ANALYSIS OF THE COSTS OF WATER RESOURCE MANAGEMENT OPTIONS TO ENHANCE DROUGHT RESILIENCE

Final Report for the National Infrastructure Commission

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February 2018

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Disclaimer

This report was commissioned as part of the evidence base for the National Infrastructure Assessment. The views expressed and recommendations set out in this report are the authors' own and do not necessarily reflect the position of the National Infrastructure Commission.

Executive Summary

i. This report provides an independent assessment of the estimated costs, and associated water resource benefits, of different infrastructure and demand management options to enhance water resources management and drought resilience in England and Wales. It is intended to provide evidence for the National Infrastructure Commission (NIC) to assist it in developing policy recommendations around the UK's infrastructure needs over the next 30 years.

ii. Fourteen different categories of infrastructure option are included in the analysis, including reservoirs, surface water and ground water resources, desalination plants, effluent reuse facilities etc. The infrastructure database constructed includes 1,251 infrastructure options, which, in aggregate, could provide a maximum output of 29,808 megalitres per day (Ml/d) of additional water, at a total discounted cost of £240.8 billion.

iii. Alongside these infrastructure options, cost models were developed for three types of demand management options that could enhance drought resilience. These costs models allow the NIC to estimate the costs of improvements in metering penetration, reductions in leakage and other demand-side efficiency measures under a range of possible scenarios.

Costs of infrastructure options

iv. Two datasets were used to analyse the costs of infrastructure. The first dataset built on data compiled as part of a 2016 study on long-term water resources planning prepared by Water UK. This dataset was subject to a number of updates and revisions. The second dataset was developed using information contained in the draft Water Resource Management Plans for 2019 prepared by each water company.

v. Infrastructure option costs include financial costs such as capital expenditure (capex) and operating expenditure (opex) as well as estimates of carbon costs, and other environmental and social costs. Information relating to the maximum output of each infrastructure option is also recorded in the database. This includes an estimate of the maximum amount of water per day that could be provided by each option on full implementation.

vi. The analytical framework developed allows for considerable optionality in how the data can be analysed. In particular, the framework allows the NIC to change the initial parameter values for various assumptions and for cost and output estimates to be adapted automatically. It also provides the NIC with the ability to generate cost curves according to different criteria. For example, costs curves can be generated: for different regions (or combinations of regions); according to whether the option is classified as strategic or not; and for different implementation periods. Infrastructure options can also be combined to generate cost curves according to whether they have high, medium, or low levels of social acceptability.

vii. Across all feasible infrastructure options the average incremental cost (AIC) is, on average, 98 pence per cubic metre of installed water capacity. The average incremental social cost (AISC) for all feasible options is, on average, £1.07 per cubic metre of installed water capacity. The relatively most expensive options are those which involve major capital expenditure such as the development or expansion of reservoirs, or the construction of desalination facilities or effluent reuse facilities. In contrast, the least expensive infrastructure options include surface water, groundwater and bulk supply.

viii. A key output of this project was to provide a uniform and consistent database to allow the NIC to generate cost curves that compared costs against ML/d for different infrastructure categories e.g. reservoirs, water reuse, aquifer recharge, desalination etc. These cost curves are presented in the main body of the report, but at a general level the following remarks can be made. First, while cost curves could be generated for England and Wales, it has not always been possible to generate regional cost curves for a number of infrastructure options given the lack of data. Second, there can be large regional differences in the costs of similar options across regions. To address this, we explored different groupings of regions to create cost curves that could be applied across various regions uniformly. Third, linear trend lines have initially been fitted, and in many cases, provide a good fit to the data. However, the distributions of the plotted data allow for the further testing of alternative functional forms where linear trends may not be the most appropriate and did not provide a good fit with the data.

ix. A number of uncertainties and limitations of the data and analysis should be borne in mind when considering the infrastructure option analysis and cost curves. Three points in particular are important. First, we have not been asked to verify or audit the accuracy of the information contained in the various datasets used as part of this study. Accordingly, there is a risk that information contained in the datasets is inaccurate and either overstates (or understates) the true costs and associated yields of different infrastructure options. Second, the cost curves represent the maximum capacity costs and output generated on the full implementation of the infrastructure options. As such, they are not representative of the cost and associated output for lower levels of capacity and output. Third, we have not engaged with the question of the need for infrastructure options, or portfolio of options. In particular, we have not sought to assess whether different feasible infrastructure options contained in the database will be needed to ensure resilience in the context of drought. Rather, consistent with the terms of reference for this project, our focus is limited to exploring the question of what infrastructure options might cost if they were to be implemented, and not whether they are needed to enhance drought resilience.

Modelling the costs of metering

x. The metering cost model developed allows the NIC to estimate costs for a range of different meter roll-out scenarios. Metering costs include financial costs (such as capex and opex) as well as estimates of carbon costs, and other environmental and social costs. The analysis also captures the benefits of metering in terms of avoiding the cost of investing in infrastructure, and the cold and hot water carbon reduction benefit of metering.

xi. The metering cost model estimates are sensitive to the various assumptions made, particularly about the relative reduction in per capita consumption achievable through the installation of a standard or smart meter. They are also sensitive to assumptions about the initial and on-going costs associated with metering, and the water savings benefit associated with increased metering.

Modelling the costs of leakage control

xii. The leakage control cost model allows the NIC to estimate the costs of different leakage control scenarios at the water company level. Specifically, the model allows the NIC to input scenarios which incorporate different assumptions about the average cost of leakage control, and different assumptions about leakage targets to 2025 and to 2050.

xiii. Three different approaches to estimating the costs of leakage were considered in developing the model. The first approach, based on Water UK (2016), applies a constant average incremental cost of leakage control. The second approach, which was developed in discussion with the NIC, develops and applies a leakage cost function, where the costs of managing leakage vary according to the volume of leakage being managed. The third approach involved estimating the costs of a specific assumed reduction in leakage using estimates contained in Water UK (2016) and UKWIR (2010).

xiv. The leakage cost modelling is sensitive to assumptions made about the assumed average cost of leakage control. While we have tried to mitigate for this by applying a range of approaches and estimates of the average cost of managing leakage, we recognise that there can be considerable differences across companies in the costs associated with leakage control. The results are also sensitive to the timing of when an assumed leakage target will be achieved; even if the same level of target leakage is achieved by 2050, the path to how that is achieved can change the level of costs.

Modelling the costs of demand side efficiency measures

xv. Cost models were developed for three types of demand side efficiency measure, including the costs of: (i) fitting houses with ‘greywater’ water saving devices; (ii) retrofitting houses with other (non-greywater) devices; and (iii) greater household efficiency measures that encourage people to consume less water (e.g.: water conservation advertising campaigns and other efficiency measures and equipment).

xvi. As with the other demand side costs models, the results are sensitive to the assumptions made about specific levels of initial and on-going costs, and in the case of greywater and retrofitting the assumed number of house converted each year, as well as the expected yield in terms of water savings.

1. Introduction

1. We have been commissioned by the National Infrastructure Commission (NIC) to assist it in developing an evidence base, and up to date assessment, of the cost of delivering different standards of drought resilience. The project is intended to provide evidence for the NIC to assist it in developing policy recommendations around UK's infrastructure needs over the next 30 years. In this context, this project aims to build a better understanding of the costs of implementing different water resource management options.[1]

2. The NIC is looking for accurate, independent and up to date information on the costs of infrastructure options and demand management measures in England and Wales. The NIC is not seeking policy recommendations but data and information to build the evidence base for the NIC's own policy analysis. Specifically, we have been asked to:

   i. Develop cost models for different types of demand management options.

   ii. Develop a long list of infrastructure options that could provide additional supply of water, complete with their: capital and operating costs; additional supply of water resource made available by the option; as well as other indicators of their effectiveness, impacts and feasibility, such as social acceptability and construction timeframes.

   iii. Use the long list of infrastructure options identified in (ii) to develop cost curves that present costs against mega litres per day (ML/d) for different infrastructure typologies e.g. reservoirs, water reuse, aquifer recharge, desalination etc.

   iv. Develop a cost database to allow for the NIC to assess different portfolios of options.

   v. Review the draft Water Resource Management Plans for 2019 to extract key information, such as proposed infrastructure options, demand reduction and leakage targets etc.

   vi. Prepare a report that details the data and methodology in a clear and concise fashion.

3. This report has drawn on data and materials provided to us by the NIC, as well as information in the public domain. It has also benefitted from comments, suggestions and clarifications from the NIC and from an external panel of fifteen peer reviewers. It should be emphasised that the analysis and views expressed in this report represent our own, independent assessment of this data and in no way constitute the views of the NIC or the peer review panel.

4. The report comprises 2 additional sections. Section 2 describes the data, methodology and findings of the analysis of the costs of infrastructure options. Section 3 describes the data and methodology used to develop the cost models for demand management options that could be applied to enhance drought resilience in England and Wales.

[1] A peer reviewer observed the report's focus is wider than simply assessing the costs of options to prevent severe droughts in the short-term, but rather focuses on the costs of wider options to enhance water resource management and drought resilience in response to population growth, climate change and sustainability reductions.

2. Costs of infrastructure options

5. This section focuses on the costs of infrastructure options. It describes the data that has been collected and used to compile the database on infrastructure options, and the methodological approach applied to organise and structure the database, particularly in terms of the calculation of various cost and output measures. It then describes the analytical framework developed to analyse the data, and to generate the cost curves according to various cost and output indicators and metrics. The initial findings of the analysis are also presented, including the average incremental cost of different types of infrastructure option, and representative cost curves that present costs against Ml/d for different infrastructure typologies. The final section notes some limitations and uncertainties regarding the data and initial analysis.

2.1 Data

6. The full database of infrastructure options consists of 1,251 supply side projects, which could provide 29,808 Ml/d of additional water at a total discounted cost of £240.8 billion.

7. Two datasets were used to analyse the costs of infrastructure:

    - The first dataset built on data compiled as part of a 2016 prepared by Water UK (Water UK 2016). This dataset was subject to a number of updates and revisions as described below. This dataset is referred to as the 'R-WUK dataset' in this report.

    - The second dataset was developed using information contained in the draft Water Resource Management Plans for 2019 prepared by individual water companies. This dataset is referred to as the 'd-WRMP dataset' in this report.

8. As described below in more detail, information contained in the R-WUK and d-WRMP datasets was used to develop a single combined dataset of the costs of infrastructure options. This is referred to as the 'combined infrastructure dataset' in this report.

2.1.1 R-WUK dataset

9. The initial starting point for the creation of the R-WUK dataset was the information on infrastructure options collected and compiled as part of Water UK (2016). According to the Water UK report, the starting point for the development of this dataset was the infrastructure options contained in the final 2014 Water Resource Management Plans (WRMP). As the primary aim of Water UK (2016) was to look at plausible supply/demand scenarios to 2065, the data compiled was screened to focus on options that were independent, or if multiple versions of the same scheme existed, the lowest cost option was selected.

10. This initial database of infrastructure options was then expanded to include other potentially plausible options that were not contained in the 2014 WRMPs. According to Water UK (2016), a questionnaire was sent to water companies (with follow-up telephone calls where appropriate) to ask them to provide suggestions for additional supply side options that were not included in their 2014 WRMP. The report's authors also carried out a review of national and regional studies into water resource options over the last 40 years,

many of which have not been implemented due to a lack of need or various delivery risks. Deployable outputs and costs for these additional options were compiled and updated as far as possible to allow derivation of net present values, such that they could be compared on an equal basis with the options in the 2014 WRMP.

11. Combining the infrastructure options in the 2014 WRMP, with the additional options identified by water companies, resulted in 292 infrastructure options. These options were provided to us by the NIC at the outset of this project.

12. Following discussions with the NIC and with the authors of Water UK (2016), it was agreed that our analysis should be based on a more expansive dataset of infrastructure options collected as part of Water UK (2016). This full dataset included an additional 310 infrastructure options that were identified by Water UK, but which were excluded from the final analysis. The use of the full Water UK (2016) dataset was deemed appropriate for this project because its focus was on the development of cost curves, rather than the identification and assessment of specific portfolio solutions. In short, the reasoning was that the more data points on the costs and associated yields of different infrastructure options the better.

13. The data were subsequently amalgamated to include additional information where necessary (as the two datasets differed in content) and to remove duplicate entries. The final R-WUK dataset comprised 581 entries.

2.1.2 d-WRMP dataset

14. The d-WRMP dataset was constructed using information on all feasible options listed in the water companies draft 2019 Water Resource Management Plans (WRMP). Information on feasible supply side options was examined for 14 water companies and for 67 different Water Resource Zones (WRZ). The draft 2019 WRMPs was provided to us by the NIC on a confidential basis.

15. Of the total of 2,337 feasible options identified in the 2019 draft WRMPs: 749 were infrastructure options; 1,541 were either demand side options, drought options or other non-supply side options; and 47 options could not be easily classified.

16. The d-WRMP dataset was constructed by using information on the infrastructure options listed in Worksheet 5 of the Excel Workbook that each company submits as part of its draft WRMP. Worksheet 5 contains, among other things, information on capital and operating costs, net present value and the Average Incremental Cost (AIC) and Average Incremental Social Cost (AISC) of all feasible options that a company has identified. The planning scenario assumed was a Dry Year Annual Average.

17. To ensure consistency across water companies and WRZs, additional information was included in the dataset, in particular regarding the type of proposed infrastructure option, the region where it is to be developed, and whether or not it was a preferred option. In most cases, this information was readily obtained from a review of the d-WRMP. However, for those options where the type of infrastructure option was not easily identifiable,

assumptions were made about the classification of the supply side option. Where such assumptions have been made, they have been noted in the database.[2]

18. Data for each WRZ was aggregated for each company, before being combined across all companies to provide a single dataset of infrastructure options. The final d-WRMP database comprised 670 supply side options.

2.1.3 Combined infrastructure database

19. To allow for the analysis of the costs of infrastructure options using an enlarged database the NIC requested that the R-WUK and d-WRMP datasets be merged into a single combined infrastructure database.

20. To allow for consistency in the combined infrastructure database some additional pieces of information were added to the options listed in the d-WRMP dataset. This additional information included:

- The region of the project
- The WRMP option category
- The WRMP option type
- Whether the project was considered strategic or not (strategic options being defined by Water UK (2016) as those yielding greater than 30 ML/d)
- The earliest possible start date
- The implementation periods

21. In addition to including this information in the combined infrastructure database, a number of calculations were applied to the raw data. These calculations were made to allow for a comparison of options contained in the R-WUK and d-WRMP datasets on an equal basis.

2.1.4 Organisation and classification of data

22. The final combined infrastructure database comprises 1251 infrastructure options which have been organised and classified in a consistent manner across the various datasets described above. Table 1 details the key classifications that have been applied to the data, and the underlying rationale for making such a classification.

Table 1: Data organisation classification

Database column	Classification	Sub-Classifications	Description and rationale
A	Region	• Central/West • DCCW (Welsh Water) • London	Allocates each option to one of eight regions. The rationale for allocating options to different

[2] For example, five water companies classified options as transfers which on closer inspection were more in the nature of bulk supply arrangements as defined by other water companies, and for the purposes of the Water UK 2016 analysis. We have therefore re-classified 109 transfer options (with a positive Ml/d output) as bulk supply for the purposes of the cost analysis. This is seen as reasonable given that the focus of this analysis is on examining the costs of different potential water supply options with a view to generating cost curves. Put differently, the focus of this report is not on how different options interact with one another at a regional or national level, but rather how much it will cost to obtain water from a range of different supply sources.

		• Northeast • Northumbrian • Northwest • Southeast (excluding London) • Southwest	geographical regions reflects a recognition that the water demand and supply conditions, as well as costs of different infrastructure options, can vary across regions
B	Company	• Water companies in England and Wales	Allocates each option to one of seventeen water companies. Only a minority of options in the R-WUK dataset are allocated to a specific company.
C	Water Supply Area	• Water Resource Zones (WRZ) in each water company area	Allocates each option to a specific WRZ served by a water company
D	WRMP Option Type Category	• Aquifer recharge • Bulk supply • Conjunctive Use • Desalination • Effluent Reuse • Groundwater new • Groundwater enhancement • New reservoir • Reservoir Enlargement • Surface water Enhancement • Surface water new • Tankering • Water treatment works capacity increase • Water treatment works loss recovery	Allocates each infrastructure option to one of fourteen categories as used in the WRMP. The rationale is to provide a common classification of infrastructure options across companies and WRZs.
E	Option Type	• Aquifer Recharge • Bulk supply • Conjunctive Use • Desalination • Effluent Reuse • Groundwater • Reservoir • Surface Water • Tankering • WTW Capacity	Applies a higher level of classification to allocate each infrastructure option to one of ten categories. This classification ignores the distinction between new and existing options for groundwater, surface water and reservoirs.
F	Further description of option	• Various	Provides a high-level description of each infrastructure option in terms of location and in some cases expected yield
G	Strategic/non-strategic	• Strategic (> 30 ML/d)	This classification was adopted as part of Water UK

		• Non-strategic (<30 ML/d)	(2016) to distinguish between options that would yield more than 30ML/d and those which would not.
H	WRMP Preferred	• True • False	Allocates options according to whether or not they were preferred in the final WRMP 2014 plan (for those options contained in the R-WUK dataset) or are marked as preferred for the draft WRMP 2019 (for those options in the d-WRMP dataset).
I	Earliest possible start date	• Allocation to a particular year	Where it has been identified the earliest possible start date for the implementation of the options
J	Implementation period	• 2015-2020 • 2020-2025 • 2025-2030 • 2030-2035 • 2035-2040 • 2040-2045	Classifies each option to a five-year implementation period. The rationale is to examine how expected costs of similar infrastructure options evolve over time.
K	Committed	• Yes • No	Classifies options according to whether or not they have been committed for development during AMP 6 or AMP 7.

2.1.5 Data accuracy

23. As described above, the combined infrastructure database has been compiled based on information contained in two datasets: the R-WUK dataset and the d-WRMP dataset. Both of these datasets were originally developed using information provided by water companies on the expected yields and costs associated with different feasible infrastructure options.

24. We have not been asked to verify or audit the accuracy of the information contained in the various datasets as part of this study. As such there is a risk that information contained in the datasets is inaccurate and either overstates (or understates) the true costs and associated yields of different infrastructure options.

25. Having regard to this important caveat, there are a number of factors that provide some comfort about the accuracy of the information contained in the datasets. In relation to the R-WUK dataset we note the following:

- The starting point for the identification of infrastructure options was those listed in the final 2014 WRMP for each company, which was subject to consultation and statutory review by a range of stakeholders (including the Environment Agency and Ofwat).

- Additional information on infrastructure options was gained via questionnaires and an extensive review of regional and national studies.

- The analysis of infrastructure options was undertaken by a major engineering consultancy who have extensive expertise in water resources planning.

- Water UK (2016) was subject to external peer-review.

26. As a further check on the accuracy of the data, a meeting was convened between ourselves, the NIC and the engineering consultancy that compiled the R-WUK database. The purpose of this meeting was to clarify areas of ambiguity and to refine the accuracy of the data for specific infrastructure options. During this meeting, it was noted that in certain cases expert opinion was applied to make individual assumptions for a small number of specific infrastructure options, and that in particular, some options were tailored to costs available from a company's 2014 WRMP. Unfortunately, the assumptions underlying specific entries were not detailed during the process, so we have taken these values and any underlying assumptions as given for the purposes of this analysis.

27. In relation to the d-WRMP dataset, we note that the infrastructure options listed in the draft WRMPs have not, as yet, been subject to the same level of scrutiny and review as those options included in the final WRMP 2014 and used in the R-WUK database. However, some comfort can be taken from the fact that the water resource planning process requires companies to thoroughly investigate and detail a range of infrastructure options that are then subject to statutory review by a range of external bodies and regulators. The fact that water companies are aware of the extensive process of external review and scrutiny of the infrastructure options they propose in their draft WRMPs could be argued as providing an incentive for water companies to present reasonably accurate forecasts. Put differently, if the WRMP review process is effective then there should be limited incentives for a water company to provide inaccurate information or to exaggerate estimates of costs or yields at the draft WRMP stage (as such options would be removed through this process, and such practices could undermine the credibility of the company in terms of other options proposed).

28. Although we were not in a position to review and verify the accuracy of all of the feasible infrastructure options in the d-WRMP dataset, we did review the dataset for obvious anomalies and inaccuracies. Based on this review we excluded a small number of infrastructure options that yielded unusual results (such as negative costs or yields). Notwithstanding these points, we suggest that a degree of caution be exercised when considering the information contained in the d-WRMP dataset as this information has not, as yet, been subject to external review and scrutiny.

2.1.6 Data exclusions from combined infrastructure database

29. One hundred infrastructure options that were initially included in the R-WUK and d-WRMP datasets have been excluded from the final combined infrastructure dataset and were not used to generate the cost curves. Eighty-two of these infrastructure options were excluded because they either had missing values (e.g. water output was zero) or anomalous values (e.g.: a negative water output value). A further eight options were excluded because they reported negative or zero costs for the option. The remaining ten options were removed

following consultation and discussion with the NIC. All of these entries tended to be obvious outliers in terms of the relationship between costs and water resource output. These entries have also been removed for the purposes of generating cost curves as described in section 2.4.

30. All of the one hundred infrastructure options removed have been separately identified and retained within the combined infrastructure database and can be easily re-introduced into the analysis if required.

2.2 Methodology

31. Once the database described in section 2.1 was populated and uniformly classified, the data was then analysed to generate a set of consistent cost curves for the different types of infrastructure option. The different steps in the methodology applied to analyse the data are described in this section.

2.2.1 Costs of infrastructure options

(a) Financial costs

32. The combined infrastructure database contains information relating to the financial costs of different infrastructure options, including those detailed in Table 2 below.

Table 2: Financial cost metrics used in database

Database column	Cost metric	Description
R	Total Costs - NPV (£million)	This captures the total discounted costs of a specific option over the planning period. Costs comprises: capital costs (capex); operating costs (opex); and environmental and social costs. These values were largely extracted from the original datasets
T	Total Capex – NPV (£million)	Capex captures all of the capital costs associated with a project over the planning period. This can include costs associated with building new assets or refurbishing or expanding existing assets. These costs are typically fixed, and therefore are, (albeit to varying degrees) largely unaffected by changes in the usage of a particular option/asset. These values were extracted from the original datasets.
U	Total Opex – NPV (£million)	Opex captures all of the on-going operating costs associated with a project over the planning period. Given their nature, these costs are affected by changes in the assumed usage of a particular infrastructure option. For example, if a particular asset only operates at 50% capacity, then this will reduce the

		operating costs it incurs. These values were extracted from the original datasets.

33. The costs for three infrastructure options had to be estimated in the R-WUK database (two for effluent reuse and one for new reservoir).[3] The NPV of total costs for these options were calculated by applying an estimate of the average cost of effluent reuse facility/new reservoir to the expected amount of Water Available for Use (WAFU) generated by each specific option. The initial values applied were those used in Water UK (2016) as shown in table 3 below. However, as described below, the analytical framework is structured to allow the NIC to change these values for these options and for the cost estimates to be automatically updated.

Table 3: Assumptions applied to certain infrastructure options used in database[4]

Infrastructure Option	£m/Ml/d
Effluent Reuse	[X]
New Reservoir	[X]

(b) Carbon, environmental and social costs

34. In addition to the financial costs, various carbon and environmental or social costs are estimated for each infrastructure option and included in the total costs of an option. A description of these cost categories is presented in Table 4 below. Although total carbon and environment and social costs were estimated and included in the infrastructure database, it is our understanding that the cost curves subsequently generated by the NIC did not include these cost categories.

35. Following discussions with the NIC, it was agreed that carbon costs should be separated from other non-financial costs in the database, as this can be included endogenously in the National Infrastructure Modelling. In addition, the removal was seen as prudent as no explicit modelling of carbon prices/costs was undertaken as part of Water UK (2016). Rather we understand that the carbon costs were based on the original WRMP14 NPV costs which had carbon allowances within it.

Table 4: Description of non-financial costs included in database

Database column	Cost metric	Description
X	Total carbon and environment & social costs – NPV (£,000)	These costs capture the combined carbon, environmental and social costs associated with an infrastructure option. In the database these costs have been estimated as the residual cost after capex and opex are accounted for: (i.e.: Total NPV (Column R) – capex NPV (Column T) - opex NPV (Column U)
Y	Carbon costs – NPV (£,000)	This captures the carbon costs associated with a specific proposal. For the R-WUK dataset these costs were estimated separately only for some

[3] The Water UK (2016) analysis provides information on the origin of these assumptions. The Water UK (2016:64) report notes that for uncosted options a means of estimating the high level capex and opex was required.
[4] Values are redacted as they are commercially sensitive information.

		options. For the d-WRMP dataset, water companies separately recorded these costs in their draft plans.
Z	Environmental and social costs – NPV (£,000)	This captures the social costs and any (non-carbon) related costs associated with a specific option. For the R-WUK dataset these costs were estimated separately only for some options. For the d-WRMP dataset water companies separately recorded these costs in their draft plans.

(c) Average incremental costs

36. The financial cost estimates (excluding social and environmental costs) and the total cost estimates (including social and environmental costs) can be divided by the expected output or capacity of a specific infrastructure option to provide an estimate of the cost per unit of capacity or output as shown in table 5. These estimates, which are known as average incremental cost, can allow for a direct comparison of the relative costs of different types of infrastructure options.

Table 5: Average incremental cost metrics

Database column	Cost metric	Description
N	Average Incremental Cost (AIC) – £/m^3	The AIC is calculated by dividing the NPV of financial costs (excluding environmental and social costs) by the discounted value of the volume of water provided by an option. The estimates follow the standard approach to convert rate per day to a volume as calculated for WRMP purposes.
O	Average Incremental Social Cost (AISC) – £/m^3	The AISC is calculated by dividing the NPV of total costs (including environmental and social costs) by the discounted value of the volume of water provided by an option. The estimates follow the standard approach to convert rate per day to a volume as calculated for WRMP purposes.

(d) Cost normalisation for some supply side options

37. As noted in section 2.1 above, the infrastructure database has been constructed based on information prepared by individual water companies either as part of Water UK (2016) or contained in their 2019 draft WRMPs. One potential limitation of constructing the database in this way is that it can lead to significantly different cost estimates for similarly sized infrastructure options. These differences arise because individual water companies make assumptions about, among other things, the expected usage of the asset once it is operational.

38. Differences in assumptions can limit the comparability of infrastructure options and lead to anomalies in the cost estimates generated. To address this, the infrastructure options for desalination and effluent re-use have been 'normalised'; meaning that the capex and opex cost estimates have been constructed based on general assumptions about costs. Specifically, costs have been normalized based on linear cost curves, using an identical approach to that adopted in Water UK (2016).

39. The specific parameter values applied to normalise the capex and opex costs for desalination options and effluent reuse options are shown in table 6 below. However, the analytical framework is structured to allow the NIC to change these parameter values and for the normalised cost estimates to be adapted accordingly.

Table 6: Specific values applied to normalise cost estimates

Option type	Capex	Opex
Effluent reuse		
Slope	1823	547
y-intercept	68505	29781
Desalination		
Slope	4077	760
y-intercept	12760	49569

Source: Water UK, Annex D pp: 65-68.

40. Incorporating the normalised capex and opex costs in the combined infrastructure database results in additional cost categories as detailed in table 7 below.

Table 7: Normalised cost metrics in database

Database column	Cost metric	Description
V	Total Normalised Capex – NPV (£000)	This captures the normalised capex costs. For desalination and effluent reuse, costs are normalised as described in paragraph 38 above. For all other infrastructure options, the capex costs are not normalised and are identical to the values contained in column T.
W	Total Normalised Opex – NPV (£000)	This captures the normalised opex costs. For desalination and effluent reuse, costs are normalised as described in paragraph 38 above. For all other infrastructure options, the capex costs are not normalised and are identical to the values contained in column U.

(e) Additional Treatment costs

41. One of the assumptions made in Water UK (2016) was that provision should be made for additional treatment costs for all surface water resource options. The underlying rationale for this assumption was discussed at a meeting between ourselves, the NIC and the engineering consultancy that compiled the R-WUK database.

42. The explanation provided was that for groundwater and desalination infrastructure options, all of the treatment costs were considered to be adequately captured in the 2014 WRMP

plans (and normalised as part of this process). However, for all other infrastructure options, it was assumed that the costs associated with the installation of treatment facilities was not adequately captured in the WRMP 2014 costs. To address this, Water UK (2016) differentiated between treatment installation costs of raw water options, and the installation costs of partially treated water. Table 8 describes how this has been reflected in the combined infrastructure database.

Table 8: Treatment capex costs adjustment

Database column	Cost metric	Description
AA	Treatment capex costs - NPV (£,000)	These costs capture additional capex costs for surface water infrastructure options that were not included in the original cost estimates provided in each water company's 2014 WRMP.

43. The specific parameter values used to calculate the additional treatment capex costs for surface water infrastructure options in Water UK (2016) are shown in table 9. However, as described below, the analytical framework developed allows the NIC to change these parameter values and for the treatment capex NPV cost estimates to be adapted accordingly. It also allows the NIC to not incorporate this adjustment into its analysis and therefore to choose to generate cost curves which do not include such additional capex costs (this is the approach adopted in section 2.4 below).

Table 9: Parameter values used to calculate additional treatment costs[5]

Option type	Calculation method
Raw water	
Reservoir Enlargement	[£X] x WAFU (ML/d)
New Reservoir	[£X] x WAFU (ML/d)
SW Enhancement	[£X] x WAFU (ML/d)
SW New	[£X] x WAFU (ML/d)
Tankering	[£X] x WAFU (ML/d)
Partially Treated Water	
Effluent Reuse	[£X x WAFU (ML/d)]
Conjunctive Use	[£X x WAFU (ML/d)]
Aquifer Recharge	[£X x WAFU (ML/d)]

Source: WRMP14 Supply Options Redacted.xls

2.2.2 Water resource output of infrastructure options

44. The combined infrastructure database contains information relating to the maximum water resource output of the different infrastructure options. This includes some measure of the Water Available for Use (WAFU) for each infrastructure option as described in Table 10 below. This output measure is critical to the analysis and to the generation of cost curves described in section 2.4.

[5] Values are redacted as they are commercially sensitive information.

Table 10: Output measures

Database column	Cost metric	Description
L	WAFU (Ml/d)	The WAFU (Ml/D) provides an estimate of the water available for use on full implementation of the option described. This is the maximum possible WAFU for the option.
M	WAFU (Ml/annum)	The WAFU (Ml/annum) provides an estimate of the water available for use per year on full implementation of the option described. This is the maximum possible WAFU for the option. It is calculated by multiplying the WAFU (Ml/d) by 365.

2.3 Data analysis

45. The analytical framework allows for considerable optionality in how the data described in the previous sections above can be analysed. This provides the NIC with the ability to generate cost curves according to different criteria and assumptions. This section describes key elements of the analytical framework developed and explains how it allows the NIC to generate different types of cost curves.

2.3.1 Parameter values and assumptions

46. A separate tab is included in the database for key parameter values that are used within the calculations to improve clarity and to allow different assumptions to be reflected in the costs analysis quickly and efficiently. The parameter values included in this tab allow for different assumptions to be made about:

- The estimated average costs of effluent reuse and new reservoirs for those infrastructure options where NPV cost values were not available.
- The values used to normalise the capex and opex costs for desalination options and effluent supply options.
- The estimated values of additional treatment capex costs for the different surface water options.
- How the infrastructure options are allocated to different cost categories based on the expected AIC/AISC (i.e.: to set allocation bands).
- The expected utilisation level for each infrastructure option.
- The period for implementation of the different infrastructure options.

2.3.2 Analysis of infrastructure options by region

47. One of the outputs requested by the NIC was that costs curves be capable of being generated at a regional level. Table 11 below shows the specific regions identified by the NIC as well as the number of infrastructure options by type in each region in the combined infrastructure database.

Table 11: Infrastructure options by region – Combined infrastructure database

	Central/ West	DCWW	London	Northeast	Northumb rian	Northwest	Southeast excl. London	Southwest	Grand Total
Aquifer recharge	1		13	2			10		26
Bulk supply	43		35	17		6	305	5	411
Conjunctive use	8		1	3		2	6		20
Desalination			11	3		3	121	5	143
Effluent reuse	7		33			12	74	4	130
GW enhancement	32		16	5		40	45	6	144
GW new	3		21	8		20	43	2	97
New reservoir	8					3	41	5	57
Reservoir Enlargement	17	4	7	7		9	22	1	67
SW enhancement	23	1		9	1	4	16	3	57
SW new	20		3	18		11	10	6	68
Tankering			1	1					2
WTW capacity increase			1	2			12	5	20
WTW loss recovery				5			3	1	9
Total	**162**	**5**	**142**	**80**	**1**	**110**	**708**	**43**	**1251**

2.3.3 Analysis of infrastructure options by implementation period

48. We also examined how the costs of infrastructure options differed by implementation period. The purpose of this analysis was to allow the NIC to assess if, and how, the costs of different infrastructure options change over time. Analysis of this type can be important when assessing the relative costs and benefits of taking action sooner rather than later (i.e.: a real options analysis).[6]

49. Table 12 below shows the expected implementation period for the different infrastructure options in the combined database. For 173 infrastructure options, particularly those included in the d-WRMP, no specific implementation period was identified. Accordingly, these infrastructure options are excluded from table 12 below.

Table 12: Infrastructure options by implementation period – Combined dataset

	2015-20	**2020-25**	**2025-30**	**2030-35**	**2035-40**	**Total**
Aquifer recharge	15	6	3			24
Bulk supply	97	163	78	14	4	356
Conjunctive use	2	12	2			16
Desalination	18	36	77			131
Effluent reuse	25	54	36	5		120
GW enhancement	45	37	19	7		108
GW new	53	17	6	1		77
New reservoir	5	20	19	6	2	52
Reservoir Enlargement	4	21	11	12	7	55
SW enhancement	16	8	29	2		55
SW new	18	15	9	15	2	59
Water treatment works capacity increase	11	4	1			16
Water treatment works loss recovery	5	4				9
Total	**314**	**397**	**290**	**62**	**15**	**1078**

2.3.4 Analysis of 'normalised' costs for certain infrastructure options

50. The infrastructure options included the database have primarily been derived from options that have featured in a company's final or draft WRMP. In developing their WRMPs companies generally consider fixed and variable costs and the expected utilisation of the options (e.g. in EBSD analysis). More specifically, the standard EBSD approach calculates utilisation for an infrastructure option required to address a particular supply-demand deficit under a single scenario for a specific WRZ.[7] As noted in Water UK (2016), one consequence of this modelling approach is that similar types of infrastructure options can have different costs depending on which region and WRZ they are located in.

[6] The deferral of projects can sometimes involve additional costs (for example, where there is a need to undertake new planning approvals processes etc.). Also to extent to which an options is scaleable or modular (i.e.: can be implemented in distinct phases over time) this can impact on the implementation profile and costs.

[7] Water UK (2016), page 64.

51. Consistent with the approach in the Water UK (2016), to address this variation, we have sought to 'normalise' the values for two types of infrastructure options where the assumption regarding utilisation is expected to have a major impact on costs. The two options normalised are desalination and effluent re-use. All of the other infrastructure option types are considered too site specific to allow for normalisation.

52. The initial parameter values applied to normalise the capex and opex cost estimates for desalination and effluent re-use options are detailed in table 6 above and based on those applied in Water UK (2016). In brief, the approach adopted to generate these initial estimates averaged varying regional values to provide a national estimate.[8]

53. Figures 7 and 10 in section 2.4 compare the normalised and non-normalised cost curves for effluent re-use and desalination respectively. It should be emphasised that this analysis provides the NIC with the option to generate cost curves on a normalised or non-normalised basis; it can choose to generate non-normalised cost curves for these specific types of infrastructure option.

2.3.5 Analysis of different assumed output levels and associated costs

54. Consistent with WRMP guidance the cost and output estimates for all of the infrastructure options in the database are based on capacity and not on expected actual output. More precisely, the total costs, AIC and AISC values for each infrastructure option are estimated based on the NPV of maximum capacity costs and outputs of the option.[9]

55. In practice it is unlikely that all of the infrastructure options will produce at maximum capacity all of the time, and this raises the risk that some costs may be overstated. For example, some financial costs such as electricity costs, can vary significantly according to the assumed level of output.

56. As part of the analytical framework, we have included the option for the NIC to change the assumed level of output for each option, and to analyse what happens to operating costs in these circumstances. Specifically, the NIC has the ability to generate cost curves based on the assumption of moderate utilisation/output of an option and low utilisation/output of an option. The initial values applied are 70% of full capacity (moderate utilisation) and 35% of full capacity (low utilisation). However, these initial assumptions can be easily changed within the framework.

2.3.6 Analysis of social acceptability

57. The analytical framework provides the NIC with an ability to generate cost curves according to different assumed levels of social acceptability for the various infrastructure options. Each of the 14 categories of infrastructure option can be allocated a ranking of either low, medium or high social acceptability. This provides another means of analysing the data and could be used to combine different infrastructure options together, according to whether they are considered to have high, medium, or low levels of social acceptability.

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[8] More detail on this approach can be found at Water UK (2016), page 65.
[9] See Environment Agency and Natural Resources Wales (2016), page 30.

58. The rationale for including the option within the analytical framework reflects the fact that customers and other stakeholders may have different preferences for the infrastructure options. Put simply, even though some infrastructure options may be assessed as least cost in terms of output, they may nevertheless not be favoured by stakeholders if they involve social or environmental impacts. This approach is also consistent with a general shift towards focussing on a multi-criteria assessment of water resource options. Indicative classifications of the 14 infrastructure options on the basis of social acceptability were included in the combined infrastructure database based on rankings contained in certain companies' 2014 WRMP. However, as it was not possible to provide an accurate classification of social acceptability within the scope of this project it is our understanding that this aspect of the analysis was not taken further by the NIC.

2.3.7 Strategic or non-strategic options

59. The analytical framework provides the NIC with an ability to generate cost curves according to whether an infrastructure option is classified as strategic or not. The classification of infrastructure options into 'strategic' and 'non-strategic' provides the ability to generate cost curves according to the expected water resource output of an option, and to therefore examine the costs associated with major infrastructure options which will generally involve larger investments. It also potentially allows for a relative comparison of how the costs of a specific large, infrastructure options compare to combinations of smaller, non-strategic infrastructure options for a given level of water resource output.

60. The initial classification of strategic options was defined based on Water UK (2016), where any options greater than 30 Ml/d in size (excluding any intra-company transfers) were classified as 'strategic'. The analytical framework allows the NIC to change this assumption and to set a higher or lower threshold for the classification of strategic options.

61. Table 13 below shows, for each type of infrastructure option category, the number of options that have been initially classified as 'strategic' and 'non-strategic', the associated output (in terms of Ml/d) and the combined NPV of total costs. It indicates that although only 18% of feasible options are classified as strategic, these options nevertheless generate 65% of the additional water resource output and account for some 61% of overall cost.

Table 13: Number of strategic and non-strategic options – consolidated database

	Strategic (<30 ML/d)			Non-Strategic (>30 ML/d)		
	No. of options	Ml/d	NPV Costs (£M)	No. of options	Ml/d	NPV Costs (£M)
Aquifer recharge				26	129	861
Bulk supply	63	4247	42319	348	4178	31,921
Conjunctive use	3	111	429	17	120	597
Desalination	35	3704	37571	108	1869	22,012
Effluent reuse	42	3683	23359	88	1059	15,288
GW enhancement	4	132	854	140	671	2,584
GW new	4	143	547	93	401	1,508
New reservoir	17	993	12917	40	668	8,828
Reservoir Enlargement	18	2698	16509	49	314	3,673
SW enhancement	16	1017	2213	41	443	1,643
SW new	25	1881	8270	43	539	3,969

Tankering	2	205	1109			
WTW capacity increase	2	479	960	18	106	829
WTW loss recovery				9	16	81
Total	**231**	**19,293**	**147,055**	**1020**	**10,515**	**93,795**

2.3.8 Analysis of cost parameters against output parameters

62. The analytical framework allows the NIC to generate a series of cost curves using different cost and output measures. The possible cost and output combinations for which cost curves can be generated are shown in table 14 below.

Table 14: Options for generating plots and cost curves

Output parameters (X-axis)		**Cost parameters (Y-axis)**	
Output Measure (NPV)	**Units**	**Cost measure (NPV)**	**Units**
WAFU	Ml/d or Ml/annum	Total costs	(£M)
		Total costs (excl. carbon)	(£M)
		Total costs (normalised)	(£M)
		Total costs (normalised, excl. carbon)	(£M)
		Capex	(£000s)
		Capex (normalised)	(£000s)
		Opex	(£000s)
		Opex (normalised)	(£000s)
		Carbon costs	(£000s)
		Environment & Social costs	(£000s)

63. Information contained in the combined infrastructure database allows the NIC to generate cost curves by making additional assumptions. Plots can be generated based on the above parameters as well as the following:

- Allowing for additional capex treatment costs that were not captured in the capex estimates for certain surface water related options

- Including or excluding carbon costs in the estimates of the NPV of total costs, and (normalised) total costs

64. Lastly, as described in this section, additional options have been included to allow cost curves to be disaggregated further by the following parameters:

- **Region:** cost curves can be generated for different regions, or all combinations of regions (see section 2.3.2)

- **Strategic option:** cost curves can be generated according to whether the option is classified as strategic or not (see section 2.3.7)

- **Implementation period:** cost curves can be generated for one or more 5-year time bands ranging from 2015-20 to 2035-2040 (see section 2.3.3)

- **Social Acceptability:** Options can be combined to generate cost curves according to whether they have high, medium, or low levels of social acceptability (see section 2.3.6)

- **Assumed output levels and associated costs:** cost curves can be generated for full, medium or low assumed levels of output (see section 2.3.5)

- **Dataset:** cost curves can be generated for infrastructure options in the R-WUK dataset, d-WRMP dataset or combined infrastructure dataset.

65. Table 15 below provides a summary of the different combinations of cost curves that can be generated using the analytical framework developed.

Table 15: Possible combinations of infrastructure cost curves that can be generated

Cost measure (NPV)	Output measure (WAFU)	Option	Region	Strategic	Implementation period	Social acceptability	Assumed output level	Dataset
• Total costs • Total costs (excl. carbon) • Total costs (normalised) • Total costs (normalised excl. carbon) • Capex • Capex (normalised) • Opex • Opex (normalised) • Carbon costs • E&S Costs	• WAFU (Ml/d) • WAFU (Ml/annum)	• Aquifer recharge • Bulk supply • Conjunctive Use • Desalination • Effluent Reuse • Groundwater new • Groundwater enhancement • New reservoir • Reservoir Enlargement • Surface water Enhancement • Surface water new • Tankering • Water treatment works capacity increase • Water treatment works loss recovery	• Central/West • DCCW (Welsh Water) • London • Northeast • Northumbrian • Northwest • Southeast (excluding London) • Southwest	• Strategic (>30 ML/D) • Non-strategic (<30 Ml/d)	• 2015-2020 • 2020-2025 • 2025-2030 • 2030-2035 • 2035-2040 • 2040-2045	• High • Med • Low	• Full • Med • Low	• R-WUK • d-WRMP

2.4 Findings

66. This section summarises some of the key findings of the initial analysis of infrastructure options.

2.4.1 Average incremental cost estimates

67. Analysis of the data provides information on the average incremental cost (AIC) and average incremental social cost (AISC) for the different types of infrastructure option, and in different regions of the country. Estimates of the AIC and AISC for different infrastructure options at an aggregate level are shown in table 16 below. This shows the AIC and AISC for all of the feasible infrastructure options in the combined infrastructure database, as well as for those options which have been specifically identified as WRMP preferred, either in a water companies final 2014 WRMP or its draft 2019 WRMP.

Table 16: Average AIC and AISC values for combined infrastructure dataset

	All feasible options		WRMP preferred options	
	Average AIC (p/m^3)	**Average AISC (p/m^3)**	**Average AIC (p/m^3)**	**Average AISC (p/m^3)**
Aquifer recharge	113.7	122.0	106.4	113.8
Bulk supply	83.9	89.0	44.2	46.7
Conjunctive use	105.1	116.4	54.8	71.2
Desalination	128.3	137.0	113.0	118.4
Effluent Reuse	128.2	156.9	117.5	129.6
Groundwater	67.1	70.4	39.3	41.2
Reservoir	172.9	185.3	85.3	86.8
Surface Water	63.3	71.8	28.7	31.8
WTW Capacity	86.4	99.9	105.7	119.7
All infrastructure options	**98.1**	**107.4**	**59.0**	**62.7**

Source: Own analysis based on combined infrastructure dataset

68. Four insights can be drawn from table 16:

- First, across all feasible infrastructure options the AIC is, on average, 98.1 pence per cubic metre of installed water capacity. The AISC is, on average, £1.07 per cubic metre of installed water capacity; implying that the (average) social and environmental cost of installing an additional cubic metre of water capacity is just under 10 pence.

- Second, in aggregate the AIC and AISC for the WRMP preferred options is significantly lower than for the all feasible infrastructure options. However, the scale of the difference varies by infrastructure option: the average AIC/AISC for reservoirs, conjunctive use, surface water and ground water are substantially lower for the WRMP preferred options than for all feasible options. In contrast, the differences between the average AICs for desalination, effluent reuse and aquifer recharge options are less marked.

- Third, perhaps unsurprisingly, on average, the relatively most expensive infrastructure options are those which involve major capital expenditure such as the development or expansion of reservoirs, or the construction of desalination facilities or effluent reuse facilities.

- Fourth, and in contrast to the previous point, the relatively less expensive infrastructure options are, on average, those relating to surface water, groundwater or bulk supply. Indeed, these options are (on average) at least half as expensive per cubic metre of installed water capacity than those which involve major capital expenditure (such as reservoirs, desalination plants or effluent re-use facilities).

69. An important point of caution when interpreting these findings is that the AIC and AISC estimates are – consistent with the WRMP planning guidelines – based on the NPV of maximum capacity costs and outputs. However, in practice it is unlikely that all of the infrastructure options will produce at maximum output, and this raises the risk that cost may be overstated. For example, some financial operating costs such as electricity costs can vary according to the assumed level of output for some infrastructure options (such as desalination plants).

2.4.2 Cost curves for different infrastructure options

70. As noted in section 1, one of the key outputs of this project was to allow the NIC to develop cost curves that present costs against mega litres per day for different infrastructure typologies e.g. reservoirs, transfers, water reuse, aquifer recharge, desalination etc.

71. This section provides a high-level overview of a set of representative cost curves generated for the different infrastructure options.[10] As described in section 2.3 there is considerable optionality in the analytical framework, meaning that a wide range of potential cost curves could be generated. Accordingly, the discussion in this section is intended, in part, to provide insight into the potential of the data and to highlight the types of cost curves that can be generated.

72. Before presenting the cost curves for different infrastructure options, some more general remarks are merited:

- First, whilst the initial aim was to develop regional cost curves for all infrastructure options the lack of data points meant this was difficult to do for some options. Moreover, in some cases where trends were identified these could be heavily biased by a single option or potential outlier.

- Second, the initial focus on individual regions highlighted large regional differences in the costs of similar options across many regions. To address this, where required different groupings of regions were also explored with the potential in some cases

[10] Tankering options are excluded, as they only comprise two observations.

to create cost curves that could be applied across various regions uniformly.

- Third, figures labelled (d) to (f) in the panels below show the regional groupings for a specific infrastructure option which provide the best fit to the data.

- Fourth, the cost curves incorporate options classed as both strategic and non-strategic.

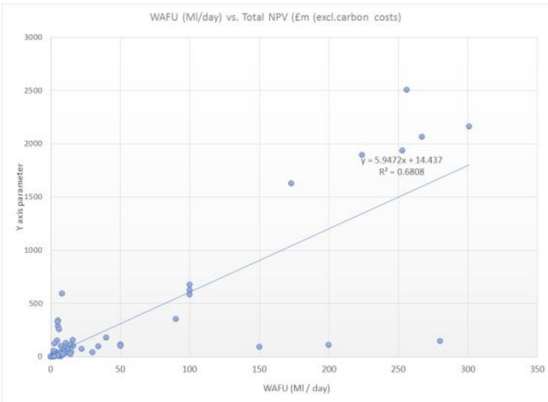
- Fifth, linear trend lines have initially been fitted, and in many cases, provide a good fit to the data. However, the distributions of the plotted data allow for the further testing of alternative functional forms where linear trends did not provide a good fit with the data.

(a) *Reservoir enlargement cost curves*

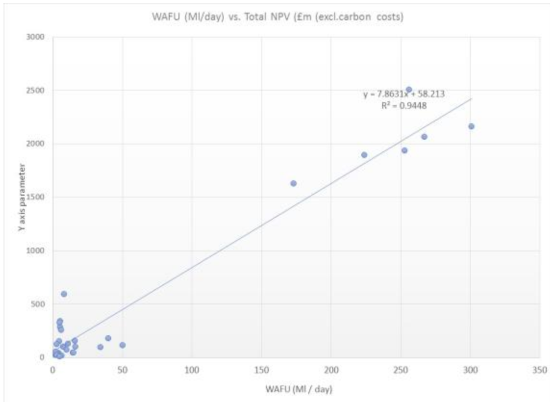
73. Seven regions include options for reservoir enlargement. Figures 1 (a) to (c) show the total, capex and opex cost curves for reservoir enlargement options for all regions, while figures 1 (d) to (f) show the total, capex and opex cost curves for reservoir enlargement options for London and the Southern regions. Across all regions, there was a reasonably good linear fit with the data. However, this fit is particularly good when London, the Southeast and Southwest are combined.

Figure 1: Cost curves for reservoir enlargement

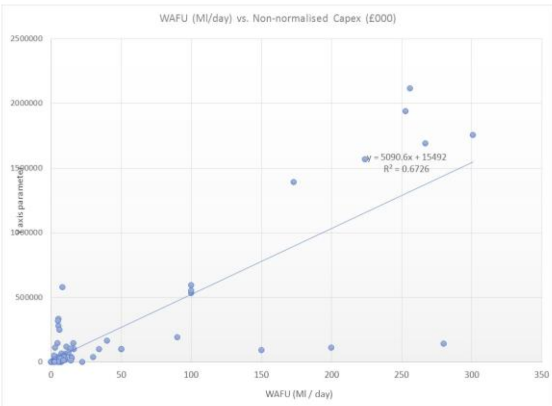
(a) Total costs curve (excl. carbon) (all regions)



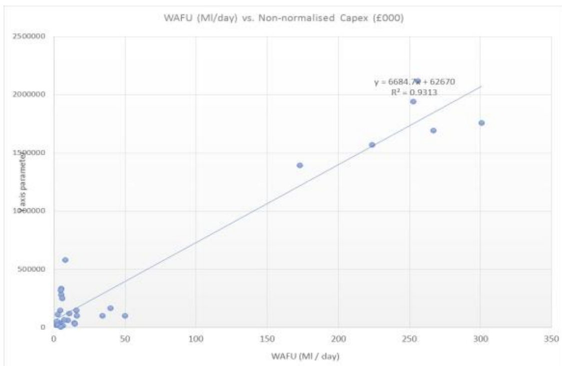
(d) Total costs curve (excl. carbon) (London & Southeast and Southwest)



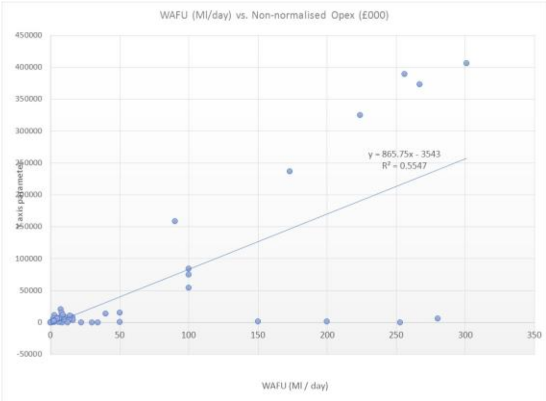
(b) Total capex cost curve (all regions)



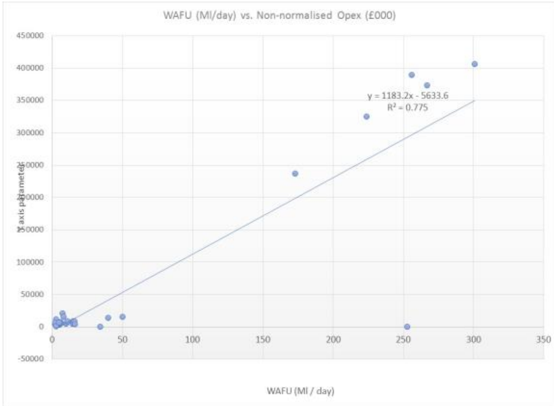
(e) Total capex cost curve (London & Southeast and Southwest)



(c) Total opex cost curve (all regions)



(f) Total opex cost curve (London & Southeast and Southwest)

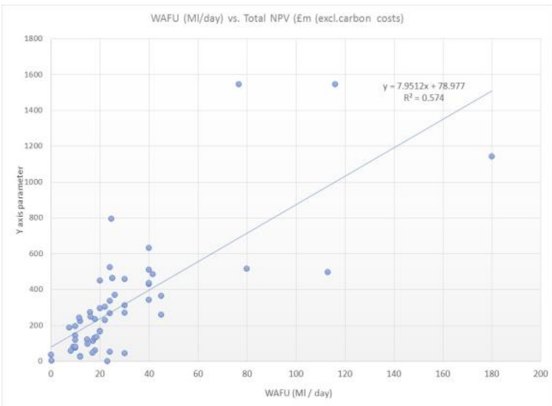


(b) *New reservoir cost curves*

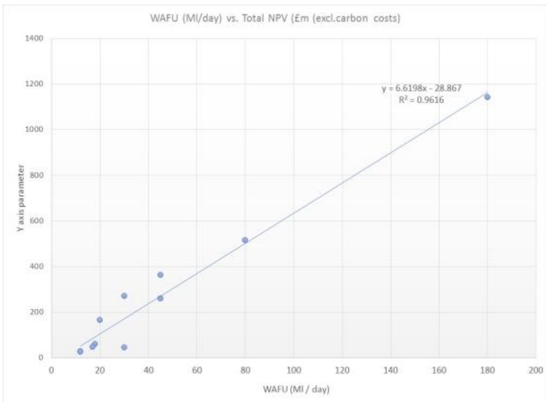
74. Although only four regions feature new reservoir options there appear to be important differences between options in the Southern regions and those in the Central/West and Northwest regions. Figures 2 (a) to (c) show the total, capex and opex cost curves for new reservoir for all regions, which overall, show a reasonable linear fit with the data. Figures 2 (d) to (f) show the total, capex and opex cost curves for new reservoirs for the Central/West and Northwest regions, which have a very good fit with the data. However, the relatively limited number of data points suggests caution in establishing the robustness of linear trends.

Figure 2: Cost curves for new reservoirs

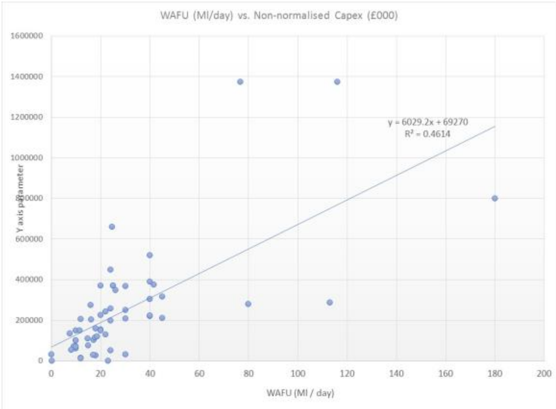
(a) Total costs curve (excl. carbon) (all regions)



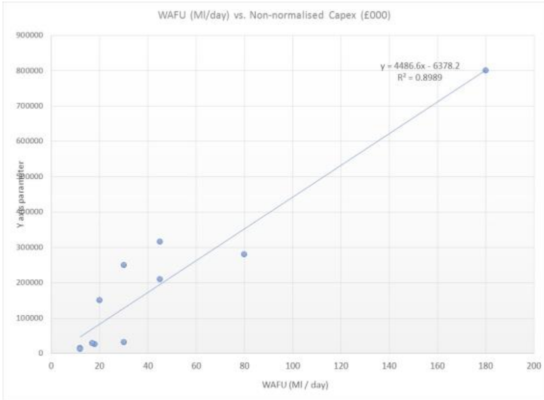
(d) Total costs curve (excl. carbon) (Central/ West & Northwest)



(b) Total capex cost curve (all regions)

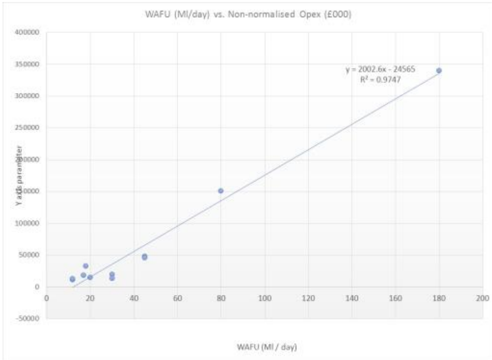


(e) Total capex cost curve (Central/ West & Northwest)



(c) Total opex cost curve (all regions)

(f) Total opex cost curve (Central/ West & Northwest)

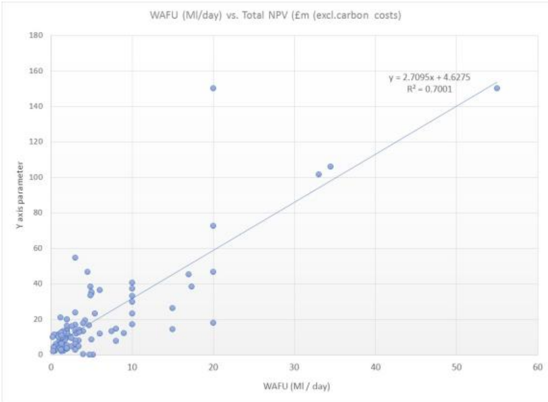


(c) New groundwater cost curves

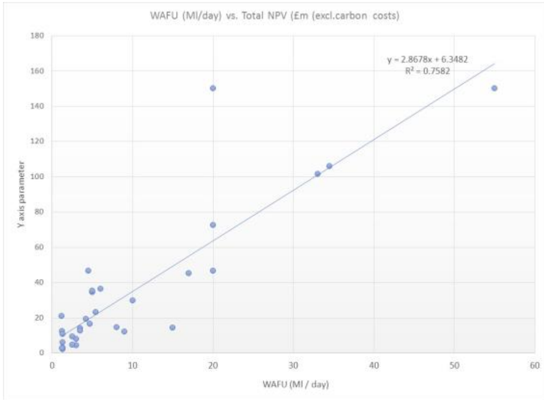
75. Six regions feature new groundwater options, and once again, there appear to be important cost differences between options in London and the Southern regions and those in the Central/West, Northwest and Northeast regions. Figures 3 (a) to (c) below show the total, capex and opex cost curves for new groundwater options for all regions. This shows a good linear fit with the data. Figures 3 (d) to (f) show the total, capex and opex cost curves for new groundwater for the Central/West Northwest and Northeast regions, which also has a strong linear fit with the data.

Figure 3: Cost curves for new groundwater options

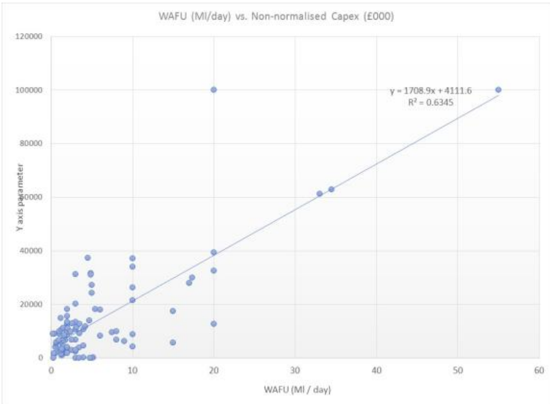
(a) Total costs curve (excl. carbon) (all regions)



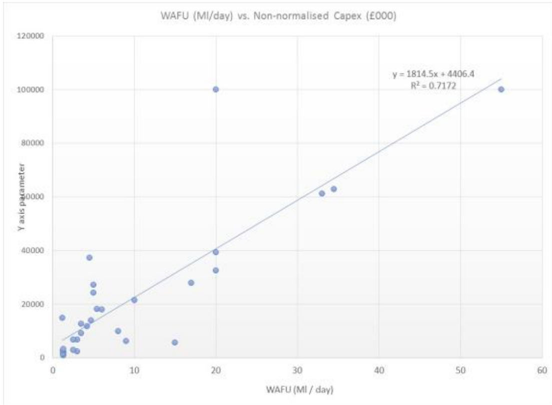
(d) Total costs curve (excl. carbon) (Central/ West, Northwest and Northeast)



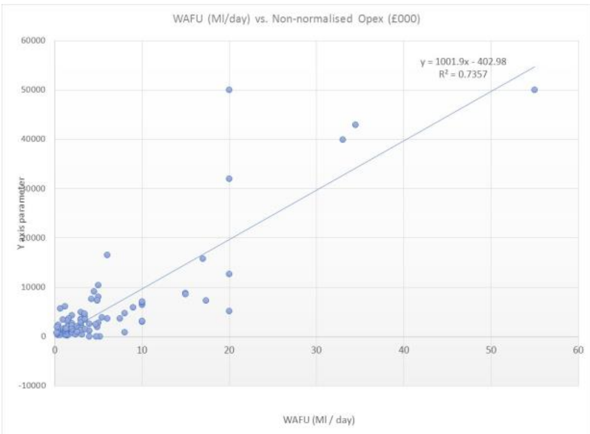
(b) Total capex cost curve (all regions)



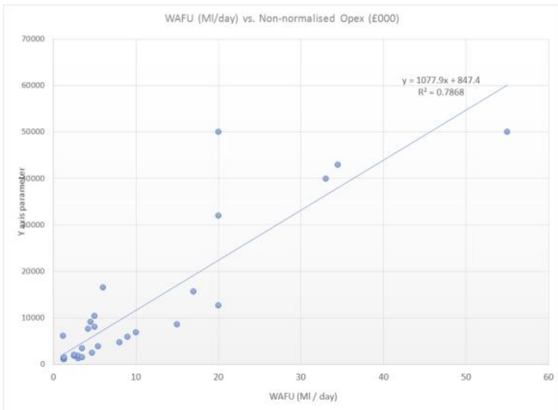
(e) Total capex cost curve (Central/ West, Northwest and Northeast)



(c) Total opex cost curve (all regions)



(f) Total opex cost curve (Central/ West, Northwest and Northeast)



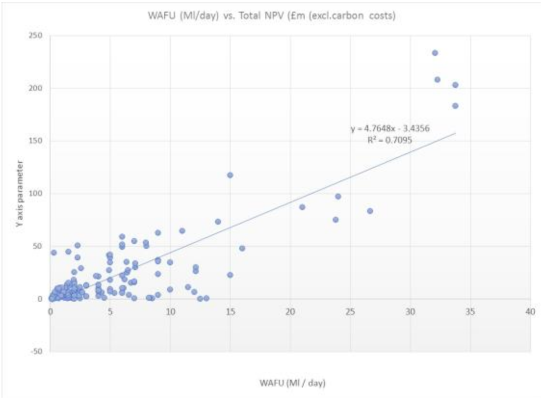
(d) Groundwater enhancement cost curves

76. Six regions feature groundwater enhancement options. Figures 4 (a) to (c) below show the total, capex and opex cost curve costs for new groundwater for all regions. This shows a good overall linear fit with the data. Figures 4 (d) to (f) show the total, capex and opex cost curves for new reservoirs for the Central/West Northwest and Northeast regions, which has a slightly improved linear fit with the data. The linear cost curves for other regions –

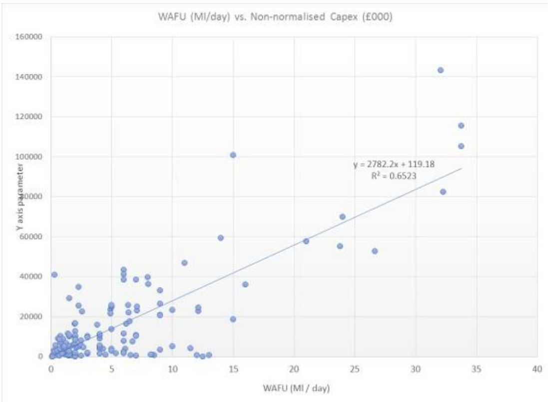
particularly London and the Southeast – show a very poor linear fit with the data. Other functional forms were fitted to the data, but the fit was still poor.

Figure 4: Cost curves for groundwater enhancement options

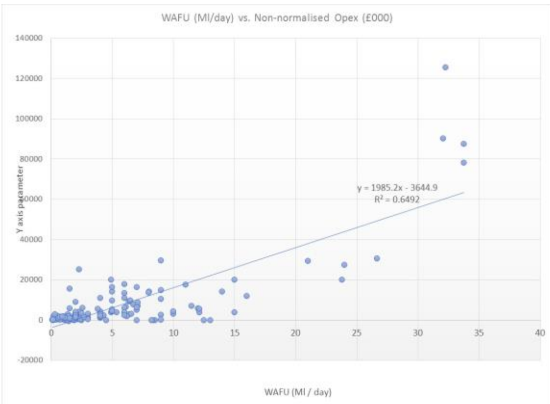
(a) Total costs curve (excl. carbon) (all regions)



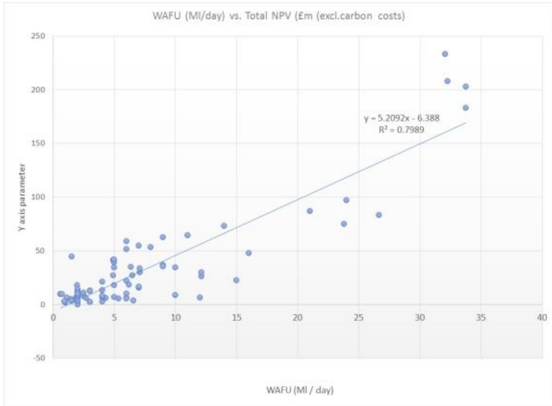
(b) Total capex cost curve (all regions)



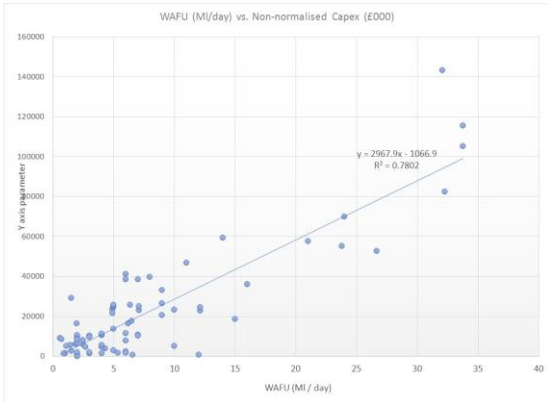
(c) Total opex cost curve (all regions)



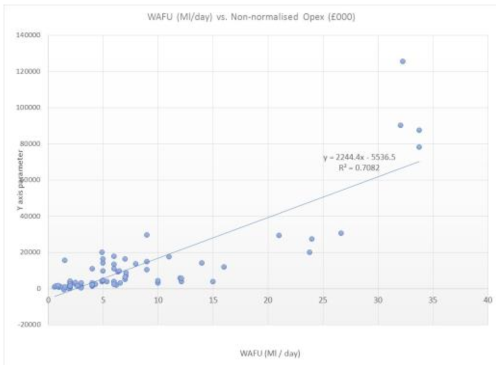
(d) Total costs curve (excl. carbon) (Central/ West, Northwest and Northeast)



(e) Total capex cost curve (Central/ West, Northwest and Northeast)



(f) Total opex cost curve (Central/ West, Northwest and Northeast)

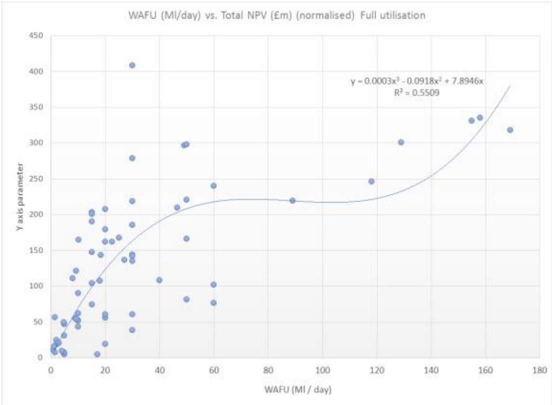


(e) New surface water cost curves

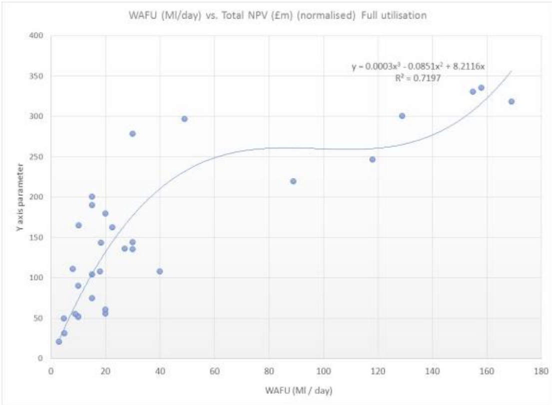
77. Figures 5 (a) to (c) below show the total, capex and opex cost curves for new surface water options for the six regions where such options feature. The initial linear cost curve generated a very poor fit with the data, and accordingly alternative functional forms were applied to the data. The best fit with the data was a cubic polynomial cost curve. Figures 5 (d) to (f) show the total, capex and opex cubic polynomial cost curves for new surface water options for the Central/West and Northwest regions, which also has a good fit with the data.

Figure 5: Cost curves for new surface water options

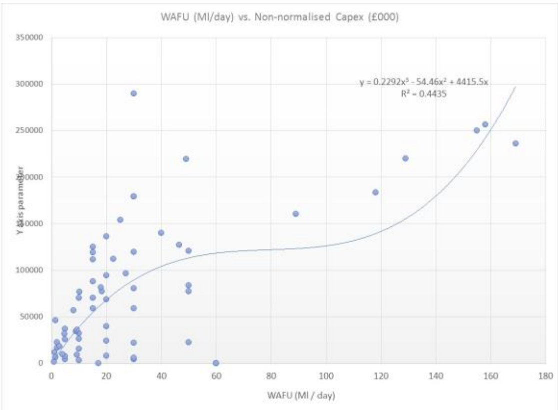
(a) Total costs curve (excl. carbon) (all regions)



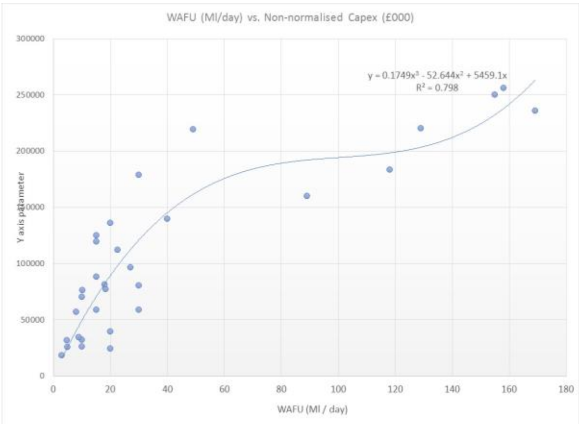
(d) Total costs curve (excl. carbon) (Central/ West & Northwest)



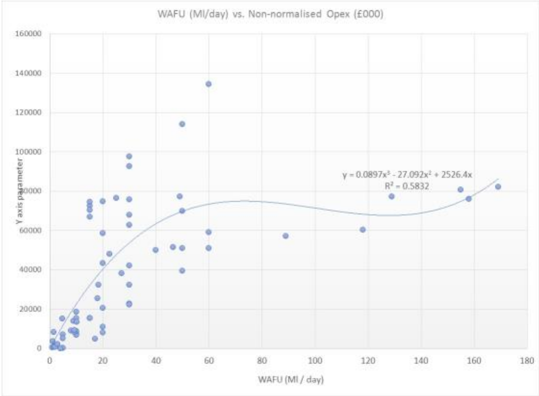
(b) Total capex cost curve (all regions)



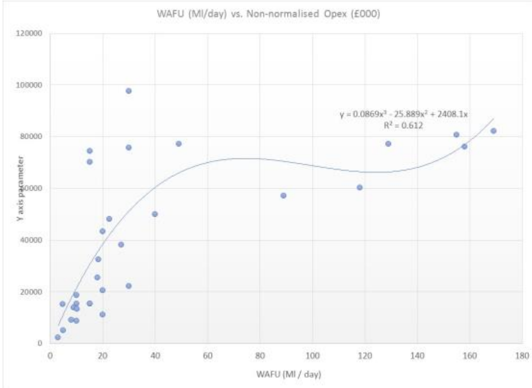
(e) Total capex cost curve (Central/ West & Northwest)



(c) Total opex cost curve (all regions)



(f) Total opex cost curve (Central/ West & Northwest)

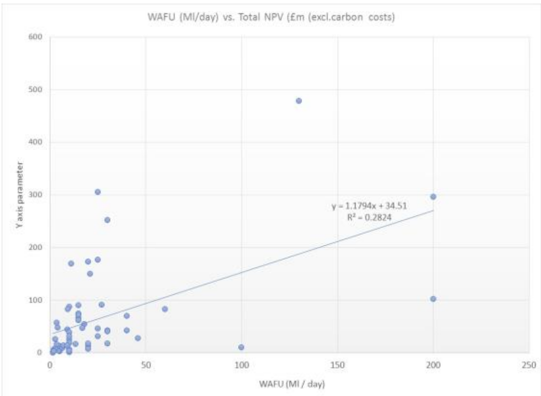


(f) *Surface water enhancement cost curves*

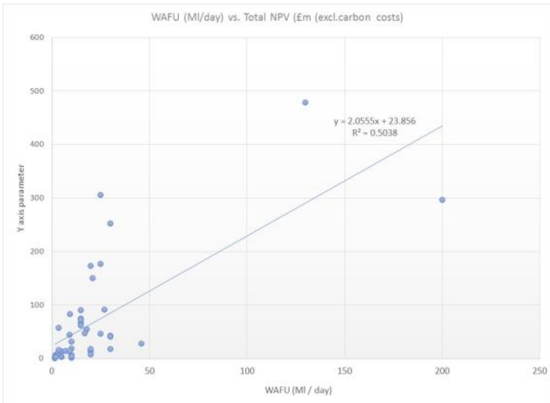
78. Figures 6 (a) to (c) below show the total, capex and opex linear cost curves for surface water enhancement options for the seven regions where they feature in the database. Although the linear cost curves presented in these figures do not show a very strong fit with the data, other alternative functional forms did not improve the fit. Figures 6 (d) to (f) show the total, capex and opex linear cost curves for surface water enhancement options for the Central/West, DCCW, Southwest and Southeast and regions, which when combined showed the best fit with the data.

Figure 6: Cost curves for surface water enhancement options

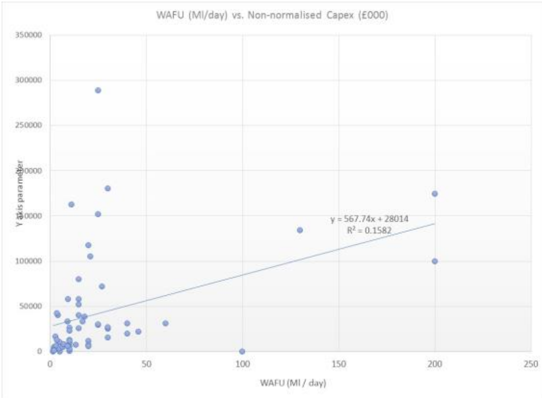
(a) Total costs curve (excl. carbon) (all regions)



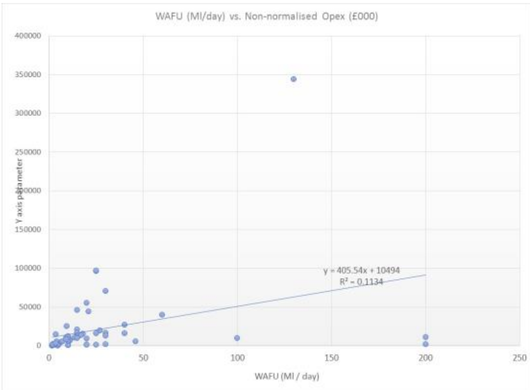
(d) Total costs curve (excl. carbon) (Central/ West, DCCW, Southwest & Southeast (excl. London)



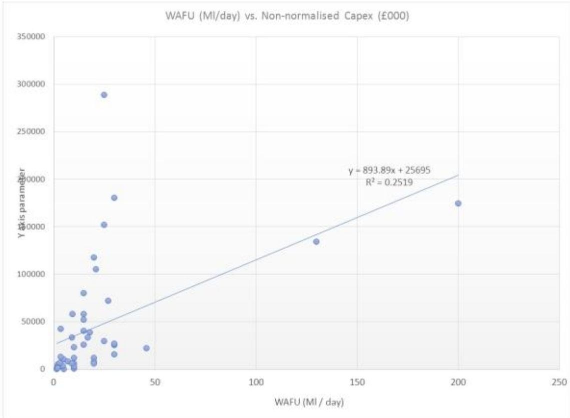
(b) Total capex cost curve (all regions)



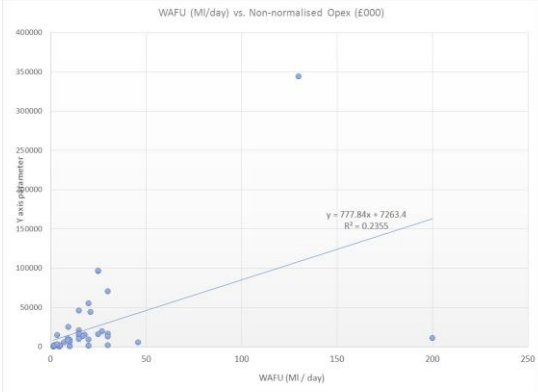
(c) Total opex cost curve (all regions)



(e) Total capex cost curve (Central/ West, DCCW, Southwest & Southeast (excl. London)



(f) Total opex cost curve (Central/ West, DCCW, Southwest & Southeast (excl. London)

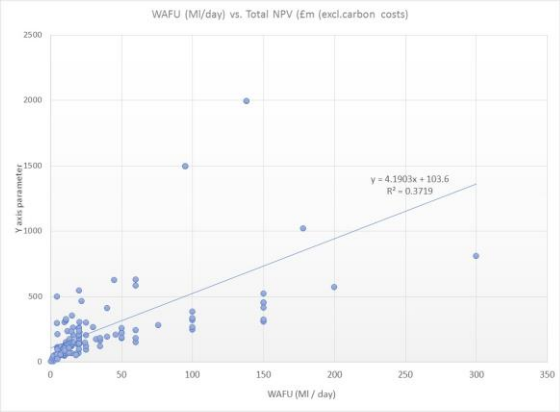


(g) Effluent reuse cost curves

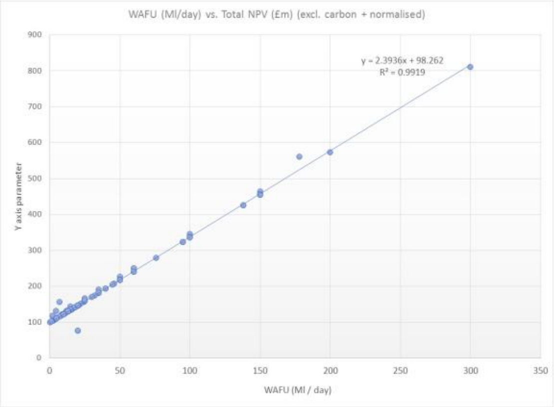
79. Five regions feature effluent reuse options. Figures 7 (a) to (c) below show the total, capex and opex linear cost curves for effluent reuse projects for all five regions. As described in section 2.3.4 above, the opex and capex costs for effluent re-use have been normalised using linear cost curve coefficients developed in Water UK (2016). Figures 7 (d) to (f) reflect these trends and show the normalised total, capex and opex linear cost curves for the five regions. This allows for a direct comparison between the normalised and non-normalised cost curves for effluent reuse.

Figure 7: Cost curves for effluent reuse options

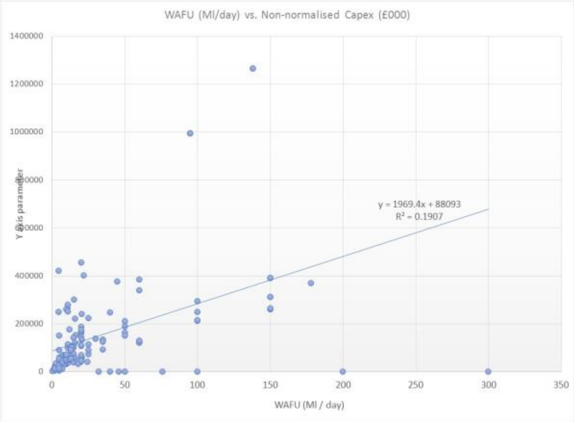
(a)Total costs curve (excl. carbon) (all regions)



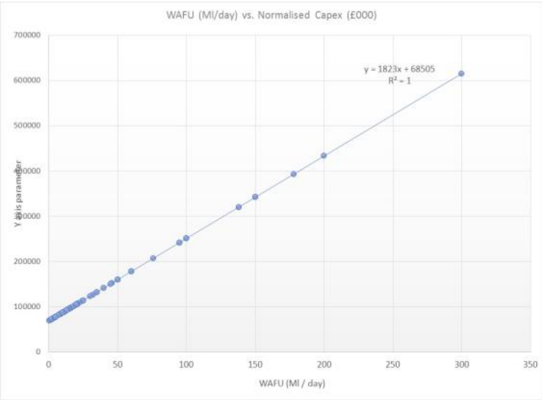
(d) Total normalised costs curve (excl. carbon) (all regions)



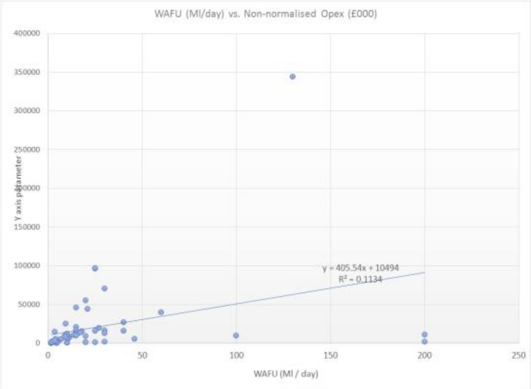
(b) Total capex cost curve (all regions)



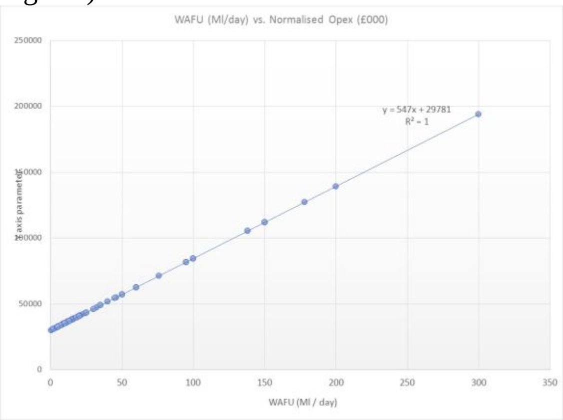
(e) Total normalised capex cost curve (all regions)



(c) Total opex cost curve (all regions)



(f) Total normalised opex cost curve (all regions)

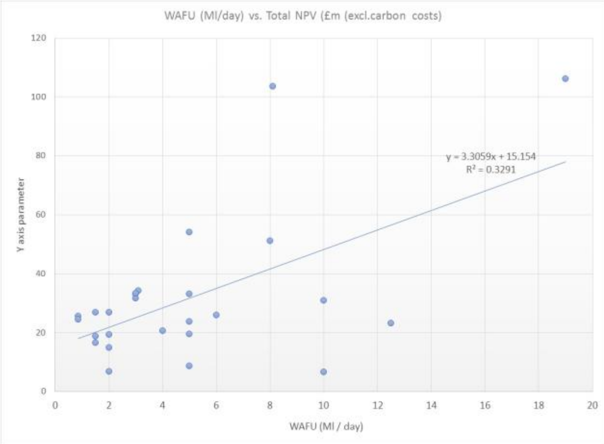


(h) Aquifer recharge cost curves

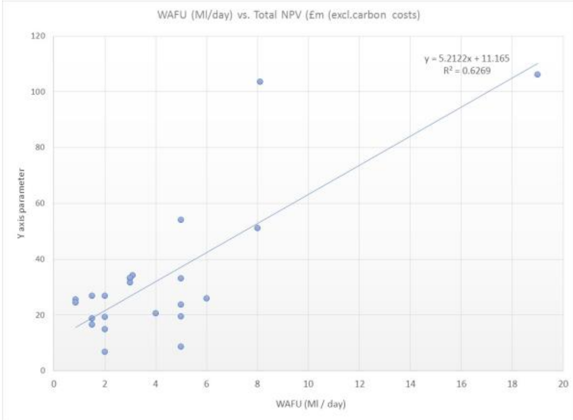
80. Four regions comprise aquifer recharge options. Figures 8 (a) to (c) below show the total, capex and opex linear cost curves for aquifer projects for the four regions. Figures 8 (d) to (f) show the total, capex and opex linear cost curves for aquifer recharge options for the London and the Southeast regions, which when combined showed the best fit with the data.

Figure 8: Cost curves for acquifer recharge options

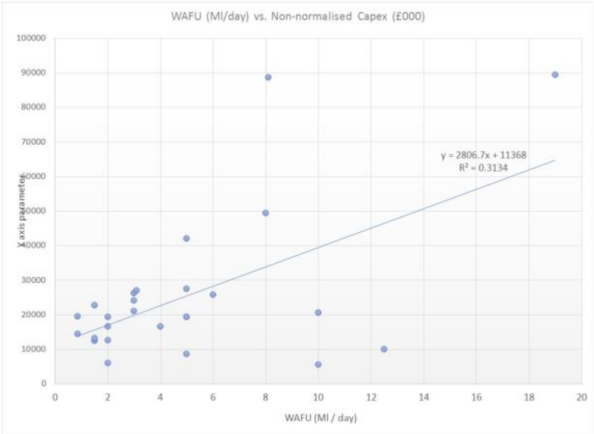
(a)Total costs curve (excl. carbon) (all regions)



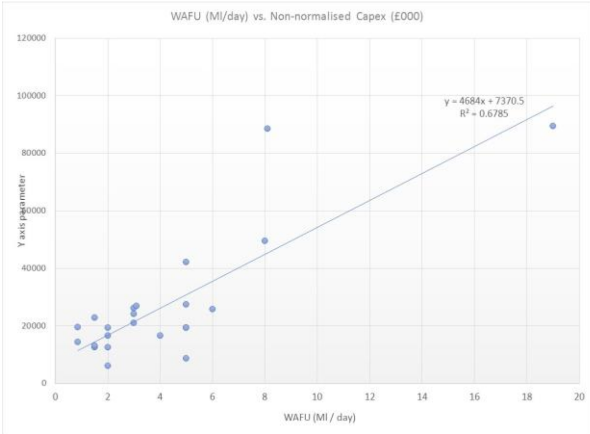
(d) Total costs curve (excl. carbon) (London & Southeast)



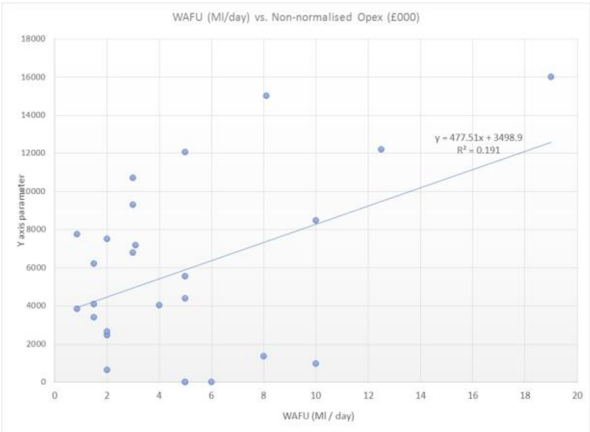
(b) Total capex cost curve (all regions)



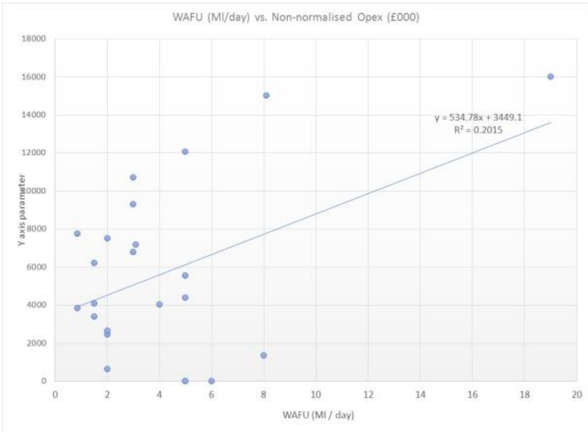
(e) Total capex cost curve (London & Southeast)



(c) Total opex cost curve (all regions)



(f) Total opex cost curve (London & Southeast)



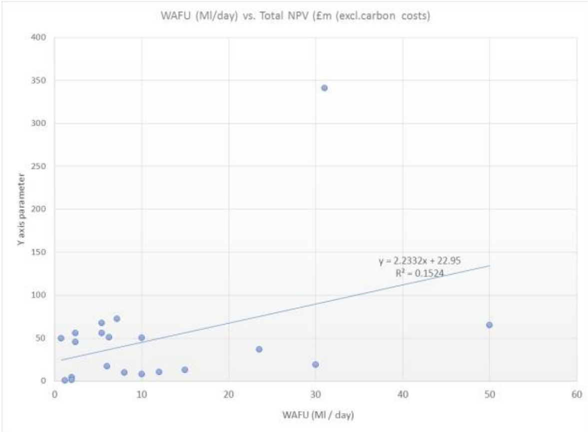
(i) Conjunctive use cost curves

81. Five regions contain options involving conjunctive use. Figures 9 (a) to (c) below show the total, capex and opex linear cost curves for conjunctive use options for all five regions. Although the linear fit with the data is poor, the fit is not improved by adopting alternative

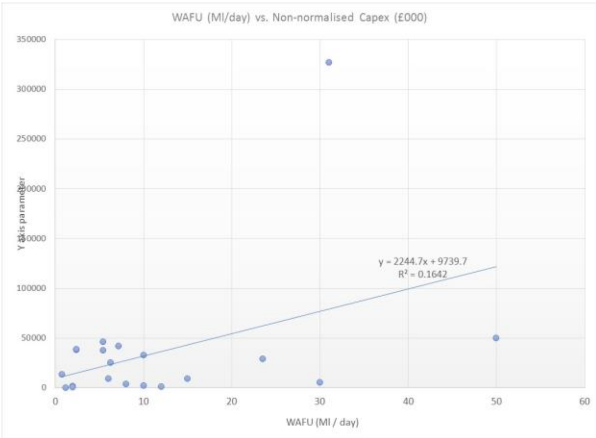
functional forms, given the significant spread in costs. Figures 9 (d) to (f) show the total, capex and opex linear cost curves for conjunctive use for the Central/West, Northeast and Northwest regions, which when combined showed the best fit with the data.

Figure 9: Cost curves for conjunctive use

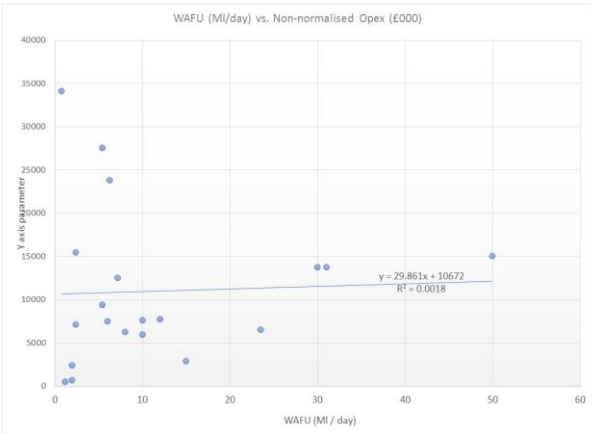
(a)Total costs curve (excl. carbon) (all regions)



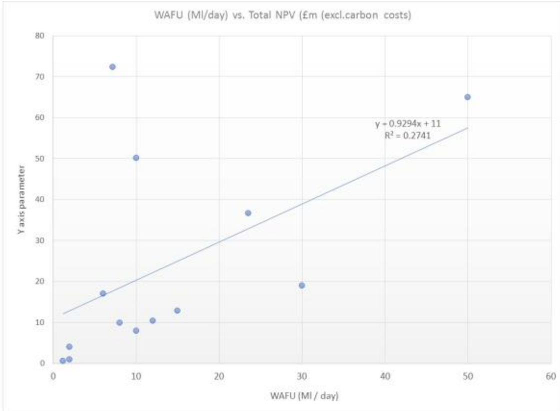
(b) Total capex cost curve (all regions)



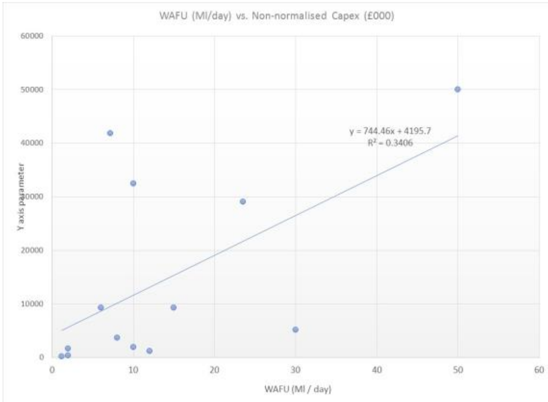
(c) Total opex cost curve (all regions)



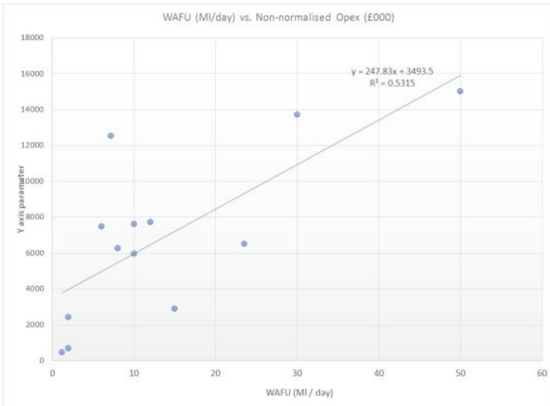
(d) Total costs curve (excl. carbon) (Central/ West, Northwest and Northeast)



(e) Total capex cost curve (Central/ West, Northwest and Northeast)



(f) Total opex cost curve (London & Southeast)

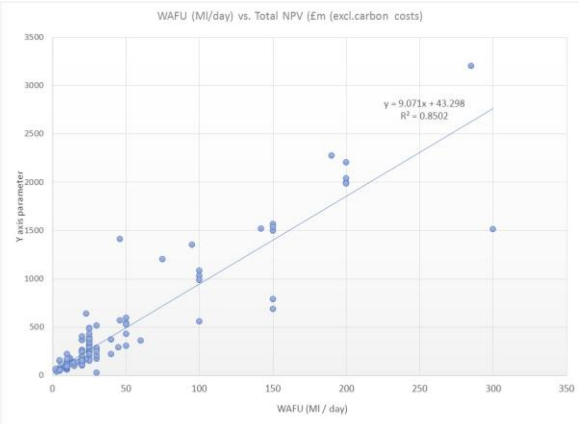


(j) *Desalination cost curves*

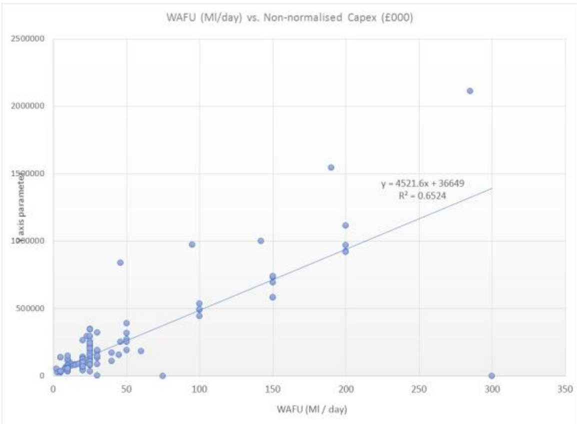
82. Figures 10 (a) to (c) below show the total, capex and opex linear cost curves for desalination projects for the five regions where they feature. As described in section 2.3.4 above, the opex and capex costs for desalination have been normalised using the linear cost curves developed in Water UK (2016) and figures 10 (d) to (f) reflect these trends, showing the normalised total, capex and opex linear cost curves for all regions. This allows for a direct comparison between the normalised and non-normalised cost curves for desalination.

Figure 10: Cost curves for deslination options

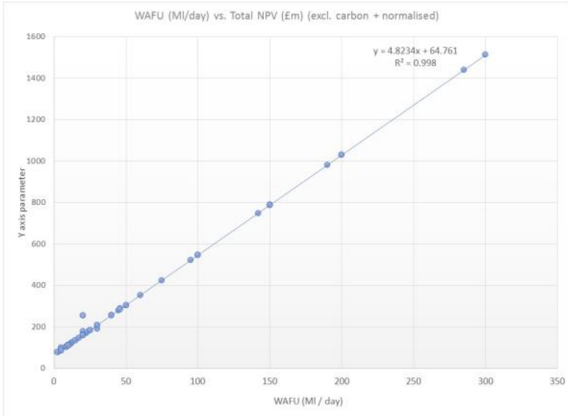
(a)Total costs cost curve (excl. carbon) (all regions)



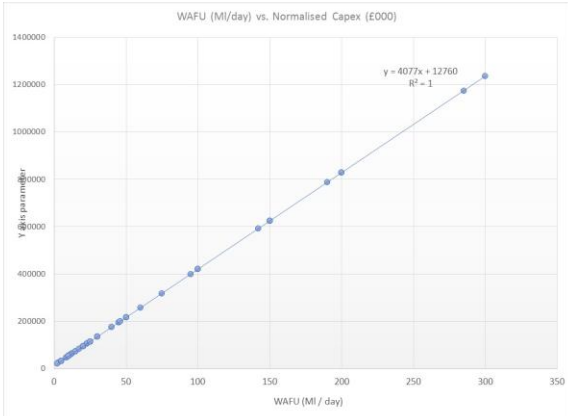
(b) Total capex cost curve (all regions)



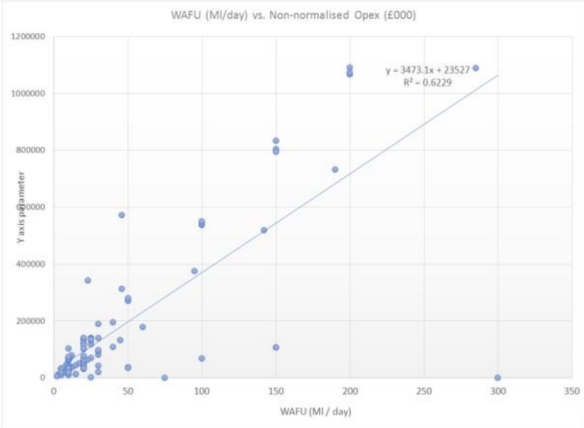
(d) Total normalised costs curve (excl. carbon) (all regions)



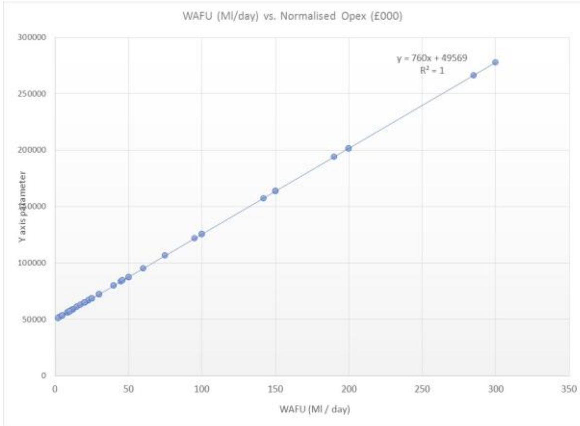
(e) Total normalised capex cost curve (all regions)



(c) Total opex cost curve (all regions)



(f) Total normalised opex cost curve (all regions)

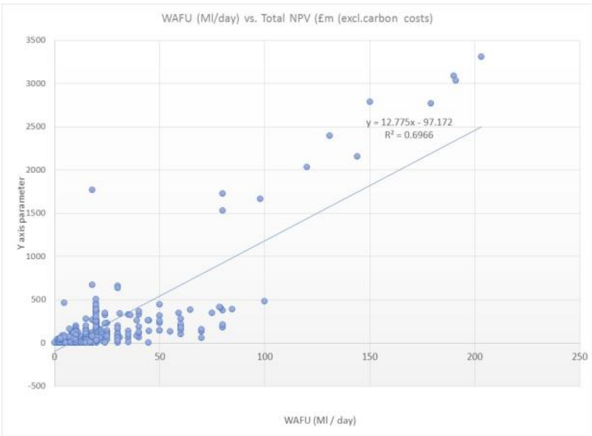


(k) Bulk supply cost curves

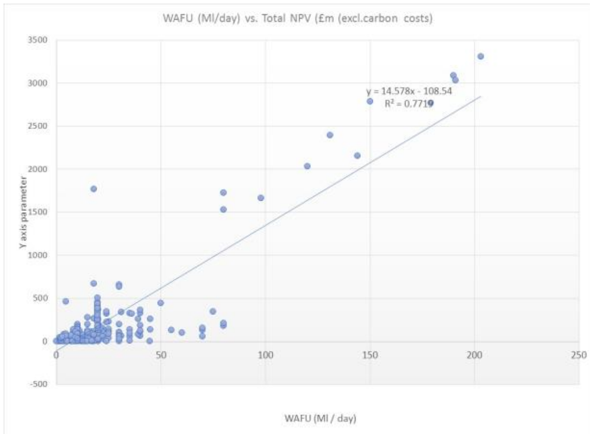
83. All but two regions contain bulk supply options. Figures 11 (a) to (c) below show the total, capex and opex linear cost curve costs for conjunctive use options for these regions. Figures 11 (d) to (f) show the total, capex and opex linear cost curves for bulk supply for London, Southeast (excl. London) and Southwest regions, which when combined, provide the best fit with the data.

Figure 11: Cost curves for bulk supply

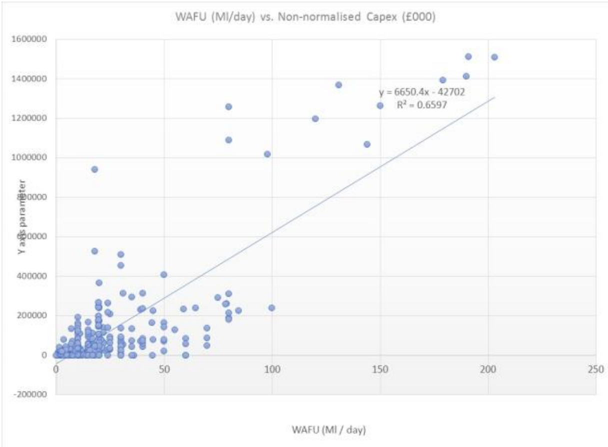
(a)Total costs curve (excl. carbon) (all regions)



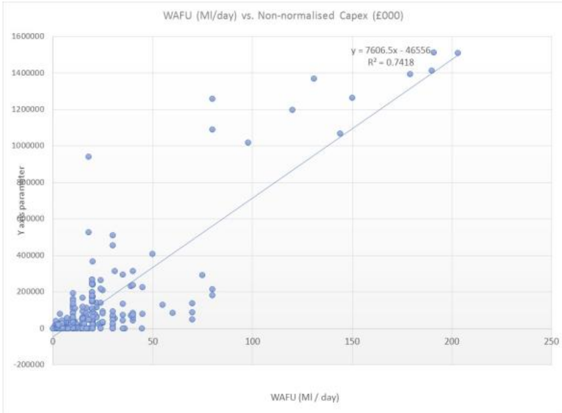
(d) Total costs curve (excl. carbon) (London, Southeast and Southwest)



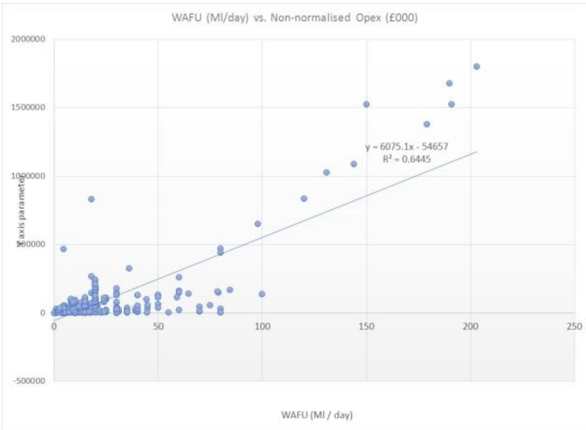
(b) Total capex cost curve (all regions)



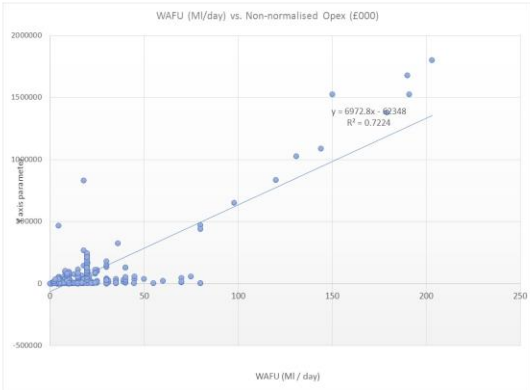
(e) Total capex cost curve (London, Southeast and Southwest)



(c) Total opex cost curve (all regions)



(f) Total opex cost curve (London, Southeast and Southwest)

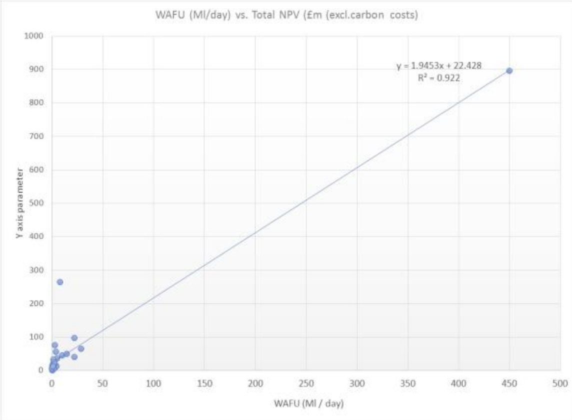


(l) Water treatment works supply curves

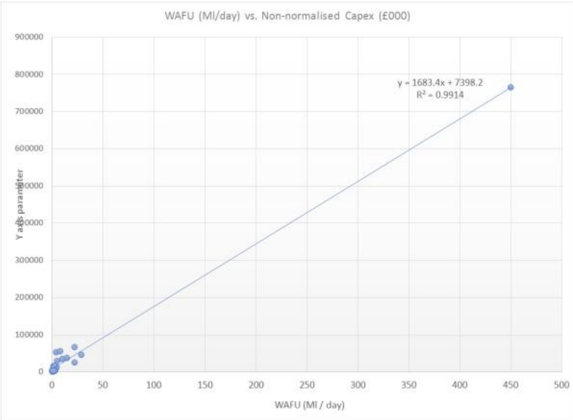
84. Four regions contain options relating to water treatment works, including capacity increases and loss recovery options. Given the limited data, and similarities in costs for water treatment works capacity increase and loss recovery options, these two options were combined for the purpose of generating cost curves. Figures 12 (a) to (c) below show the total, capex and opex linear cost curves for these water treatment options for all four regions.

Figure 12: Cost curves for water treatment works

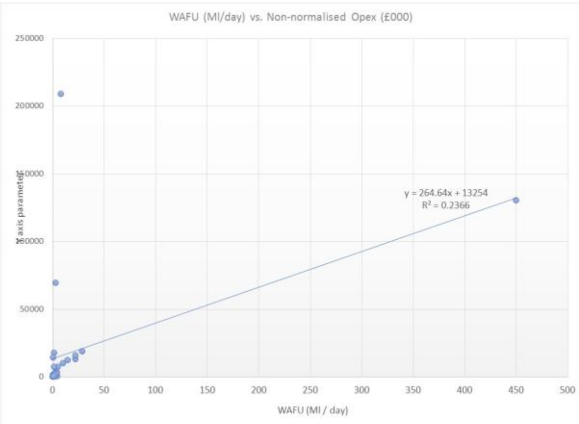
(a)Total costs curve (excl. carbon) (all regions)



(b) Total capex cost curve (all regions)



(c) Total opex cost curve (all regions)



2.5 Limitations and uncertainties

85. A number of uncertainties and limitations of the data and analysis should be borne in mind when considering the initial findings described in section 2.4. The following points in particular should be noted:

- The cost curves presented in section 2.4 are intended to provide an overview of total, capex and opex costs for the different infrastructure options at the national level, and to highlight the best fitting cost curves at the regional level. As described in section 2.3, there are many different possible combinations of cost curves that could be generated using the data. As such the curves presented in section 2.4 are only illustrative and do not represent the full suite of cost curves that could be generated using the available data.

- The ability to develop regional cost curves for some infrastructure options is limited by the lack of data points. In some regions there are no specific proposals for some types of infrastructure option, or alternatively there are only a small number of data points with the result that any trends identified could be heavily biased by a single option or potential outlier.

- It is clear from the discussion in section 2.4 that some of the cost curves generated fit the data better than other cost curves. In most cases a linear cost curve provided the best fit of the data. However, where a linear function did not provide a good fit given the spread of the data points, alternative functional relationships were examined. For some infrastructure options, quadratic or cubic cost curves have been generated where they significantly improved the fit with the data. However, in most cases the use of alternative non-linear functional forms did not significantly improve the fit with the data.

- A review of the data for similar infrastructure options across different regions often shows considerable variation. In particular, the costs of infrastructure options in the Central/West and Northern regions are often of a different magnitude to those for a similar option in London or the Southern regions (particularly the South-east). The drivers of these differences can reflect various factors such as the location of the infrastructure option, population density, existing water assets and resources, degree of interconnection etc. Variation can also reflect: different cost estimation methodologies between companies; different levels of efficiency; relative levels of availability of the different source types in different regions (which is itself a mixture of geography and the current supply system in each region); relative levels of capacity available within existing networks to accommodate the new options; different hydrogeological settings which can impact on whether high levels of pre and post treatment are required; and for desalination options whether they are coastal or estuarine settings which can also impact on pre and post treatment costs.

- There are some limitations associated with the approach that has been adopted to normalising capex and opex costs for effluent reuse and desalination options. As discussed, our approach has been based on Water UK (2016) which applied estimated coefficients for opex and capex to the raw capex and opex costs. However, we note that this approach is potentially circular in that the linear trends from one dataset are being used to normalise costs in another dataset with the aim of generating a normalised cost curve.

- As described in section 2.2, we have adopted a relatively cautious approach to removing observations from the database, and have only removed observations that had a negative or zero value or that were very clear outliers (on the recommendation of the NIC). As such there is clearly some scope to remove other data points which could potentially improve the fit of cost curves to the majority of the data points for a particular infrastructure option. However, such an approach potentially risks generating cost curves that do not reflect the full potential spread of costs associated with different infrastructure options.

- Generally speaking, the costs associated with some of the d-WRMP infrastructure options tend to be higher than those included in the R-WUK dataset. There are a number of possible reasons for this, including: (a) the R-WUK dataset is largely based on infrastructure options identified in the final 2014 WRMP, and costs may have increased since that time;[11] (b) there may be differences in the discounting methods applied, the 2019 dWRMP now requires that financing costs are included in Capex costs and then the total costs are discounted using the "green book" rate;[12] (c) the d-WRMP is only in draft form, and includes options which are not 'final' and have not be subject to external review and assessment (e.g.: through the statutory consultation process); and (d) the d-WRMP costs have not been subject to expert review and as such no adjustments have been made to the data.

- More broadly, a number of the options included in the combined infrastructure database are yet to be fully designed, costed and evaluated for WAFU benefit. In particular, this is the case for a number of the largest infrastructure options in the R-WUK dataset. The Water UK report noted that for these options *"accuracy of costs and WAFU benefit is no better than 50%. This is sufficient for high-level ranking of options, but not for any detailed planning at a regional or local level."*[13] This underlines the point noted earlier that the underlying cost and output data for the cost curves has not been audited or subject to external review or assessment for feasibility, efficiency or accuracy.

86. In addition to these points, two other wider considerations are important when considering the cost curves generated:

- First, as already discussed, the cost curves represent the <u>maximum</u> capacity costs and output generated on the full implementation of the infrastructure options. As such, they are not representative of the cost and associated output for lower levels of capacity and output.[14]

- Second, we have not engaged with the question of the need for infrastructure options, which is influenced by various social, economic, legal and environmental considerations. In particular, we have not sought to assess whether different infrastructure options will be needed to ensure resilience in the context of drought.

[11] This could include the impacts of inflation. No adjustment has been made for two reasons. First, the R-WUK dataset includes options not included in the WRMP 2014 and therefore recorded in current prices. Second, it is not clear whether Water UK made any adjustments to costs to account for inflation in their analysis.

[12] In contrast, it has been suggested by a peer reviewer, that at WRMP14 and Water UK (2016) financing costs were excluded and a discount factor of 4.5% was used.

[13] Water UK (2016), page 69.

[14] A peer reviewer notes that the use of WAFU as an output measure is itself is problematic and that a better measure to use for benchmarking of costs would be the option capacity (independent of hydrological constraints and zonal effects) and a better measure for high level assessments of the costs versus benefits of different infrastructure types would be to use a source deployable output (which includes hydrological constraints but doesn't account for zonal effects). However, the reviewer notes that neither of these measures are readily available in water resources planning tables and that the approach used in the analysis seems to be the best available one.

Rather, consistent with the terms of reference for this project, our focus is limited to exploring the question of what infrastructure options might cost if they were to be implemented, and not whether they are needed to enhance drought resilience.

3. Costs models for Demand Management Options

87. One of the aims of this project was to develop simple cost models for different demand management options that could be implemented to improve drought resilience. Following discussions with the NIC, cost models for three types of demand management option have been developed as part of this project: improvements in metering; reducing leakage; and other demand side efficiency improvements.

88. For each demand management cost model, the discussion that follows first sets out a description of the data collected and used to construct the cost model. It then describes the assumptions and methodological approach applied for the calculation of various costs. Finally, some limitations and uncertainties regarding the cost models are noted.

3.1 Metering cost models

3.1.1 Parameters

89. Various data and information were used to develop the metering cost model. A description of the data collected, and sources, are summarised in table 17 below. As with the infrastructure options costs analysis presented in section 2, the model provides the NIC with the option of changing the initial value of each of these parameters and to assess the resultant impact on metering costs and output indicators.

Table 17: Initial parameter values used in metering model[15]

Data	Source	Description
Standard water meter installation cost	£[X] per installation	Mott MacDonald for the NIC (2017). Includes £[X] installation cost and £[X] purchase cost for standard meter
Standard water meter replacement cost	£[X] per replacement	Mott MacDonald for the NIC (2017). Includes £[X] replacement cost and £[X] purchase cost for standard meter
Standard meter reading cost	£[X] per annum	Calculated based on assumptions in Mott MacDonald for the NIC (2017) including: • Average cost of £[X] per reading • Average of [X] readings per meter per year • Vehicle fuel costs of £[X] per mile
Smart water meter installation cost	£[X] per installation	Mott MacDonald for the NIC (2017). Includes £[X] installation cost and £[X] purchase cost for standard meter
Smart water meter replacement cost	£[X] per replacement	Mott MacDonald (2017). Includes £[X] replacement cost and £[X] purchase cost for standard meter
Average household supply pipe leakage reduction	£[X] l/h/d	Mott MacDonald for the NIC (2017)

[15] Values are redacted as they are commercially sensitive information.

Water company O&M costs	£[X] h/per year	Mott MacDonald for the NIC (2017)
Running costs	£[X] h/per year	Mott MacDonald for the NIC (2017)
Customer portal running costs	£[X] h/per year	Mott MacDonald for the NIC (2017)
Cost of dealing with enquiries per year	£[X] per enquiry	Mott MacDonald for the NIC (2017)
Number of enquiries per year	[X] h/per year	Mott MacDonald for the NIC (2017)
Social cost of disruption of reading and installing meters	£2 per meter	Ofwat (2011)
Discount rate	3.5% per annum	HM Treasury Green Book (2003) standard assumption for evaluating costs and benefits of projects over 30 years
Proportion of households with combination boilers	70% of households	Ofwat (2011)
Proportion of water saved that would otherwise have been heated	30% of total water used by combination boilers	Ofwat (2011)
Energy consumption hot water	0.04 kWh/l	DECC (2012)
Cost of gas per kWh	2.8 per kWh	UK Power (2017)
Cost per Ml of heated water	£1,120 M/l	Calculated
Marginal/incremental cost of water	Varies by company on a £ per m^3 basis	Based on the maximum of either the regional AIC for each company as estimated from the combined infrastructure database or the Ofwat (2011) estimate of 0.4 per m^3. The AIC applied was for all feasible options.
Average value of carbon price traded	£60.5 / tCO2e	BEIS data supplied by NIC (this is the average price over the period 2020 to 2035)
Average carbon price non-traded	£82.4 / tCO2e	BEIS data supplied by NIC (this is the average price over the period 2020 to 2035)
Assumed reduction in water heating associated with metering	30%	Ofwat (2011)
Carbon emitted by production of 1 Ml of hot water	8.1 tCO2e	Ofwat (2011)
Carbon emitted by production of 1 Ml of cold water	0.344 tCO2e	Ofwat (2011)
Carbon embedded in meter installation	0.0198 tCO2e	Ofwat (2011)

Carbon embedded in meter reading	0.00013 tCO_2e	Ofwat (2011)
Carbon embedded in meter replacement	0.0048 tCO_2e	Ofwat (2011)

90. In addition to these specific data sources, other relevant information on metering costs considered included:

- The Walker Review (2009) of charging for household water and sewerage services.
- Information and data provided in a recent report for Defra on average costs of household bills.
- Information and data compiled and provided as part of Water UK (2016).

3.1.2 Methodology for estimating costs and benefits of metering policy options

91. As agreed with the NIC the focus of the metering model was on the costs associated with different meter roll-out scenarios at the water company level. Accordingly, the cost model required projections of metering penetration rates (including type of meter), population, and per capita consumption data and provides costs and benefits on a yearly basis as well as total costs over the considered time horizon (2020 to 2050).

(a) Estimating the costs of metering

92. The methodology for estimating the costs and benefits of different metering scenarios was developed in discussion with the NIC. The method builds on, and is consistent with, methods used in the analysis carried out by Ofwat (2011) and by Mott MacDonald (2017) for the NIC. The method involved applying the various assumptions about financial costs, social costs and carbon costs described in table 17 above. Specifically, costs were separated into initial costs (such as meter installation and replacement) and on-going costs that are incurred each year a meter is in operation. Financial costs include capex and opex. Environmental and social costs include the cost of disruption associated with meter installation or replacement, and the associated carbon cost.

93. Assumptions about the values for each of these cost categories were then used to estimate a per unit capital cost[16] (incurred on installation and replacement of a meter) and a per unit operating cost (incurred each year a meter is in operation).[17] These per unit costs were calculated for both standard meters and smart meters.

94. To estimate the total costs of metering in each year the per unit capex and opex costs for standard or smart meters was multiplied by the assumed size of the metered population at the water company level in that year. Households who installed a new meter or replaced a meter in a particular year would incur the capital costs associated with that

[16] This also included the carbon and social costs on installation and replacement.
[17] This included the costs of meter reading (for standard meters) and customer management costs.

installation/replacement as well as the operating costs incurred in that year, while the remaining metered population would incur only the per unit opex cost incurred in that year. These costs were then summed across all of the metered households served by a water company and discounted to 2020.

(b) Estimating the benefits associated with metering

95. The approach to estimating the benefits of metering involved applying the various assumptions detailed in table 17 above to estimate three types of benefit: (a) a water saving benefit; (b) a hot water carbon reduction benefit; and (c) a cold water carbon reduction benefit. Following the Ofwat (2011) method, the initial model did not include the energy saving benefit associated with the avoided cost of heating hot water. However, these were subsequently included by the NIC, to assess the results with or without these costs.

96. The calculation of the water saving benefit associated with metering applied the assumed marginal (incremental) cost of water for the region in which a company operates to the amount of water saved by each water company in each year. This approach is based on the reasoning that because metering will result in lower water consumption, water companies can avoid the need to incur the expenditures on infrastructure (both capex and opex) needed to deliver water to households. The estimated water saving benefits of metering are assumed to be cumulative and were calculated and discounted on a yearly basis.

97. The calculation of hot water carbon reduction benefit is calculated by multiplying the assumed reduction in water heating associated with metering by the amount of carbon emitted through the production of 1 Ml of hot water, and then multiplying the sum of this by the average discounted non-traded price for carbon. The cold water carbon reduction benefit is calculated by multiplying the assumed reduction in cold water associated with metering by the amount of carbon emitted through the production of 1 Ml of cold water, and then multiplying the sum of this by the average discounted traded price for carbon.

98. The energy saving benefit associated with a reduction in hot water heating involves applying the assumption that 30% of the water saved because of metering would otherwise have been heated. The energy saving represents the avoided cost of gas that would have been used to heat that water. Again, the estimated energy saving benefits of metering are assumed to be cumulative and were calculated and discounted on a yearly basis.

(c) Estimating the NPV of metering and associated £Ml/d saving

99. The final step was the estimation of the total NPV, which involved calculating the present value of the differences between the streams of costs and benefits provided by each scenario to 2050.

3.1.3 Limitations and uncertainties

100. A number of uncertainties and limitations should be borne in mind when considering the metering cost model.

101. First, the initial meter costs estimates used in the analysis were primarily based on values in Mott MacDonald (2017) and Ofwat (2011).[18] As might be expected there are some differences between the assumed unit values of costs in these two studies. This highlights the fact that there can be wide variation in per unit cost estimates, and the importance of the optionality in the cost models to change the underlying assumptions.[19]

102. Second, the estimation of the benefits of water metering is only partial and captures some but not all of the types of benefits that could arise. The types of benefits included in the analysis are those associated with the avoided infrastructure costs of developing and maintaining a water system to deliver water, and those associated with carbon emissions and energy savings. Other social and environmental benefits associated with a reduced consumption of water, including the option value of water in areas where water is scarce, are not included in the analysis. This means that the estimation of benefits might understate the true benefits of water metering.[20]

103. Finally, in estimating the water savings benefit we have applied the AIC estimate for each water company developed in the analysis of the costs of infrastructure in section 2, rather than the actual need for infrastructure to cover particular deficits. The results are obviously very sensitive to the particular AIC value assumed.

3.2 Leakage control cost models

3.2.1 Parameters

104. Various assumptions about parameter values were made in constructing the leakage control costs model. Table 18 sets out the key parameters used in the analysis, the initial values adopted, and the source of the initial value. When considering these initial values, it should be noted that the leakage control cost model developed allows the NIC to change the value of these assumptions and to assess the resultant impact on leakage costs and output indicators.

Table 18: Initial parameter values used in leakage costs model

Parameter	Value	Source
Discount rate	3.5% per annum	HM Treasury Green Book (2003) standard assumption for evaluating costs and benefits of projects over 30 years

[18] Following discussion with the NIC, it was agreed that we should not apply the AIC values for metering for each company listed as recorded in the dWRMP in part because one of the purposes of this study was to allow the NIC to have in place an independent cost model which could allow it to assess the robustness of these dWRMP estimates. Nevertheless, the cost model allows the AICs contained in the dWRMPs to be applied by the NIC should it wish to do so.

[19] A peer reviewer observes cost can also differ according to meter location. Internal meter fitting is lower cost, but may reduce the opportunity for supply pipe leaks to be identified (and equally avoid creating a potential point of leakage on the underground supply pipe).

[20] A peer reviewer points out that there may also be dis-benefits associated with metering in terms of a loss of utility associated with lower water consumption.

Marginal/incremental cost of water	Varies by company on a £ per m^3 basis	Based on the AIC for each company as estimated from the combined infrastructure database. The AIC applied was for all feasible options.
Average value of carbon price traded	£60.5 / tCO2e	BEIS data supplied by NIC (this is the average price over the period 2020 to 2035)
Carbon emitted by production of 1 Ml of cold water	0.344 tCO2e	Ofwat (2011)

3.2.2 Methodology for estimating leakage costs

105. The focus of the leakage control modelling was on the estimation of costs, whilst the calculation of the value of the benefits was subsequently included by the NIC in a separate analysis.

(a) Estimating the costs of leakage control

106. There is no commonly agreed methodology for estimating leakage costs across the industry. As part of this study three different approaches for assessing leakage control costs were tested using specific leakage policy scenarios provided by the NIC.[21]

107. The first approach, which built on the approach in Water UK (2016), assumed a constant average cost of leakage control. The second approach, which was developed in discussion with the NIC, develops and applies a leakage cost function, where the costs of managing leakage vary according to the volume of leakage being managed. The third approach involved estimating the costs of a specific assumed reduction in leakage using estimates contained in Water UK (2016) and UKWIR (2010).

(i) <u>Constant AIC of leakage control</u>

108. This approach to estimating leakage control costs involved multiplying the annual amount of water saved (the NPV WAFU) as a result of leakage control by an assumed constant AIC of leakage control per cubic metre, discounting it to 2020.

109. Three different AIC values of leakage control were applied – e.g.: £0.20 per m^3; £0.28 per m^3 and £0.31 per m^3. The estimates of £0.20 per m^3 and £0.31 per m^3 were taken directly from Water UK (2016). The estimate of £0.28 per m^3 was calculated based on an estimate of the costs of Active Leakage Control (ALC) cost per property per year for Bournemouth Water as presented in Atkins (2013). In that study, Atkins estimated that the cost per property of ALC between 2009 and 2012 in the Bournemouth area was £6.46 per property per year. We took this annual cost estimate and summed it over 25 years, before discounting

[21] We did consider using the AIC leakage values for each company listed in the dWRMP. However, part of the purpose of this study was to allow the NIC to have in place an independent modelling framework which could allow it to assess the robustness of each of these dWRMP estimates (which unsurprisingly showed considerable variation). Nevertheless, the cost model allows the leakage costs contained in the dWRMPs to be applied by the NIC.

to give a net present cost per property of £110.23. We then estimated the total leakage savings (per property, per water company) from Water UK (2016) and divided this by this estimate of £110.23 per property to yield an AIC of active leakage control per/m^3 for each company. The average of these AIC estimates across all water companies was £0.28 per m^3.[22]

110. The estimated costs of leakage control for nine scenarios was examined as set out in table 19 below. These scenarios combine three different leakage target profiles with the three different AIC's of leakage control per m^3 just described.

Table 19: Leakage control scenarios examined

Scenario	Cost assumption	Leakage target assumption
1	Water UK low cost per m^3	Reduction on linear basis to WRMP 2040 target
2	Bournemouth cost per m^3	Reduction on linear basis to WRMP 2040 target
3	Water UK enhanced cost per m^3	Reduction on linear basis to WRMP 2040 target
4	Water UK low cost per m^3	Reduction on linear basis to Ofwat 15% reduction target by 2025 and then to WRMP 2040 target
5	Bournemouth cost per m^3	Reduction on linear basis to Ofwat 15% reduction target by 2025 and then to WRMP 2040 target
6	Water UK enhanced cost per m^3	Reduction on linear basis to Ofwat 15% reduction target by 2025 and then to WRMP 2040 target
7	Water UK low cost per m^3	Ofwat target for 2025 with another 15% target reduction between 2025 and 2040
8	Bournemouth cost per m^3	Ofwat target for 2025 with another 15% target reduction between 2025 and 2040
9	Water UK enhanced cost per m^3	Ofwat target for 2025 with another 15% target reduction between 2025 and 2040

(ii) Leakage control cost function

111. A limitation of the first approach to estimating leakage costs was the assumption that the marginal cost of leakage control is constant, and as such the same per unit AIC is incurred irrespective of the leakage target set and the amount of leakage a water company manages/controls. This assumption is inconsistent with the general recognition that the marginal cost of leakage is an increasing function of the leakage target set.[23]

112. To address this limitation, we developed a cost function where the cost of leakage control varies according to the leakage target set and the amount of leakage controlled over time. Specifically, less ambitious leakage control targets are assumed to involve less intensive leakage monitoring and management activities (in terms of detection, repair and potentially replacement) and, accordingly, are assumed to result in lower per unit costs of leakage control being incurred. In contrast, more ambitious leakage targets involve more

[22] A similar approach to estimating AICs of leakage control was applied in Water UK (2016) where the costs of pressure management and maximum ALC was estimated at £122 over 25 years. This yielded an average AIC of £0.34 per m^3, assuming that leakage is reduced by 42% from baseline level. See Water UK (2016) Table App-3.
[23] UKWIR (2011) notes the principle that the cost of reducing leakage by 1 unit is less at higher leakage levels, because the leaks running is larger but no more expensive to detect or fix.

active leakage control management as well as potentially renewal of pipes and investment in other equipment (e.g.: communications equipment). Other things equal, this more intensive leakage control activity is assumed to involve higher per unit costs of leakage control being incurred.

113. The cost function developed built on information contained in Water UK (2016) about the average incremental cost (AIC) of different levels of leakage control. Table 20 describes the AIC estimates, the leakage level at which AIC is applied, and the underlying activities they relate to.

Table 20: Leakage cost function

Leakage control activity	Leakage saving from current level (%)	Assumed AIC per m^3 over 25 years
Current level of leakage control	Current level varies by company	
Maximum pressure management	Up to 28% than current level	£0.27
Pressure management and active leakage control (ALC)	Between 28% and 42% from current level	£0.34
Pressure management and active leakage control and maximum renewal	Greater than 42% reduction from current level	£4.21

Based on Water UK (2016), Table App-3.

114. To allow the NIC to apply the leakage control cost function three additional scenarios were developed as shown in table 21.

Table 21: Additional leakage control cost scenarios examined

Scenario	Cost assumption	Leakage target profile to 2040
10	AIC per m^3 determined by leakage cost function as shown in table 20	Reduction on linear basis to WRMP 2040 target
11	AIC per m^3 determined by leakage cost function as shown in table 20	Reduction on linear basis to Ofwat 15% reduction target by 2025; and then from 2025 to WRMP 2040 target
12	AIC per m^3 determined by leakage cost function as shown in table 20	Ofwat target for 2025 with another 15% target reduction between 2025 and 2040

(iii) Applying the AIC for a specific leakage reduction

115. A limitation of the first two approaches was that the AIC values applied were calculated exogenously by dividing the an estimate of Net Present Cost of leakage control over 25 years by a specific expected (discounted) WAFU saving over that same period. Accordingly, the AIC estimate is, by derivation, only accurate for the assumed costs incurred and for that assumed level of water saving. Put differently, if a lower level of water is saved than assumed – and the costs incurred are assumed to be fixed – then the AIC for

that lower level of water saving will be higher.[24] In short, applying an (exogenously determined) AIC estimate in the cost model implicitly assumes that: (i) the amount of water saved through leakage control activities is broadly similar to that assumed when the AIC estimate was calculated; and (b) total leakage control costs are largely fixed (i.e.: they do not change with greater or lower levels of leakage control).

116. To address this potential limitation of the first two approaches (both of which apply exogenously determined AICs), a third approach was developed which allowed the NIC to directly estimate the costs for a specific amount of leakage reduction using estimates presented in Water UK (2016). Table 22 presents the relationship between total leakage per property per day reductions and the resultant AIC over 25 years. This table can be used to estimate the specific AIC associated with a particular level of water reduction. As such, the table can be used by the NIC to estimate what it would cost if leakage was reduced by 58 litres per day over 25 years by applying the AIC (of £0.34 per m^3) to the estimated number of properties served in twenty five years.

Table 22: Leakage and NPV projections under current conditions (UKWIR, 2010)

Leakage control activity	Total leakage (l/prop/ day)	Leakage saving from baseline (l/prop/ day)	NPV of Demand saving (m3/prop over 25 years)[1]	Net present cost per property (£/prop)[2]	AIC per m^3 over 25 years
Baseline	137	0	0	0	
Maximum pressure management	98	39	243	65	£0.27
Pressure management and active leakage control (ALC)	79	58	361	122	£0.34
Pressure management, ALC and maximum customer metering	76	61	380	265	£0.70
Pressure management, ALC, customer metering and maximum renewal	41	96	598	2,933	£4.91

Notes: (1) This is estimated by multiplying the leakage saving per property per day by 365 to get an annual figure and then discounting this saving over 25 years at a rate of 3.5%. (2). This follows the approach of Water UK (2016) in not adjusting the per property cost estimates for inflation between 2011 and 2018.
Based on Water UK (2016), Table App-3.

[24] For example, if the cost per property is assumed to be £110 over 25 years and the amount of water saved from leakage control activities is 400 m^3 per property, then the AIC is £0.3 per m^3. However, if the amount of water saved through leakage control activities is only 200 m^3 per property, then the AIC is £0.6 per m^3.

(b) Estimating the net present cost of leakage control to 2050

117. For all three cost methods, the final step involved the estimation of the net present cost associated with the different leakage control scenarios. The net present cost for each of the leakage control scenarios was estimated for the period 2020-2050.

3.2.3 Limitations

118. A number of uncertainties and limitations should be borne in mind when considering the leakage cost modelling just described.

119. First, the results are clearly highly sensitive to the assumptions made about the assumed AIC of leakage control per m^3. As just described, to address this, we have developed three different methods for estimating leakage costs that apply range of estimates of the AICs of managing leakage. These AIC estimates have principally been drawn directly from Water UK (2016).

120. Second, we recognise that there can be considerable variation across companies and regions in the costs of leakage control. Among other things, this variation can reflect differences in: population density and geography covered; the age and physical condition of the infrastructure; and whether significant fixed capital expenditure (for example, on communications equipment for pipe monitoring) has to be incurred. It also depends on the leakage target set, as noted, the more ambitious the target the higher the costs incurred.

121. Third, as noted, it is generally recognised that the marginal/incremental cost of leakage control increases as more ambitious leakage targets are set, and leakage minimised. The precise nature of the cost curve for each water company in managing leakage is difficult to determine in the abstract and without access to detailed data and information. For the purposes of the analysis in this report, we initially followed the approach adopted by Water UK (2016) and applied a constant AIC per m^3 of water saved through enhanced leakage control. However as this is an average cost, this approach likely understates the leakage control costs for some water companies and overstates the cost for other water companies. We sought to mitigate this risk by developing a leakage cost function where the marginal cost of leakage control is an increasing function of the amount of leakage controlled (and water resources conserved), and also by developing a third approach where the AIC is directly related to a specific reduction in leakage per property per day.

122. Fourth, the cost calculations are sensitive to assumptions regarding population growth. We have applied the NIC Raw Pop High growth estimates at the water company level. However, we note from the other analyses of leakage that different assumptions around population growth can affect the costs of managing leakage.

3.3 Demand side efficiency cost models

123. Cost models for three types of demand side efficiency options were developed as part of this study to allow the NIC to estimate:

- the costs of fitting houses with 'greywater' water saving devices

- the costs of retrofitting houses with other (non-greywater) devices

- the costs attached to greater household efficiency measures that encourage people to consume less water (e.g.: water conservation advertising campaigns and other efficiency measures and equipment).

3.3.1 Parameters

124. The parameter values for the demand side efficiency option cost modelling are shown in Table 23. The cost models developed allow the NIC to easily change the value of these assumptions and to assess the resultant impact on demand side efficiency costs.

Table 23: Parameter values used in demand side efficiency cost models

Parameter	Value	Source
Household occupancy rates	2.4 persons per household	ONS (2017)
Discount rate	3.5% per annum	HM Treasury Green Book (2003)
Greywater cost model		
Savings	50 litres/prop/day	Water UK (2016)
Assumed number of houses	100,000 per year	Water UK (2016)
Cost per property of greywater conversion	£1,000 per property	Water UK (2016)
Ongoing cost of efficiency measures	£25 per property per annum	Water UK (2016)
Retrofitting cost model		
Savings litres/property/day	20 litres/prop/day	Water UK (2016)
Assumed number of houses	100,000 per year	Water UK (2016)
Cost per property of retrofitting	£100 per property	Water UK (2016)
Ongoing cost of efficiency measures	£20 per property per annum	Water UK (2016)
Greater household water efficiency cost model		
Cost of efficiency measure	£0.05 per m^3	Water UK (2016)
Scope	Efficiency measures apply to metered properties only	Water UK (2016)

125. Other sources of information on the costs of demand side efficiency measures were also consulted including in particular information provided in Waterwise publications

3.3.2 Methodology for estimating demand side efficiency costs

126. As agreed with the NIC the focus was on developing cost models for three different demand efficiency measures.

(a) Estimating the costs associated with greywater conversion

127. The cost models developed for estimating the costs of the greywater conversion of households involve applying the initial assumptions in table 23 about the number of homes that would be converted (on an annual basis), the initial cost of conversion and any on-going annual maintenance costs per property. Assumptions about water savings (in l/h/d) were used to estimate the amount of water saved (in m^3 and in Ml/d) for houses with a greywater water saving device installed. The discounted results of this analysis were estimated to 2050.

(b) Estimating the costs associated with retrofitting of households

128. A similar approach was used to develop the models for estimating the costs of retrofitting households. Costs were estimated by applying the assumptions in table 23 about the number of homes retrofitted annually, the initial cost of conversion and any on-going maintenance costs per property. The amount of water saved (in m^3 and in Ml/d) for retrofitted houses was calculated using the savings per property per day estimate. The discounted results of this analysis were estimated to 2050.

(c) Estimating the costs associated with greater household water efficiency

129. The cost model developed for household water efficiency adopted a different approach to greywater conversion/retrofitting. Specifically, data in Water UK (2016) on the change in PCC for each water resource zone was first scaled up to provide an estimate of the overall water savings expected in 2040 and 2065 (in Ml/d) for each company. These expected savings in 2040 and 2065 were used to estimate the annual efficiency savings per company on a linear basis between these periods. This annual Ml/d reduction associated with household efficiency was used to provide an estimate of the total volume of WAFU by annualising the reduction for each year and company. To estimate costs, the water saving was multiplied by the relevant (assumed) unit cost of demand side efficiency measures as detailed in table 23.

130. For each of the demand side efficiency options (greywater conversion, retrofitting and household efficiency actions) the net present costs to 2050 were estimated.

3.3.3 Limitations

131. As with the other demand management options described in section 3, there are a number of uncertainties and limitations of the cost models just described.

132. First, the total cost estimates are sensitive to the initial assumptions made about per unit cost levels and values. As described above, we incorporated the assumptions made in Water

UK (2016) in the cost models. However, these assumptions have not been independently assessed and verified, and therefore should be treated with caution. The cost models allow the NIC to change the value of these assumptions to generate different total cost estimates.

133. Second, the total costs of greywater conversion and retrofitting show a high level of sensitivity to assumptions made about the timing and number of houses converted each year, as well as the expected yield in terms of water saving. Again the cost models allow the NIC to change the number of households converted to generate different total cost estimates.

134. Third, the household demand efficiency option estimates show particular sensitivity to assumptions about changes in per capita consumption over time, and the costs of applying efficiency measures (which was low in Water UK (2016)). The NIC can change the values of PCC and costs to generate alternative scenarios.

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