summarised typical energy consumption figures per m^3 treated for these processes in Tables 3-2 and 3-3. The difference between these would be expected to be apparent in operational power costs when comparing groups of STWs of similar size and characteristics.

Table 3-2 : Comparative small works operational energy demand

Process type	kWh/m3 - opex power only	Source
RBC	0.4	Adapted from comparative high level quote for 800PE plant - Jacopa (2017) 2.5kW RBC rotor running 24/7 Excludes sludge management
SAF	1	Adapted from comparative high level quote for 750PE plant- Jacopa (2017) 5.5kW SAF blower running 24/7 Excludes sludge management

Table 3-3 : Comparative medium large works operational energy demand – secondary treatment only

Process type	kWh/m3 range – opex power only	Source
Biofilter (low rate)	0.16-0.13	http://www.waterrf.org/PublicReportLibrary/4454.pdf
ASP	0.29-0.16	http://www.waterrf.org/PublicReportLibrary/4454.pdf

Within fixed film processes and typically at smaller works, a SAF solution is likely to require some 50% more operational power energy than an RBC solution.

Within large works, an ASP is likely to require between 30 – 120% more power than an equivalent biofilter process depending in consent, aeration type and other factors.

The factor of energy usage between small and medium - large works processes is much more substantial:

- An aerated attached growth SAF process could use over 700% of the energy of a medium-large biological filter
- An attached growth non-aerated RBC is still likely to use over 150% of the energy of a medium to large activated sludge process and over 300% of a biological filter process. But this is an unlikely comparison as we see from Table 3-1 – the two technologies cover varying size works. A small scale package ASP plant or crude oxidation process (which SVT has few of from our assessment) will not offer the same degree of process control and economies of scale of a medium/large ASP and in this instance an RBC would likely be more cost effective than this type of package ASP.   A SAF would still likely have a higher energy demand, however.

Theoretical analysis and historic experience indicates that in wastewater treatment, aeration power demand is significant and typically **comprises 50% of a wastewater treatment works power demand** where FBDA aeration systems are used[16] and greater than this where surface aerators are used. Whether a works requires carbonaceous or nitrification treatment could cause this figure to reduce significantly to 25%, and the extent of nitrification required will also cause variation in the oxygen required. Power demand for aeration is linearly related to the incoming treatment load and depends on the type of consent (e.g. BOD or ammonia) that the works must meet.

Where a tertiary nitrification (e.g. with high rate plastic media trickling filter) and/or tertiary solids removal (e.g. with a rapid gravity sand filter) are undertaken, these could each comprise another 20% of site power demand.

Pumping power demand is also relevant and although site specific (depending on hydraulics), suspended growth processes will always require return activated sludge pumping of flows up to twice the incoming DWF and comprises typically 5-10% of site operational energy demand[17]. Where used for nitrification, fixed film filter processes – biofilters – will also often require minimum wetting flows to maintain ammonia removal and dilute flows onto filters. For certain types of high rate plastic media filters, these pumped recycles are likely to require a similar or potentially higher energy demand to a suspended growth process.

[16] UKWIR (2010) Report Ref No 10/CL/11/3
[17] UKWIR (2010) Report Ref No 10/CL/11/3 pg. 36

Other operational power costs are typically much less significant and associated with inlet screens and other pumps.

Nevertheless, if we set aside concerns about the weakness of the AVE analysis this is a good question: can we see consistent evidence at industry level of material increases in costs for higher levels of treatment in any or all size bands? The answer is 'not really' – perhaps there are too many other competing considerations.

3.3.2 Summary - key operational cost drivers

We have considered the impact of changes in consents, process type and size of treatment works on costs:

- Whether the works requires BOD only or (BOD and) ammonia removal – a step change **(+/- 10-15% opex cost based on power + associated manpower)**
- The extent of load removed for ammonia for a stringent versus relaxed ammonia standard (BOD reduction and secondary treatment is undertaken universally; ammonia consent limits differ significantly throughout the UK) **(+/- 5-10 opex cost based on power + associated manpower)**
- Whether a tight BOD or solids consent requires a tertiary solids removal stage – a step change **(+/- 5-10% opex cost based on power + associated manpower)**
- Whether P standard requires chemical dosing and associated costs. Whilst chemical purchase costs wouldn't be expected to be a significant >5% of works operational costs for P removal applications, Severn Trent Water dataset suggests chemicals alone are 3-12% of total opex **(+/- 7% opex cost based on power + associated manpower)**
- Treatment type applied for otherwise equal treatment size, type and consent characteristics – fixed film processes would be expected to be lower cost **(+/- 10-50% opex cost based on power + associated manpower)**
- Size range of treatment works; economies of scale in treatment and reduced load variability would be expected to reduce operational costs for larger works compared with smaller works **(+/- 10-50% opex cost based on power + associated manpower).**

The numeric quantifications are estimates of potential operational cost savings as total operational cost. These are based on power cost savings from theoretical basis and our experience and that fact that power costs comprise approximately 40% of STW Opex costs. They are provided for context only as to what we might expect to see as an order of magnitude, all other factors being equal – which is rarely the case.

In the next sections, we investigate the identified potential cost drivers and provide quantitative SVT and industry data assessment. We first consider the SVT context which has an impact on considerations presented in this section; we then consider and discuss treatment costs at a SVT wide level (across all 1014 treatment works) and within bands and also at a works level through a deep dive analysis which considered approximately 60 sites across the 6 size bands.

3.4 SVT wastewater cost driver analysis

Findings

- SVT has the highest rate of phosphorus removal and the second highest for ammonia removal.
- Based on SVT asset types, we might expect relatively efficient power usage and ammonia removal at lower band sites due to its homogenous mix of biological filter and RBC works.

3.4.1 Treatment requirements

We first provide an overview of the nature of SVT assets and treatment requirements relative to other companies with a focus on what we have discussed we would expect to be significant in terms of wastewater treatment cost drivers. SVT has the highest rate of phosphorus removal and the second highest for ammonia removal.

Almost all of the SVT region is a designated P sensitive area under the UWWTD. Table 3-4 shows that SVT has the highest degree of P consents as shown in Table 3-4 by a significant degree. The next closest is Anglian who have some 50% of their load subject to no P permit as compared with 21% of SVTs. SVT also has the most load in stringent 0.5-<=1mg/l category. This typically necessitates both chemical dosing plus tertiary solids removal as compared with a 1-2mg/l standard which is likely just to require chemical dosing depending on works treatment type.

Table 3-4 : Proportion of load within P consent ranges

	<=0.5	0.5 – <=1mg/l	>1mg/l	No permit
ANH	0.0%	30.5%	17.8%	51.8%
NWT	0.0%	0.0%	13.1%	86.9%
NES	0.0%	15.9%	12.0%	72.1%
SRN	0.0%	9.8%	0.5%	89.7%
SVT	0.0%	**61.3%**	**17.8%**	**21.0%**
SWT	0.0%	1.0%	4.8%	94.2%
TMS	0.0%	27.8%	11.3%	60.9%
WSH	0.0%	13.3%	8.1%	78.5%
WSX	0.0%	9.4%	16.1%	74.5%
YKY	0.0%	1.2%	0.9%	97.9%

For SVT, required rates of P removal are low in bands up to band 4 inclusive. In band 5, approximately 40% of the load requires P removal and this increases to almost 90% in band 6. Accordingly, most chemical dosing for P removal is will be at larger band 5 and 6 works.

Ammonia consents are set under the WFD based on site specific analysis and background water quality and classification to meet the UK WFD obligations. This will include watercourse specific modelling and analysis in the river basin context. As a result, SVT has stringent ammonia standards and very low degree of works with no permit for ammonia. Table 3-5 shows SVT are second only to Thames both in terms of load removed to stringent standards of 3mg/l ammonia or less and in terms of proportion of load without an ammonia standard.

Table 3-5 : Proportion of load within ammonia consent ranges

	Ammonia <= 1mg/l	Ammonia >1 to <=3mg./l	Ammonia >3- <=10mg/ l	Ammonia >10mg/l	Ammonia no permit
ANH	0.0%	13.4%	47.2%	16.4%	22.9%
NWT	0.0%	2.5%	13.2%	23.5%	60.8%
NES	14.7%	29.2%	27.7%	6.7%	21.8%
SRN	0.0%	12.4%	15.4%	10.9%	61.3%
SVT	0.0%	**46.3%**	**42.8%**	7.2%	**3.7%**
SWT	0.1%	0.9%	29.9%	13.8%	55.3%
TMS	5.3%	80.2%	13.0%	1.1%	0.4%
WSH	0.0%	1.9%	21.6%	43.6%	32.9%
WSX	0.0%	4.1%	42.4%	13.3%	40.2%
YKY	0.0%	40.7%	34.3%	9.1%	15.9%

The operational cost impacts of ammonia removal and operational cost inefficiencies associated with ammonia removal at small treatment works could be material to SVT. SVT's stringent ammonia and P consents may make it difficult to see evidence of a step change in treatment costs due to the presence of an ammonia standard and/or P standards.

3.4.2 Works size and type

If we consider the size of SVT works with respect to the industry band definitions, we see the proportion of SVT loads within each size band.

Table 3-6 : % Load received at works by band

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6
PE	<250	250-500	500-2000	2000-10000	10000-25000	>25000
Load	0.4%	0.4%	1.7%	7%	8%	83%

In terms of treatment types, the industry descriptors for process type are used to describe the highest level of treatment at site. For SVT sites this is either secondary or tertiary. Secondary processes are divided into ASP and biological filtration or contactors (RBCs). Tertiary processes are described according to their secondary process and according to type of tertiary process (TA or TB). They are further divided into two types of tertiary processes:

- Type 1 – settlement in lagoons, wetland treatment, drum filters, microstrainers, slow sand filters, tertiary nitrifying filters amongst others.

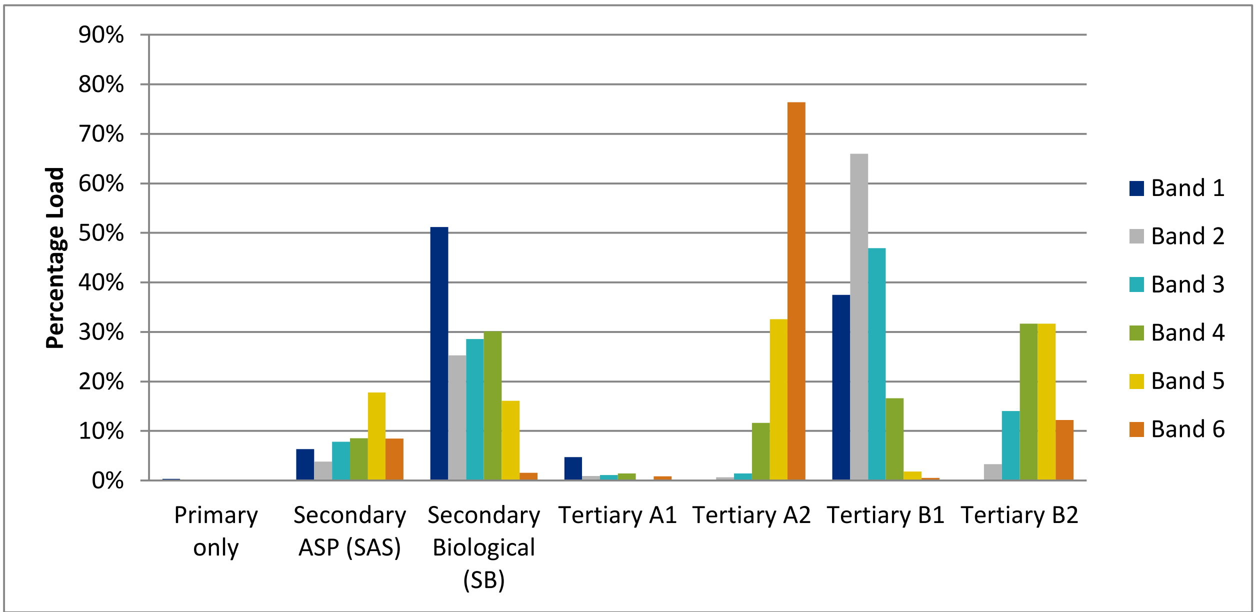
- Type 2 – rapid gravity sand filters, other types of filters, nutrient removal with chemical dosing or biological methods, disinfection, further treatment where used as a tertiary treatment stage.

Generally, type 1 processes are less energy intensive than type 2. The inclusion of tertiary nitrifying filters in Type 1 could lead to difficulties in interpretation wider industry data; some tertiary nitrifying filters are low rate, low energy and may not require interstage pumping; others are high rate with significant recycles and high static lift pumping. The term ‘nutrient removal with chemical dosing or biological methods’ could also suggest tertiary nitrifying filters and it is not clear how these should be categorised.

For secondary classifications, we have highlighted the potential increased operational cost in power for a SAF type treatment plant as compared with an RBC. SVT have a prevalence of RBCs; others WaSCs will have more extensive use of SAFs[18]. Both are classified as biological processes.

SVT assets can be classified proportion of load within their band (figure 3.5). As we might expect, bands 1, 2 and 3 have a prevalence of biological rather than ASP secondary processes. The tertiary Type 1 processes is likely to include the significant number of lagoons and constructed wetland that SVT has – in contrast to some other WaSCs. Bands 4 and 5 still show a high proportion of biological (secondary and tertiary) processes whilst band 6 is dominated by activated sludge treatment process with tertiary treatment of some sort. The deep dive analysis further investigates this in 0.

Figure 3.5: SVT treatment types as proportion of band load



Further indication of treatment type is available from interrogation of the *SVT asset size data1* dataset in terms of the type of secondary process – as either fixed film or activated sludge – but also the type of fixed film process – for example RBC, SAF, and biofilter The data analysis does not allow exact resolution of treatment types for all sites given time available but accounts for 72% of band 1 processes, 86% of band 2 and over 90% of bands 3, 4 and 5. All band 6 has been accounted for. Given our understanding of the operational cost variation we might expect in secondary processes; in particular fixed film versus ASP, and within package plants at lower size ranges (RBC vs SAF vs small biological filters) this knowledge may provide useful context for analysis of costs.

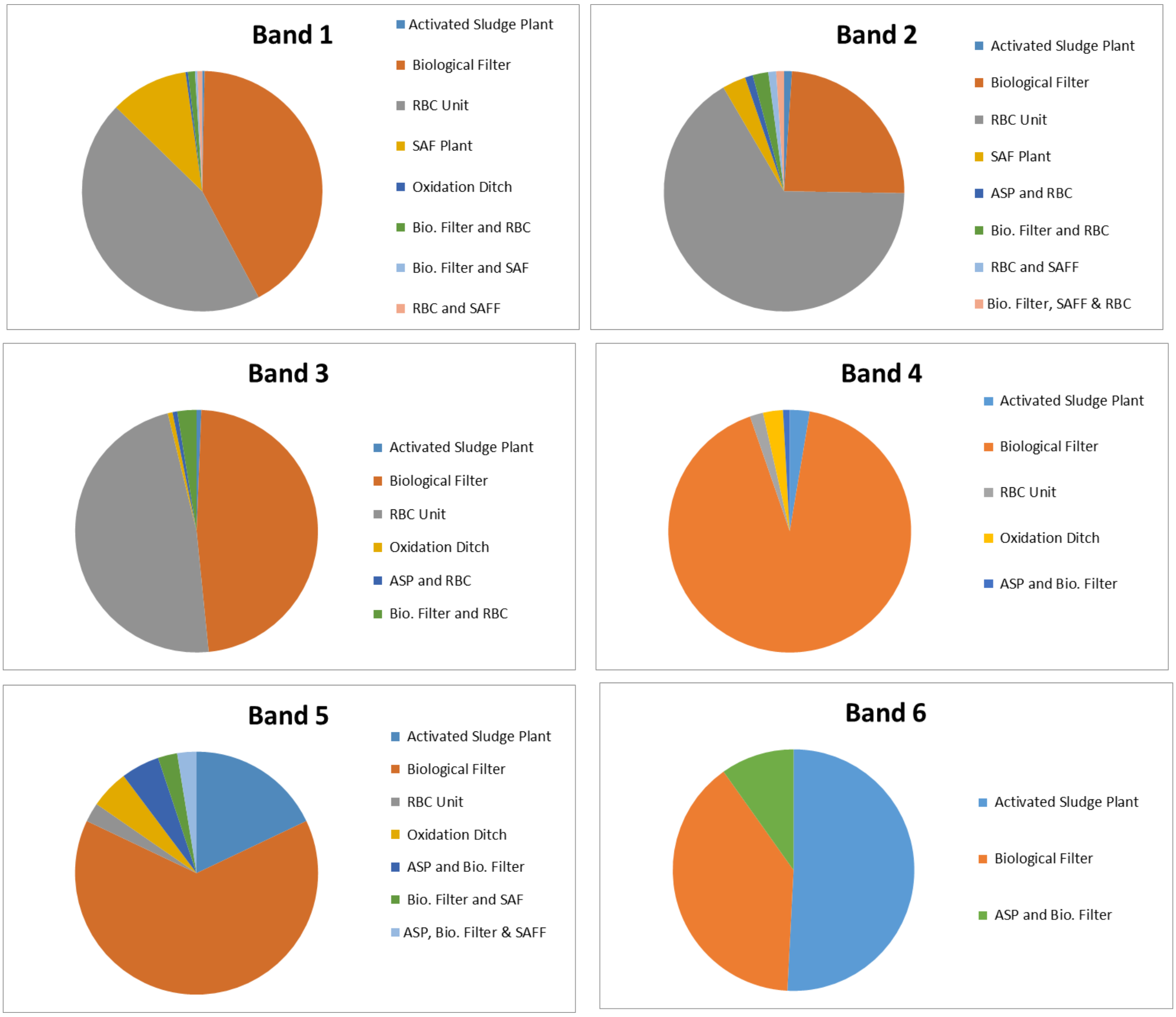
[18] From Jacobs analysis across historic project work, SAFs will have a higher operational cost but lower capital cost than RBC.

Figure 3.6 shows this process across bands:

- RBCs are prevalent in band 1 and dominate band 2.
- Band 3 is half biological filters and half RBCs.
- Band 4, too big for RBCs, is dominated by biological filter works (though these have varying degrees of tertiary treatment which may mean cost correlations are not as uniform as the dominant process type may indicate if these tertiary treatments vary in type).
- Band 5 offers a large range of process types and combination of processes which suggests a more significant extent of enhancement has taken place on these 2,000-10,000PE treatment works. The deep dive investigations will discuss this further.
- Band 6 is a mix of ASP and biological filter with slightly more ASP plants.

Based on SVT asset types, we might expect relatively efficient power usage and ammonia removal at lower band sites due to the very homogenous mix of biological filter and RBC works.

Figure 3.4: SVT Asset secondary treatment type within treatment bands



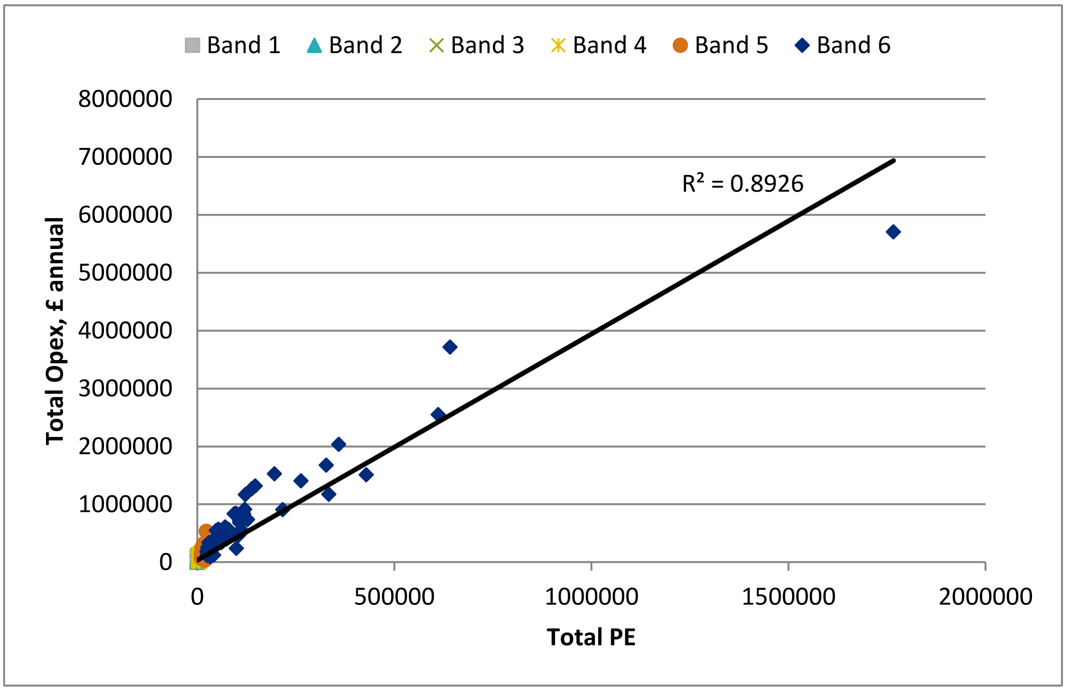
3.5 Load removed analysis

Findings

- There is evidence within the SVT dataset of reasonable differences between consented load removed and actual load removed.
- Correlations between expenditure and load removed at works level are poor, especially for smaller works.
- For SVT, with high rates of demanding ammonia consents, load-in and load removed are often similar making it difficult to isolate the impact of changing this scaling factor.

We investigated the current cost driver of load or PE and considered Bands 1-6 sites. We also considered a load-removed driver. This was calculated using the works PE and SVT per capita ammonia (or BOD) rate and from this incoming or received load we subtracted the outgoing final effluent load. We did this by taking consented concentration (based on 95%ile compliance which equates to around 50% of the 95%ile value) and multiplying this by the works average flow data. The difference between these two loads gives us ‘load treated' or ‘load removed’. We note that where there is no significant load removed (e.g. the works has no ammonia consent) then the works PE is equivalent to the works incoming load – this allows us to directly compare PE (load incoming) and costs.

Figure 3.5: Band 1-6 incoming load as PE vs Opex



The analysis loses detail on Bands 1-5 and subsequent analysis considers these separately. We consider operational cost versus PE, ammonia load removed and BOD load removed in the subsequent figures for Bands 1- 5. There is evidence within the SVT dataset of reasonable differences between consented load removed and actual load removed.

The relationships are all similar and show association with the load characteristic and opex. We see significant ‘noise’ in all bands and some potential outliers which are likely to be based on erroneous data[19].

Because SVT has a high degree of ammonia removal (50% even at Band 2) and significantly higher proportions up to Band 6 we would not expect load-in (as PE) and load-removed (as either ammonia or BOD load) to differ much as drivers. We see a significantly different conclusion using the industry dataset (analysed in Appendix D).

[19] Suspected outliers were reported back to STW as a list of sites for potential further investigation as to whether data is correct.

Figure 3.8: Band 1-5 Incoming load as PE vs Opex

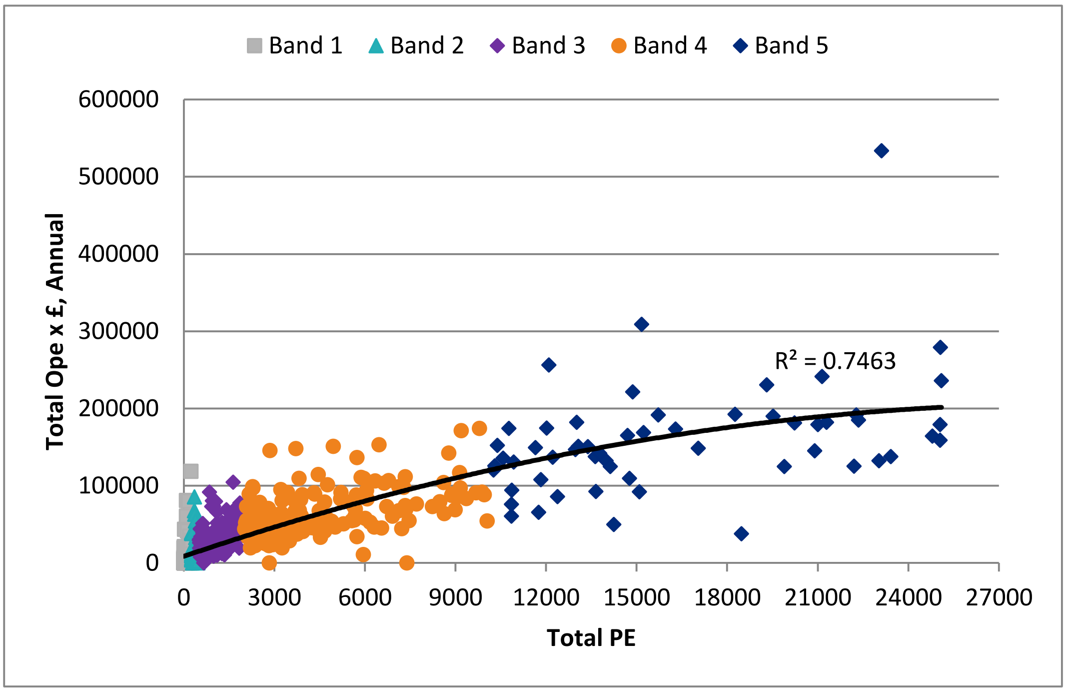


Figure 3.9: Band 1-5 SVTs Ammonia load removed vs Opex

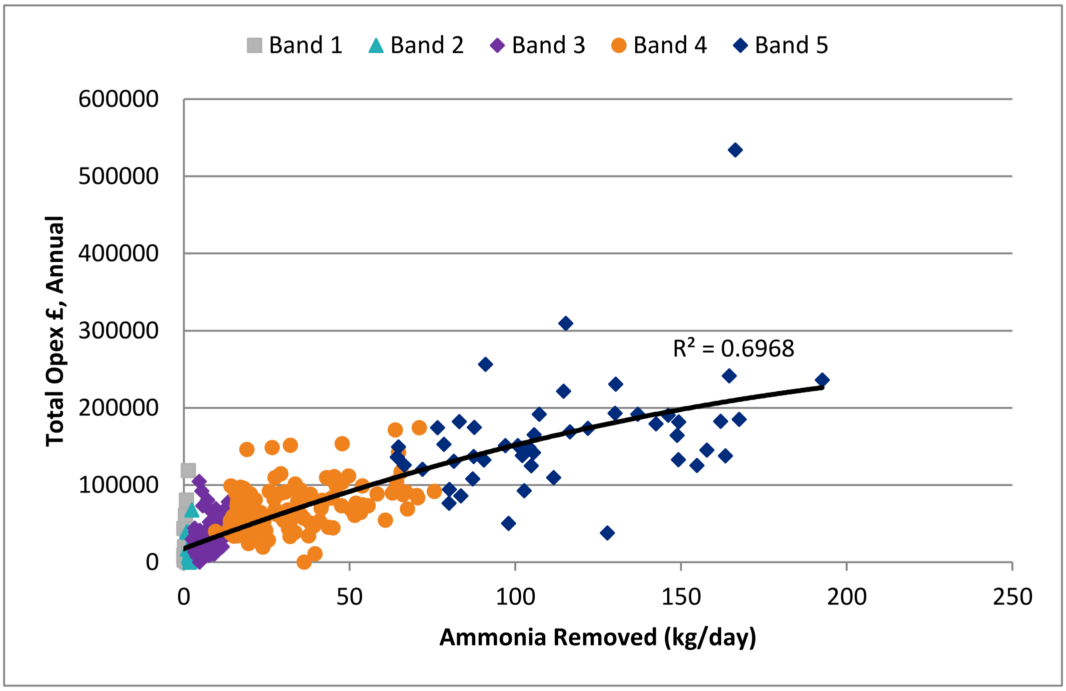
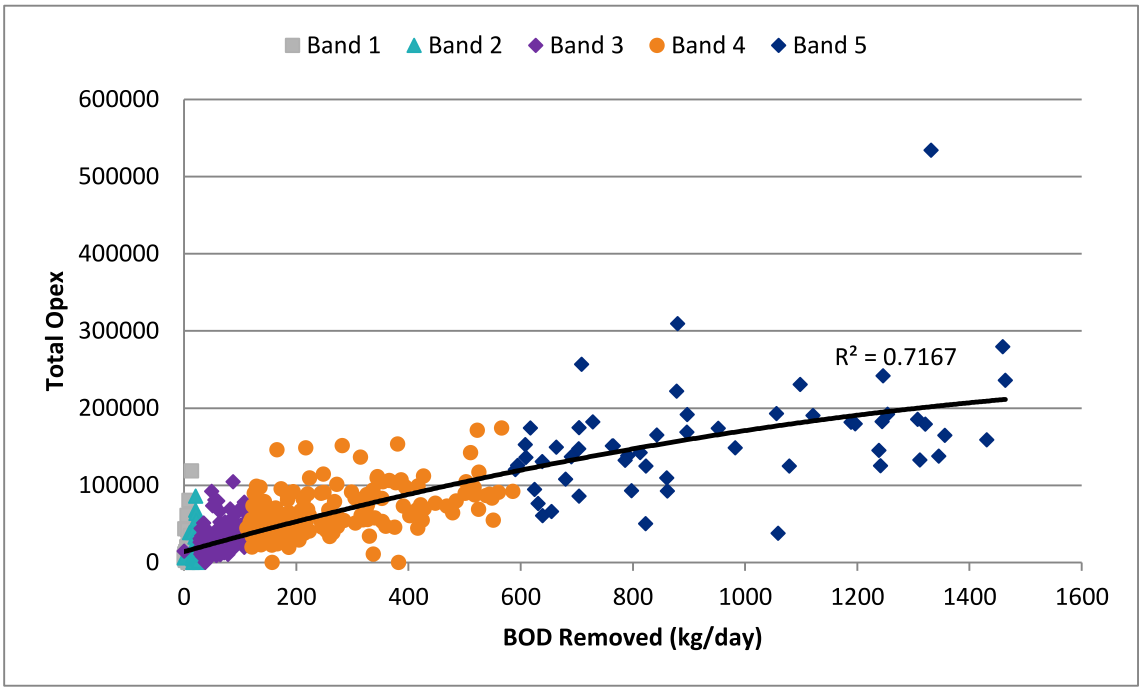


Figure 3.10: Band 1-5 Load removed BOD versus PE



Considering the bands separately does not improve the band 1 – 5 correlations but this does allow the treatment unit cost variation to be examined. The charts below show the best correlations.

Figure 3.11: Band 1 Opex vs works PE load

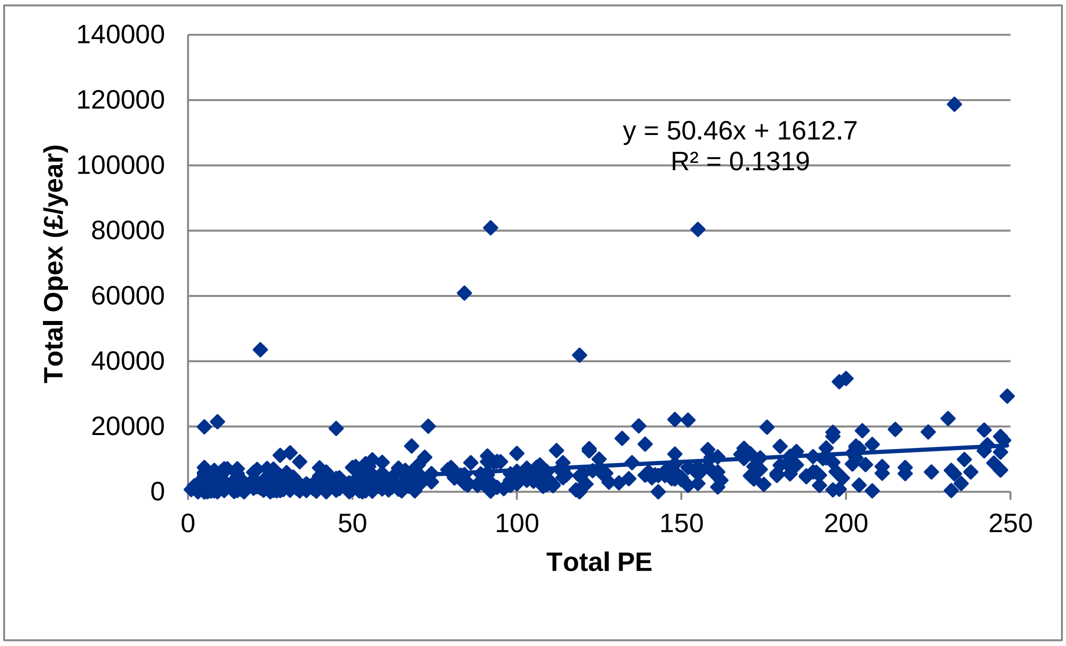


Figure 3.12: Band 2 Opex vs works PE load

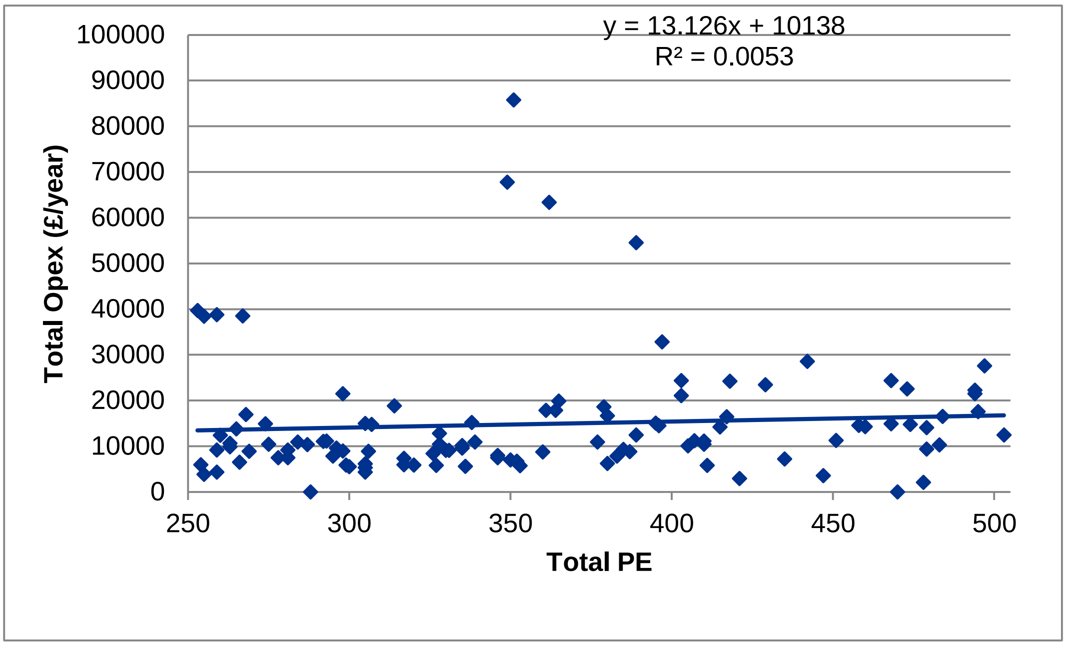


Figure 3.13: Band 3 Opex vs works PE load

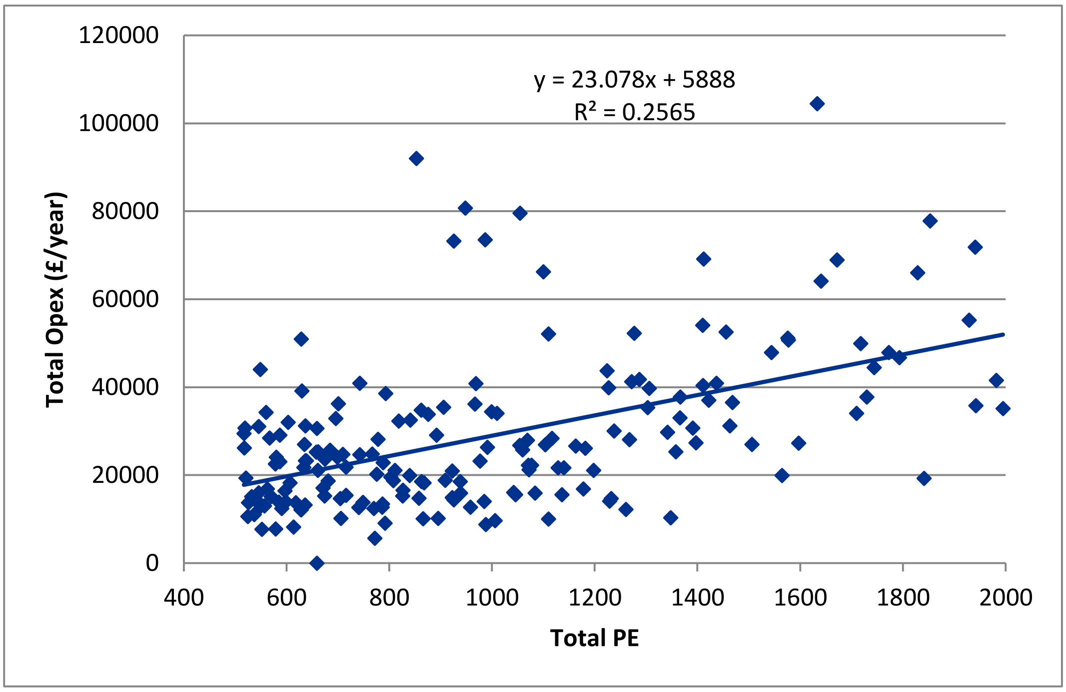


Figure 3.14: Band 4 Opex vs works PE load

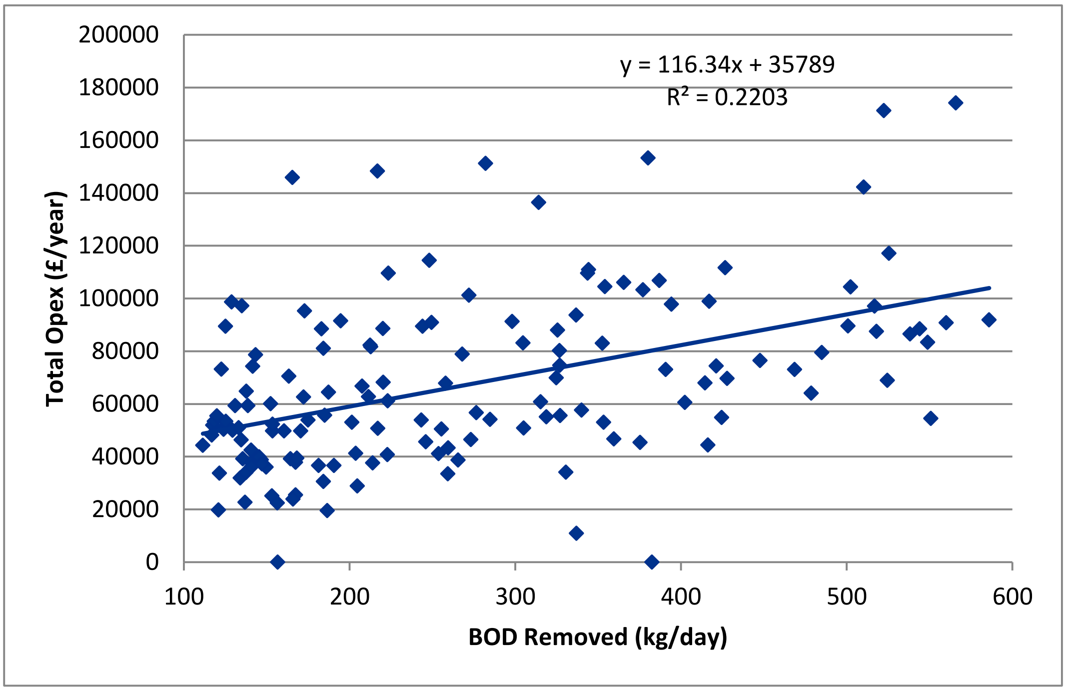
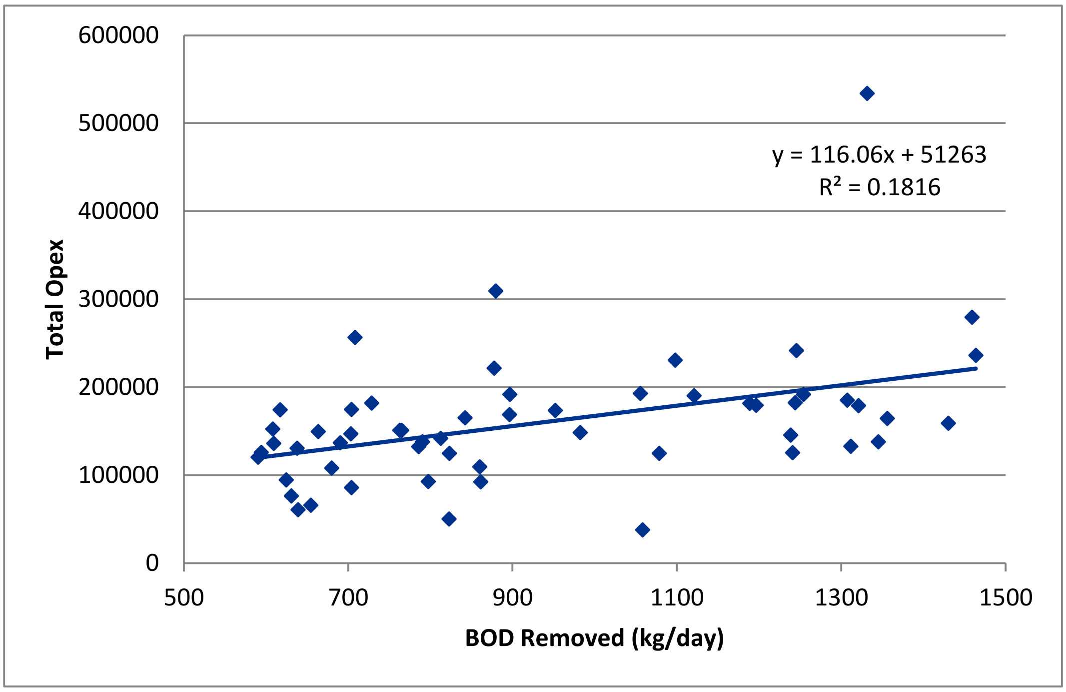


Figure 3.15: Band 5 Opex vs works BOD load removed



The correlations are poor and it makes little difference whether we use PE or load removed (whether BOD or Ammonia). For bands 1 and 2 we see a very flat correlation and only marginal change for bands 3, 4 and 5 and no real correlation. This suggests that from the data assessed, load-received (as PE) or load-removed may not be the dominant cost driver for small works. There is significant scatter and some obvious outliers and erroneous data with zero cost figures:

- Bands 1 and 2 show variability which we might expect due to the presence of variable process solutions which can have substantially different operational power cost requirements (RBC versus biological filters, and the more extreme SAF versus either process which is more prevalent in band 1); other opex components are best investigated in the deep dives analysis.
- With some improved data cleansing following confirmation of potential outliers as erroneous or otherwise, the correlations for bands 3, 4 and 5 may be improved but even band 4 with the most uniform secondary treatment type (biological filters) shows little correlation. This is investigated further in deep dives.

If we revert to band 6 we see the following series of more linear correlations and much stronger relationships evidence of more dominant cost drivers.

Figure 3.16: Band 6 Total Opex vs Load as PE

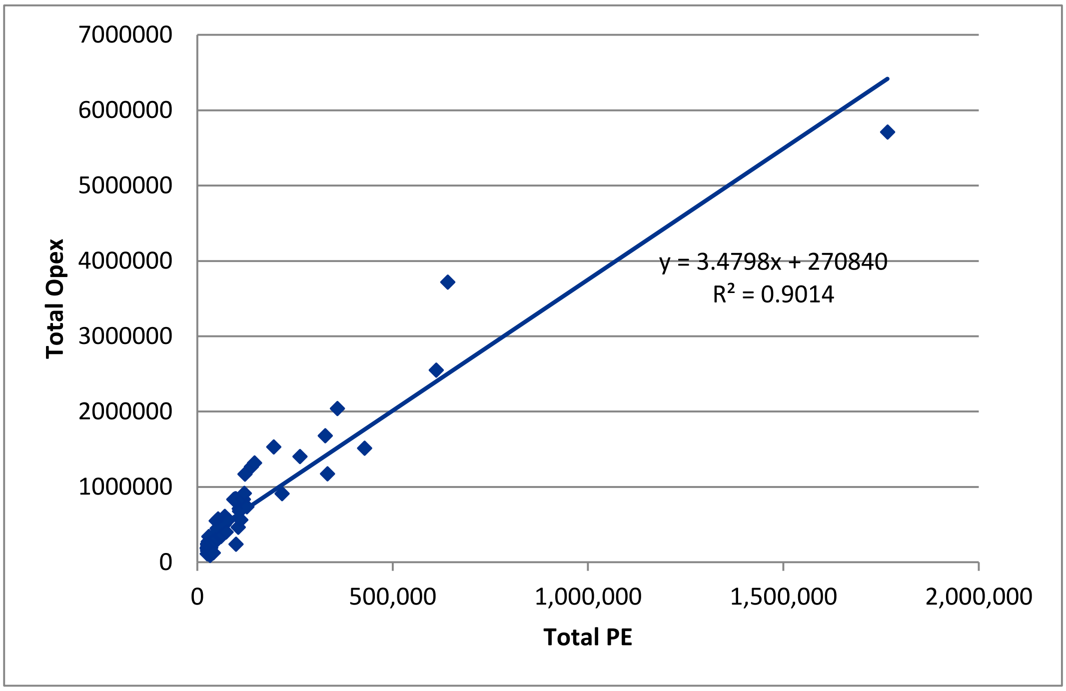
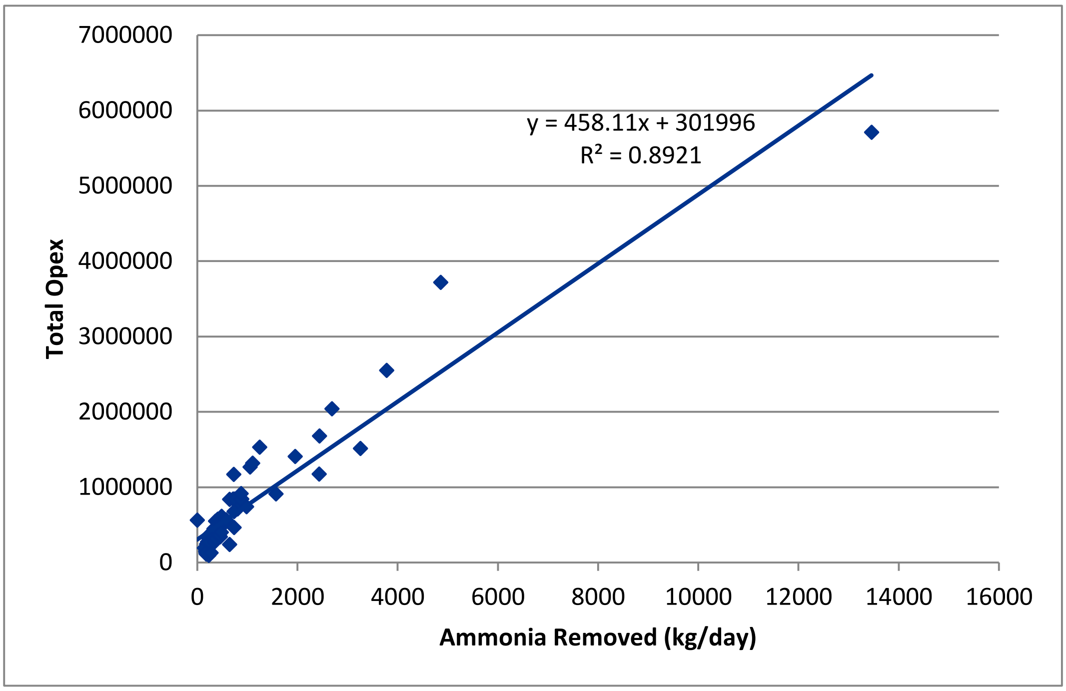


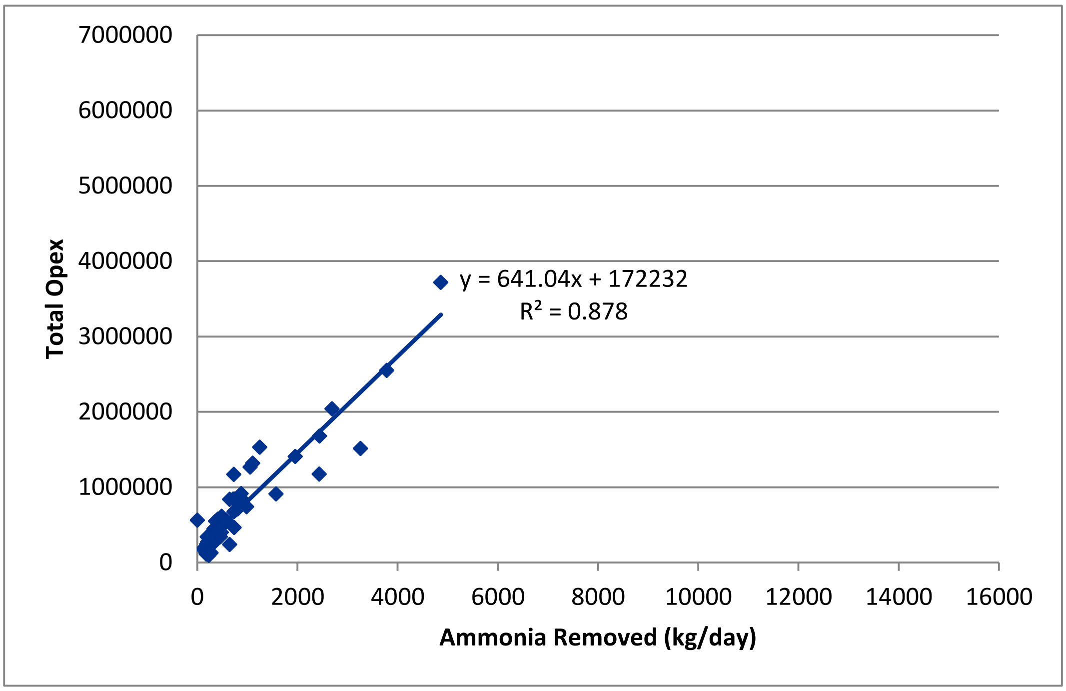
Figure 3.17: Band 6 Total Opex vs Ammonia Load removed



Given the high degree of ammonia removal required in band 6 it is hardly surprising that there is little difference between load incoming as PE and load removed; both give a linear correlation with R^2 of around 0.9. For companies with less demanding ammonia consents we would expect to see a different picture; this is discussed further in section 4 of Appendix C.

Minworth is an obvious point on the extremity of the graph and as a very large treatment works we would expect it to have an economy of scale effecting its costs that other band 6 works do not have. We can remove this to see how this impacts on the operational cost relationship with load and in we can see in figure 3.18 that excluding Minworth produces a steeper opex vs load removed trend line.

Figure 3.18: Band 6 Total Opex vs Ammonia Load removed excluding Minworth



3.6 Discharge consent and treatment type analysis

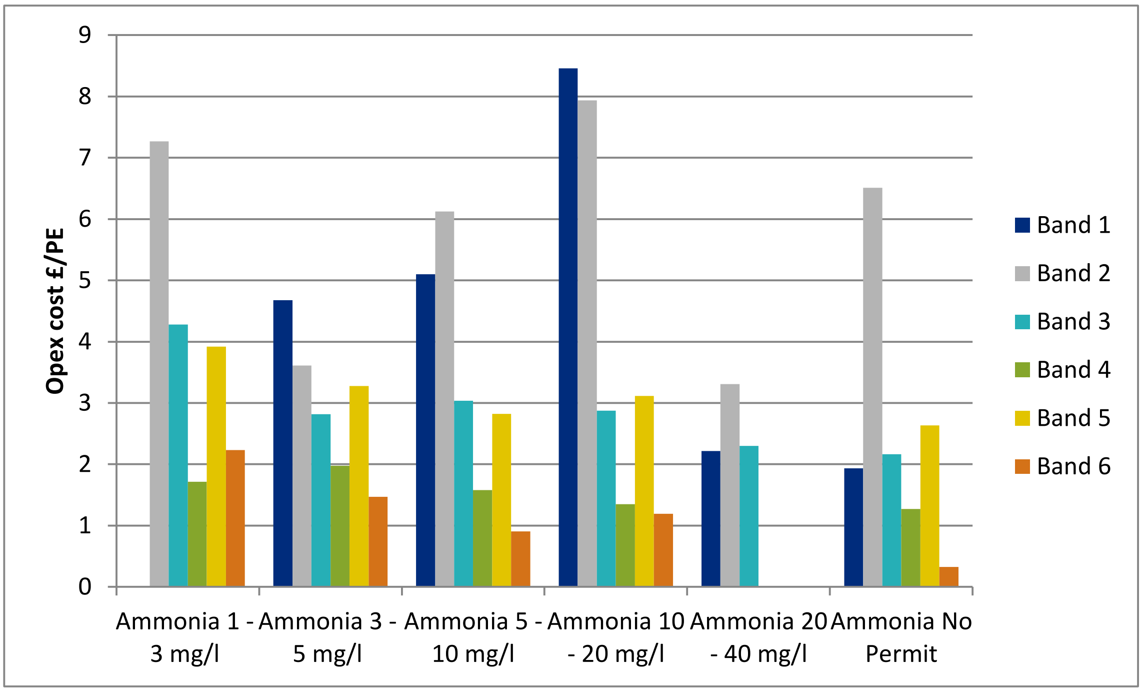
Findings

- Evidence of increased costs across Bands 3, 4 and 5.
- Little evidence in Bands 1 and 2 given other factors.
- Difficult to see in Band 6 due to lack of BOD only sites for SVT dataset.

This section investigates whether we can identify relationships between discharge consent quality requirement and cost – and if there is evidence that an increase in consent leads to higher costs. We also consider treatment type within different bands.

We test the hypothesis that beyond ammonia load being a cost driver, more stringent ammonia standards will result in higher treatment costs and that certain types of process within certain bands will result in higher treatment costs. It also presents and discusses works size related data.

Figure 3.19: Annual Opex per PE for ammonia consents of decreasing stringency



We see some evidence of decreasing opex per PE but only if we consider removing band 1 and 2 which have far less requirement for ammonia removal. The band 1 and 2 cost data shows little relationship with ammonia consent stringency. The analysis probably suffers due to the high degree of ammonia removal required across almost all bands 2-6 for SVT. The most evident reduction in Opex with decreasing consent stringency is across band 6; band 5 displays a very flat graph with little apparent impact of ammonia standard possibly due to the divergence of process solutions within this band for SVT.

If we consider cost per ammonia removed for bands which have a reasonable number of ammonia versus non-ammonia permits, we see results below.

Table 3-7 : Comparison ammonia vs no ammonia sites

	Band 3	Band 4	Band 5
Average cost (ammonia consent)	31,634	69,966	163,763
Average cost /PE (£/PE)	31	17	10.5
No. sites (ammonia consent)	120	126	48
Average cost (no consent)	23,381	50,891	138,512
Average cost /PE (£/PE)	27	12.5	7.4
No. Sites	63	23	8
% increase in average cost	26%	27%	15%

	Band 3	Band 4	Band 5
% increase in ave. cost per PE	12%	26%	29%

This analysis is not ideal because still the significant majority of sites in bands 3, 4 and 5 require ammonia reduction – however it shows clear increase in average opex cost. It does not align neatly with Figure because it considers at a broader level sites with and without ammonia standards and not the costs of compliance with specific ammonia ranges. Generally, data in bands 3, 4 and 5 does suffer from more variability due to the different process types present and resulting impacts of these on treatment costs as discussed in Section 3.2.2.

If we look at treatment type versus opex cost we would expect that sites with particular process types of a certain size and consent may have similar treatment costs and that ASP sites may have an increased **power** opex compared with biological filter processes. We do see this in Table 3-8 with regards to Power costs but not total opex. Given the high degree of ammonia removal undertaken, the use of kg ammonia removed or PE makes little difference and we see power costs for ASP processes around 144% of biological processes as TB2. This aligns well with what we would expect for power but other opex costs counter the same increase in total. However, we need to be careful; there are TB1 and BF sites which should have lower power requirements too but it is less clear how their processes compare with TB2 or TA2.

Table 3-8 : Band 6 Process Type Comparison

	Power TB2	Opex TB2	Power TA2	Opex TA2
£/kg ammonia rem.	0.86	2.72	1.23	2.79
% increase TA2			**144%**	**103%**
£ annual/PE	2.29	7.26	3.18	7.22
% increase TA2			**139%**	**99%**

We can only make a reasonable comparison with the full SVT dataset for band 6 as generally all works are nitrifying and have a tertiary process to meet P standard and all processes are either an ASP or Biological Filter. We know the extent of tertiary sand filters is limited to around 20% of the plants in band 6. With more time, we could take the analysis further and delineate those works with filters (and likely interstage pumping) and those without to assess the impact of the tertiary filter – we expect it could be 5-10% total opex. SVT appear fortunate not to have a high degree of tertiary pumping and treatment at their band 6 sites, from what we can tell and compared with WaSCs with a prevalence of RGFs, BAFFs and NTFs we would expect their treatment costs to compare favourably for works with similar degree of ammonia removal required.

3.7 Economies of scale associated with treatment complexity

Findings

- Evidence of economies of scale in removing ammonia and BOD

We see a clear economy of scale in removing ammonia and BOD as per below figures which plot Opex per PE versus load removed. The amplified band 1 unit costs likely capture higher treatment costs as well as the relatively low load of ammonia requiring removal and a variable dataset with some extremely high unit treatment costs which if often the case for very small works. Bands 3, 4 and 5 with >70% of ammonia load requiring removal are more likely representative of economies of scale

Figure 3.20: Band 1-6 comparative Opex per kg ammonia removed £/kg

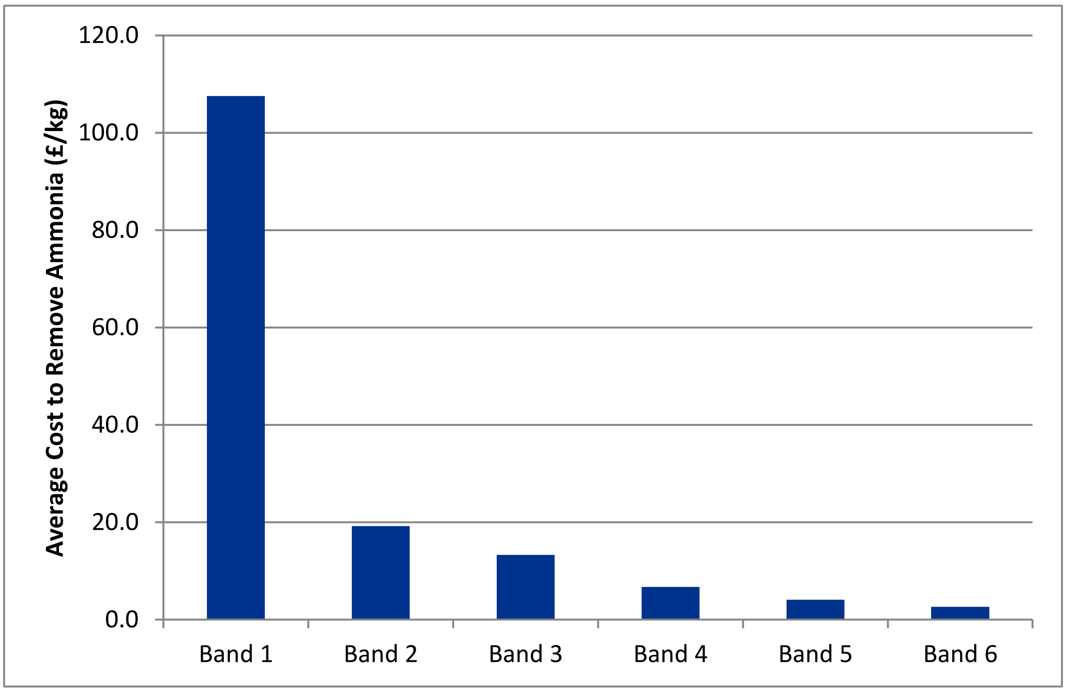
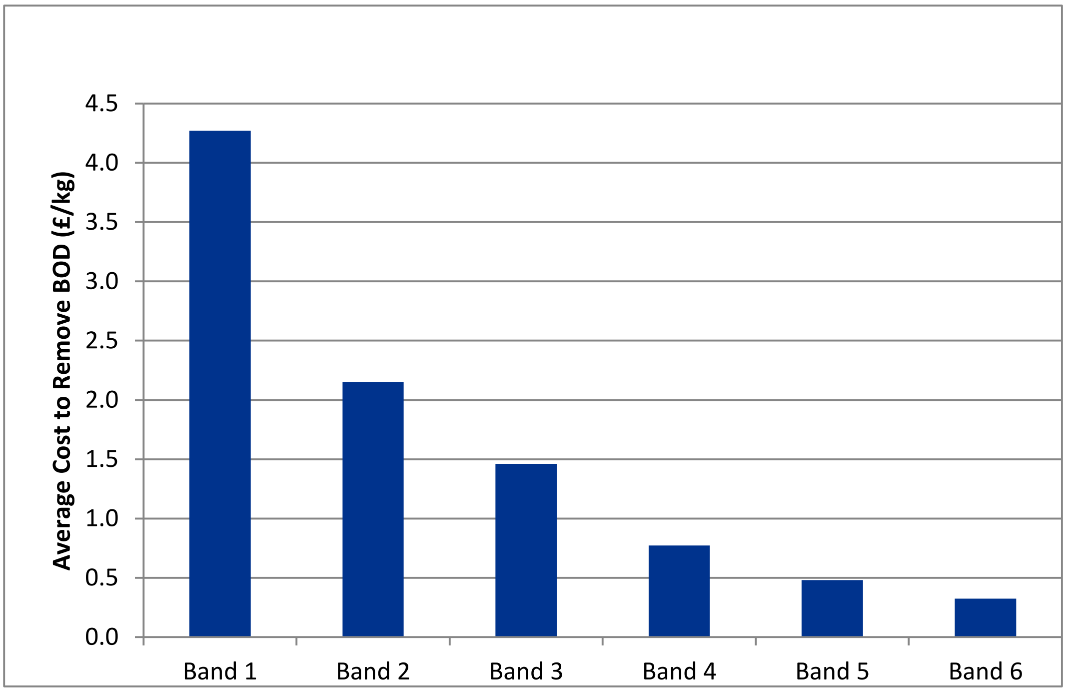
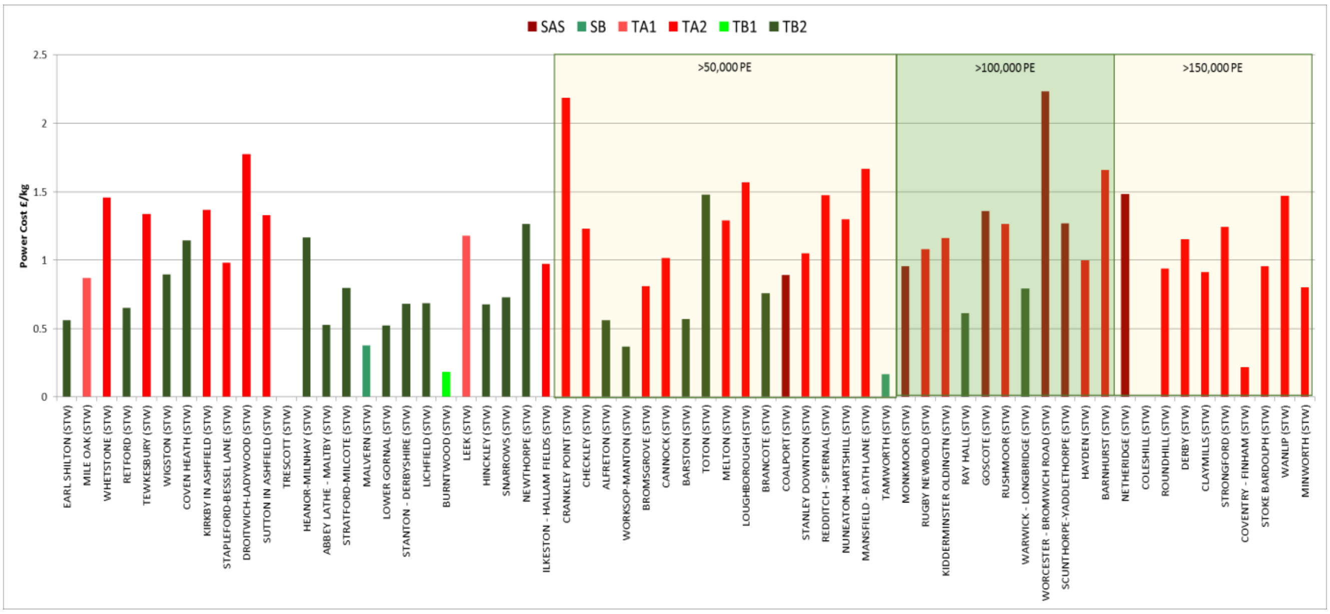


Figure 3.21: Band 1-6 comparative Opex per kg BOD removed £/kg



Within band 6 where we see a prevalence of similar processes and the size range we can assess the unit treatment costs across the band based on treatment process to assess whether the larger band 6 works show a downward trend in treatment cost due to economies of scale.

Figure 3.22: Band 6 Power Opex per ammonia load removed

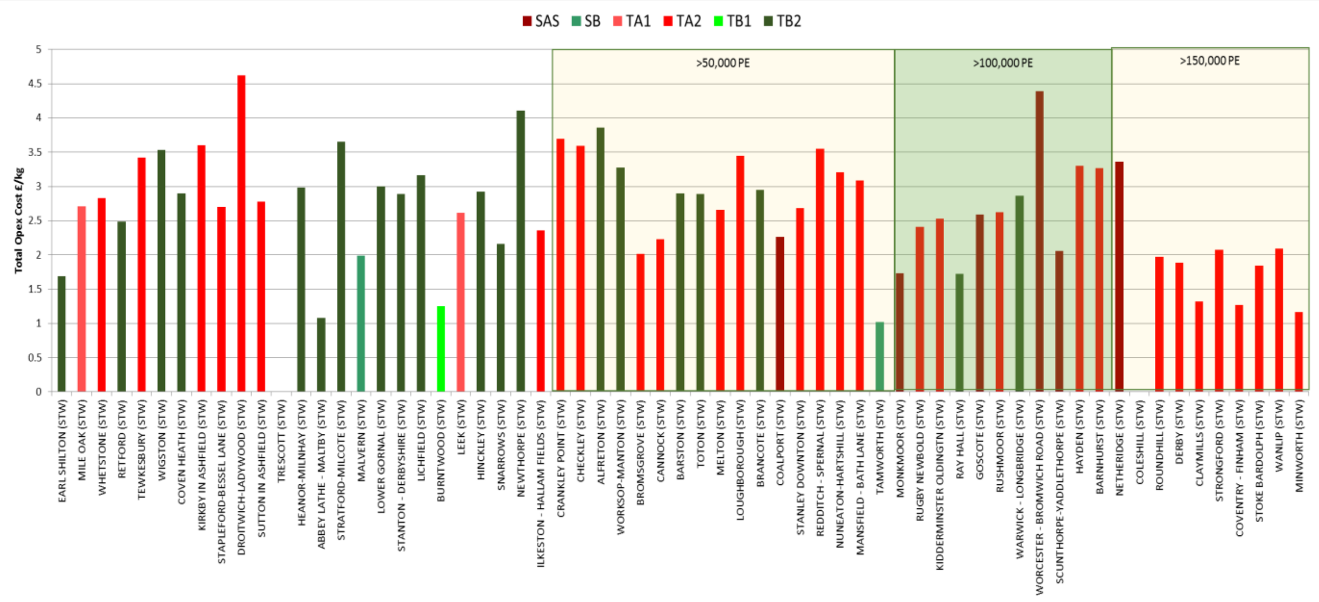


We see the lack of TB2 sites above 100,000PE and that, generally, similarly sized works adjacent on the bar graph, show lower cost power costs if TB2, TB1 or SB as compared with ASP processes. We do note that some biological filter or TB1 sites have relatively high costs. Site-specific analysis is required to investigate this further.

We see a general trend in reducing unit power costs for ASP plants are they increase in size, as would be expected. We do not see this for biological works. We would need to undertake site specific analysis to investigate this further,

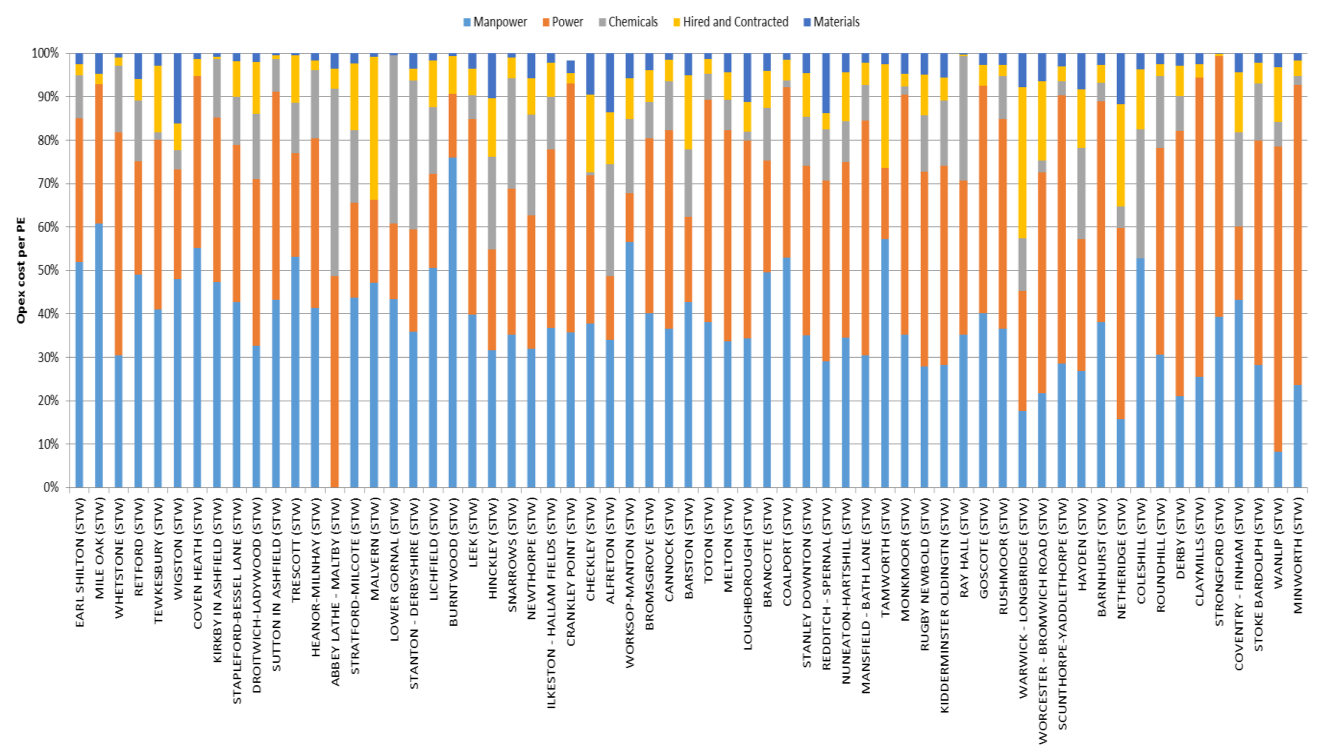
Despite the total opex figures not offering any evidence of cost savings for TB2 processes versus TA2, we do see some evidence of economies of scale here but a site-specific analysis across band 6 would be suggested.

Figure 3.23: Band 6 Total opex per kg ammonia removed



If we look at opex split in Band 6 in Figure , it appears the cause for reduced opex relates to manpower at the larger works. There is evidence of a cost driver for large works – likely related to both power and manpower economies of scale for ASP works but less power related and more manpower, perhaps, for non-ASP works. We would expect power costs to be proportional to works size for identical process types with some scaling efficiencies; we would expect materials cost (e.g. chemicals) to increase with increasing works size. We don't see evidence of these aspects and further investigation would be required with more analysis of band 6 specifics.

Figure 3.24: Band 6 Opex Breakdown



3.8 Conclusions

In section 3 we used data on SVT's costs and treatment to develop an understanding of the issues at SVT.

- We see a reason to consider ammonia load removed in costing models. We see better correlation between ammonia removed than ammonia load incoming from the SVT dataset though the opportunities within SVT dataset are limited given the very high degree of ammonia removal required across all bands. When we make some assumptions about load removed for the Industry dataset, we see significant variability in costs across the industry to treat (remove) ammonia though further analysis, possibly using the EA database, would be recommended.

- However, correlation between load (whether incoming or removed) and operational costs is poor across the lower treatment band sizes. It improves as we increase through bands in our analysis of the SVT dataset. This would be expected for reasons we have discussed and examples from our deep dive analysis highlight the challenges of treatment at small works. Bands 5 and 6 may be most useful to consider here in terms of cost drivers.

- We observed better correlations with specific load removal when using power costs rather than total opex costs. However, given the proportion of power as 40% of local treatment opex, we would expect to see similar effect in opex total costs as more power often requires more operational inputs too. We did not see this – possibly is due in part to variability in manpower costs (or allocation).

- We see significant variability in manpower costs regardless of works size, treatment type or consent. We also see significant variability in chemical costs per PE which we would not expect particularly when all other site factors appear otherwise equal – however, our investigations haven't included discussions with site or validation of the data provided for sites.

- We have explained why power costs for ammonia treatment versus BOD only are higher. We see evidence of this step change between BOD only and BOD/ammonia consents when we consider what SVT data we can in bands 3, 4 and 5. Given the lack of SVT band 6 sites with no ammonia standard further conclusions are difficult but we would expect to see this effect in WaSCs with lower ammonia consents across band 6 and we would expect it to be significant in terms of treatment costs and could be developed further in consideration of special factor claims.

- However, the increased costs due to increased aeration treatment for ammonia load removed for a stringent versus relaxed ammonia standard that we would expect is evident from deep dives analysis in all bands with comparative processes and particularly in bands 5 and 6. This is most obvious as increased power costs due to the noted variation in manpower and chemical costs. Further investigation of the industry dataset using EA database could be undertaken here with Power Opex costs from the Industry dataset.

- To provide industry comparisons in literature with operational energy usage, power tariffs and any site-specific energy breakdown would be useful for high level and deep dive analysis, respectively, such that kWh usage per load and volume of sewage treated can be estimated and benchmarked.

- We see clear operational power cost correlation with process treatment type where other factors are likely similar from the SVT dataset and deep dive analysis. This is particularly evident across higher bands with regards to Biological filter works versus Activated Sludge plants. Extending this analysis to the industry dataset is challenging given the broad process type descriptors used; analysis using the EA database and Industry costs could be warranted with a focus on band 6.

- We see some opportunities for consideration of process type in band 6 treatment but this would be complicated by the presence of more energy intensive tertiary processes downstream of lower opex biofilter plants which is more prevalent in some WaSCs than others. This may benefit from further analysis using the EA database.

- In high level and deep dive SVT dataset, we clearly see the economies of scale in treatment and reduced load variability reducing operational costs for larger works compared with smaller works. Highest unit costs are most magnified in works <250 PE in band 1. Economies of scale are more significant as we increase to band 6 as we would expect. Our analysis suggests that further economies of scale are perhaps more evident beyond approximately 150,000 PE within band 6 though further analysis around process type would be of benefit along with further consideration of manpower costs/allocation.

- Whilst we expected that a tight BOD or solids consent requiring a tertiary solids removal stage would result in an operational cost step change, this wasn't evident in the SVT band 6 dataset due to the prevalence of ASP and Biofilter processes in the deep dive sites selected at random and widespread use of lower energy solids removal (reed beds, lagoons). Further investigation of specific sites would be of benefit here to assess the impact of tertiary pumping and treatment despite that SVT appear to have less of it than some. This could be further investigated across WaSCs and may be of relevance for those with increased use of tertiary nitrification (e.g. high rate filters, BAFF plants) or tertiary solids removal downstream of biological filter processes (e.g. sand filters) as compared with SVT. This analysis could be undertaken using the industry cost dataset and EA database.

- The industry dataset via EA database could provide information industry wide to further develop considerations around ammonia drivers. The current Industry dataset and process type descriptors do not allow enough information to draw conclusions at this stage and further interrogation of the EA database would be required. It should better characterise the actual treatment processes on site from our initial review than the current descriptors.

4 Other issues concerning costs assessment

Findings

- The EA consents database provides detailed information for all discharge consents in England. It has the potential to support the development of a modelling factor would allow models to take account of the impact of demanding consents on expenditure.
- Companies may face different surface water risks and may have sewerage networks that are designed drainage with a particular approach to drainage in mind. There could be a material cost impact – however there is limited descriptive data.
- Sewer infiltration is a complex issue with links to management decisions (maintenance policy) and geography. We were not able to identify data on costs and variables that offered an immediate factor either for use in models of for special factor claims.

In this section, we review the remaining issues identified by AVE in their January work addition to the key areas of economies of scale and the impact of consents on treatment expenditure we considered:

- The impact of the choice of technology on expenditure
- The potential of the EA consents database to inform wastewater models
- How surface water drainage risks might affect expenditure
- The potential for sewer infiltration to be a material wastewater cost factor

4.1 Load removed within treatment types – use of EA database

Findings

- The EA database:
  - offers a resource that could, when used with expenditure data from other sources, show costs are linked to consents.
  - Shows some regional pattern of consents that may be linked to a preference for particular solutions. This could have an influence on company costs.

We are concerned that the industry sourced metrics on loads received at treatment works and population equivalents may not give a true picture of the outputs of treatment works. Our work on the Severn Trent data shows the variation we would expect theoretically based on load removed and treatment types is reflected in available datasets. At an industry level, we can see evidence that operational costs per load removed offer improved explanation though the load removed must be estimated from within consent ranges which requires further sensitivity analysis.

From the industry dataset, there is limited information on treatment types to allow us to test hypotheses presented with respect to the SVT dataset. The industry dataset allocates load to different treatment types within each band and to different ammonia consents within each band. We would expect to see different treatment types associated with different quality consents. From the industry dataset, we could:

- Assume proportions of load attributed to different consent types within treatment types based on what we might expect.
- Look for the expected correlations between consent stringency, treatment type and operational costs on a band 6 level.

Using the industry dataset is unlikely to offer much more than this outside of band 6 due to the increased diversity in both consent types and treatment types.

4.1.1 Using the EA database

We have worked to find external data that may help fill in these data gaps. The EA database provides the exact consents for treatment sites for each water company in terms of quality and flow and a significantly more detailed description of treatment type. This could be used to build for each company a dataset that to much more degree than possibly with the industry dataset matches the SVT dataset in level of detail. This would require sufficient time for the required data manipulation and cleansing; part of this would be consolidating the treatment type with works consent for each of the 6372 treatment sites, or an agreed subset of these which would provide useful information (e.g. initially for band 6 perhaps which would comprise around 390 sites).

Whilst the EA database does not directly provide incoming load data, this could be assumed using the process set out in section 3. This information would not be critical for all the analysis below.

This further analysis could allow us to:

- Ascertain the discharge standards for band 6 treatment works with regards to potential quality/consent drivers for each company and compare these to SVT sites
- Calculate the actual load per band removed for contaminants of ammonia, phosphorus. Using the cost per band data we already have along with a broad estimate of ammonia load removal, we could calculate with significantly more accuracy the relative unit costs of ammonia removal for each site within the database.
- Understand treatment type and load removed within bands to better degree than the existing company dataset. This could help understand cost variation.

Limited interrogation of the EA database has been undertaken as part of this work. It requires considerable manipulating and our initial analysis around what we estimate are band 6 treatment works. We have been able to estimate a portion of band 6 treatment consents and categories these into more detailed ammonia criteria than with the Industry dataset. We could, with further time, allow these to be cross referenced with other quality parameters which is not currently possible with the industry dataset - though broadly, we know ammonia consents are likely the significant quality consent related cost driver within band 6.

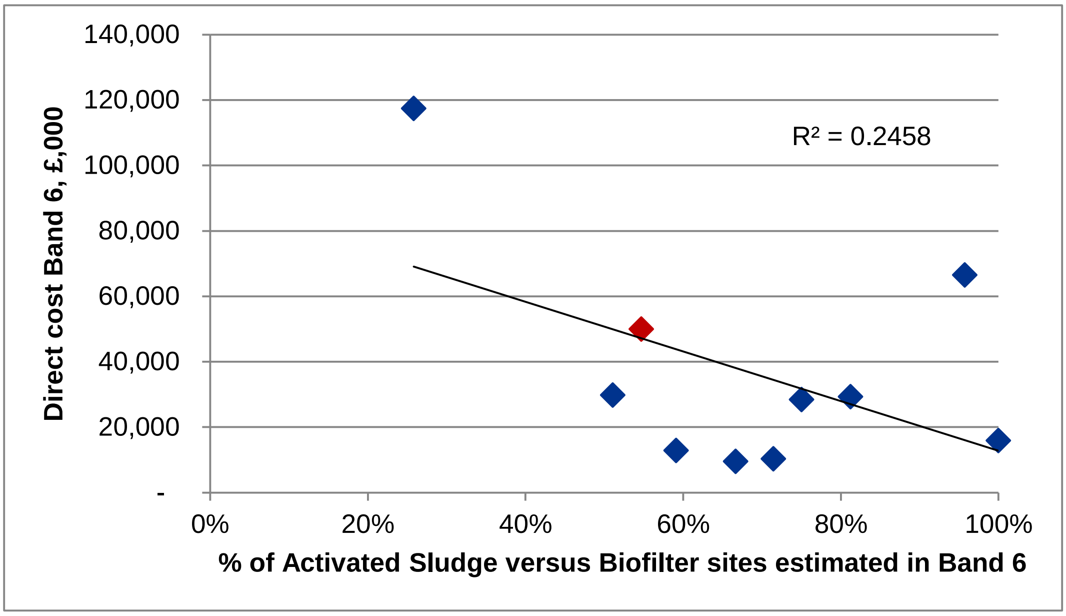
Table 4.2 and figure 4.7 show some band 6 summary analysis from the EA dataset. We are aware that this may not be representative of company data as banding has been inferred from DWF and significant portions of Welsh, UU and Yorkshire data is missing, and SVT is over-estimated. This information is included at as an example only and we make no inference from the assessments. It shows the importance of sufficient time and attention to data cleansing and reconciliation as significant numbers of sites are missing or being included as band 6 erroneously. There is an issue with the way some companies are listed and variance in names which make cleansing of data laborious – though it is likely these issues could be overcome with enough time.

With more time, actual load removed could be calculated across selected sites and process type and consent type analysis undertaken using Industry cost datasets.

Table 4-2: Indicative summary of consent ranges for ammonia removal – EA database and missing data from initial analysis

	1 - 3 mg/l from EA	4 - 5 mg/l from EA	6-10 mg/l from EA	11- 20 mg/l from EA	21-40 mg/l from EA	No Permit (Industry dataset)	Total Sites EA database	Total sites (master waste)	Missing sites
Anglian Water	0	2	6	8	0	13	29	49	41%
DWR Cymru Water							0	21	100%
Northumbrian Water	1	1	3	2	2	11	20	21	5%
Severn Trent Water	7	35	34	13	0	2	91	64	-42%
South West Water	0	1	1	4	1	10	17	15	-13%
Southern Water Services	2	6	5	1	0	23	37	42	12%
Thames Water	4	6	9	11	4	0	34	55	38%
United Utilities	0	0	1	1	0	12	14	65	78%
Wessex Water	1	6	9	4	2	6	28	24	-17%
Yorkshire Water	0	3	1	5	1	3	13	34	62%
Total							**283**	**390**	

Figure 4.7: Direct industry cost from Industry data versus % of ASP sites in band 6 from EA database



4.1.2 Regional consent variations

Finally, we recognise that the regional nature of the EA and its consenting teams may result in a variation in the application of consents and solutions across England and Wales for otherwise similar sites. This is not an operational or environmental problem - there is often more than one valid approach to an environmental issue and the final decision will take account of technical economic and human factors.

Nevertheless, over time regional differences could lead to materially different reported expenditure and have some influence on important regulatory decisions. It may be worth investigating this area further through use of the EA database.

4.2 Surface water drainage

Findings

- Design characteristics of sewerage systems will have an impact on company costs.
- More data is required to investigate this to the degree that it could be included in the models. However, some companies, with high levels of combined sewers might develop a case for a special factor.

Combined sewerage systems impact on treatment processes in terms of infrastructure and operational costs for pumping. Where catchments have a high proportion of combined sewers and treatment works have significant interstage pumping (e.g. to meet stringent tertiary treatment requirements for consent), the additional storm flows pumped will impact on operational pumping costs.

The volume of stormflows requiring to be stored and treated differs from site to site but could be around 2 hours at FtFT so sites with surface water inflows will have additional treatment costs which could be considered of the order of 8% pumping costs after a storm event which fills storm tanks. As this is rainfall depending it would be difficult to assess further though companies with a high degree of combined systems and higher than average rainfall could be expected to incur higher cost more frequently due to inflows. Although stormflows are generally more dilute and therefore won't require as much aeration treatment; the initial 'first flush' which storm tanks are designed to capture often does contain significant organic load and could feasibly result in more than 10% additional load to the treatment process over the return period which could impact power proportionally.

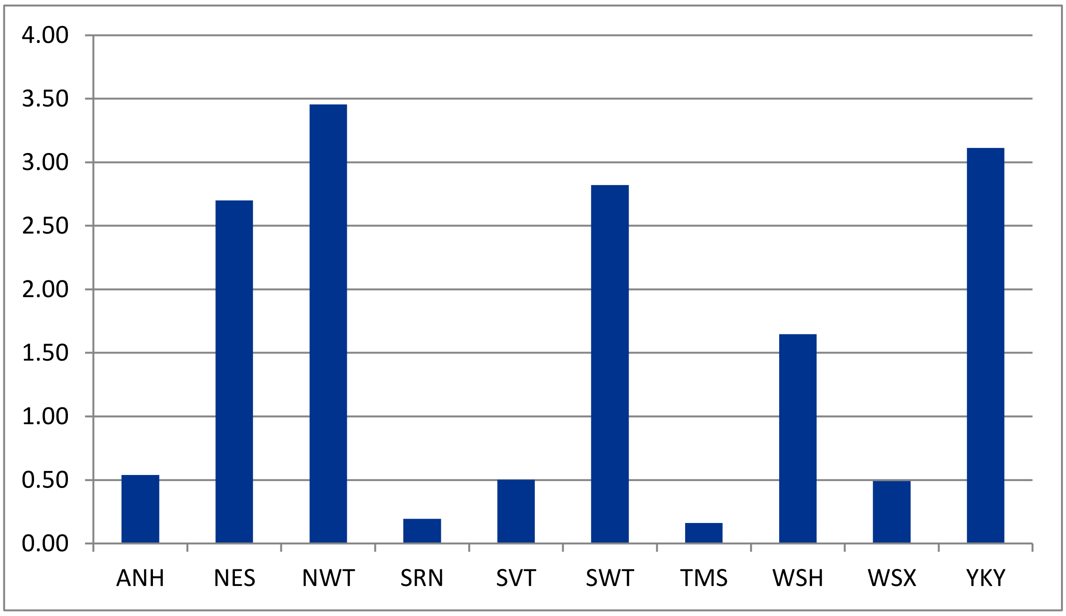
This effect may be expected to impact smaller bands 1-3 less than larger bands with more process control in bands 4-6.

Based on the Industry dataset, we see SVT have approximately half the length of combined sewerage to separate foul sewerage – approximately 1/3 of the gravity sewerage is subject to surface water impacts. For 2015-16, Figure 4.8 shows the reported % combined sewers relative to foul sewers across all water companies.

WaSCs with higher proportion of combined systems have larger diameter assets to maintain and stormflow to deal with at SVTs which will impact both capital and operational costs. WaSCs with a higher proportion of separate systems have smaller diameter pipework and less asset base to maintain.

Further asset information would be required to assess the cost impacts of surface water inflows on Severn Trent assets but it is unlikely to be significant. The intensity and frequency of rainfall events will impact on WaSCs with high levels of combined sewerage. Although unlikely a significant factor for SVT, analysis around regional weather patterns and rainfall could be used to take this assessment further if of interest to SVT.

Figure 4.8: WaSC combined versus foul sewers



Yorkshire, UU, Northumbrian and South West water have over 2.5 times the proportion of combined versus foul sewerage. Welsh is mid-range whilst the other 5 companies have a less than 50%

combined sewers compared with foul. There is a marked difference between the top 4 and bottom 5; with Welsh central.

4.3 Infiltration

Findings

- A largely theoretical issue – more data would be needed to understand the impact on company costs
- May have some relationship to asset condition and capital maintenance expenditure

Infiltration can occur into separate or combined sewerage systems and is typically defined per length of sewerage – the more pipework in the ground the increased likelihood of infiltration into them. The older the pipework, the more likelihood of deterioration and if not addressed through maintenance this is likely to lead to increased infiltration. WaSCs who spend more on maintenance to reduce infiltration[20] will incur higher network costs.

Higher rates of infiltration mean more dilute sewage, a higher DWF, larger infrastructure (tanks) and more pumping. Infiltration for the SVT dataset is estimated at approximately 32% of domestic PG using a G value of 135L/PE/d. This is a low level of infiltration and would suggest good/average conditions for the network; infiltration of 100% or more may indicate systems in poor condition[21]. There is no evidence of correlation between higher rates of infiltration and higher operational cost per PE for the SVT dataset when we consider PE and DWF in the deep dive analysis[22].

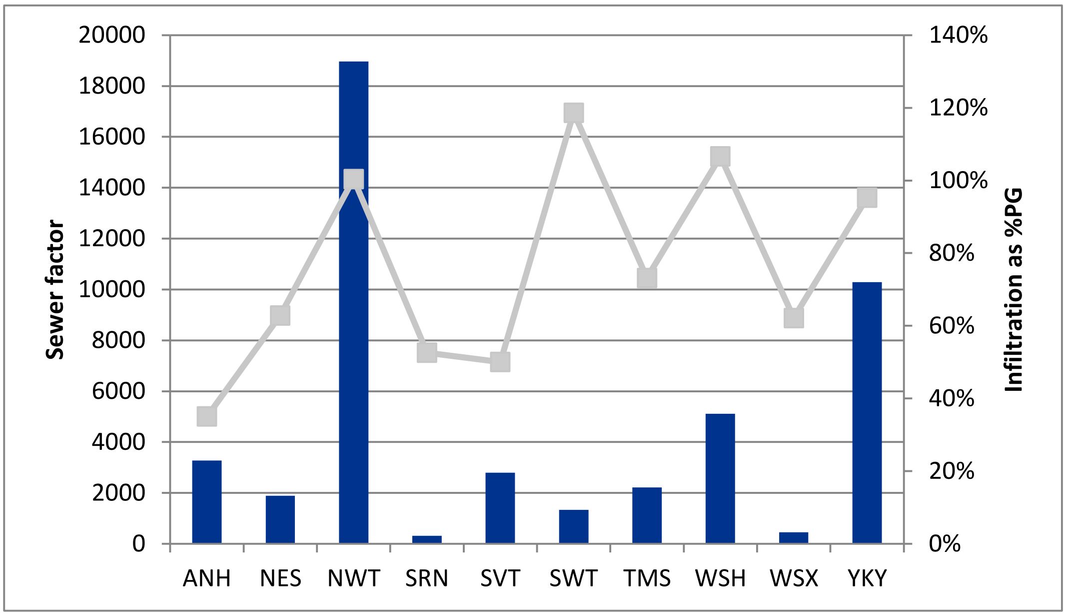
We can make some assessment of potential infiltration across the industry using the Industry database figures from *Master waste hc 20161221*. Taking the total flow to sewage treatment works, dividing this through by a factor of 1.25 as an estimate of ADF/DWF, subtracting trade flow and dividing through by the works-connected PE and the PCC of 135L/PE/d gives us an estimate of infiltration as %PG. Whilst peaking factors and PCC may differ per company to some extent, the variation should not be significant and the analysis should give an indication of relative infiltration between WaSCs.

The extent of infiltration we might expect would be relevant to the age, and extent of sewerage infrastructure. If we consider a sewerage network factor, f, as calculated below we can plot this estimate of infiltration versus f in Figure 4.9.

f = proportion of sewerage <1960s era x proportion of combined to foul sewerage x gravity sewerage length

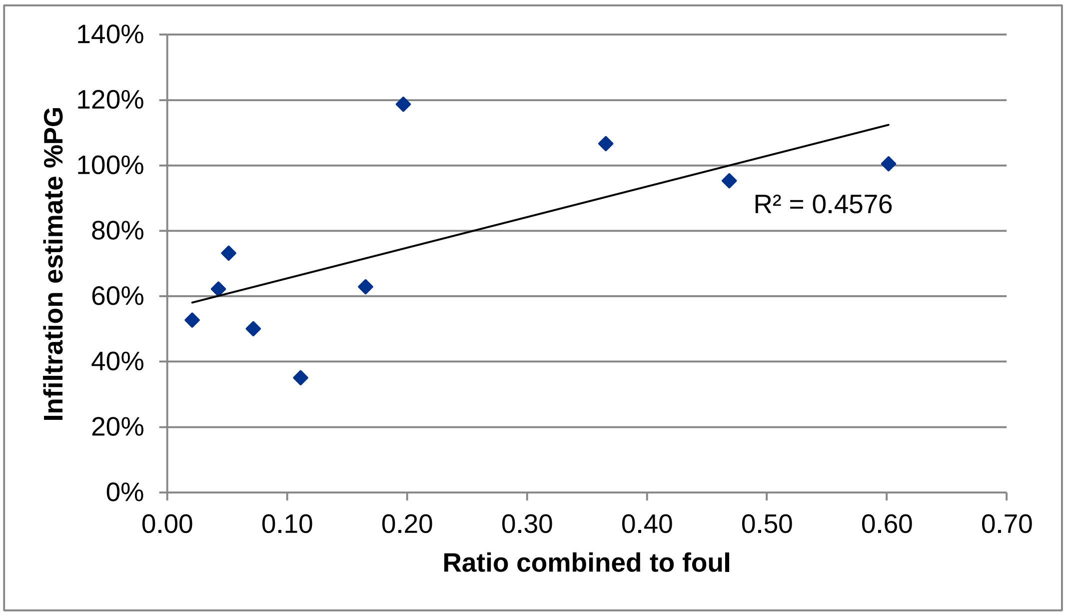
[20] Such as sewer and manhole sealing, sewer replacement and, more removed, water mains leakage reduction.
[21] UWIR Report Ref No 10/CL/11/3 pg. 9
[22] DWF = PG + I + E. From the STW dataset we know P, G and E so can derive an estimate of I as %PG and compare across sites. We found no evidence to link sites with high infiltration to high treatment costs within deep dive analysis from a high level analysis. With time series flow data a more accurate analysis of infiltration would be possible though given relatively low levels in STW network wouldn't be suggested as required.

Figure 4.9: Sewer factor and estimated infiltration as %PG



The plot shows some correlation between higher flows and higher factor f but R^2 values are low. The best correlation of R^2 0.46 was found to be when we look at proportion of combined to foul sewerage only and we ignore (various assessments around) sewer age and extent (length) of sewerage system.

Figure 4.10 Ratio of combined to foul sewerage vs infiltration estimate



We assume the average annual inlet flows in the Industry dataset, quoted as Ml/yr, are the average of all flows inlet to the SVT. Accordingly, companies with combined systems will have increased flows due to surface water inflow. This apparent relationship therefore may be more reflective of increased flow due to inflow (surface flows) and may not be due to infiltration. Further analysis would be required to investigate this.

With the third lowest estimate of infiltration and similar low placing in terms of combined/foul sewerage ratios, it is unlikely to be a significant cost driver for SVT but may be of interest to consider for some.

When we consider ammonia removal, increased infiltration dilutes incoming sewage which can improve the operation of nitrifying biological processes which require minimum wetting rates. If we have two sites with the same ammonia consent as concentration but varying levels of infiltration, the site with more infiltration will have less ammonia load to remove to achieve the same concentration. A WaSC with infiltration of 100% PG as compared with SVT’s 30%PG will need to remove 3% less ammonia load if both are working to meet a 5mg/l standard (on 95%ile basis).

Theoretically they should not have the same consent. Ammonia consents should be set based on an allowable load to receiving waters based on background Q95 watercourse flows and quality and sewage treatment works flow. However, the same numerical values appear to be widely adopted in setting ammonia standards industry wide. This may be worthy of further investigation which would be possible using EA database and industry datasets.

5 Conclusions

We have used the variable data on industry costs and explanatory variables (alongside public data on exogenous factors) to challenge and develop the Arup/Vivid Economics work on wastewater cost assessment. In some areas, we identified scope to improve or develop the AVE conclusions, in these areas we have produced new recommendations and in some cases new data sets.

Our approach has been to understand the AVE work and to consider their methodology and proposals. From this position, we have undertaken a full and comprehensive review of the PR14 modelling data and the 2016 submission to Ofwat. We have identified and commented on trends in wastewater costs across the industry. We have discussed the matter of economies of scale and challenged the AVE work in this area.

Like AVE we found that the lack of good quality subsidiary data on costs and outputs within bands and consent levels hindered our ability to draw robust conclusions, especially for the impact of consent types on costs where our conclusions are based on some key assumptions – albeit ones we feel are reasonable.

Our review of the relationship between costs and outputs at the company level we found that the company size explained most costs and that there was evidence of economies of scale relating to the incidence of very large treatment works.

We used data on costs and loads for treatment works size (bands) to improve our understanding of the factors driving observed costs. While the poor quality of this data meant that our results were illustrative rather than definitive they did demonstrate that it was the pattern of load across all works sizes that determined observed costs – not just the preponderance of small works.

There is a large range in company size from the smallest (SWT) to the largest (TMS). We found that:

- SWT was an outlier for high costs in most analyses – we believe that this relates, at least in part to its socio-geographic environment – in particular, the lack of scope to develop very large treatment works. But it also related to SWTs comparatively high unit costs for larger works.

- Observed economies of scale at the company level (demonstrated by high coefficient polynomial curves) are almost entirely due to the impact of TMS. When TMS is taken out of the data set the trend line more closely approaches a high coefficient straight line.

- In the most recent years of the data we note that SVT and UUW are showing increasing divergence from the trend lines. This seems to be due to legitimate changes in capital maintenance expenditure. This could cause challenges for Ofwat when building models.

- There was little supporting evidence for AVE’s assertion that ‘% load in bands 1-3’ was an appropriate factor for use to explain economies of scale. While there are clear economies of scale at the small works level the related costs do not, on their own have a material impact on the overall cost curve. And while SWT’s high unit costs may relate, at least in part, to the very high proportion of small works, it equally relates to not having many big works.

- Our review of the strategic relationship between consent types and costs showed the benefit of consideration of ammonia load removed for the wider industry dataset – something less evident in SVT’s dataset due to the high degree of ammonia removal required.

We did not accept AVE's assertion that asset level metrics should be used because the coefficients of two of Ofwat's main metrics - load squared and density - are not consistent. One of the reasons for the inconsistent coefficients is poor quality of Ofwat's density measure – we have shown that it is possible to identify alternatives. We believe that a good density measure may introduce all the necessary rural/urban bias needed to produce high quality models.

We considered the potential of other factors to explain material differences in costs. In some cases, there is limited available data (surface water drainage, infiltration), however, we concur with the AVE assessment that these are unlikely to have a material effect on any single company.

We considered other factors not mentioned by AVE. We found that there was a material relationship between network costs and treatment costs – and that observed economies of scale in the treatment function may be offset by additional network costs incurred as the treatment function is grossed up.

We considered SEMD costs (for which there is data on capex costs only) and concluded that that these were unlikely to have a material effect on reported costs – and were best dealt with through the special factor regime. Further observations are summarised in Appendix B.

JACOBS

Appendix A Data sources, assumptions and abbreviations

A.1 Data sources

Document title	Document name	Type
Project Update- Ofwat Waste Water	240117 CAWG Deck Final (vividarup)	Powerpoint presentation
ARR16 STW categorisation	ARR16 STW categorisation (to Jacobs)	Excel spreadsheet
Waste OPEX PE and permit data	Waste OPEX PE and permit data (tidied-raw data)	Excel spreadsheet
Master waste hc	Master waste hc 20161221	Excel spreadsheet
Appendix 3	pap_tec 1402 Feeder Basic Cost Appa Sewerage	Excel spreadsheet
PR14 Data	PR14 Data	Excel spreadsheet
SVT 2016 wastewater cost modelling submission (including resubmissions)	SVT 2016 wastewater cost modelling submission (including resubmissions)	Excel spreadsheet

A.2 Assumptions

- **Load incoming** or **load received** and population equivalent, PE, are the same: PE is calculated from BOD using the assumption that 60g of BOD is equivalent to one PE or equivalent nutrient (ammonia, phosphorus) per capita loadings.
- Where we calculate **load removed** or **load treated** we also consider the load outgoing in final effluent by using the works license (a fraction of the 95%ile limit) and the works average measured flow data. We use load removed as terminology in this report.
- Sludge treatment considerations do not form part of this scope of work.
- All general wastewater treatment technical notes and figures are based on Jacobs' experience in the industry, from Severn Trent design guides, where relevant or from literature sources, where quoted.
- The SVT dataset provided for wastewater treatment assets as per document *Waste OPEX PE and permit data (tidied-raw data)* and contains operational (opex) costs only. Whilst discussion of potential capital and capital maintenance cost considerations is made in this work with regards to the Industry datasets, analysis of the SVT dataset is on an opex basis only.

A.3 List of acronyms and abbreviations

ASP	Activated sludge plant
AVE	Arup Vivid Economics
BAFF	Biological aerated flooded filters – type of tertiary process, not used by SVT
BOD	Biochemical oxygen demand (P)
Botex	Base operational expenditure plus base capital maintenance expenditure
Capex	Capital expenditure
DWF	Dry weather flow

FtFT	Flow to full treatment
NH_3	Ammoniacal Nitrogen, Ammonia, NH_3-N
Opex	Operational expenditure
P	Phosphorus – referring to Total Phosphorus
PE	Population Equivalent
RBC	Rotating biological contactor –naturally aerated secondary biological process, typically package plant at smaller works
SAF	Submerged aerated filter –mechanically aerated secondary biological process, typically package plant at smaller works
STW	Sewage Treatment Works
SVT	Severn Trent Water
TSS	Total suspended solids
Totex	All expenditure
WaSC	Water and sewerage company

Appendix B Supporting analysis – industry expenditure

This appendix includes the annual expenditure vs load charts for both the PR14 and the 2016 datasets. In each case we have highlighted SVT (red), Anglian (turquoise) and South West (orange).

B.1.1 2011 to 2016 Opex vs population equivalent charts

The charts show average annual opex per population equivalent for each year from 2011 to 2016.

Figure B-1 : 2011- 2012 treatment opex vs PE

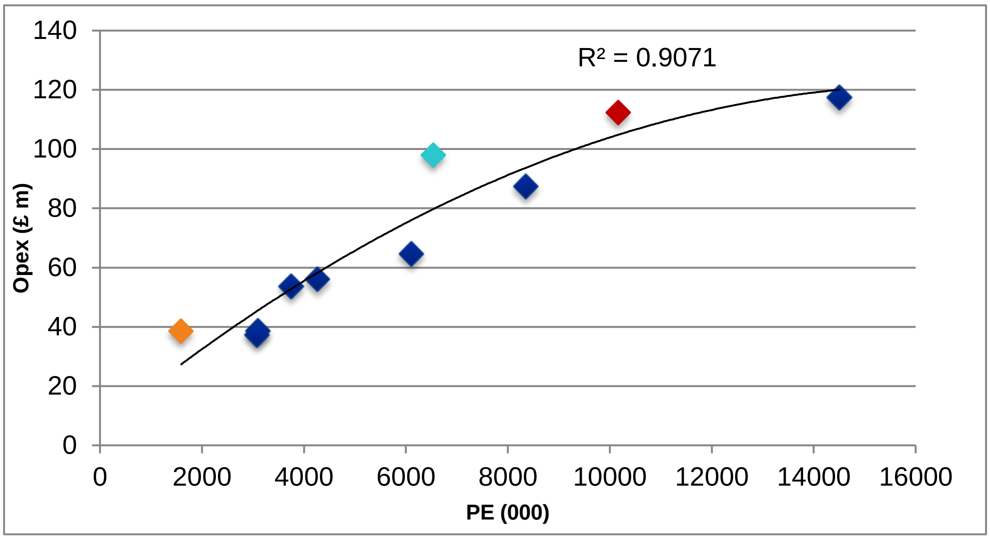


Figure B-2 : 2012- 2013 treatment opex vs PE

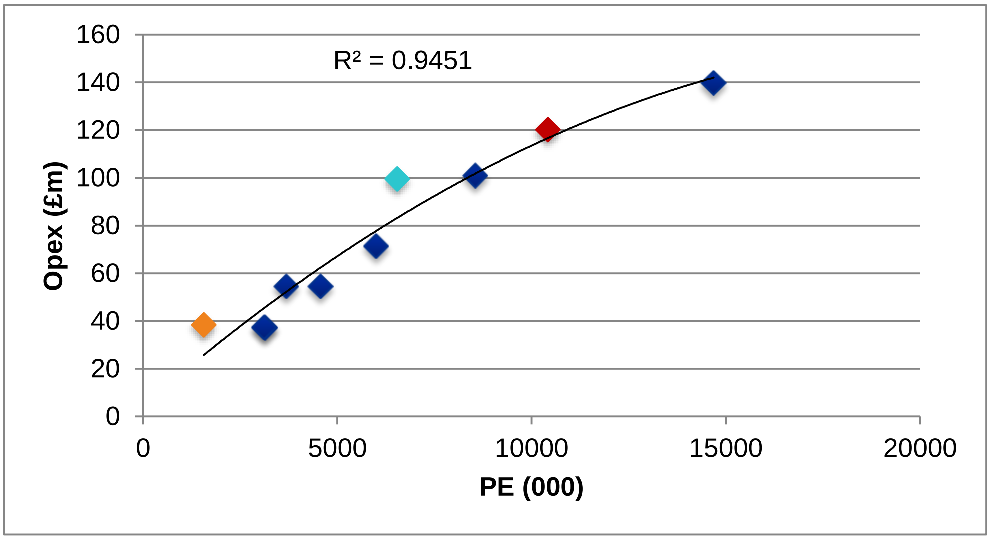


Figure B-3 : 2013- 2014 treatment opex vs PE

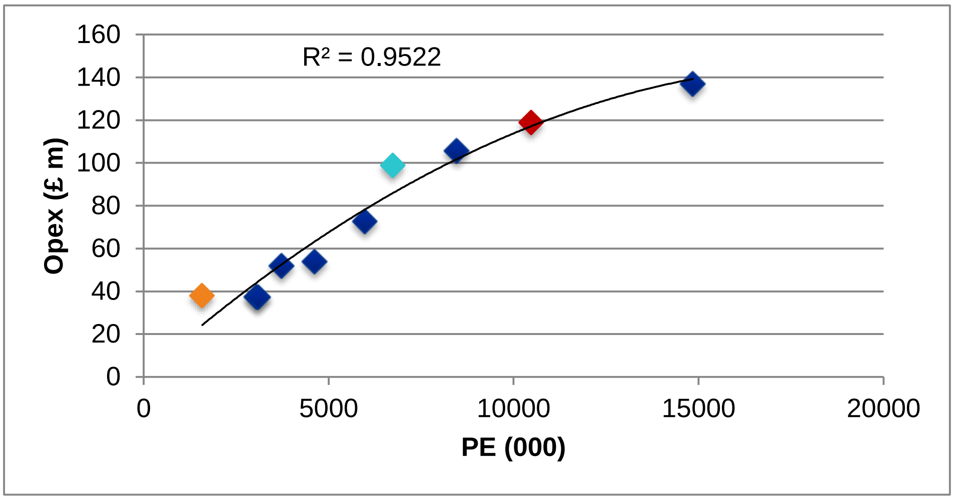


Figure B-4 : 2014 - 2015 treatment opex vs PE

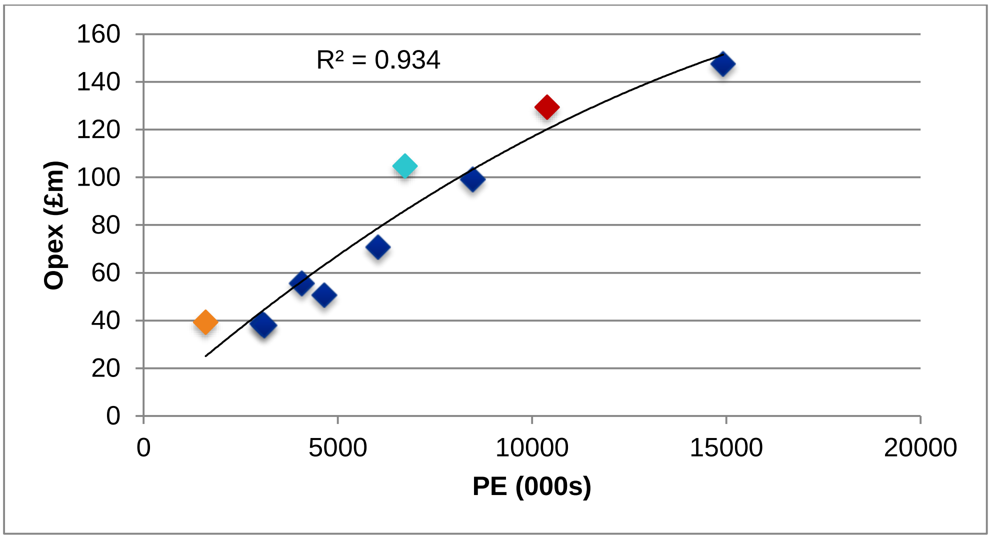
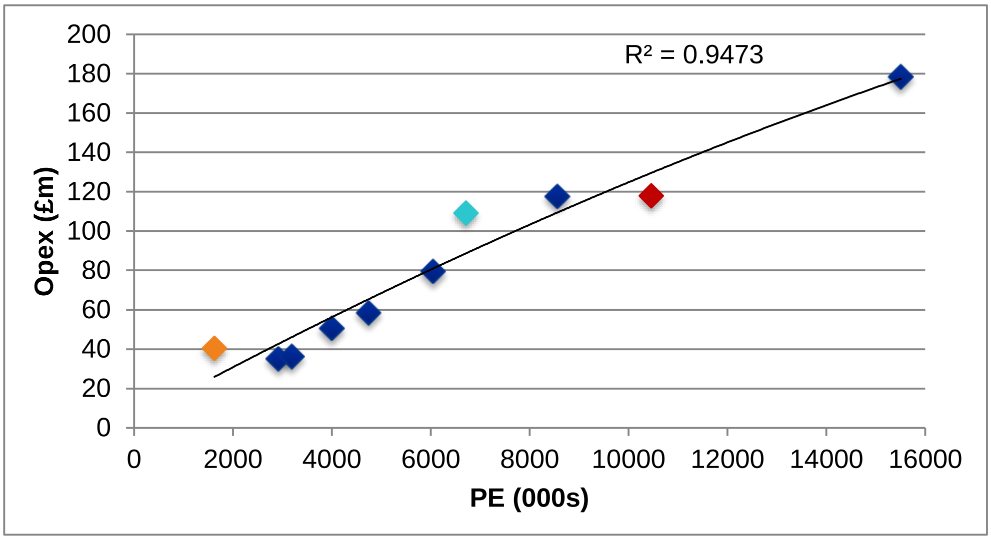


Figure B-5 : 2015 – 2016 treatment opex vs PE



B.1.2 2011 to 2016 Treatment botex vs population equivalent charts

The charts show the average annual botex (opex plus capital maintenance expenditure) per population equivalent for each year from 2011 to 2016.

Figure B-6 : 2011-12 Botex vs PE

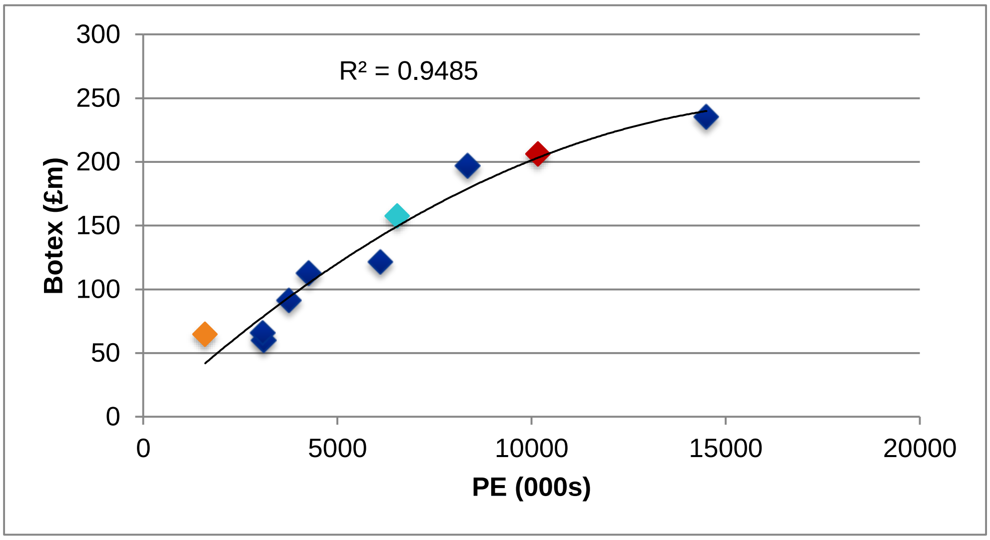


Figure B-7 : 2012-13 Botex vs PE

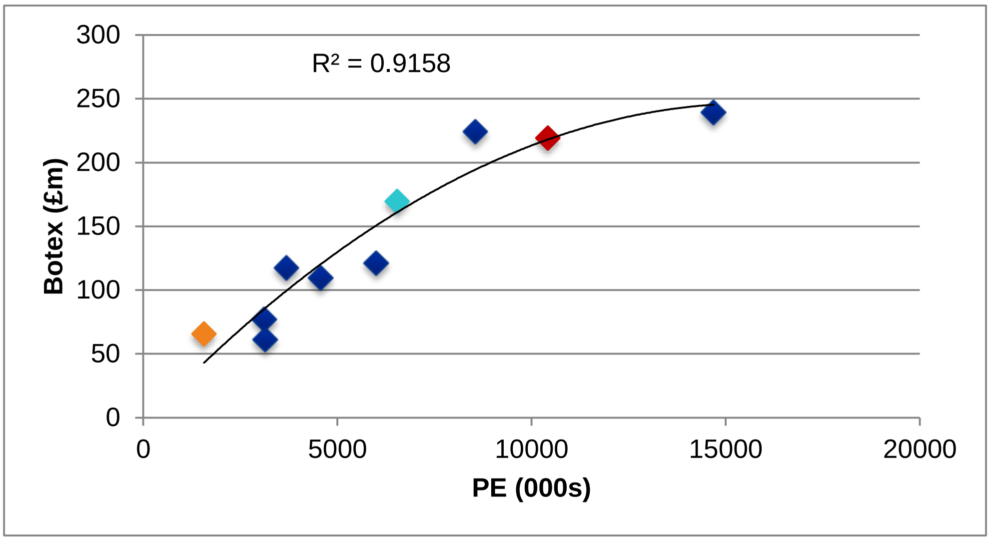


Figure B-8 : 2013-14 Botex vs PE

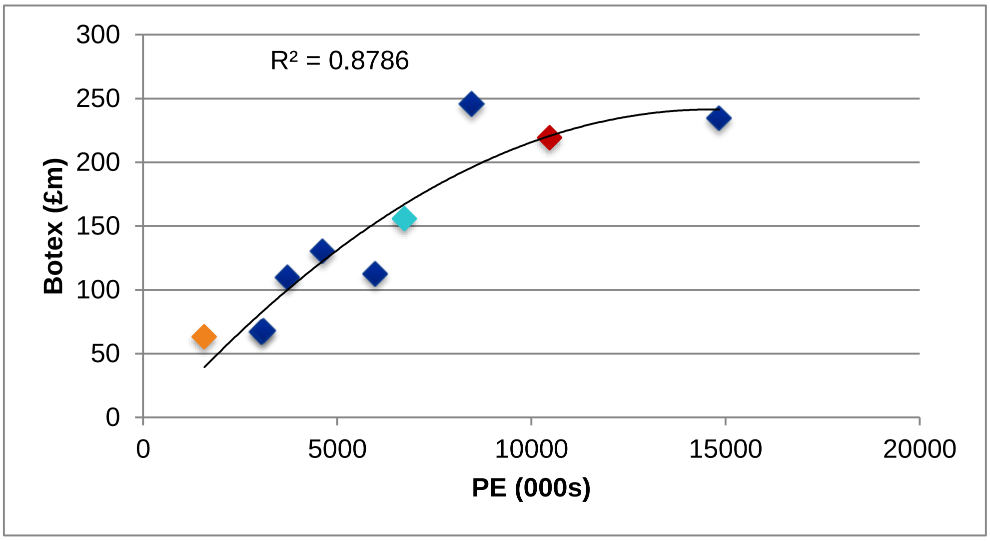


Figure B-9 : 2014-15 Botex vs PE

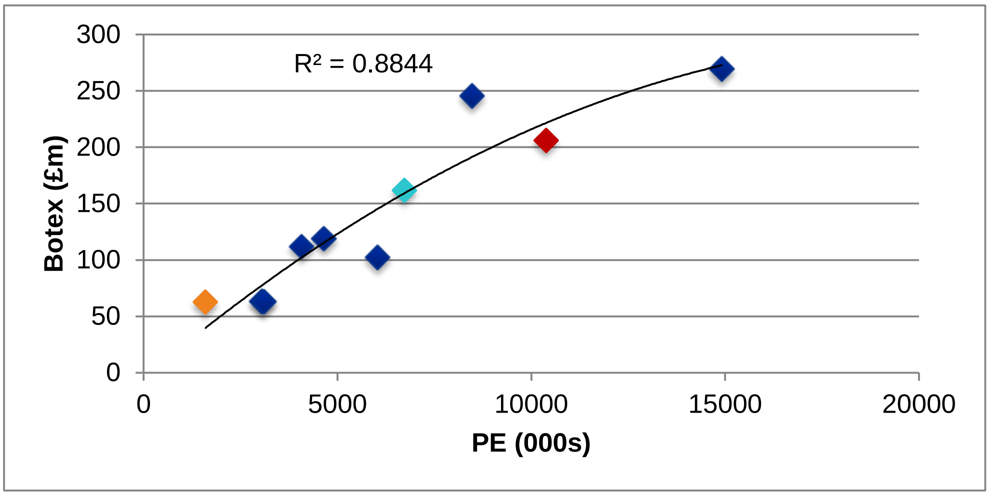
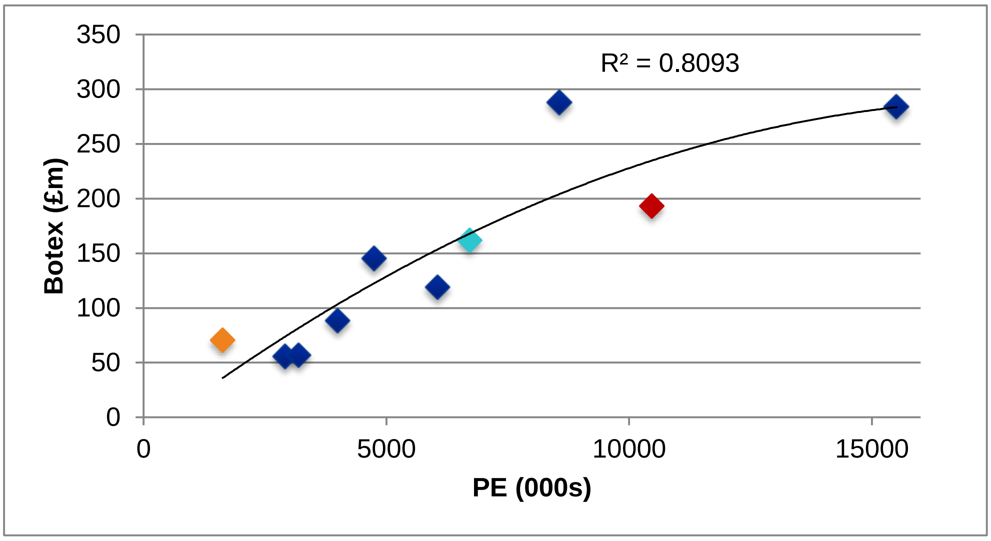


Figure B-10 : 2015-16 Botex vs PE



B.1.3 2011 to 2016 Treatment totex vs population equivalent charts

The charts show the average annual totex (operating expenditure, capital maintenance expenditure and capital enhancement expenditure) against population equivalent for each water company from 2011 to 2016.

Figure B-11 : 2011-12 Totex vs PE

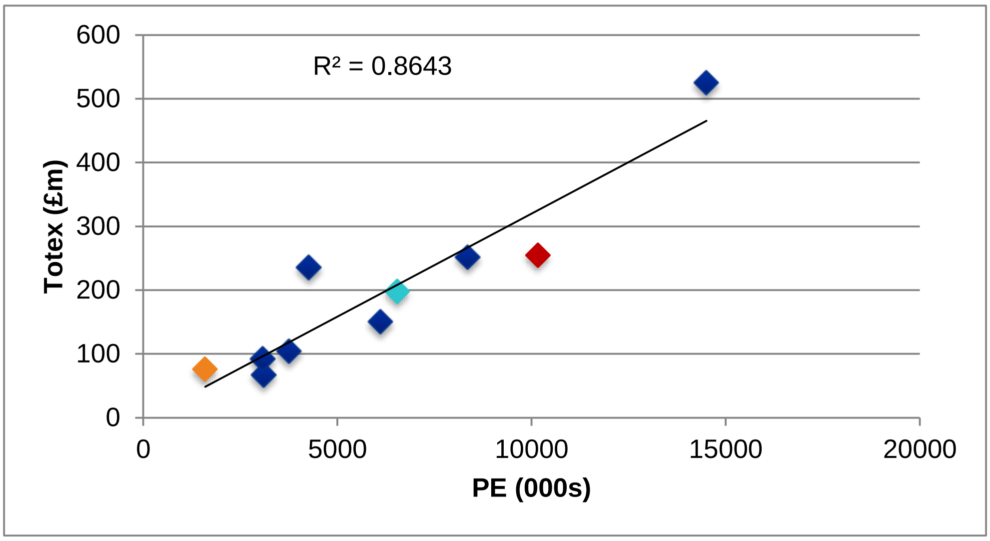


Figure B-12 : 2012-13 Totex vs PE

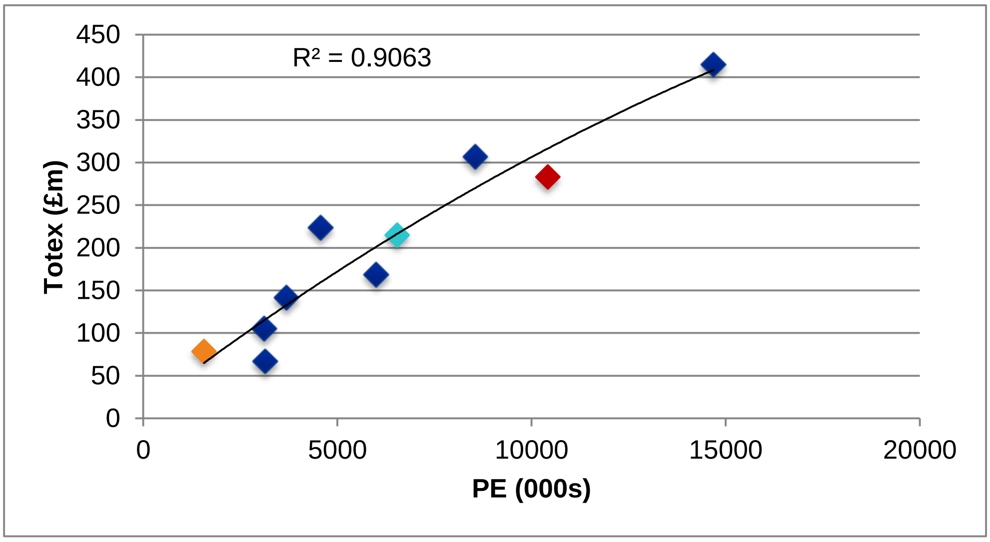


Figure B-13 : 2013-14 Totex vs PE

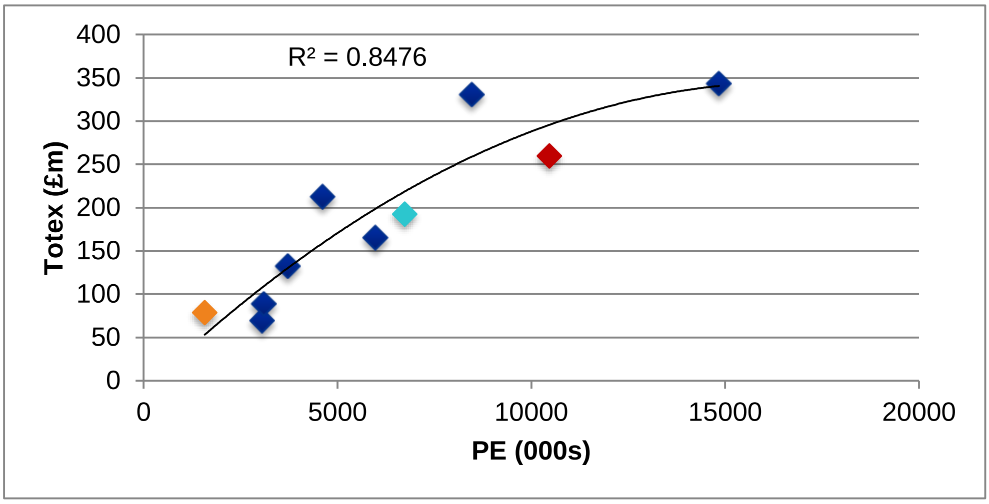


Figure B-14 : 2014-15 Totex vs PE

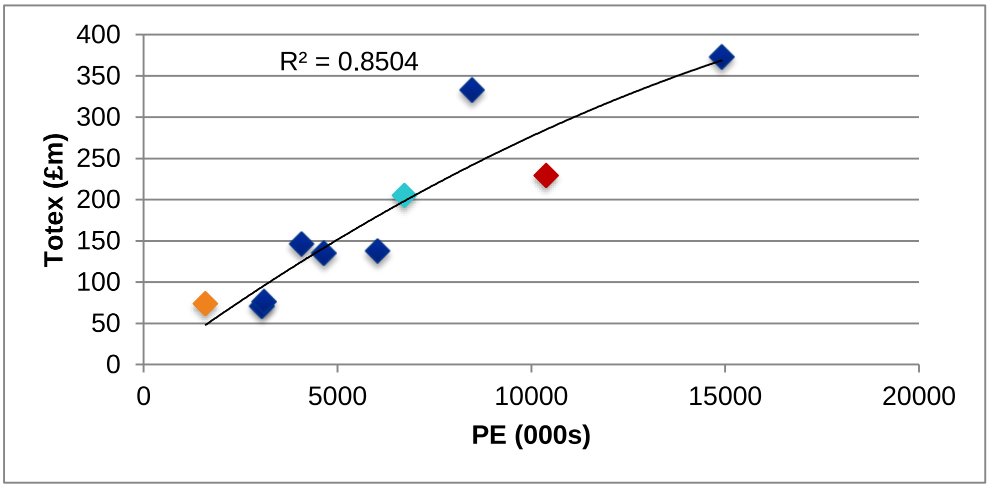
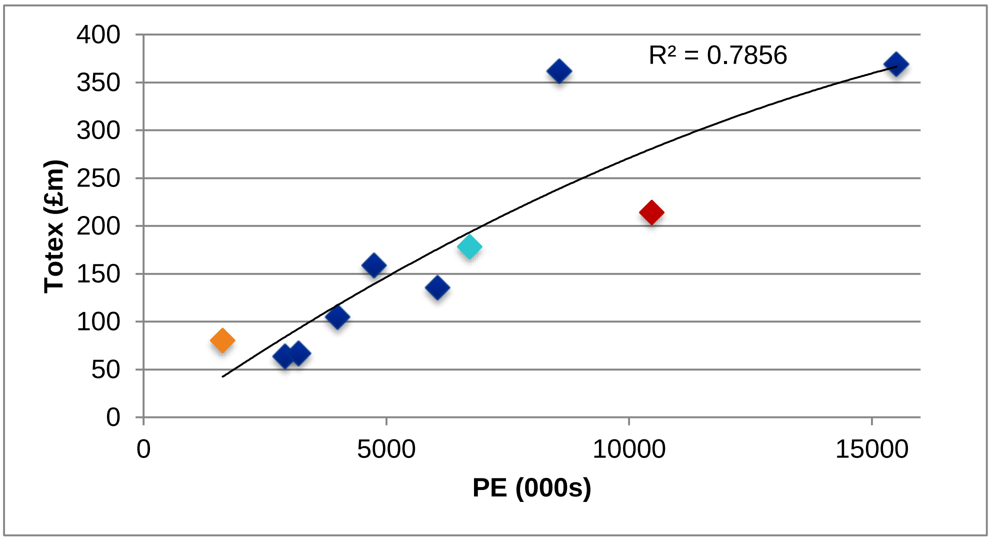


Figure B-15 : 2015-16 Totex vs PE



B.1.4 2007-14 Treatment opex vs load

The follow charts show the annual operational cost per load (kg BOD/day) for each year from 2011 to 2016.

Figure B-16: 2007-08 Treatment opex vs load

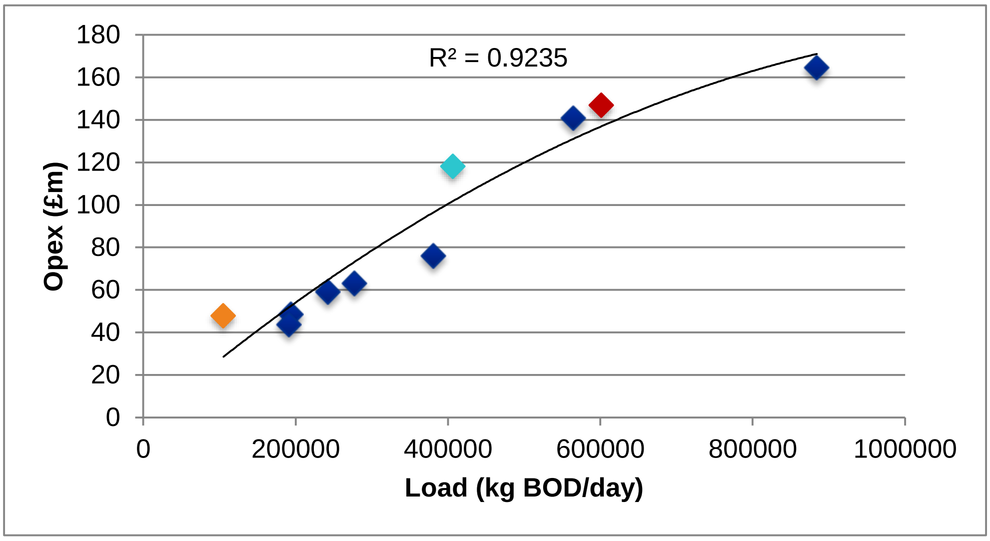


Figure B-17: 2008-09 treatment opex vs load

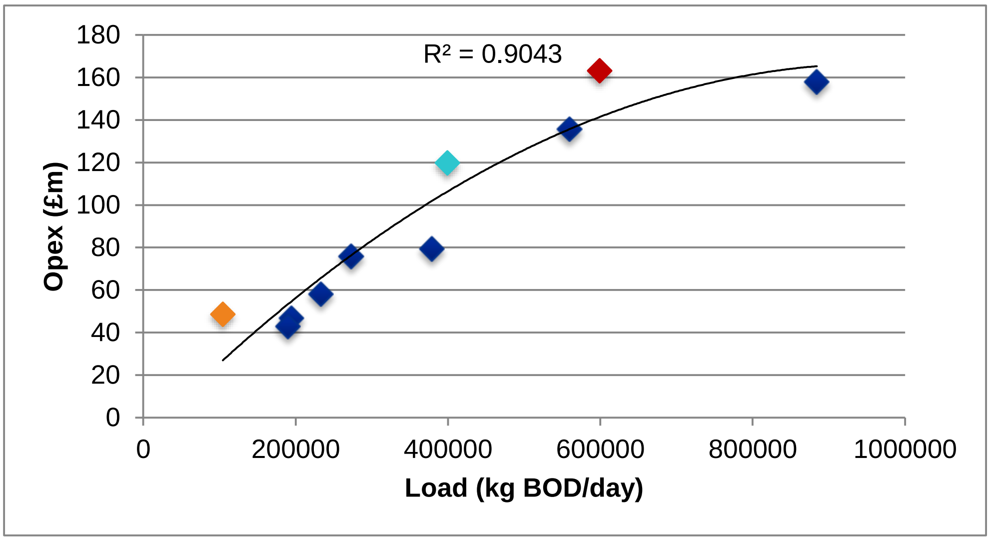


Figure B-18 : 2009-10 Treatment opex vs load

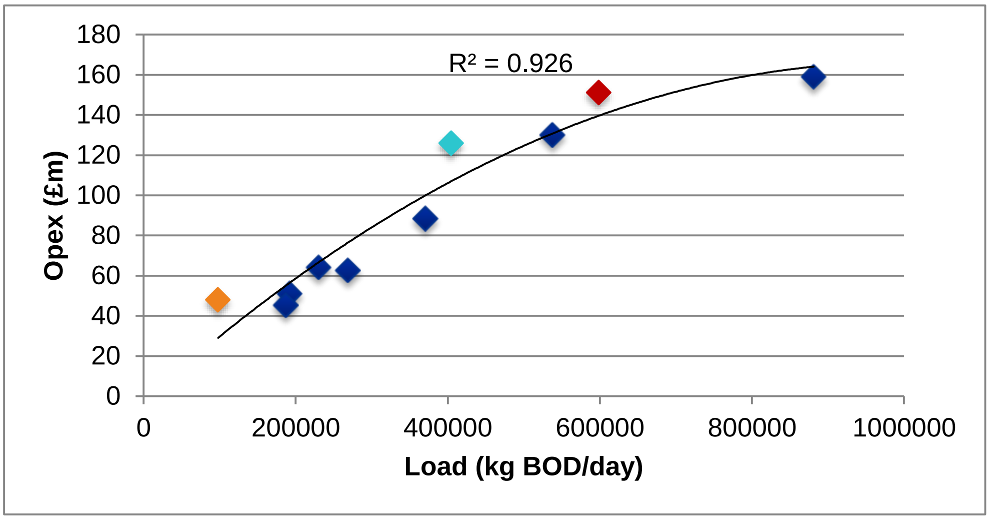


Figure B-19 : 2010-11 Treatment opex vs load

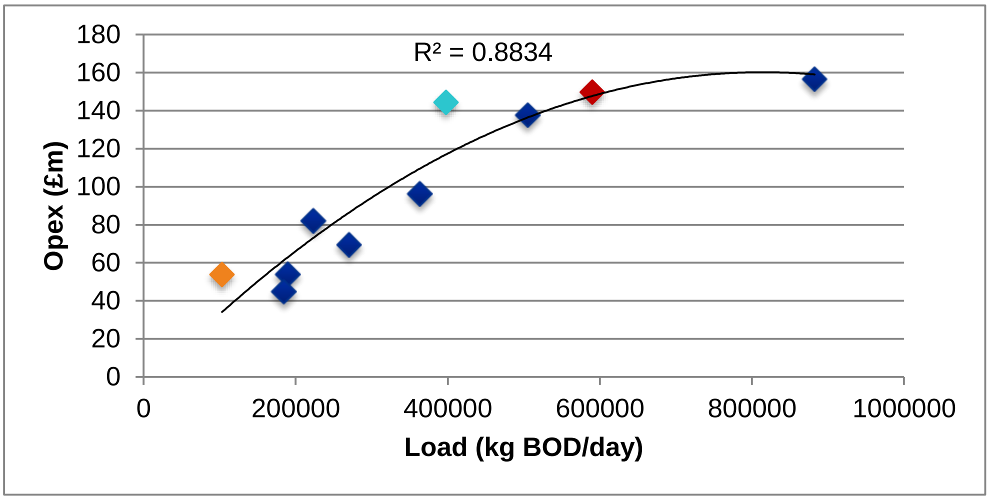


Figure B-20 : 2011-12 Treatment opex vs load

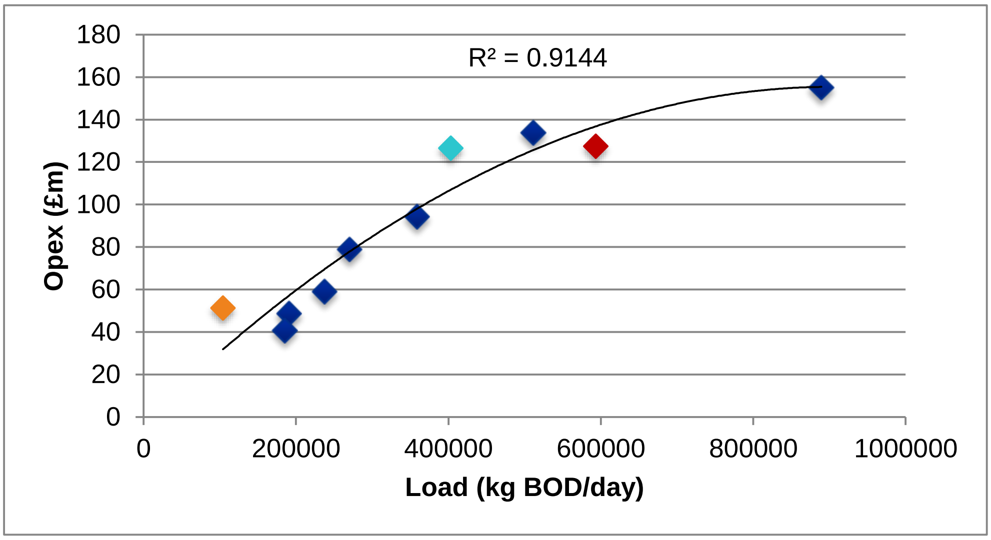


Figure B-21 : 2012-13 Treatment opex vs load

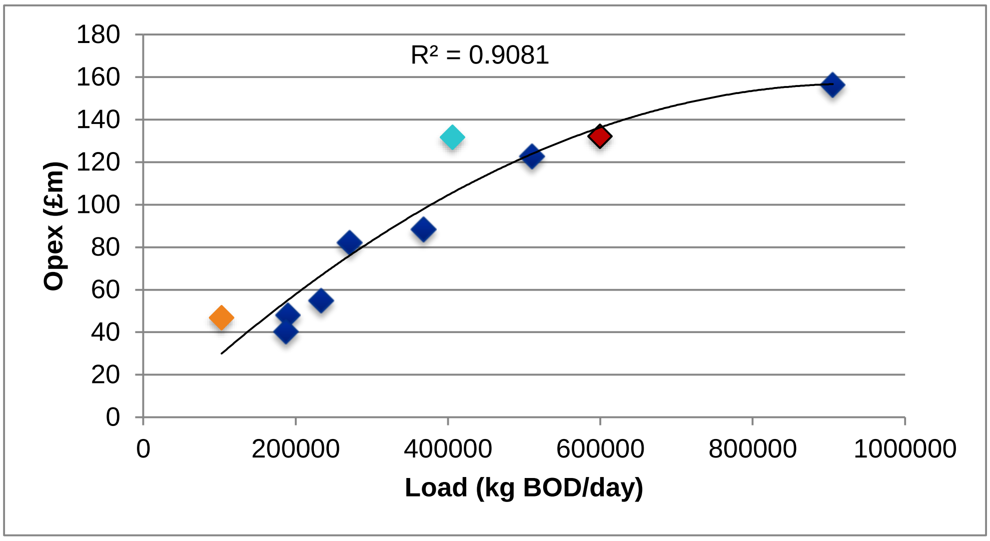
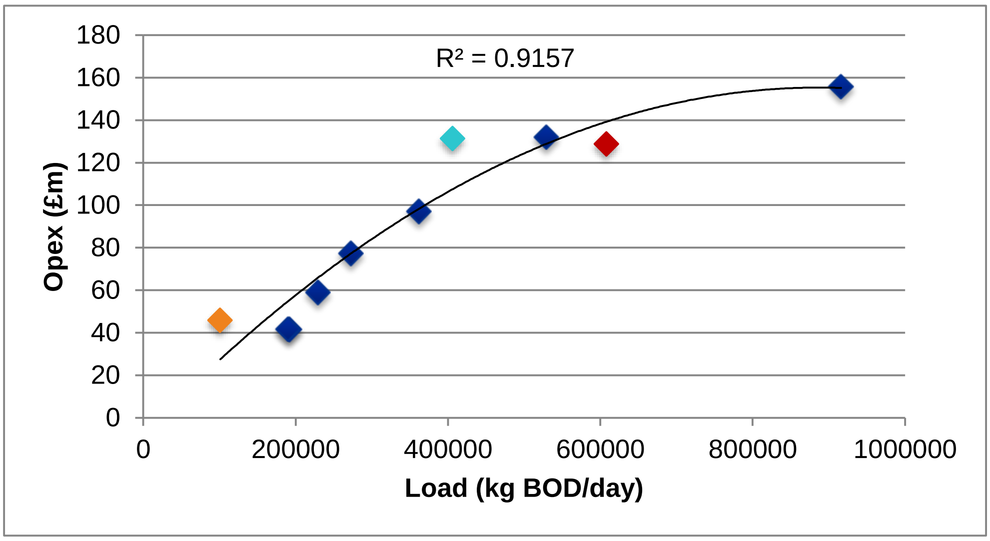


Figure B-22 : 2013-14 Treatment opex vs load



B.1.5 2007-14 Botex vs load

The charts show the average annual botex annual base capital plus operational expenditure per load (kg BOD/day) for each water company from 2011 to 2016.

Figure B-23 : 2007-08 treatment botex vs load

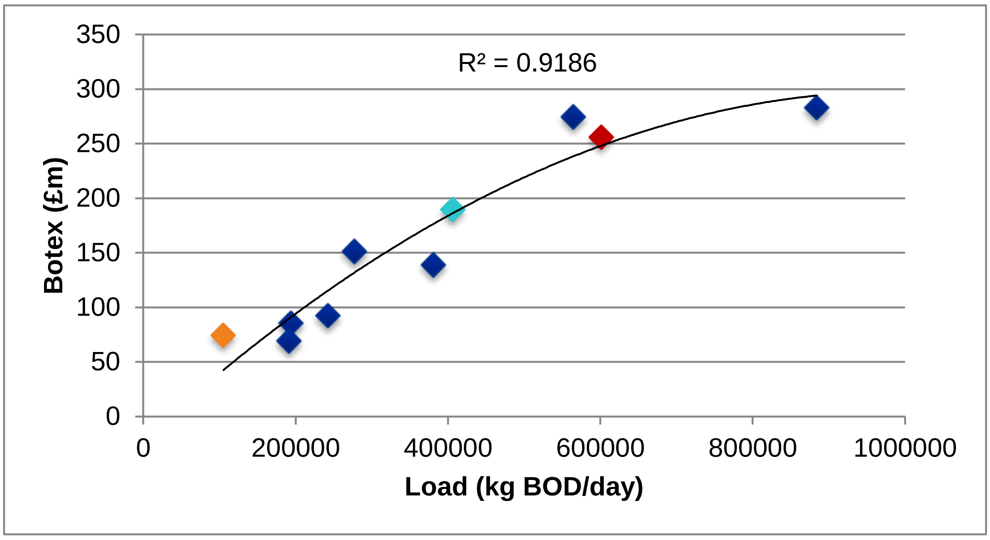


Figure B-24 : 2008-09 treatment botex vs load

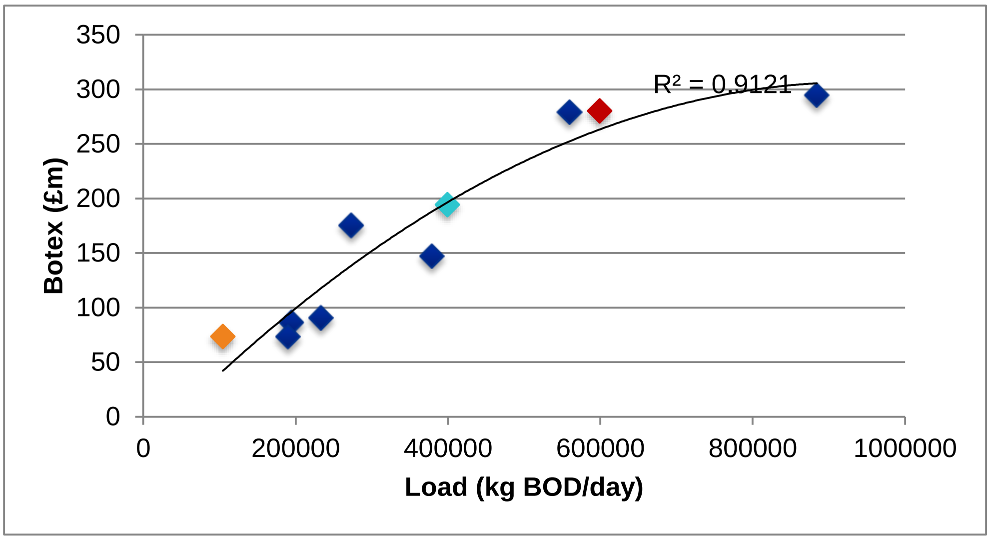


Figure B-25 : 2009-10 treatment botex vs load

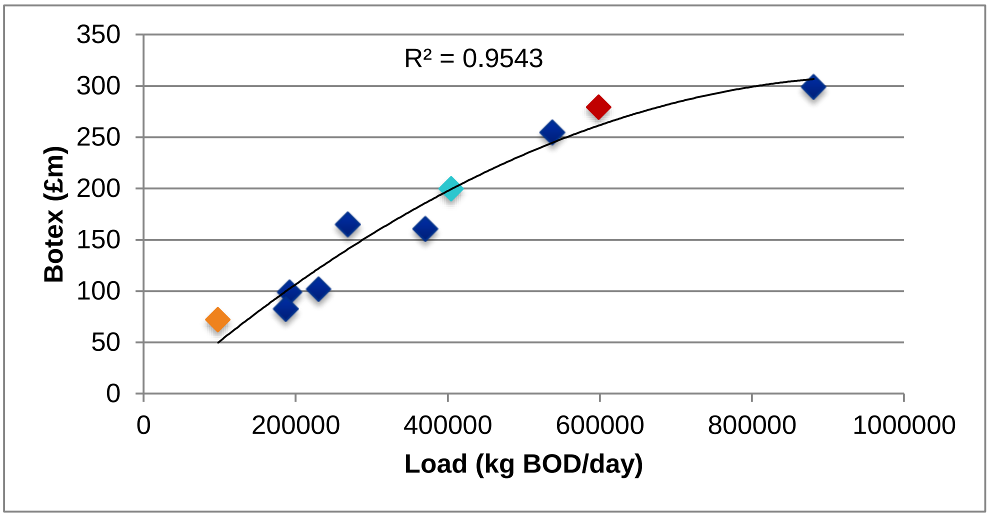


Figure B-26 : 2010-11 treatment botex vs load

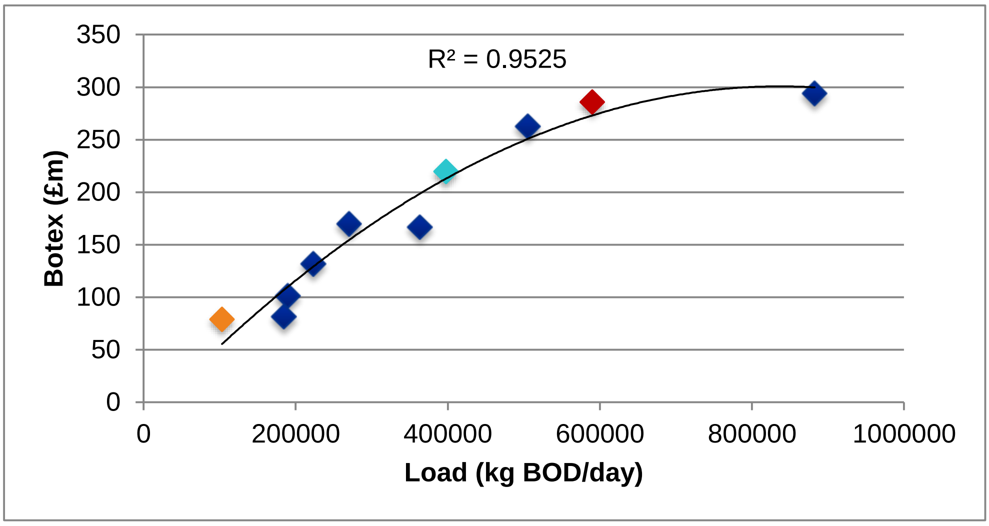


Figure B-27 : 2011-12 treatment botex vs load

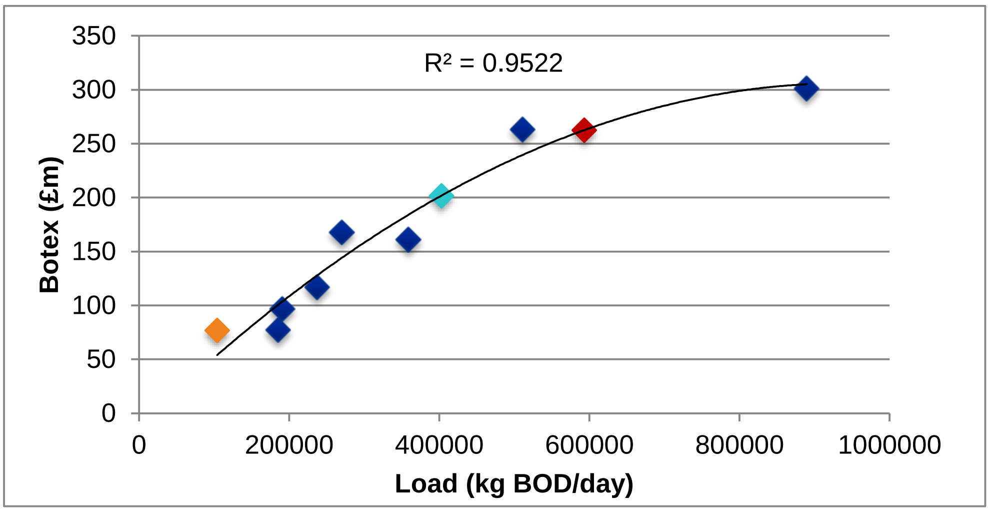


Figure B-28 : 2012-13 treatment botex vs load

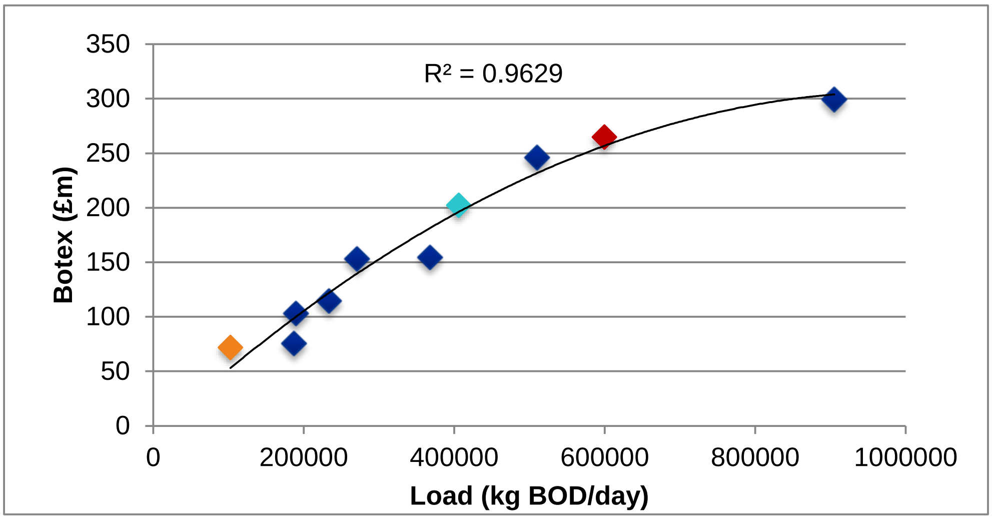
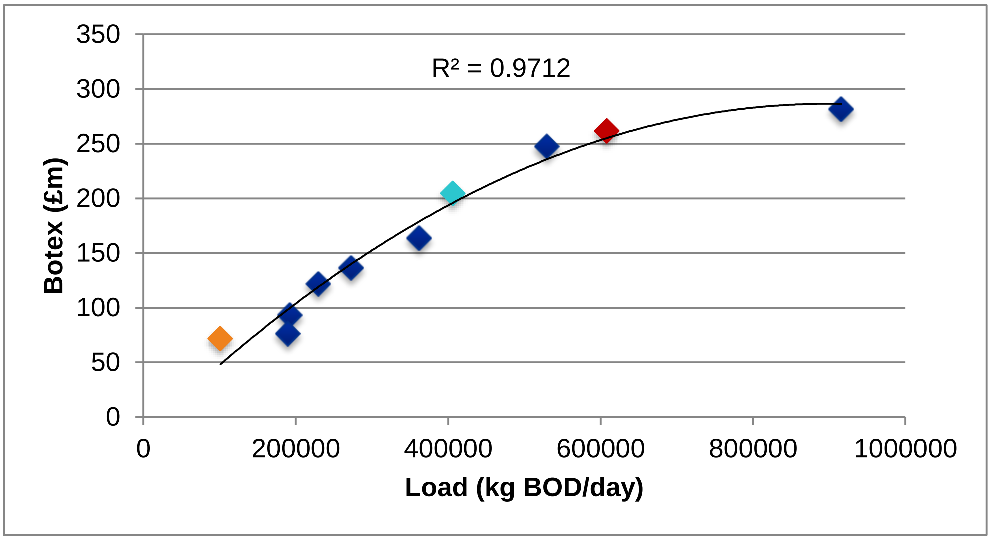


Figure B-29 : 2013-14 treatment botex vs load



Appendix C Supporting analysis for section 3

C.1 Deep dive analysis

C.1.1 Further investigation and deep dives

The purpose of deep dive analysis was to provide supporting commentary and examples for the high-level hypotheses and analysis undertaken for the SVT wastewater assets operational cost dataset:

- Poor correlation between operational cost and load removed is evident in lower bands given the variety in process type and consent stringency. Some correlation is apparent in bands 3, 4 and 5 but this still exhibits a high degree of scatter.

- The stringency of works consent would be expected to drive costs and show differences between nitrifying (ammonia and BOD) and carbonaceous (BOD only) works.

- Fixed film processes would be expected to offer operational power and overall operational cost savings compared with more energy intensive processes.

- Economies of scale in treatment indicated by SVT assets dataset would be evident across the deep dive band sites.

- Band 6 should offer a more aligned dataset with lower operational unit costs.

To support work in Section 4, the degree of infiltration and inflow where possibly was investigated as a potential cost driver or explanatory factor.

As previously discussed, we would expect to see variation within operational costs within treatment bands for reasons including:

- Different consent types – the need to remove ammonia or not, to provide BOD and/or TSS reduction or phosphorus removal which will necessitate variation in operational costs for power, chemicals, pumping, resources. More stringent versus mid-range or low ammonia standards would be expected to result in operational cost differences.

- Different process types – e.g. historic considerations which saw land intensive, low tech processes (like percolating filters) provided to meet quality drivers versus modern higher energy, lower footprint processes (like activated sludge treatment, or package SAF plants). The need for mechanical tertiary filters downstream of existing filter works would be expected to drive their costs up though not to the level of an ASP works. An ASP works would be expected to have a higher unit operational cost than biological filter works with otherwise similar characteristics.

- Site and region specific issues – e.g. hydraulics, location, site specific infiltration or inflows, regional population characteristics.

Whilst the industry available dataset does not allow such detailed comparison it is useful to help support the SVT dataset.

C.1.2 Overview of sites selected

Sites were selected randomly. Appendix A shows their position on correlations presented previously and geographical location. The following sections provide a summary of the deep dive analysis and commentary. Acronyms not used previously for process type are as follows: BF – biological filter, RB – reed bed, Ox – oxidation ditch, TC – tertiary clarifier, SF – sand filter. Consent limits are given as 95%Ile values of BOD/NH3/TP. Opex costs for manpower, chemicals and power only are summarised.

We start with a detailed analysis of band 6 where the overall SVT dataset gave best correlations.

C.1.3 Band 6 analysis

Band 6 comprised a random sample of works from approximately 25,000 PE to 260,000PE. All works had total phosphorus and ammonium standards with ammonia requirements ranging from 3mg/l (Ray Hall STW) to 20mg/l (Stratford-Milcote STW).

In line with the wider band 6 dataset, the random selection offered a representative mix of activated sludge and biological filter works. Only two of the works had tertiary filtration stages; one a modular sand filter and the other an RGF. All works had ammonia and phosphorus standards but two of the works had relatively relaxed >15mg/l ammonia limits.

Table C-1 : Deep dive summary Band 6

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	Chem/PE £/PE	BF	ASP	Sand filter	Lag.
Brancote	73,800	25/5/2	569,986	£7.72	£1.99	£3.82	£0.95	x		x	
Earl Shilton	25,237	15/5/2	111,602	£4.42	£1.47	£2.30	£0.44	x			
Lichfield	37,243	24/17/2	270,360	£7.26	£1.57	£3.67	£1.12	x			
Lower Gornal	34,479	25/10/2	255,293	£7.40	£1.29	£3.21	£2.87	x			
Nuneaton-Hartshill	96,892	15/10/1	841,879	£8.69	£3.52	£2.99	£0.82		x		
Ray Hall	111,416	25/3/1	560,524	£5.03	£1.79	£1.77	£1.45	x			
Roundhill	262,768	10/5/1	1,404,525	£5.35	£2.54	£1.64	£0.88		x		
Rushmoor	117,807	15/5/1	833,979	£7.08	£3.41	£2.59	£0.70		x		x
Stapleford-Bessel Lane	27,785	15/5/2	200,083	£7.20	£2.62	£3.07	£0.80		x		
Stratford-Milcote	34,203	45/20/2	189,967	£5.55	£1.21	£2.43	0.93		x		

Operational costs ranged from £4.42/PE (25,000 PE Earl Shilton biological filter works) to £8.69 (Nuneaton-Hartshill ASP - 97,000 PE).

The selection offered a good basis for comparison of **activated sludge** versus **biological filter** type works, all with chemical P removal and only one site (Brancote STW) with an energy intensive tertiary sand filter.

As would be expected, activated sludge works had higher operational energy costs than filter works with on average 55% lower operational power costs between pairs of sites which were otherwise the same size and license but only different in treatment process – e.g. **Stapleford-Bessel Lane STW** and **Earl Shilton STW** and **Ray Hall STW** and **Rushmoor STW**. Overall operational costs for filter works were 60-70% of ASP works.

As would be expected, works with less stringent ammonia standards required less total opex and power opex than those with more stringent standards – with **Stratford-Milcote STW**, a 20mg/l ammonia ASP works having almost identical operational costs to the much larger **Roundhill STW** ASP at 263,000 PE with 5mg/l ammonia limit.

Surprisingly, Stratford-Milcote also shows 23% lower power operational costs than the similarly sized **Lichfield STW** which also has a relatively relaxed 17mg/l standard and is a biological filter works. Assuming minimal trade effluent flows and load the reason for this cost differential which would expected to be in favour of a filter works may be due to **base infiltration** which is estimated 100%PG for Stratford-Milcote and approximately 40%PG for Lichfield using actual 2016 DWF and connected PE. The increased infiltration and more dilute sewage may mean that less nitrification (and operational power) is required given less ammonia reduction is necessary. Whilst higher levels of infiltration will necessitate more pumping and larger structures when enhancement is taking place, the dilution that results would be expected to result in operational cost savings in aeration.

Chemical costs, which would be expected to be relatively similar on a PE basis ranged from £0.44/PE to £2.87/PE for works with 2mg/l standard and £0.7/PE and £1.45/PE for works with 1mg/l TP standard. Actual phosphorus compliance varied with clear differences in control philosophy and compliance. Generally chemical costs for activated sludge works were lower than for biological filter works which would be expected with increased biological uptake in ASP biomass the variation suggests opportunities to investigate optimisation of chemical dosing plant.

Manpower costs vary considerably between STWs even where these would appear to be very similar in process type and size.

Nuneaton-Hartshill STW stands out with the highest power and operational cost despite a relatively relaxed 10mg/l ammonia standard. This could be due to site hydraulics, aeration control or other issues and may indicate there are opportunities for operational efficiencies.

8 out of 10 sites were meeting ammonia levels well below the SVT standard 50% of the lower tier license limit. This may indicate opportunities to challenge existing operational control and set points to enable opex savings via treatment optimisation.

We see evidence of works with otherwise similar consent levels but different process types exhibiting expected variation in operational cost to treat.

Brancote STW (74,000PE) for example has a cost to treat of £7.7/PE as compared with **Earl Shilton STW's** £4.4/PE (25,000PE). Both sites have a similar consent requirement (Earl Shilton is more stringent (15/5/2) but Brancote (20/5/2) has a modular sand filtration stage). As expected, Brancote's energy costs are higher than all other biological filters works which would be expected to be attributed to the sand filter which would receive pumped flows and require backwash. Power costs are 25% lower and it is likely modular sand filters accommodate for a significant portion of this.

Despite having the same P standard, Brancote's chemical costs are double those of Earl Shilton which would not be expected. With additional tertiary filtration stage and more chemical usage, it is perhaps not surprising that Brancote's operational man-hour costs are also higher than Earl Shilton operational man-hour costs although given the works is 3 times the size of Earl Shilton the man-hour costs appear high.

Nuneaton-Hartshill STW is a 96,000PE activated sludge works with mid-range ammonia standard of 10mg/l which shows higher energy process and cost to treat of £8.7/PE and a power cost of >2.5 times the above biological filter works and 1.75 times the biological filter + sand filter Brancote despite having a much more relaxed ammonia standard. When compared with **Rushmoor STW,** a similarly sized ASP plant with a more stringent ammonia standard of 5mg/l, Nuneaton-Hartshill still has significantly higher operational costs and appears to have a larger fraction of costs in Materials and Hire & Contracted Opex costs; reasons for which haven't been assessed as part of this analysis.

Ray Hall STW is a large 111,111PE filter works which has a slightly tighter ammonia standard of 3mg/l than above. Overall, operational cost is a lot lower at £5/PE compared with the smaller size filter works though operational power costs slightly higher than the 5mg/l filter works; lower than the works with modular sand filter and significantly lower than the activated sludge process as would be expected. This size works appears to exhibit economies of scale we don't see in the smaller works.

Roundhill STW at 263,000PE is an ASP and has cost to treat of £5.4/PE. At almost twice the size of Ray Hall STW this works has a similar cost to treat – likely an economy of scale as other factors are reasonably similar.

C.1.4 Band 5 analysis

Band 5 sites were reasonably representative of our understanding of typical SVT treatment types in Band 5. The highest operational costs are associated with the treatment types we might expect – ASP and RBC as compared with BF works. The one BF site with a sand filter, **Edwinstow STW** has an extremely high chemical usage cost per PE which drives up total Opex and would be worth investigation given a directly comparable site in **Branton STW** with very similar PE, consent level (actually more stringent) and same process uses a quarter of the chemical per PE. Manpower is variable across process types – with the most expensive sites **Codsall STW** and **Powick STW** an ASP/BF and BF works respectively.

Table C-2 : Deep dive summary Band 5

Site	PE	Consent BOD/NH4/TP	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	Cheml/PE £/PE	BF	ASP	RBC	Sand filter	Ox
Ashbourne	19,310	25/10	11.94	4.53	5.3	0.21			X		
Branton	21,294	20/5/2	8.56	2.46	3.6	0.89	X			X	
Brockhampton	16,288	15/5	10.66	4.17	4.7	0.14		X			
Codsall	13,383	20/5	11.27	2.75	8.3	0.15	X	X			
Edwinstowe	18,258	25/10/2	10.55	2.27	4.0	3.60	X			X	
Little Aston	23,025	20/10	5.76	1.44	3.9	-	X				
Market Drayton	12,017	10/5/2	14.53	6.96	5.0	1.15		X			X
Powick	11,651	25/20	12.82	1.51	8.0	0.95	X				

C1.5 Band 4 analysis

Band 4 appears to offer the greatest uniformity in secondary process type from the overall SVT dataset and we see that 7 out of 10 selected sites are biological filter works, 2 of these with reed beds which whilst unlikely to impact on opex power cost can impact significantly on operational manpower cost depending on how this is accounted[23]. We see significant variation in opex costs for otherwise similar sites (e.g. **Baschurch, Bottesford** versus **Kirton-In-Lindsey**) which we cannot explain without more site specific analysis.

Table C-3 : Deep dive summary Band 4

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	ChemI/PE £/PE	BF	ASP	RBC	Sand filter	RB
Baschurch	4,668	20/5	78,841	16.89	5.68	10.67		X			X	
Bottesford	3,894	20/5	61,158	15.71	1.80	12.1		X				X
Bramcote	2,110	15/5/2	33,701	15.97	3.65	9.8	1.29			X		X
Kirton-In-Lindsey	3,259	20/5	19,594	6.01	1.15	4.9		X				
Long Whatton	2,443	20	37,158	15.21	2.61	10.7		X				
Longhope	3,660	10/3	81,637	22.31	7.03	10.3	2.3		X			
Marchington	2,616	10/5	60,049	22.96	2.91	18.0		X				X
Mattersey Thorpe	6,007	25	57,626	9.59	1.00	5.6	2.52	X				
Ripley	8,606	15/5	104,432	12.13	4.99	6.7			X		X	
Shardlow	4,652	25/15	50,515	10.85	2.10	7.7		X				

C.1.6 Band 3 analysis

Band three comprised a mix of filter, ASP and RBC sites with a range of tertiary treatment, half of which were reed beds which would not be expected to be contributing any power opex. The two highest opex figures are ASP plants as we might expect; one of these, **Wychbold STW** has a 10mg/l ammonia standard and uses 3 times the power per PE of carbonaceous **Luddington STW** and **Misson STW**. A similarly sized biological and sand filter site, **Scarcliffe STW,** which also has a 10mg/l ammonia standard, uses around half the energy of the ASP **Wychbold**. Actual ammonia compliance is typically significantly below SVT asset standard requirements which for small plants would be expected – they will have little process control and scope for optimisation.

We again see a large range in chemical costs per PE between otherwise similar sites (**Ashover STW** and **Earlswood Springbook STW**).

Table C-4 : Deep dive summary Band 3

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	ChemI/PE £/PE	BF	ASP	RBC	SAF	SF	RB	TC
Ashover	675	15/5/2	23,687	35.10	8.76	22.61	2.46			X				
Avening	1,071	10/5	22,282	20.81	4.74	15.93				X			X	
Braithwell	1,104	20/5	30,559	24.40	5.05	15.70				X			X	
Earlswood Springbrook	1,929	15/5/2	55,270	28.65	4.56	15.43	5.67	X			X		X	

[23] Reed beds or constructed wetlands can incur significant maintenance costs on an intermittent basis and every 5-10 years m ay require substantial clean out and reconstruction to remove accumulated solids.

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	Cheml/PE £/PE	BF	ASP	RBC	SAF	SF	RB	TC
Holly Green Works	1,163	25	26,643	22.91	0.37	22.33		X					X	
Luddington	1,437	25	40,931	28.50	4.33	18.85			X					
Misson	578	25	22,567	39.00	4.79	30.79	3.02		X				X	X
Scarcliffe	1,303	20/10	35,365	27.14	6.15	16.02		X				X		
Tregynon	628	15/5	12,130	19.31	6.32	11.93		X				X		
Wychbold	1,641	20/10	64,121	39.10	12.34	23.56	0.27		X					

C.1.7 Band 2 analysis

There was no chemical usage across band 2 works randomly selected. RBCs dominate and most have reed beds. Excepting **Llandyssil STW**, similar sized RBC/reed beds have similar opex, power and manpower costs. Operational power costs, despite almost identical processes, consents and similar sizes, very from £2/PE through to £6.4/PE; reasons for this are unclear. Opex per PE ranges from £20-40/PE for all sites except the two biological filter sites which have very high costs of £150/PE. This is a very large factor difference and perhaps helps explain the high degree of scatter and lack of correlation in band 2.

Table C-5 : Deep dive summary band 2

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	BF	ASP	RBC	RB	Tert. Cl.
Chelmorton	305	40/5	5,307	17	6.36	11.04			X	X	
Headon Cum Upton & Askha	327	25	5,794	18	6.42	11.30			X	X	
Little Llandyssil	254	25/15	5,958	23	6.10	17.36			X	X	
Llandyssil	263	25	10,606	40	2.05	37.94			X	X	
Lower Strensham	255	25	38,425	151	32.35	97.01	X				
Ridge Lane-Mancetter	458	20/10	14,573	32	4.24	22.43			X	X	
Upper Arley	317	50	7,309	23	3.97	19.04			X		
Weston Underwood	259	25/15	38,797	150	12.09	127.34	X				
Willoughton	484	15	16,518	34	6.14	27.99		X			X
Yockleton	287	25	10,356	36	3.39	26.11			X		

C.1.8 Band 1 analysis

Band 1 works investigated 4 RBCs and 6 biological filter works. Operational costs per PE ranged from £27/PE for the largest **Aston Magna STW** to £140 for the smallest **Perthy Windy-Ridge STW** with just 21PE. Power costs ranged from £0/PE up to £40/PE – both small filter works. There is no correlation between carbonaceous versus nitrifying works but we would not expect to see much evidence of this at such a small scale and for catchments of these size, site specific factors and catchment population activities will have a significant impact on treatment.

Table C-6 : Deep dive summary band 1

	PE	Consent BOD/NH4/TP	Opex £	Opex/PE £/PE	Pow/PE £/PE	Man/PE £/PE	BF	RBC	RB
Aston Magna	226	25/15	6,032	27	5.23	21		X	X
Cannock - Four Crosses	56	75	5,333	95	8.15	81	X		
Gailey	85	90/15	2,819	33	3.33	30	X		X
Little Hucklow	53	40/5	5,683	107	10.81	96		X	X
Pebworth Middlesex	40	75	4,771	119	8.94	110	X		X
Perthy - Windy Ridge	21		2,932	140	48.83	86	X		
Putley Green	80	25/10	7,487	94	12.20	81		X	X
Rockhall Villas	25		1,123	45	0	45	X		
Walton Cottages	51		3,737	73	7.93	65	X		
Wyaston	148	25	6,046	41	4.11	37		X	

C.1.9 Summary

The deep dive analysis allowed the key hypotheses and expected cost drivers to be investigated and generally supported. It highlighted the benefit of site specific analysis and some key considerations which could be taken forward to provide more explanation around operational treatment costs – particularly around chemical costs for P removal which were highly variable even where expected to be relatively similar – and around manpower although this could also be a cost allocation issue.

Our observations are summarised below:

- **Consented versus actual DWFs**

  Some consented DWFs appear incorrect for actual measured Q90 and Q80. SVT could seek to challenge these – typically the EA uses them to calculate required license concentration limits so if a lower DWF is justified, it is possible that standards could be relaxed or a summer/winter consideration could be varied or at the least the conversation would provide evidence of SVT improving environmental water quality.

There are sites (e.g. Brancote WwTW – a 75,000PE filter, sand filter works with 20/5/2 BOD/NH3/TP standard) where it is apparent that the DWF has been challenged but now appears lower than the required flow in this instance).

- **Consent requirements versus actual works compliance**

  Opportunities may exist to undertake process optimisation within existing works to reduce operational aeration, pumping and chemical dosing costs. Many works assessed showed high levels of consent compliance well below the requirement to meet 95%ile compliance in line with SVT's asset standards. Optimisation of aeration, mixed liquor inventories, filter wetting rates and tertiary plant operation would typically be considered for treatment cost efficiencies.

- **Chemical P dosing**

  There may be an opportunity to optimise chemical dosing due to the observed variation in chemical consumption across banded sites which would not be expected to show such variation.

- **Man-hour variation between sites**

  There is significant variation in man-hour costs between similar sites as noted in the deep dive analysis. Given manpower is approximately 40% STW opex costs, this variation is worth further investigation. It could due to the way manpower is allocated within SVT regions and/or site specifics which we were not able to investigate as part of this work.

- **Site outliers, validity of data sets**

  Sites, where mentioned, which showed costs significantly higher than would be expected for the given works type and consent, could be investigated to assess whether this may be a technical issue or an issue with the data. Some sites had incomplete operational cost data.

C.2 Deep dive geographical and correlation positons

C2.1 Band 6 deep dive sites

For band 6 deep dive sites the following key is used to relate the sites to their respective position on the graphs. The graphs below exclude Minworth STW to avoid data being skewed.

Table C-7: Band 6 deep dive key

Site Tag	Site Name
○	Brancote (STW)
○	Earl Shilton (STW)
○	Lichfield (STW)
○	Lower Gornal (STW)
○	Nuneaton-Hartshill (STW)
○	Ray Hall (STW)
○	Roundhill (STW)
○	Rushmoor (STW)
○	Stapleford-Bessel Lane (STW)
○	Stratford-Milcote (STW)

Figure C-1: Band 6 deep dive site locations

Figure C-1 : Band 6 deep dive site positions with respect to ammonia

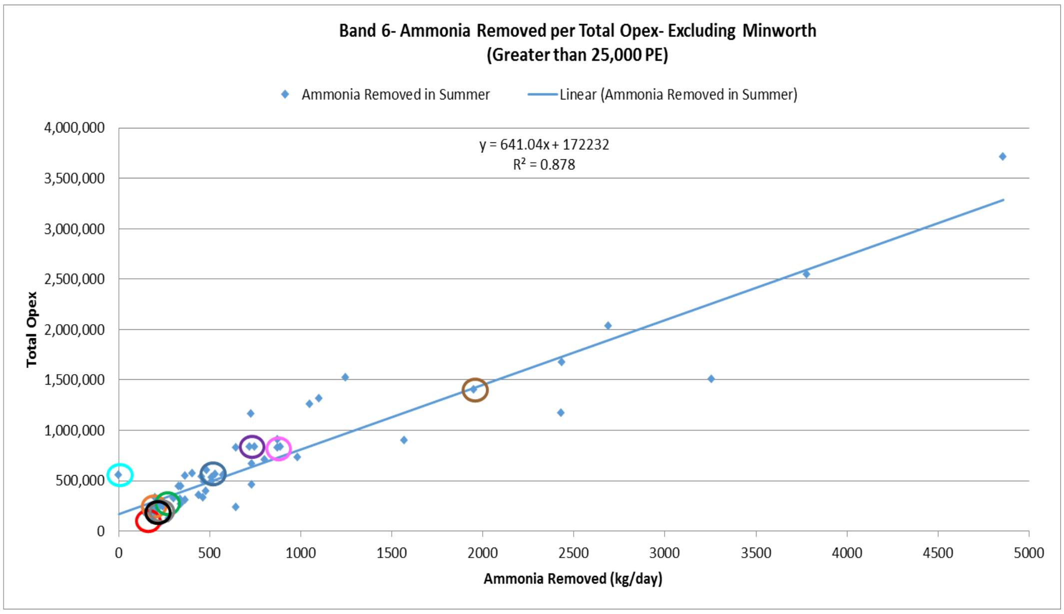


Figure C-2 : Band 6 deep dive site positions with respect to BOD

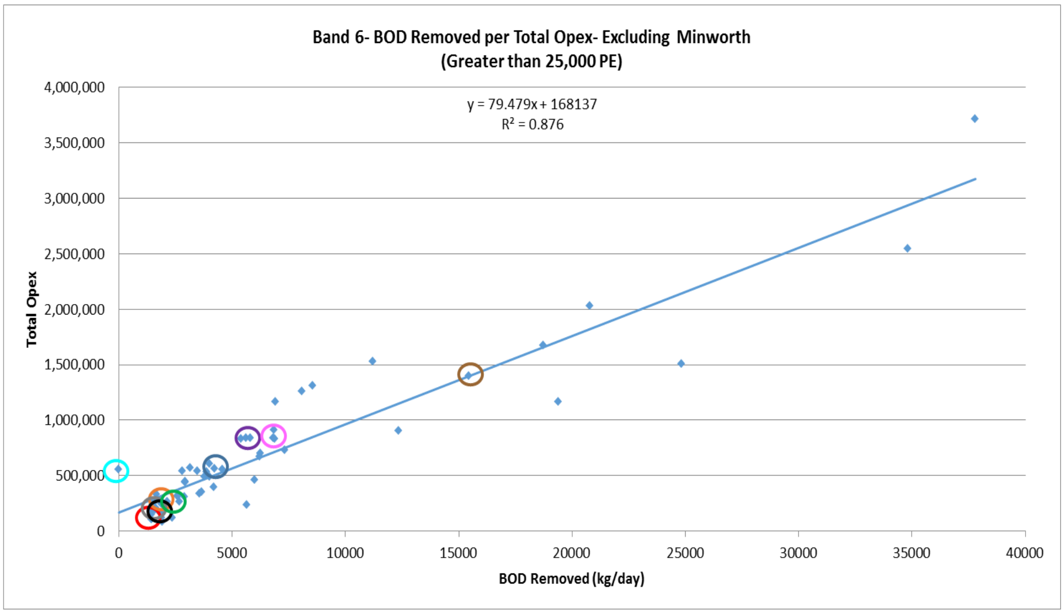
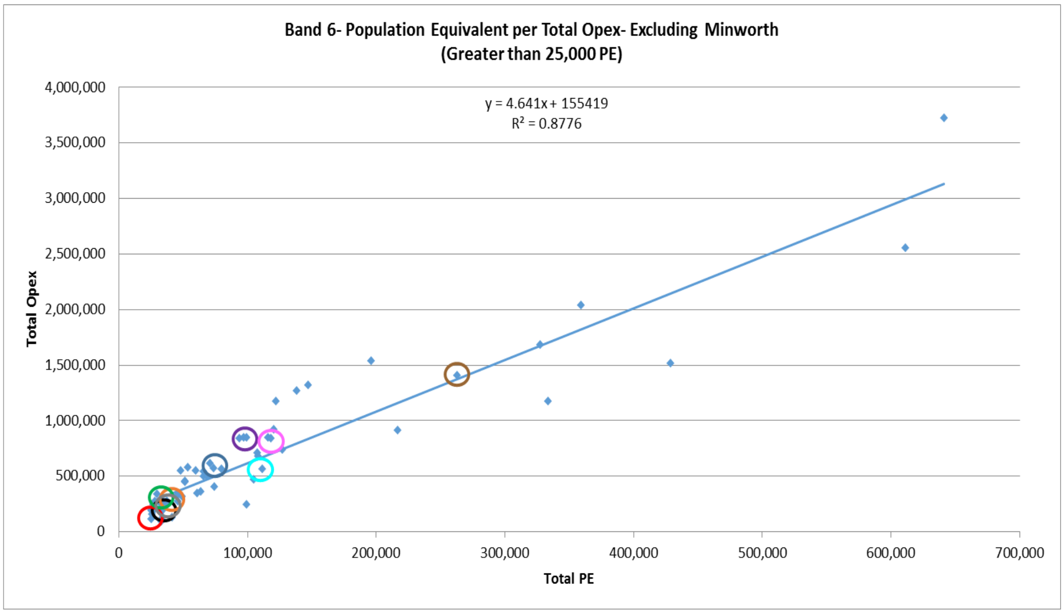


Figure C-4: Band 6 deep dive site positions with respect to population equivalent



C.2.2 Band 5 deep dive sites

Table C-1: Band 5 deep dive site key

Site Tag	Site Name
○	Ashbourne (STW)
○	Branton (STW)
○	Brockhampton (STW)
○	Codsall (STW)
○	Edwinstowe (STW)
○	Little Aston (STW)
○	Market Drayton (STW)
○	Powick (STW)

Figure C-5: Band 5 deep dive site locations

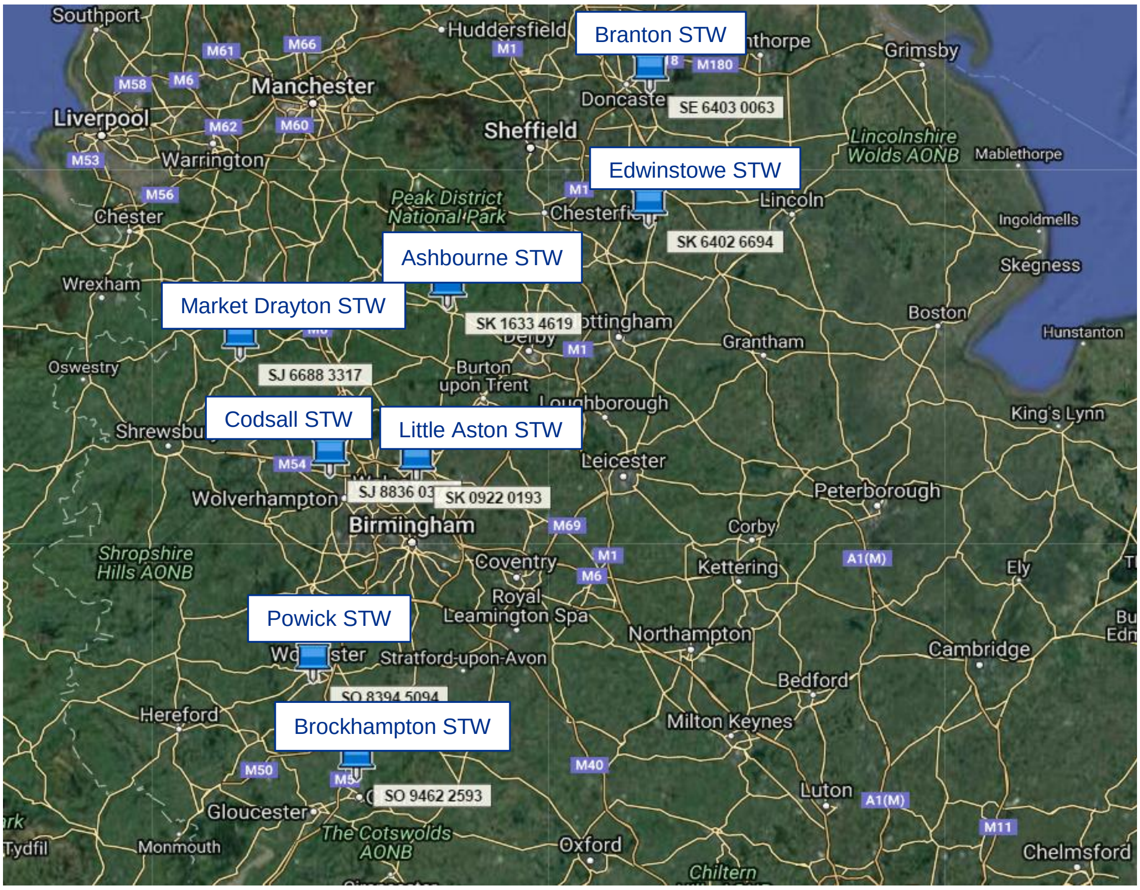


Figure C-3: Band 5 deep dive site positions with respect to ammonia

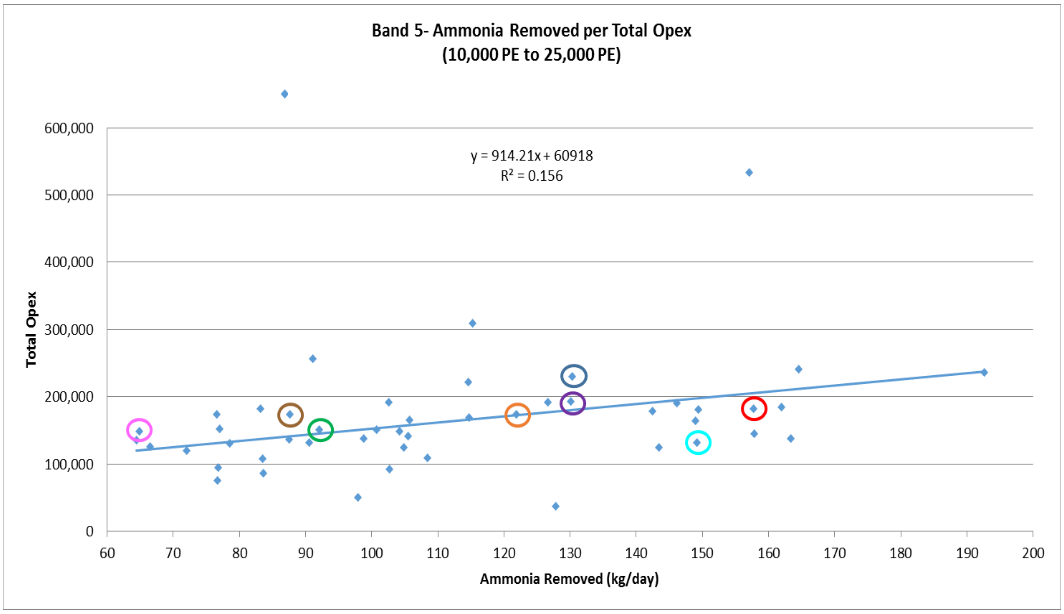


Figure C-4 : Band 5 deep dive site positions with respect to BOD

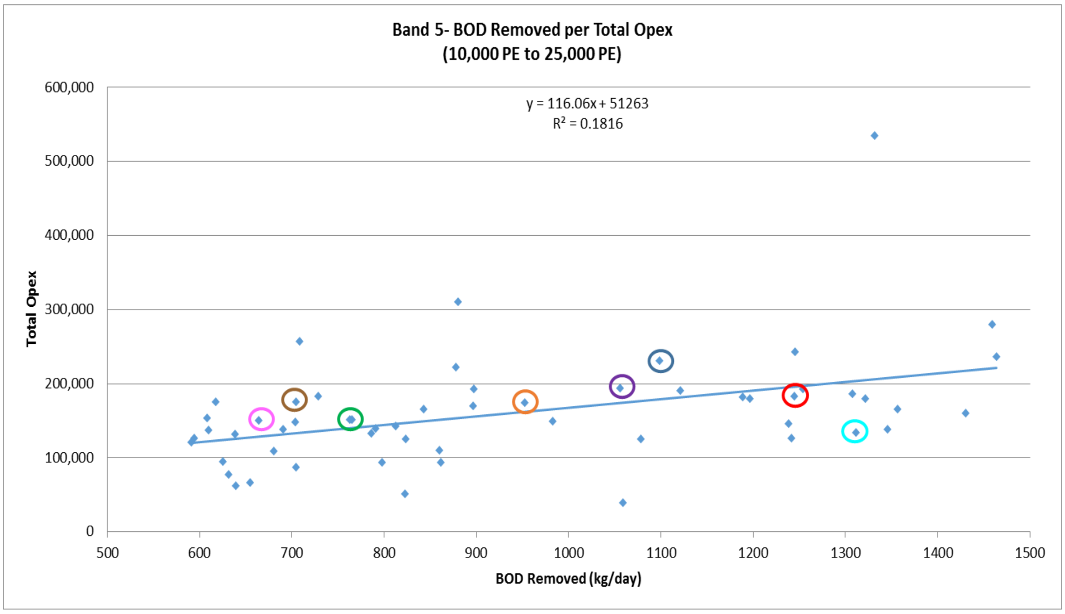
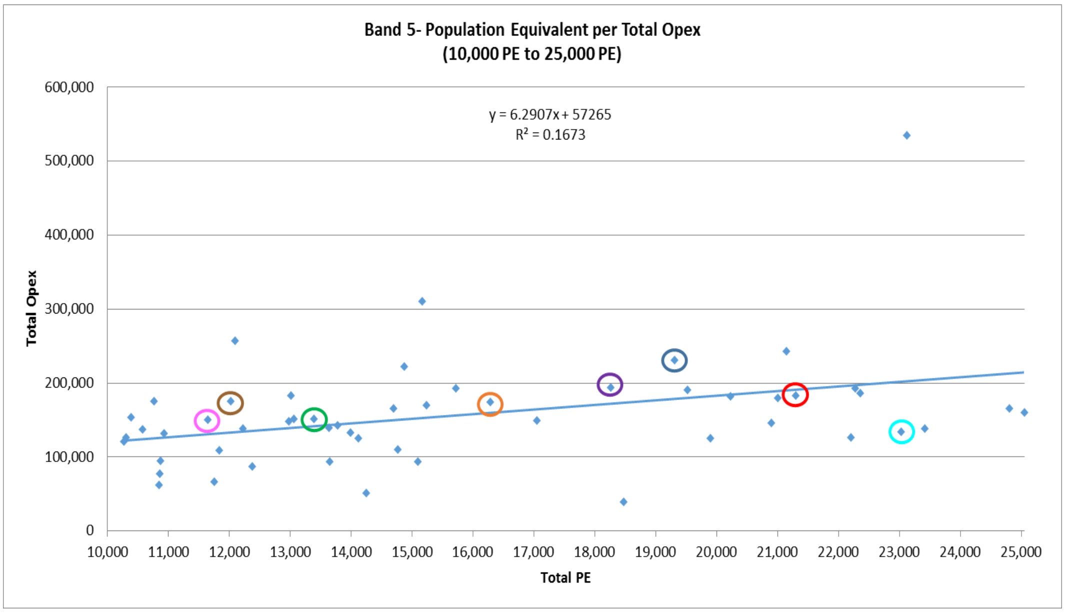


Figure C-5: Band 5 deep dive site positions with respect to population equivalent



C.2.3 Band 4 deep dive sites

Table C-2 : Band 4 deep dive site key

Site Tag	Site Name
	Baschurch (STW)
	Bottesford (STW)
	Bramcote (STW)
	Kirton-In-Lindsey (STW)
	Long Whatton (STW)
	Longhope (STW)
	Marchington (STW)
	Mattersey Thorpe (STW)
	Ripley (STW)
	Shardlow (STW)

Figure C-6 : Band 4 deep dive site locations

Figure C-7 : Band 4 deep dive site positions with respect to ammonia

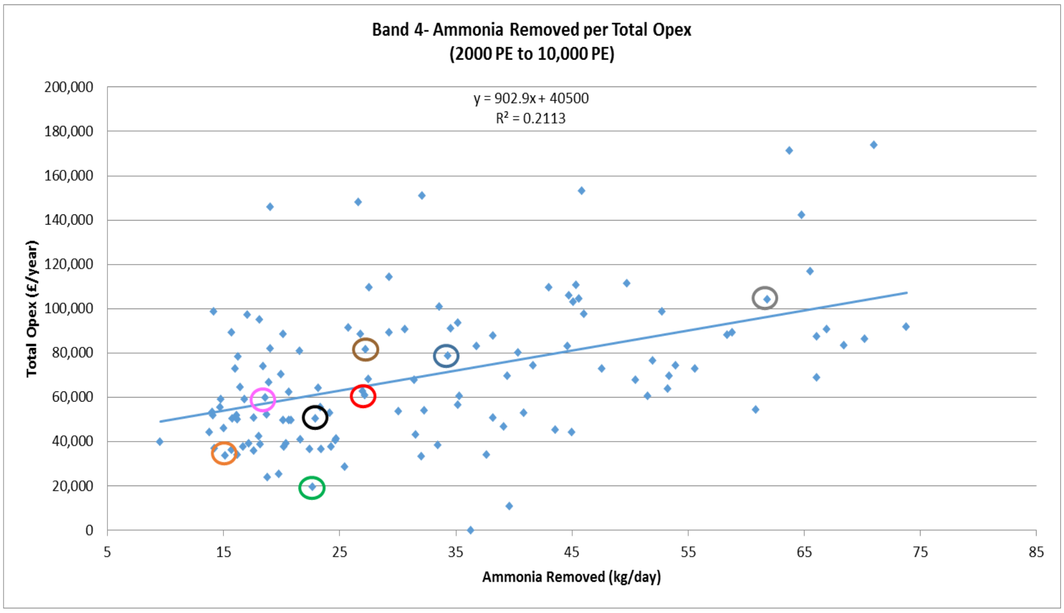


Figure C-8 : Band 4 deep dive site positions with respect to BOD

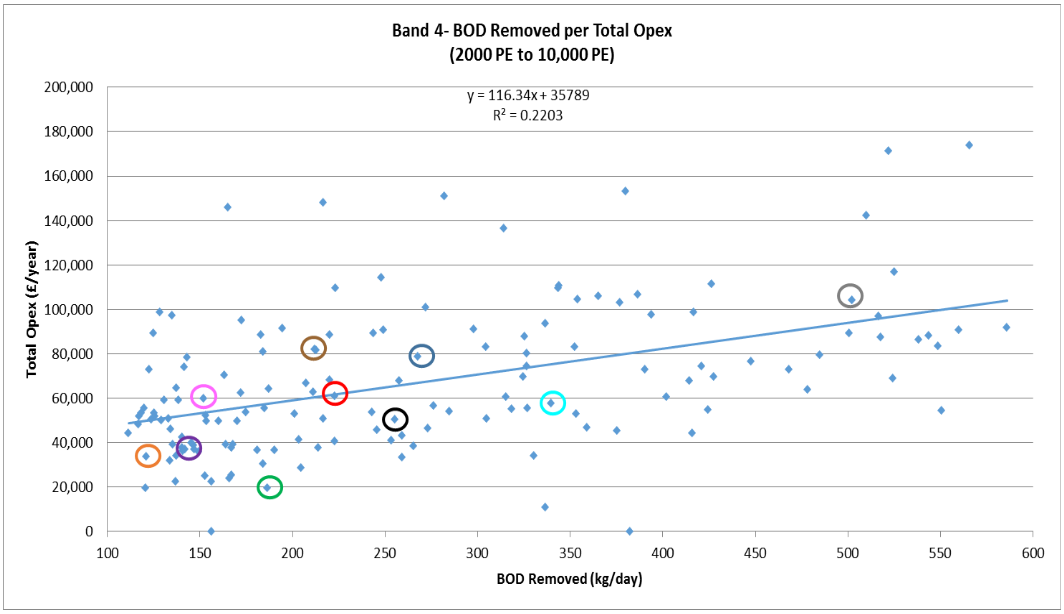
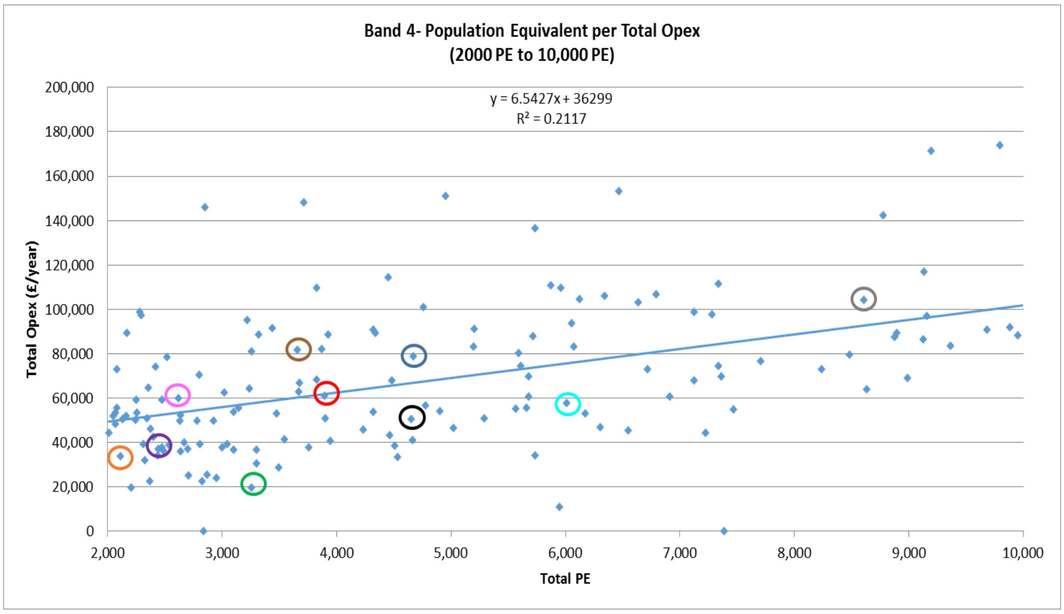


Figure C-9 : Band 4 deep dive site positions with respect to population equivalent



C.2.4 Band 3 Deep dive sites

Table C-3: Band 3 deep dive site key

Site Tag	Site Name
○	Ashover (STW)
○	Avening (STW)
○	Braithwell (STW)
○	Earlswood Springbrook (STW)
○	Holly Green Works (STW)
○	Luddington (STW)
○	Misson (STW)
○	Scarcliffe (STW)
○	Tregynon (STW)
○	Wychbold (STW)

Figure C-10 : Band 3 deep dive site locations

Figure C-14 Band 3 deep dive site positions with respect to ammonia

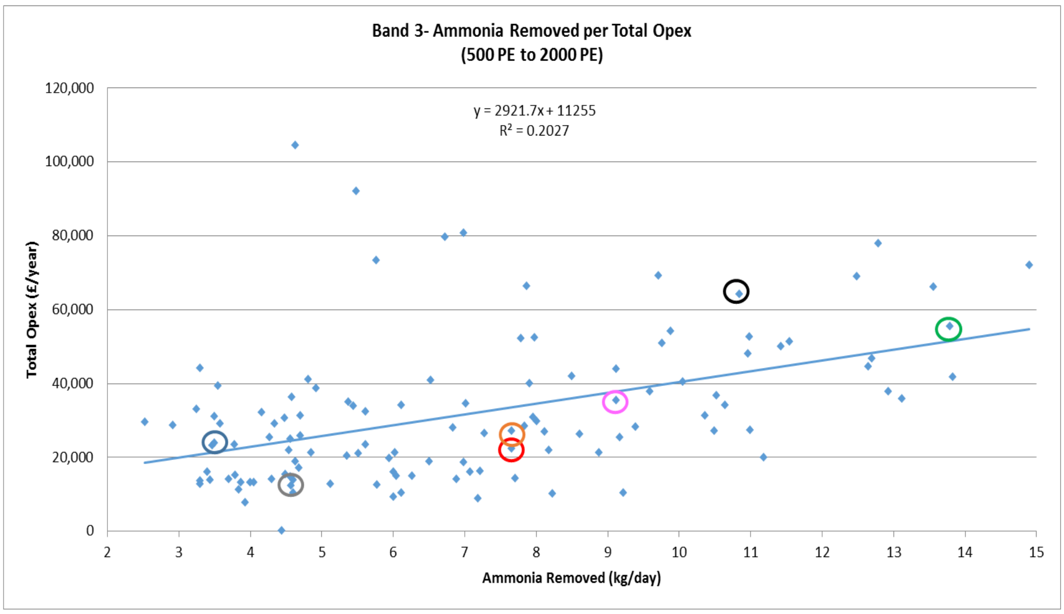


Figure C-11 : Band 3 deep dive site positions with respect to BOD

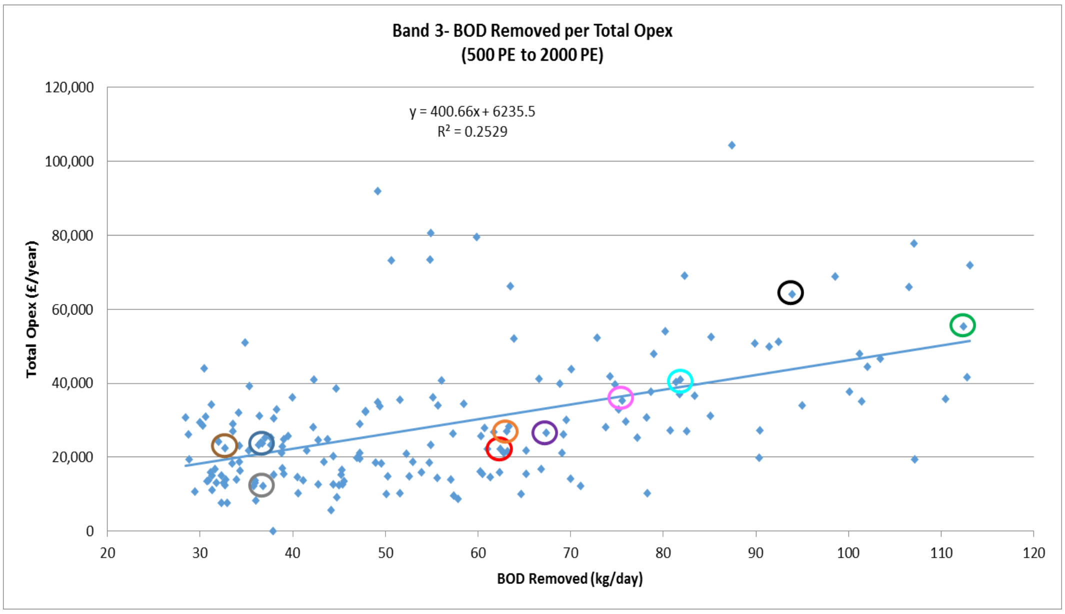
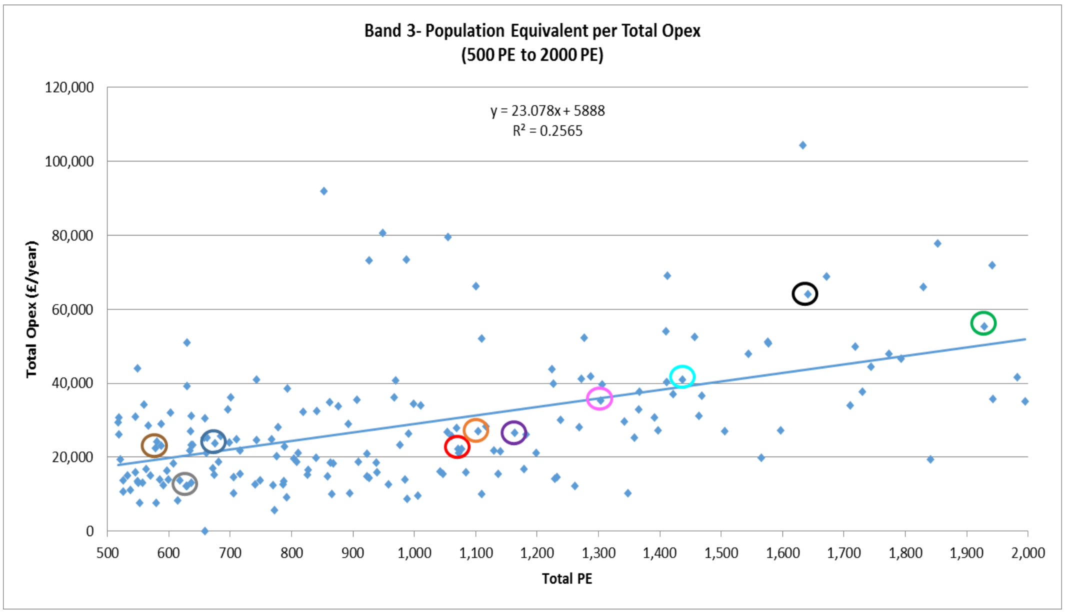


Figure C-12 : Band 3 deep dive site positions with respect to population equivalent



C.2.5 Band 2 deep dive sites

Table C-4: Band 2 deep dive site key

Site Tag	Site Name
	Chelmorton (STW)
	Headon Cum Upton & Askha (STW)
	Little Witley (STW)
	Llandyssil (STW)
	Lower Strensham (STW)
	Ridge Lane-Mancetter (STW)
	Upper Arley (STW)
	Weston Underwood (STW)
	Willoughton(STW)
	Yockleton (STW)

Figure C-13: Band 2 deep dive site locations

Figure C-14 : Band 2 deep dive site positions with respect to ammonia

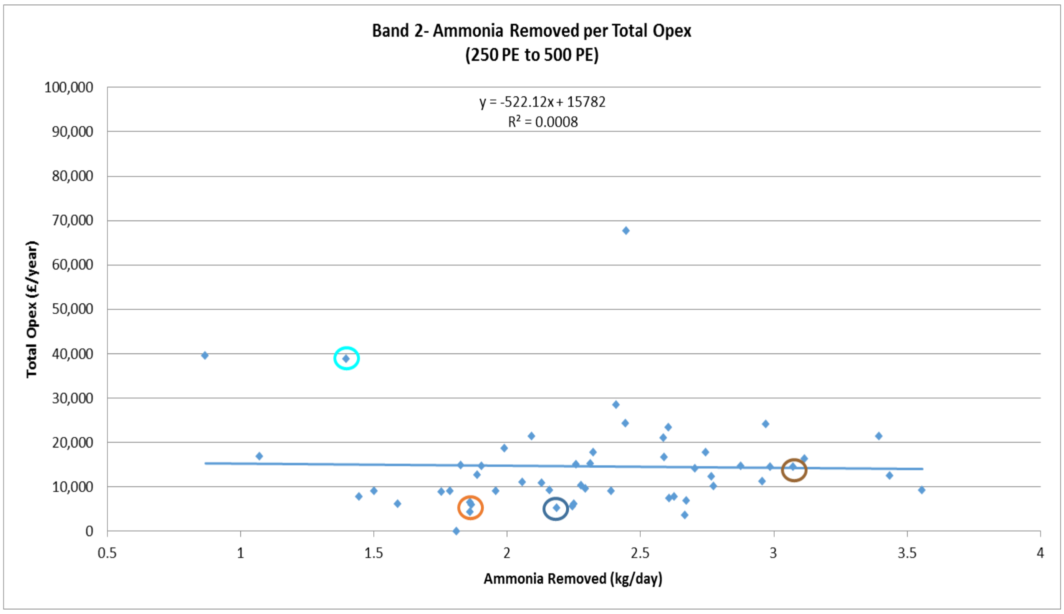


Figure C-15: Band 2 deep dive site positions with respect to BOD

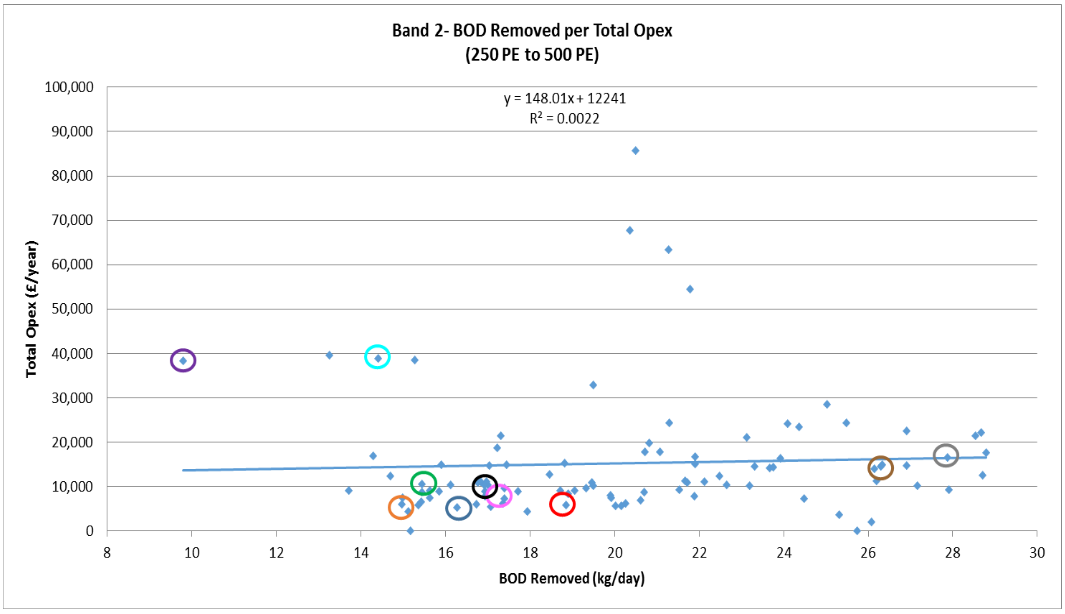
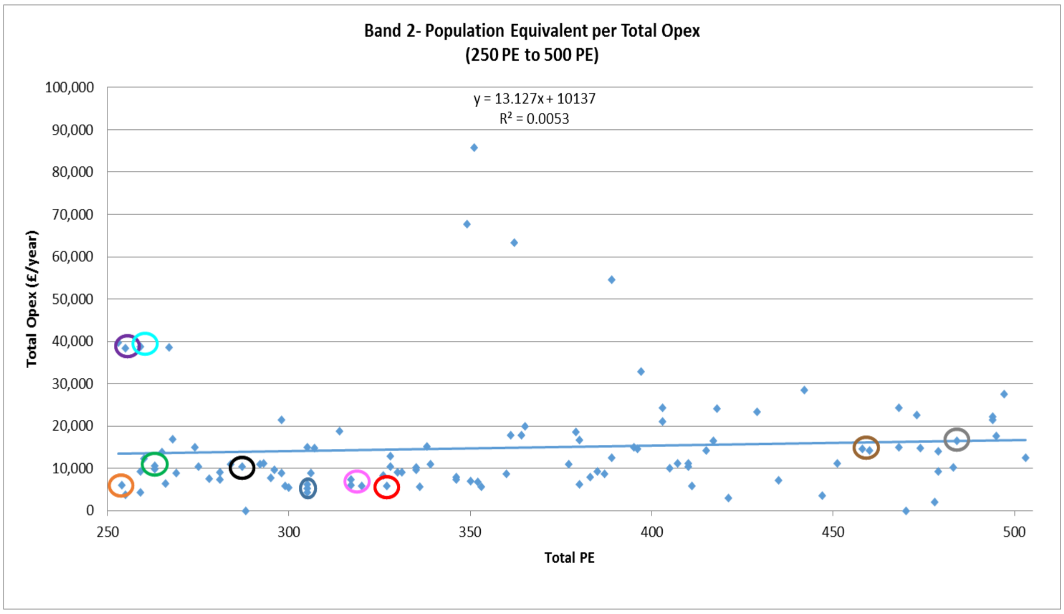


Figure C-16 : Band 2 deep dive site positions with respect to population equivalent



C.2.6 Band 1 deep dive sites

Table C-5 : Band 1 deep dive site key

Site Tag	Site Name
	Aston Magna (STW)
	Cannock - Four Crosses (STW)
	Gailey (STW)
	Little Hucklow (STW)
	Pebworth Middlesex (STW)
	Perthy - Windy Ridge (STW)
	Putley Green (STW)
	Rockhall Villas (STW)
	Walton Cottages (STW)
	Wyaston (STW)

Figure C-17: Band 1 deep dive site locations

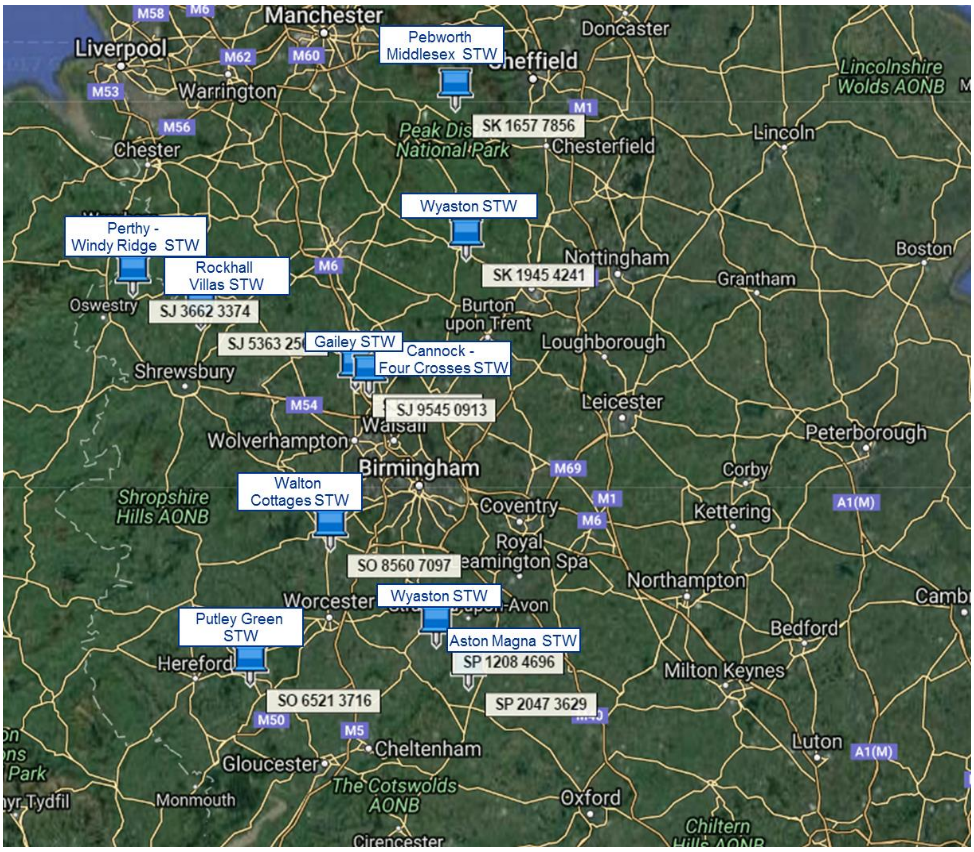


Figure C-18 : Band 1 deep dive site positions with respect to ammonia

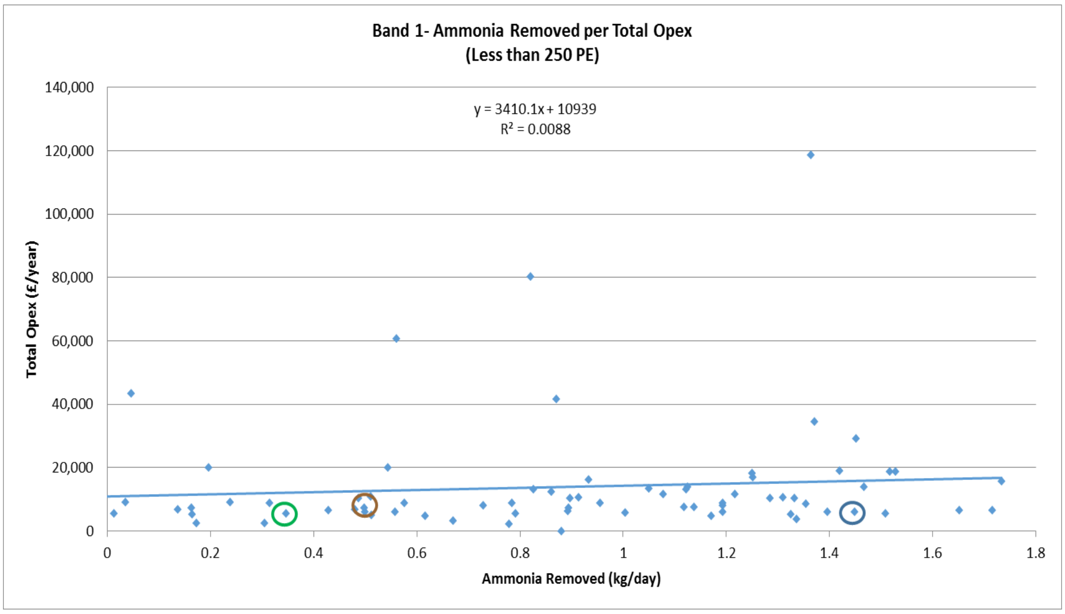


Figure C-19 : Band 1 deep dive site positions with respect to BOD

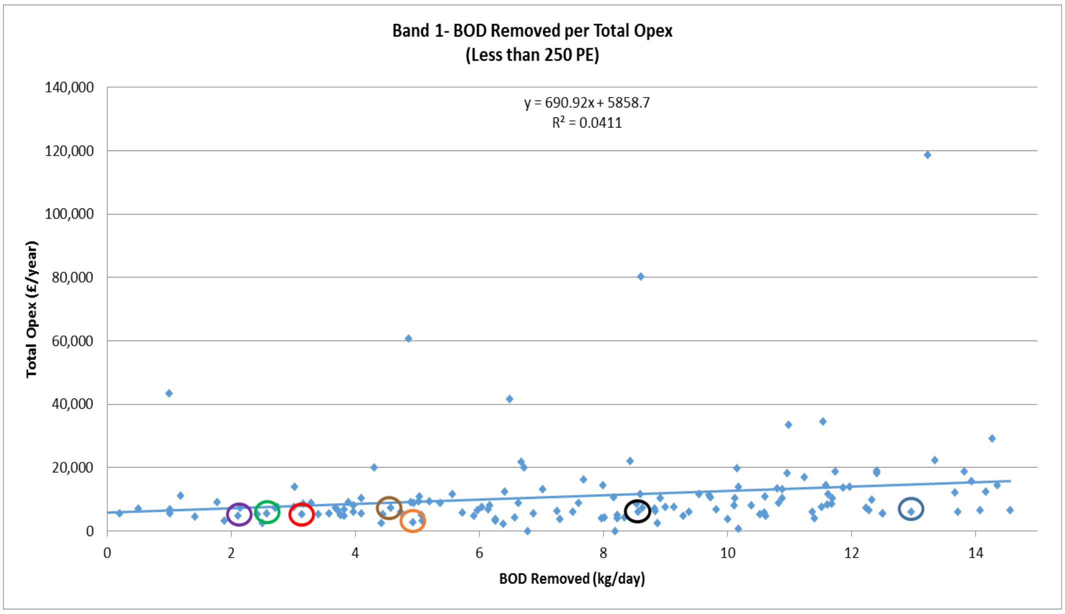
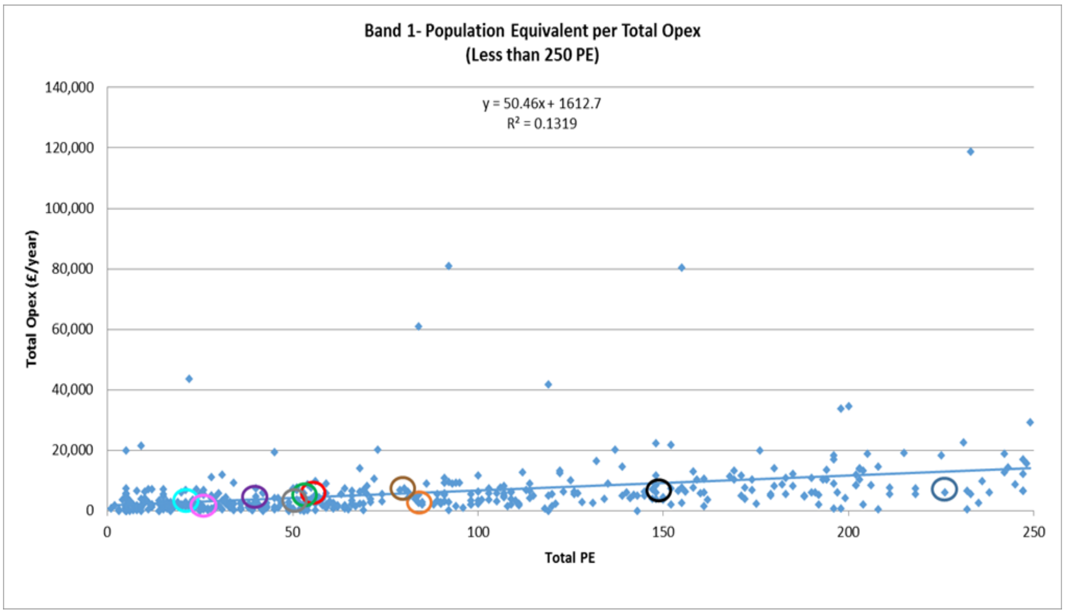


Figure C-20 : Band 1 deep dive site positions with respect to population equivalent



C.3 WaSCs process type comparison

The graphs below show the percentage of load, in terms of kg BOD/day, for each water company compared to its process treatment type.

Figure C-21: Band 6 WaSC load for each treatment type

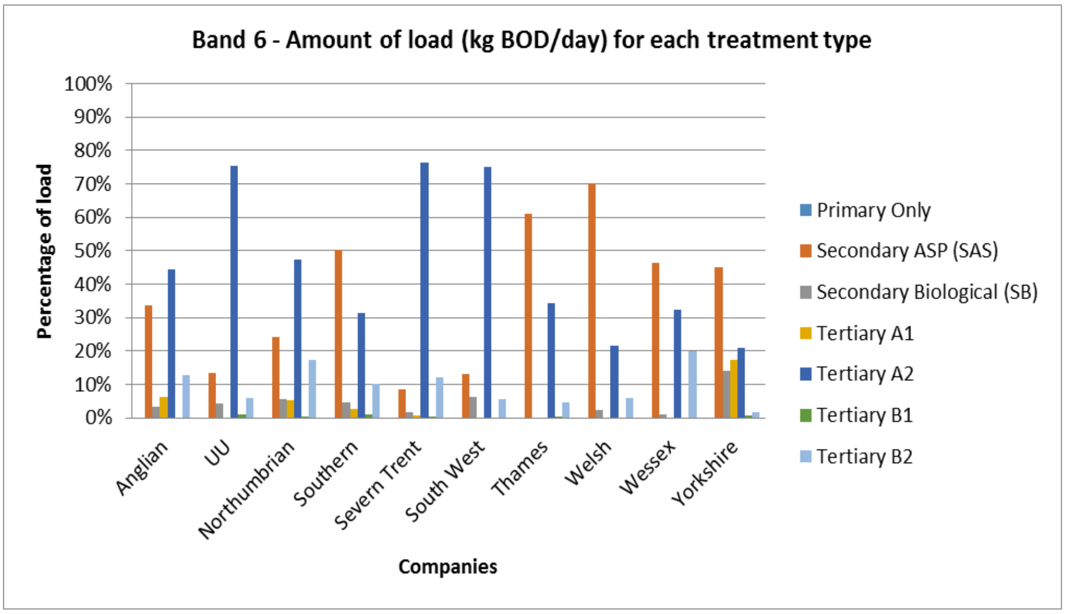


Figure C-22: Band 5 WaSC load for each treatment type

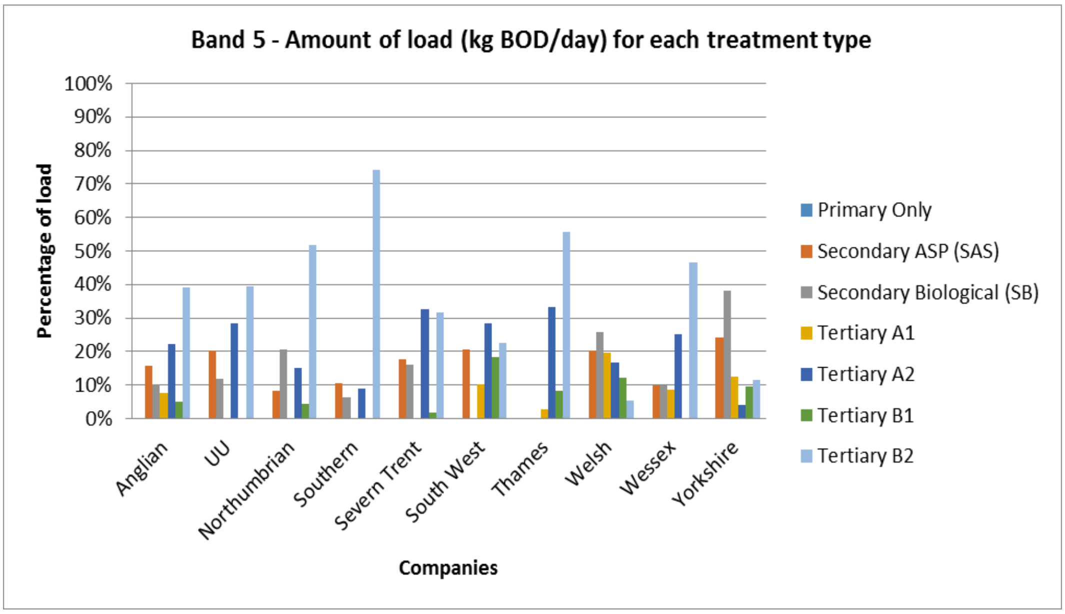


Figure C-23: Band 4 WaSC load for each treatment type

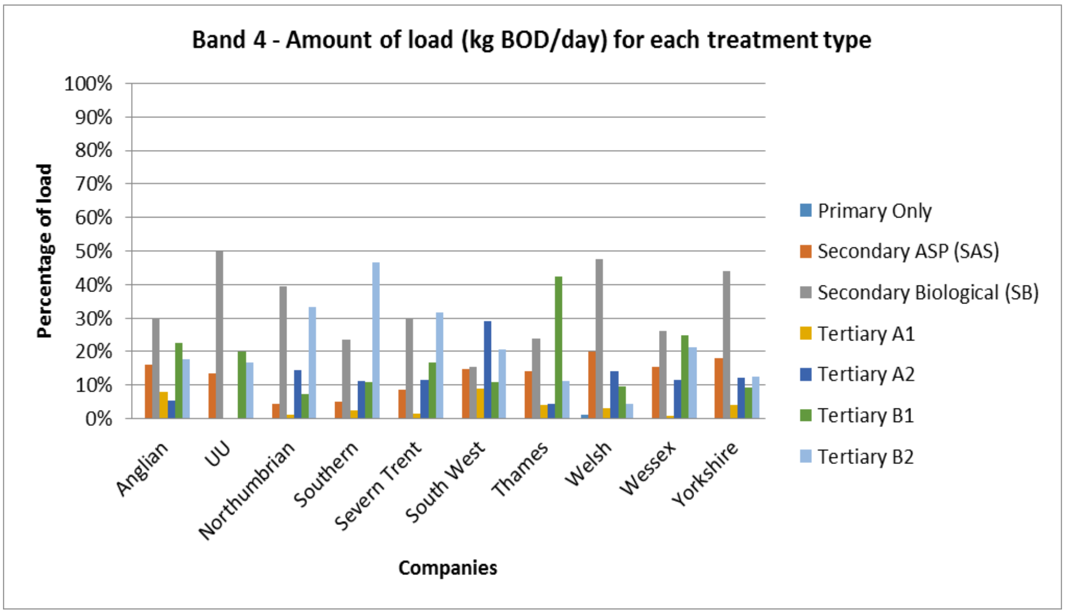


Figure C-24: Band 3 WaSC load for each treatment type

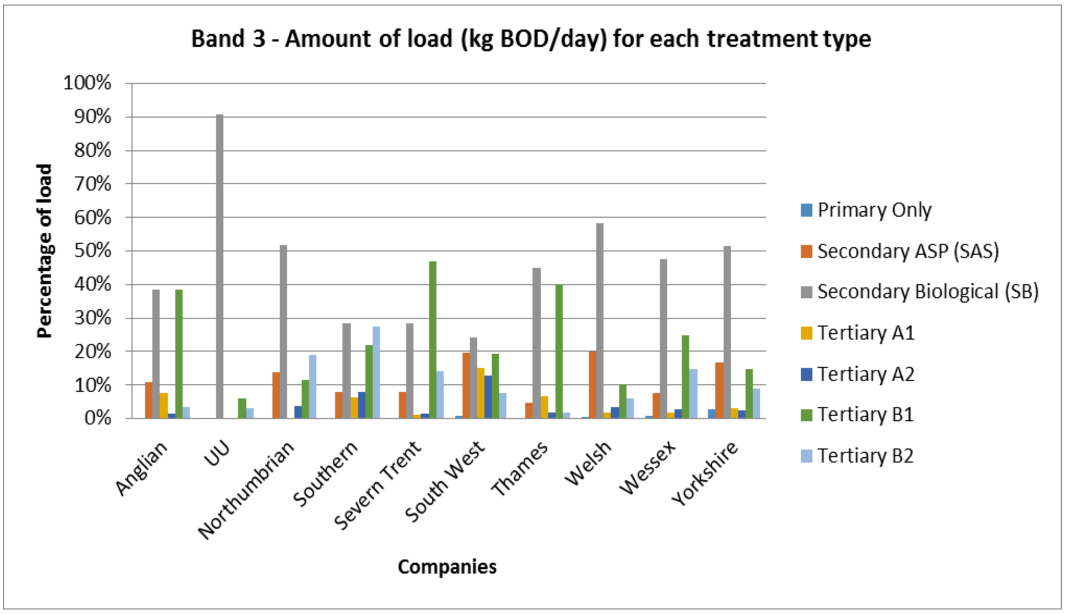


Figure C-25: Band 2 WaSC load for each treatment type

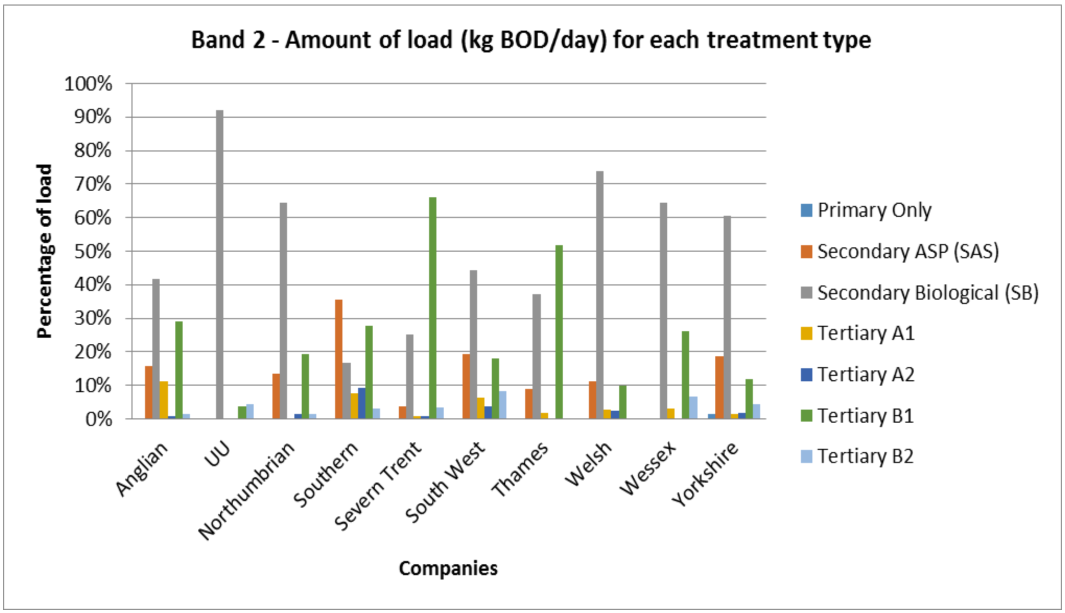
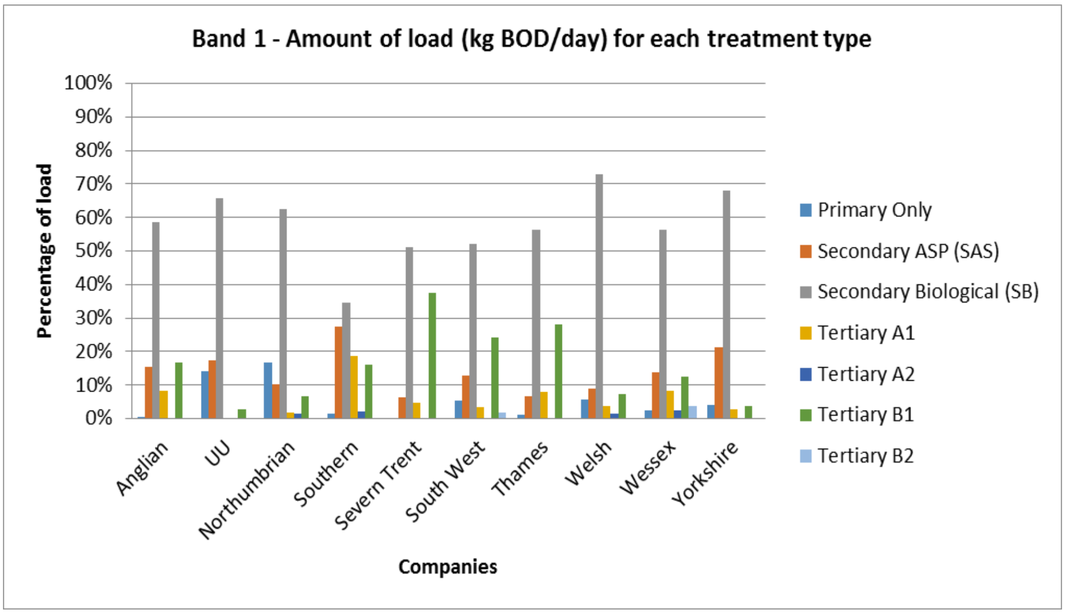


Figure C-26 : Band 1 WaSC load for each treatment type



C.3.1 Treatment choices - conclusions

From the graphs above the primary secondary treatment process from bands 1-4 appears to be biological. As size increase in the use of ASPs and further tertiary treatment processes begin to be used. When compared to the other companies a significant proportion of the load removed by STW sites (76% in band 6) required an ASP followed by a tertiary treatment process. Other water treatment companies, such as Thames, Welsh Water, Wessex and Yorkshire appear to be able to only require an ASP, indicating they are not treating the sewage to the same degree as Severn Trent and therefore may be have a lower power usage and operational costs.

C.4.1 Unit direct costs and load removed – industry-level analysis

AVE suggested that more demanding consents would mean more complex and expensive treatment across the range of size bands. We would expect this to show up in the analysis of company level expenditure. We used the 2016 data set (the only one to provide company data on the loads received, direct costs and consents) to consider this.

One option with the data is to consider how the degree to which companies are subject to consents affects costs. Table 4.8 shows the % of load that is not subject to any permit (so the most relaxed consent level) for each company.

Table C.8: % load with no permit

% load subject to no permit	Phosphorus	BOD	Ammonia
ANH	52%	1%	23%
NES	87%	1%	61%
NWT	72%	0%	22%
SRN	90%	30%	61%
SVT	21%	0%	4%
SWT	94%	2%	55%
TMS	61%	0%	0%
WSH	79%	1%	33%
WSX	74%	0%	40%
YKY	98%	13%	16%

We have compared the data in the table to company costs – both direct costs and operating costs – at the industry level and the company level. We found no coherent relationship based on the raw dataset (Figure C.31).

Figure C.31: All works NH3 no permit vs 2016 opex

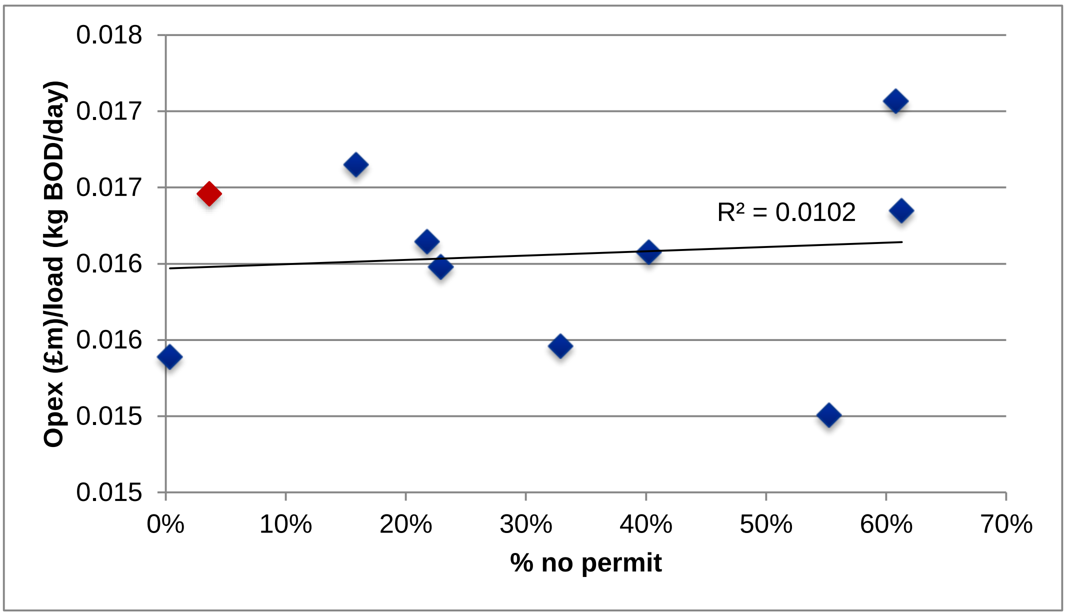


Figure C.31 seems counterintuitive – the chart tells us that more demanding consent regimes (with a lower % no permit) lead to lower unit costs. But it may be our expectations are based on what we would expect to see at works level. At the company level, one response to demanding consent is to invest capex and develop a treatment regime that can not only deliver a demanding consent but also do it cheaply and at a large scale. For companies without significant load subject to ammonia permits other explanatory factors may exist.

AVE also appeared to encounter similar problems in this area – under its Exogenous Factors Narrative on page 15 of the presentation says that it found clear asset-level variation but comments that 'data quality masks company-level variation'.

However, we can plot an assumption about the load within each ammonia consent band. Figure C.32 shows opex vs **incoming** ammonia load for band 6 - once again there is no obvious correlation.

Figure C.32: Band 6 works ammonia load in band required versus 2016 Opex

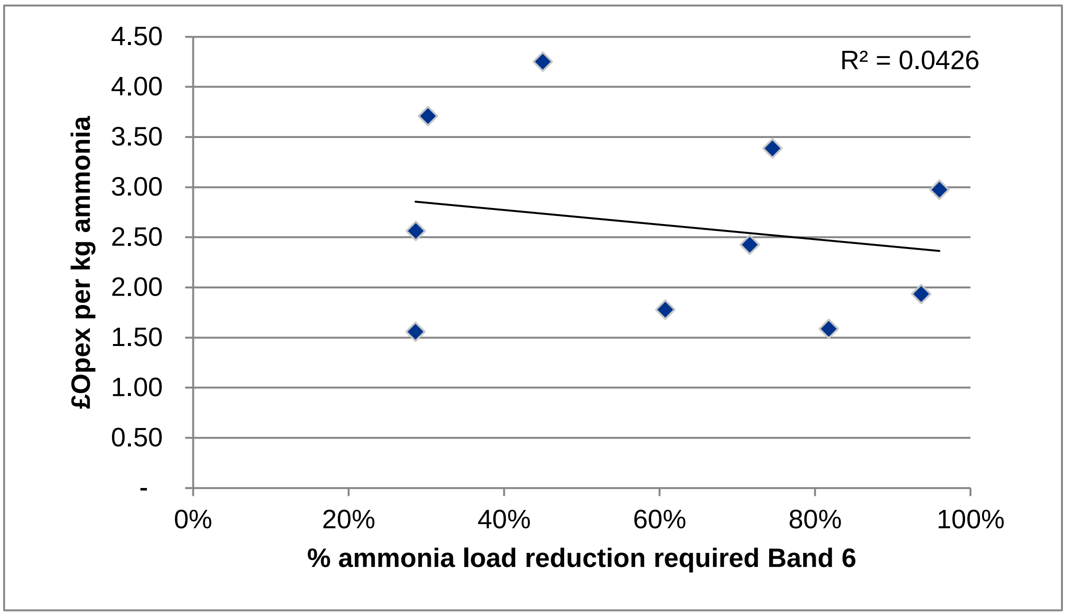
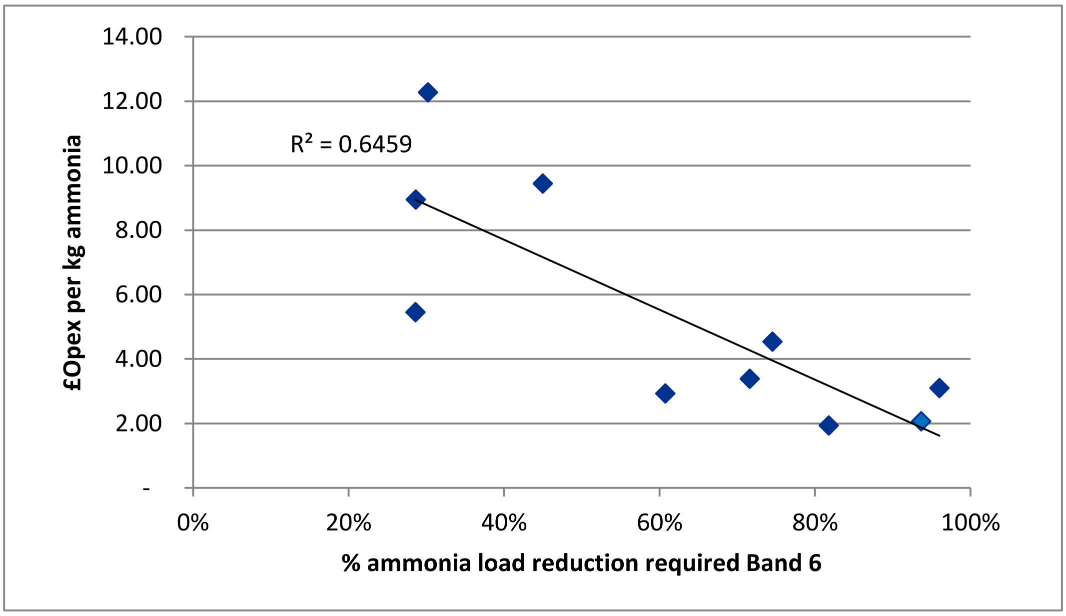


Figure C.33 shows some signs that companies that are required to remove similar significant levels of ammonia (>60%) in band 6 show and these show similar ranges of operational cost per load removed. For the companies with more relaxed consents (<50%) unit costs to remove the lower loads required are higher.

Figure C.33: Band 6 works ammonia load removed versus 2016 band 6 Opex



We might expect that power opex would provide a better correlation than total opex; however, this is only available for the band wide dataset. If we consider power cost versus ammonia load removed across the industry dataset and simply considering ammonia load in or ammonia load reduced, we see below in figures C.34 and C.35 that the correlation is improved to R^2 >0.7 though power cost per ammonia load in rather than load removed offers a slightly better correlation which would not be expected. This could be because some companies have low levels of ammonia removal in band 6 and other more relevant cost drivers. This could also be due to the known variables and factors around process type (e.g. biofilter versus ASP).

Figure C.34: Ammonia load incoming band 6 vs total power opex

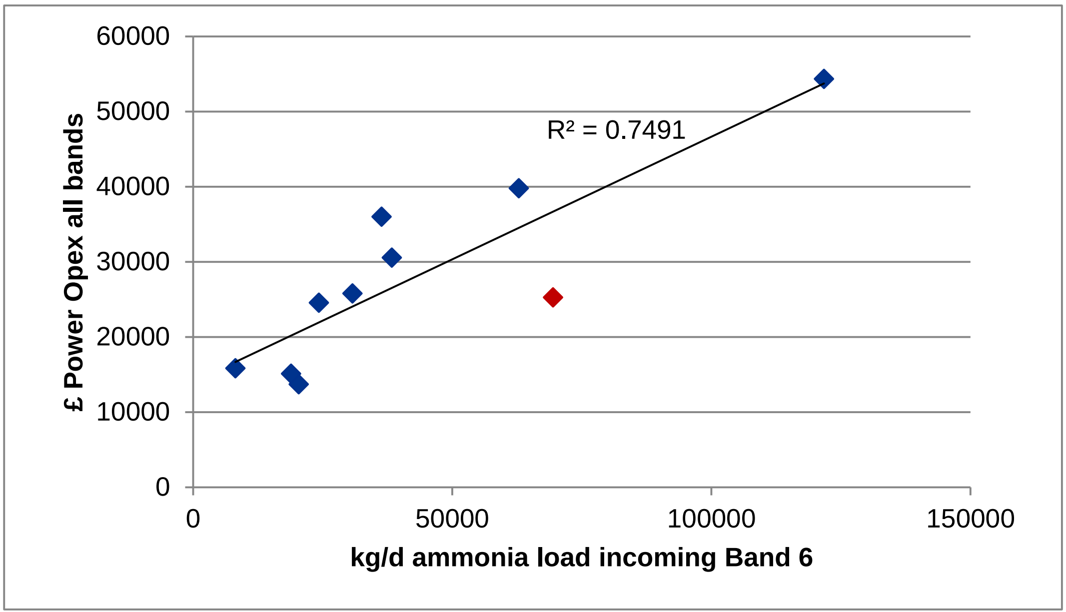
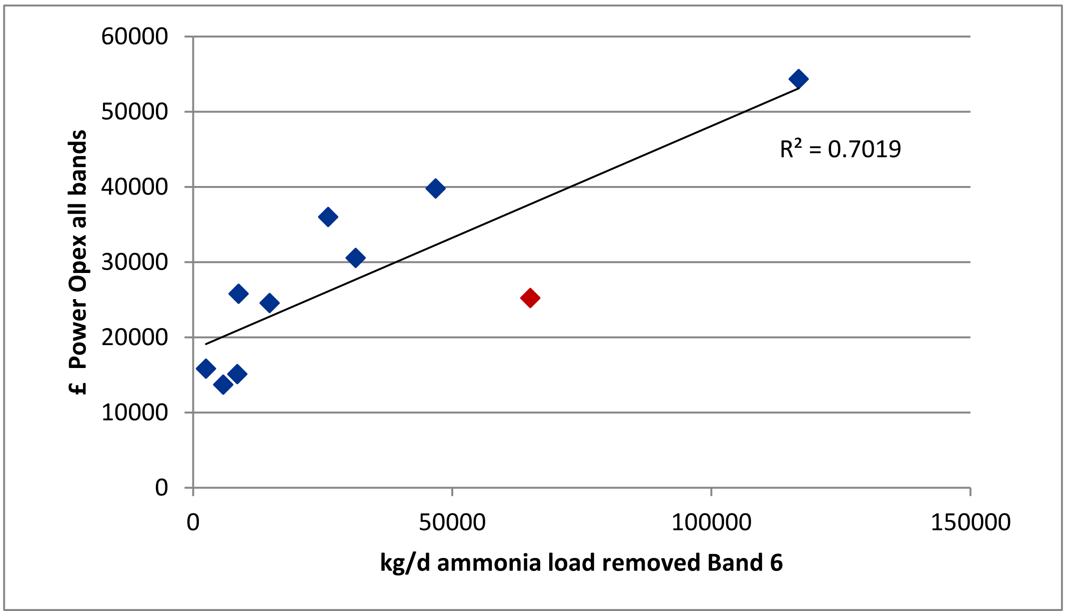


Figure C.35: Ammonia load removed band 6 vs Total Power Opex



We have undertaken this analysis for band 6 where we would expect more consistency in treatment type (usually either biofilters or activated sludge). It could be repeated for all bands - the EA consents database would allow a more detailed analysis of actual permit ammonia levels. While this could improve this analysis significantly the EA data does need preparation and cleansing. This analysis currently assumes a percentage load reduction to an assumed ammonia level as described in Section 3.4.1

Removing Thames from the dataset significantly reduces all correlations except Band 6 Opex versus Ammonia removed which remains at R^2 of 0.65. There would appear to be merit in consideration of ammonia load removed but the dataset requires more work and sensitivity analysis. This could be done relatively easily by considering the full range of consents within the ammonia bands such that a range of correlations could be developed which will encompass the actual load removed.

Appendix D Industry and other available datasets

This section summarises the industry wide datasets available which may allow the investigations we've undertaken on the SVT dataset be extended to the industry. We provide some of this industry dataset analysis in Section 4 as part of our review. This section describes the technical information included within these datasets and their potential use and limitations.

Ofwat's 2016 cost modelling data submission - as provided to Jacobs by SVT as *Master waste hc 20161221-* provides the following information:

- Number of sites, incoming load (kg/d) and broad consent details on a band Level basis
- Load summarised as treatment works type – classified as Primary, Activated Sludge, Biological, Tertiary (A1, A2, B1, B2)
- Operational costs at a band Level
- Capital costs at company level

Deficiencies in the dataset include the following:

- Capital costs are for the entire dataset and not segregated by band, consent type or load (though we lacked SVT capital costs anyway)
- Ammonia consent based load information for each band is based on reasonably broad categories of:</= 1mg/l ammonia from >1 – 3mg/l, from >3mg/l to 10mg/l, >10mg/l and no permit. These allow some analysis but not a true reflection of actual required ammonia removal and where we have used this dataset, we have had to make assumptions and have recommended further sensitivity analysis.
- The treatment type classifications do not allow sufficient information about tertiary treatment processes to allow improved commentary around operational treatment costs around treatment type which, as discussed in this work, may be a cost driver consideration.
- No actual Q80 or Q90, consented or peak flow data is provided. If this data, which is publically available in the EA database were included within bands, it could support further analysis of load removed and infiltration characteristics and corresponding operational cost analysis.

The **EA consent database dataset**[24] provides information on:

- Works level detail DWF, FFT, location, consented limits
- Historic variance in consent levels
- The type of treatment works present and level of treatment (primary, secondary, tertiary; biological filter, ASP etc.).

[24] EA Consents Database 2015 (available from www.data.gov.uk).

This database may fill the data gaps identified in the Industry dataset above. This work has only been able to assess the potential for use of this dataset to derive further information. It is presented in Section 3.7. The results of this initial investigation suggest that:

- The database is a potentially powerful tool which would allow assessment of all WaSC treatment costs at a **Band level** with relation to **load removed** (in particular for ammonia consents) and **treatment type.**

- The database allows individual license details to be assessed at an **individual treatment works level** such that like for like comparisons could be made across a series of 'unit' treatment plant sizing/process types. This would allow like for like comparisons across WaSCs to provide an idea of a 'typical' treatment works of certain size and consent.

- The database allows what seems to be a reasonably accurate assessment of treatment type such that the split between fixed film and suspended growth; secondary and tertiary processes can be made at a treatment works level which, given work to date, could be used in further analysis of Industry data costs and company performance.

- The database may, with sufficient time for analysis, allow for regional variance in setting of ammonia consent levels within similar sub-catchments of River Basins under WFD to be explored and to identify potential variation in regional EA licensing. This may be of most interest with respect to nutrient removal (ammonia and phosphorus).

The deficiencies in this dataset from initial analysis may include:

- Whilst DWF and FtFT is provided, trade component (E) is unknown and infiltration is unknown meaning that at a treatment works level, works PE cannot be calculated except as a broad estimate. The main issue here is that accurate classification into bands which align with Industry Opex cost figures is challenging though it is likely that a 'best estimate' could be made by Jacobs if further analysis was to be undertaken.

- The dataset is extensive and requires considerable manipulation to derive data. There are multiple consent listings which appear to align with historic variations which makes data analysis challenging but with more time it is likely that sufficient cleansing could be undertaken to allow a reasonable data extraction.

Treatment types and cost driver implications

The industry datasets describing treatment type classification are of some benefit in extending our analysis to all WaSCs but the EA database may provide a useful cross referencing tool here due to the issues we have encountered considering treatment types within the broad industry bands and how various tertiary processes would/are classified within the tertiary treatment bands. Appendix A for includes a summary process types.

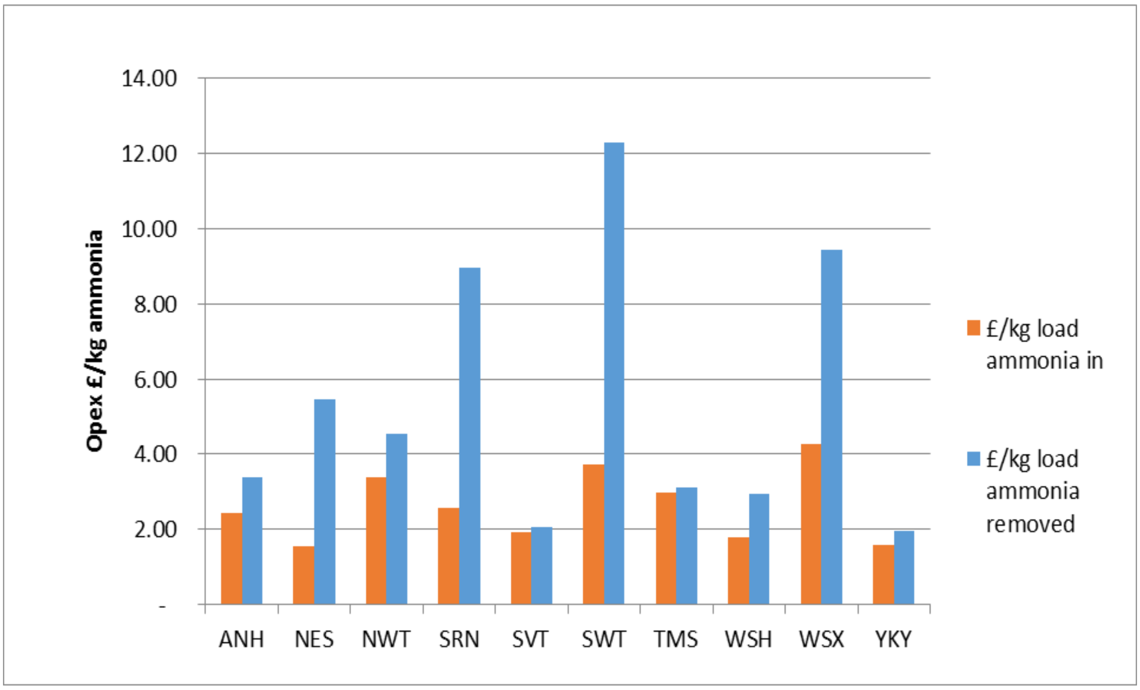
Consent levels and cost driver implications

Given the relationships discussed in Section 3 and the significance of treatment requirements for ammonia removal, an assessment of operational cost versus ammonia removed allows a comparison of the relative cost across WaSCs in the most cost significant band 6 which we include here.

This analysis has been developed assuming an average removal rate across the banded ammonia standards for which load is reported in the industry dataset. This analysis for the SVT dataset only showed no impact between load in or load removed due to the very high ammonia standards SVT require to meet within band 6. Across other bands, differential was assessed as per Section 3.5.

The resulting unit treatment costs are approximate only given the assumptions required around average consent limits within the reported ammonia bands (for example within 3-10mg/l, an average 5mg/l standard has been assumed but some Water Companies may have tighter or more relaxed limits). The analysis shows the potential difference in calculated efficiencies for water companies with low overall ammonia reduction requirements if we consider opex per load removed – including Northumbrian, South West Water and Southern who may only be removing of the order of 30% ammonia load in band 6 and Wessex with 45% load reduction. The same considerations could be applied to BOD load remove but we would expect the results to be less contrasting.

Figure D-1: Band 6 Industry comparison Opex per ammonia load versus load removed



This may imply an advantage for some companies by the (current) use of load in or PE in recent cost assessment models.

Appendix E Cost factors considered during the review

Appendix B Summary of costs factors

Issue	Ref	AV view	Jacobs view	Further work?
Load measurement	4.8, 4.9	Can do this better	Load removed, measured load received and assumed load received are all different. Most comparative analysis uses Ofwat's load received data. Some scope to develop data from EA/consents sources.	Scope for companies to improve understanding of risk and adopt more efficient position on dealing with load
Surface water drainage	4.10	Run-off a significant driver of network asset and pumping costs		
Treatment quality	4.7	Consent requirements are a significant driver of treatment unit costs	Must impact on costs – but it is difficult to see the impact of different consent requirements on industry costs. Changes in treatment requirements can lead to redesign allowing access to scale economies) (based on manpower reductions). The industry data set does not provide much insight.	Obtain improved data on costs, load and consents
Economies of scale	4.5, 4.6,	Asset-level economies of scale affect treatment unit costs – suggest '% load in bands 1-3' is suitable a modelling variable to address concerns	Observed economies of scale relate to opportunities to serve very large urban areas. Companies with unbalanced catchments can face unusual challenges. Some offset from network costs – poor quality data at sub-company level	Develop a variable that can offset the lack of opportunities to use very large works

Population density	4.6.3	Asset level metrics affect costs	Density determines opportunities to increase treatment scale. Each company's asset profile reflects its population distribution. Very wide variation across England and Wales – lowest unit costs in most densely populated areas	Need a factor that reflects the whole density profile not just one end (least dense is least important for easing costs)
Regional wages	4.6.4	See as a regional variation factor – think there are better equivalent factors	Wages are part of non-power opex and a key component of the cost area most sensitive to economies of scale. There is meaningful variation and external data but needs careful validation. Easy special factor adjustment.	Needs testing in models
Sludge	n/a	Stand-alone models needed	Outside scope. 2016 data excludes sludge costs – may contribute to decline in coefficients	Ofwat will have to develop new models.
Functional form		Simpler models improve model stability/predictive power	Models should be coherent with operational and engineering reality. Data issues are, unfortunately, likely to restrict model design and use.	
Rainfall intensity	n/a	Not significant	Not enough data to test this	
Topography	n/a	Difficult to assess	Linked to surface water drainage and works design	
Industrial load	n/a	Already included in overall load	Should be offset by charges – could need some explanation in expenditure data set	Assess materiality
Planning conditions	n/a	Investigated the influence of national parks – found no effect	Not investigated – but additional costs relating to urban creep and changing public attitudes could lead to higher botex	No industry data but scope for materiality testing and special factor claim

Resilience	n/a	Difficult to evidence	Ofwat allows resilience investment if risks demonstrated. Solutions mostly physical and enhancement capex based. Limited impact on modelled botex	Scope for evidence based special factor
Network infiltration	4.11	Believe contributions to sewer flow are small	Not much evidence but we have set out an approach that might help asses this. Ofwat likely to challenge claims on the basis that well maintained systems minimise infiltration	Unless SVT has evidence of higher costs probably not for development into a modelling factor
Socio-economic deprivation	n/a	No evidence of link to wholesale costs	Unlikely to have an impact on wholesale treatment costs	No action without evidence based hypothesis
Network costs	4.5.1	Not considered	There is a trade-off between consolidation of works to access treatment economies and network length. We tested network and treatment expenditure against load – some signs that observed treatment scale economies were reduced.	Check outcomes of any network modelling
Security and emergencies	n/a	Not considered	Possibly an issue related to the sensitivity of location sand to scale (lots of small works more difficult to protect)	Comparative data not easily available
Consenting regime	4.9.1	Not covered	Some evidence that application of consenting policy varies across England and Wales	Assess materiality