Water Efficiency Evidence Base - Review and Enhancement

Report – EPBLW 12032/5

Final Version, 21 June 2012

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Executive summary

The Environment Agency has a key responsibility to ensure sufficient water for people and the environment. This responsibility involves advising and consulting with water companies on the Water Resources Management Planning process, which includes a twin-track approach, combining demand management measures with new supply sources as required.

Water companies have been testing and applying demand management solutions, principally in small pilot studies, for a number of years. Since 2007, Waterwise has been compiling, reviewing and analysing the evidence base produced by individual water companies. The Waterwise Evidence Base Phase I and Phase II reports, published since 2008, represent the most significant available compendium of water efficiency research undertaken and related results.

Other available water efficiency evidence is included in the UKWIR water efficiency database. Additional isolated studies have also been undertaken by individual water companies; and OFWAT have compiled a table of water efficiency savings attributable to different devices, to be used for assessing performance against water efficiency targets.

In preparation for the coming cycle of Water Resource Management Plans (WRMPs), and to give increased confidence in the evidence base for water efficiency, the Environment Agency commissioned an independent review and scrutiny of the available evidence base to date, to test its robustness and reliability.

The review covers principally the Waterwise Evidence Base, Phases I and II, as well as other evidence on water efficiency measures; and makes recommendations to inform the next cycle of WRMPs.

The analysis carried out during the study confirms that most water efficiency projects reviewed lead to reductions in water consumption; and the study has identified a number of improvements that could be made to the existing water efficiency evidence base, which should lead to a greater confidence in its use. The results of the study also indicated the following:

- Amongst water companies interviewed, the general consensus was that the available water efficiency evidence base provides a useful reference point for best practice guidelines and for drawing together experience on the effectiveness of water saving devices and measures; and experiences from carrying out the trials or studies.
- There is a need for unifying existing evidence sources, including the Waterwise Evidence Base and the UKWIR WR25 database. The Ofwat assumed water savings and uptake rate tables should be consistent with this evidence.
- Analysis of data from a number of projects within the Waterwise Evidence Base, demonstrated that the water savings achieved were statistically significant in most cases.

Some key improvements in the statistical treatment of the evidence base data could lead to a greater confidence in its use, namely:

- The Waterwise Evidence Base places great weight on the use of linear regression modelling for providing insights into water efficiency studies.

However the review conducted suggests that linear regression may not be appropriate in the analysis of results or as a first order prediction of savings.

- Where data is excluded from evidence base analysis, it is essential to report how much data is excluded and the reasons why it has been excluded. This will increase the reader's confidence in the data. It also suggests that the method used to derive the confidence intervals for the results should also be reviewed.
- To provide greater confidence in the results, water savings in evidence base studies should be reported using 90% confidence limits calculated using the standard error of the mean. The normality of the data sets should also be investigated. These two recommendations should be implemented to demonstrate the statistical significance of water savings and give further confidence in the findings.

The significant amount of data assembled by Waterwise in the preparation of the Evidence Base reports, could be subject to additional statistical analysis, including aggregation and multiple regression, to provide additional useful evidence with regards effectiveness of the measures and transferability between geographical locations.

The separate sources of water efficiency evidence used by water companies should be consolidated, namely the Waterwise Evidence Base and the UKWIR 25 data base. The Ofwat water savings table should be consistent with this evidence. The consolidated information could include:

- A comprehensive list of trials, studies and projects that have been carried out, with details of where to access the reports.
- Summary of statistical analysis of the water savings from different devices or approaches, which are robust and which include summary information about the trials and guidance on how the results could be applied and used.
- Detailed information about the experiences from those who conducted the trials; in setting up and carrying out water efficiency activities, the logistics, level of engagement with customers and stakeholders, and information on what worked well and what did not.

Collaborative work should be led by water companies to review the available data, update, re-analyse, consolidate and publish summary information from the evidence base. This data should be published so it is widely available.

The following areas have been identified for consideration as future project topics to strengthen the evidence base:

- Guidance on how to project water savings forward in time, taking into account risks and uncertainties.
- Quantifying the impact of education and behaviour change initiatives on water consumption.
- Evaluating the water savings from new measures being developed by product suppliers.
- Development of guidance on the planning and execution of water efficiency studies, to increase the robustness of data collection and analysis.

The Waterwise Evidence Base Phase III projects are already taking forward studies addressing bullet points 2 and 4 above.

Future evidence base work should routinely capture data from water efficiency studies from water companies and other sources, in order that the evidence base can be kept fully up to date and relevant to the water industry's needs.

User feedback could be included in future evidence base studies, potentially to provide information that measurement of water consumption may not be able to do, and so help explain and understand the other factors that might or might not lead to reductions in consumption.

To ensure that the most appropriate statistical techniques are applied and that the application of those techniques can stand up to challenges, future evidence base work would benefit from expert peer review by statisticians.

To implement these recommendations, collaborative work should be led by water companies to review the available data, update, re-analyse, consolidate and publish summary information from the evidence base. This data should be published so it is widely available

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1 Introduction

1.1 Background

The Environment Agency has a key responsibility to ensure sufficient water for people and the environment. This responsibility involves advising and consulting with water companies on the Water Resources Management Planning process, which includes a twin-track approach, combining demand management measures with new supply sources as required.

The Government's Water White Paper, published in December 2011, puts a strong emphasis on water companies' use of demand management solutions in addressing any present and future supply-demand gap. The use of such solutions is dependent on a strong evidence base to demonstrate the effectiveness of water efficiency measures in decreasing water consumption by customers.

Water companies have been testing and applying demand management solutions, principally in small pilot studies, for a number of years. These have involved retrofitting or refurbishing initiatives, often in partnership with Local Authorities or Local Housing Authorities; and direct mailing and installation of water efficiency devices to selected optant households. However, robustness of the evidence base for large-scale water efficiency was often cited by water companies as a significant barrier to water companies' water efficiency activity.

To address this, since 2007, Waterwise has been compiling, reviewing and analysing the evidence base produced by individual water companies, with the goal to provide effective information for application. The Waterwise Evidence Base Phase I and Phase II reports, published since 2008, represent the most significant available compendium of water efficiency research undertaken and related results.

Prior to 2007, water efficiency evidence was available but often held in various places, and therefore difficult to compare. Over the last five years through the development of the Evidence Base, the water industries' knowledge and understanding of water efficiency and how to analyse it has grown.

Other available water efficiency evidence is included in the UKWIR water efficiency database. Additional isolated studies have also been undertaken by individual water companies; and OFWAT have compiled a table of water efficiency savings attributable to different devices to be used for assessing performance against water efficiency targets[1].

[1] Estimated savings and uptake rate tables presented in Section 8 of Appendix 1 of PR09/20 Water Supply and Demand Policy: Water efficiency targets 2010-11 to 2014-15. http://www.ofwat.gov.uk/pricereview/pap_pos_pr09supdempolapp1.pdf

1.2 Objectives of the study

In preparation for the coming cycle of Water Resource Management Plans (WRMPs), and to support water companies' decisions regarding demand management measures, the Environment Agency commissioned a study to:

- Provide independent review and scrutiny of the available evidence base to date, and to test its robustness and reliability. The review covered principally the Waterwise Evidence Base, Phases I and II, as well as other readily available evidence on water efficiency measures;
- Undertake a review of water efficiency demand management measures not covered by the Waterwise Evidence Base, but which have been identified, tested and tried by water companies and other bodies;
- Prepare a summary and recommendations to inform the next cycle of WRMPs.

The activities of this review consisted of:

- conversations with water companies, Waterwise and Ofwat to gather views on the evidence base;
- consideration of the use of the evidence base to support the WRMP process and water efficiency targets;
- review of the Waterwise Evidence Base to select studies for more detailed analysis;
- detailed statistical analysis of these studies using the raw data;
- reviewing of pertinent or more recent studies not included in the Waterwise Evidence Base; and
- formulating conclusions and recommendations to improve the confidence and reliability of the existing overall evidence base.

1.3 Approach to the study

The Environment Agency commissioned WRc and Artesia, two established consultancies in water demand management, to conduct the study described above. The selected project team have extensive experience of applying a range of statistical techniques to the analysis of water conservation and other data. Given the tight timescales and the need to provide analysis to support the development of Water Resources Planning guidelines, a detailed review of key evidence was agreed to be more valuable than a superficial review across the whole evidence base. To achieve this objective, the study was divided it into two main stages:

- Stage One: Short-listing of water efficiency trials for subsequent review.
- Stage Two: Detailed review of these short-listed projects.

The initial stage of review considered the Waterwise Phase I and Phase II reports described in section 1.1. The detailed review focussed on a selection of studies included in the Phase II reports only, for which it was possible to obtain and review the raw data used to produce the water saving figures.

During the project and before any detailed analysis of the data, conversations were also carried out with Waterwise to get the organisation's views on the evidence base, the background on how the evidence base had developed and evolved, and to answer specific queries raised during the early stages of the review. This information has been incorporated as appropriate and highlighted within the report. Waterwise's comments are summarised in Appendix D.

1.4 Reporting

This report contains an overview of each of the elements of work undertaken, together with discussions and conclusions. The details of the work undertaken are presented in the appendices.

This report has the following content:

- Section 2: Details of the current opinion of the water industry towards the water efficiency evidence base.
- Section 3: Discussion on how the evidence base information has previously been used within WRMPs, and how potentially it could be better integrated into future plans.
- Section 4: Description of approach taken to identifying the trials for further detailed analysis in this study.
- Section 5: Detailed review of the Waterwise Evidence Base studies, including statistical approaches.
- Section 6: Results of analysis on recent water efficiency studies not included within the Waterwise Evidence Base.
- Section 7: Summary of conclusions from the review conducted.
- Section 8: Recommendations relating to the evaluation of the confidence or uncertainty in evidence base studies, to future methodologies to ensure objective and robust results, and to particular areas where further investigation could result in benefits for further understanding of the water efficiency evidence base.
- Section 9: Complete reference list of all literature reviewed as part of the study.
- Section 10: List of abbreviations used.

The report is supported by Appendices A-G, providing more detailed information on different aspects of the study.

2 Current Water Industry opinion of the water efficiency evidence base

2.1 Water company discussions

As part of the review, we wished to establish the current opinions of the UK water industry towards the existing water efficiency evidence base, covering both the Waterwise work and other studies.

In order to gain insight into current opinions, a questionnaire was developed by the consultants, and discussed with relevant contacts within UK water companies through telephone conversations. Appendix A contains the questions that were put to the water industry, whilst Appendix B provides the full list of the contacts that the project team were able to interview. Note that a number of companies could not be contacted within the time constraints of the project.

The responses to the questionnaire have been summarised to maintain the anonymity of individual respondents' comments. The discussions sought information around three key themes:

1. Understanding how the evidence base has been used by individual companies, and any strengths or weaknesses that the company / representative perceive exist.

2. Willingness by water companies to share any detailed data that has been fed into the evidence base.

3. Information regarding any additional company trials or evidence that have not been included within the evidence base – and willingness to share this information/data with the study.

Section 2.2 below provides a summary of the discussions and reflects the views expressed by those interviewed, not the views of the project review team. Some of the views are quite consistent and some are contradictory. The project team sought the views of individuals who use or are involved with the evidence base, and the responses provided therefore offer an insight into how the evidence is used or regarded; they should not be taken as an indication of company policy.

2.2 Summary of interview results

2.2.1 Use of the evidence base

There were a wide range of views expressed on this subject:

A significant number of people involved in water efficiency and water resource planning do not use the existing evidence base at all.

A number of people make extensive use of the background information on previous trials and studies, for example what measures were used, how they were installed, what worked well and what did not, how local customer and stakeholders were engaged.

Some people use the evidence base to help develop their water efficiency strategy and target their water efficiency activities.

The Ofwat assumed savings table was used consistently by water companies to assess performance against water efficiency targets, and in some cases was used to make decisions on water efficiency strategies.

2.2.1 Strengths of the evidence base

There was a general consensus amongst those interviewed that the Waterwise reports on the water efficiency evidence base provided a useful reference point for best practice guidelines and for drawing together experience on the effectiveness of water saving devices and measures; and experiences from carrying out the trials or studies.

It was seen as valuable that the Waterwise Evidence Base provides a common baseline where water efficiency information is in one place for water companies to work from. Many companies also suggested that this database is the best source of information currently available for this purpose. They commented that many of the known water efficiency trials were included in the Waterwise Evidence Base, although some companies did identify studies that they had conducted that were not included. Typically these were recent studies that had been completed after the Waterwise Evidence Base reports had been published.

Others commented that the existing evidence base provided useful information on the experiences of other water efficiency practitioners in setting up and carrying out water efficiency activities, the logistics, the level of engagement with customers and stakeholders, and information on what worked well and what did not.

It was also mentioned that the evidence base work to date has provided a focus for developing or evolving the approach to water efficiency studies.

2.2.3 Concerns over the evidence base

A number of concerns were expressed over the confidence in the data analysed and the presentation of water savings results in the Waterwise Evidence Base.

There appeared to be confusion over the relationships between the Ofwat assumed savings tables, the Waterwise Evidence Base and the UKWIR WR25 data base; and particularly the comparative robustness of the different evidence bases.

When determining compliance with the Ofwat water efficiency targets, many individuals relied on either data from their own studies, or used the water efficiency savings table published by Ofwat in preference to evidence base information. The intended purpose of the Ofwat table was to assess performance against the targets. However, it should be recognised that the Ofwat assumed water saving table was not designed (and should not be used) as evidence. It is a matrix by which water efficiency activity can be recorded and assessed. By contrast, the Waterwise Evidence Base was specifically intended to be used for planning and designing effective water efficiency retrofit initiatives.

Concern was expressed over the modelling of savings in some evidence base studies, and that potential influencing factors such as occupancy, demographics, installation

methods, metered/Rateable Value (RV) customers, etc., are not dealt with sufficiently. Linked to this, some thought that there was a lack of guidance on how to apply (or not apply) the results to different geographic or demographic areas.

A number of those interviewed said that they were surprised that there was no evidence on trials or studies that did not produce strong savings; they commented that it would be valuable to know what does not work so that they could also use this information when planning future studies. Phase II of the Evidence Base did include one trial in which water savings were negative. However, companies are often unwilling to share negative data, in particular prior to clarifying the reasons for the results.

There were many comments about the length of the Waterwise Evidence Base reports. Some said that the reports were too long or too complicated, making them difficult to use (these comments are being addressed by Waterwise in the presentation of Phase III reports). There was a sense that people in water companies would like to access the information in a concise and well signposted format, so that information could be found quickly.

There were also concerns expressed about the often short-term and small-scale nature of the trials contained within the evidence base. This is a reflection of the character of the studies conducted, which were compiled by Waterwise within the Evidence Base reports.

A number of people interviewed showed scepticism over the water savings determined by the studies, with many believing they were not realistic. This was a particular concern when considering whether savings would be sustained; and the transferability of savings from one area of the country to another, or to customer groups with different demographics.

There were a number of comments that the scenarios contained in the evidence base were unrealistic. They suggested that the scenarios fail to capture the true costs of doing large projects, and the assumptions that third parties will provide services free of charge are not realistic. Even where third parties do work at reduced costs, the effort and time required of water company's direct staff are often not factored in.

2.2.4 Suggestions for future evidence base development

There was broad support amongst those interviewed for an evidence base to be maintained, kept up-to-date and improved. In particular there was interest in ensuring that it sought to establish sound longevity data. Some questioned the need for three sources of evidence (Waterwise, Ofwat and UKWIR WR25, the UKWIR database).It was felt that the concerns raised by the water industry should be used as targets for the improvement of the evidence base. It was also suggested that trials resulting in 'negative' conclusions (i.e. no water savings), or those not supporting efficiency measures should be included in the evidence base.

More peer review of the data analysis was recommended, to give users and regulators greater confidence in the savings results. There were a number of suggestions that more innovative or different statistical approaches should be used to try and obtain additional value from the data that has already been collected.

An additional comment was made that the expansion of the scope of the evidence base to include industrial and municipal water use, would significantly improve the impetus of the evidence base.

When asked whether there were any devices or measures that should be included in the evidence base, a number of suggestions were put forward. These were:

- Bath displacement devices.
- Water valves (flow restrictors).
- Garden products.
- Water savings from replacing whole appliances (e.g. white-goods) or whole bathroom fittings (such as complete WCs, baths or showers).
- Impacts of behaviour change.
- The persistence or longevity of water savings.
- Impact of water saving measures in new homes.
- How customer engagement impacts water efficiency.
- Water efficiency education and behaviours in schools.
- Water efficiency in non-households.
- How ownership (numbers of devices per property) and occupancy impact water savings.

Finally, a number of water companies suggested that greater transparency of the derivation of the values in the Ofwat assumed water savings tables from the evidence base would help improve the integrity of the data, increase the reliance on the evidence base and improve domestic water efficiency.

Some companies commented that they felt there was a lack of legislative incentive for the further development of water efficiency measures. This issue has in part being addressed by Ofwat's recent changes to the Water Efficiency Targets methodology.

3 Application of the existing Evidence Base

3.1 Water Resource Management Plans

As part of the review of the water efficiency evidence base, we wished to determine the extent to which the available evidence had been applied to calculate demand management values in the last cycle of Water Resource Management Plans (WRMPs). A review of WRMPs and available appendices was therefore carried out by the project team, to ascertain the values used by companies both within their demand forecast (i.e. forecast savings from water efficiency measures) and under their water efficiency activities (either baseline or SELWE (Sustainable Economic Level of Water Efficiency)).

The level of detail provided by most companies was descriptive in nature and tended to quantify a level of proposed activity and then a total projected demand saving; and did not readily allow the reviewer to document values used or data sources. The preparation of the last set of WRMPs was carried out at around the same time as the start of the Waterwise Evidence Base work. Therefore the amount of data that the companies could use was limited to their own studies, a selection of studies that had been published, or shared experience from the 'Water Efficiency Network'.

Where companies included a table of micro-components for their Final Planning scenario in their WRMP (WRMP Table 7a), water efficiency was included as a single line. Therefore it was not possible to explore whether the evidence at the time was reflected in the savings in the Final Planning scenario.

Most companies expressed the view that the existing evidence base was seen as valuable and provided consistency. For demand forecasting purposes, many companies appear to use their own data and own savings values, obtained from local trials and studies, rather than the values from the evidence base. When questioned further this was seen to be the most applicable to their area and customer base, and hence it seems that the issue of transferability of results is a perceived problem.

To encourage further application of the evidence base values of water saving, and the evidence base demand management tools, their transferability and reliability therefore require further testing or demonstration.

3.2 Water efficiency targets

Ofwat's Water efficiency targets, set in 2009, require individual companies to demonstrate savings of 1 litre per household per day (halved for companies with average per capita consumption below 130 litres per property per day) as part of their water efficiency activities. The available evidence base can be used by companies to help plan how to achieve Ofwat's water efficiency targets, and Ofwat's assumed water savings tables are used to assess whether or not they have been met.

The basis for the Ofwat 'Estimated savings and uptake rate table' is explained in section 2.2.4 of Appendix 1 to PR09/20 (Ofwat, 2008). In summary, Ofwat fixed yield and uptake rate assumptions within the tables to provide certainty to stakeholders about what they expect water companies to achieve, and certainty to water companies

when reporting performance against their water efficiency targets. Ofwat's ultimate goal was to encourage companies to gather more accurate information on the impact of water efficiency measures. In preparing the tables, Ofwat sought input from Waterwise to ensure that assumed savings align as well as possible with the Evidence Base.

Ofwat has made clear that it would review, and where necessary, revise their assumptions if companies or other stakeholders were to provide them with new evidence. Before taking this step, Ofwat would consult with water companies and other stakeholders. Ofwat did not allow the use of any company specific evidence in the calculation of adherence with water efficiency targets.

To date, Ofwat have received evidence from both water companies and manufacturers to support new water-saving products, and to amend existing assumptions. They reviewed the evidence and informally consulted with stakeholders, particularly Waterwise, to decide whether or not to make changes to the Ofwat table.

The interviews conducted suggest companies are using the Ofwat values (rather than values from the Waterwise Evidence Base) to plan how to meet the targets, as well as to document how these targets have been met. In principle water companies should be using the best available evidence in planning to meet their base water efficiency activities. In practice it is to be expected that the Ofwat values would be used, as they are part of the guidance that the companies are required to use for reporting water savings. Ofwat suggest that this is a disadvantage of the current activity-based targets, and something that they are looking to address at the next price review.

The research carried out in this review shows that some companies are using the Ofwat assumed savings tables as a planning aid instead of the Waterwise Evidence Base. In some cases, companies also use the values for water resource planning.

There are a number of people who use the Waterwise Evidence Base to support the planning of water efficiency projects aimed at delivering water efficiency targets, but generally more for the experiences contained within the evidence base reports rather than the actual water savings values. There are also a few who rely mostly on their own trials for planning purposes.

4 Identification of trials for detailed review

4.1 Overview

In an effort to review and test some of the issues raised by the water companies during interviews, the consultants were asked to undertake a detailed review of the Waterwise Evidence Base reports.

Work on the Waterwise Evidence Base started in earnest in 2007 and has produced two significant bodies of work: the Phase I and Phase II evidence bases. Phase I was a collation of some of the work already carried out by water companies, augmented by analysis to attempt to disaggregate the savings into individual device savings, plus additional work to forecast the persistence of savings, examine direct and indirect costs, and carry out scenario modelling. Phase II reviewed larger scale trials carried out by water companies and analysed the raw data to produce values for water savings, investigate savings over time, explore energy costs and present additional information about the experiences from the trials, and carry out cost benefit analyses. The evidence base work, whilst carried out by Waterwise, was overseen by a steering group consisting of water companies, the Environment Agency, Defra, Ofwat, the Consumer Council for Water, the Water Industry Commission for Scotland, DECC, CLG and WRAP.

For the initial phase of the present review, the consultants briefly reviewed all trials included within the Waterwise Evidence Base (Phases I and II), and used this alongside other information to shortlist trials for a subsequent, more detailed review. The tasks that were carried out to inform this assessment were:

- Review of all trials using prepared pro-forma to extract key information
- Initial statistical review of core 'pre-intervention and post-intervention' data, and headline statistics within Phase II reports.
- Conversations with water company representatives to identify critical components of evidence and how savings values have been used within WRMPs.

A pro-forma (presented in Appendix C, Section C2) was developed to allow key information to be rapidly extracted from trial reports. A focus was given to summarising the availability of measured data (or otherwise), the level of customer-side information collected as part of the trial, the types of devices installed and conclusions drawn. A total of 31 trials were reviewed in this fashion.

An initial review of summary statistics, tables and plots provided within the Waterwise Phase II Evidence Base reports was also undertaken by a senior statistician, to assess the robustness of the results. The studies that were reviewed in this way are presented in Tables C.1 to C.3 in Appendix C. These studies represent only those within the Phase II report where data have been plotted.

Comments against each of the trials from the initial review can be found in Table C.4 in Appendix C. Issues linked to statistical analysis of the data collected were used to identify the studies for detailed analysis. As detailed in Section 2, interviews were held with representatives of water companies who are familiar with and have used the water efficiency evidence base. Individuals were asked to identify any trials that were of

particular concern to them, or might be seen as particularly good examples. However, there was no information to point towards the need to review a particular trial over another from these conversations.

The information gathered through the three review activities detailed above were considered by the project team and used to identify trials for in-depth review. In addition, a number of specific points were taken into account when undertaking the short-listing. These are also detailed in Appendix C.

4.2 Final selection of trials for in-depth review

Prioritisation was carried out to allow the statistics team to review as many trials as possible within the time constraints of the project. The trials below were selected as priority 1 and 2, and the reasons for selection are provided here.

- South West Water (SWW) Water Efficiency Trial (2006) (Jacobs, 2007)
  - Report includes detail on statistics carried out, some longevity information and a control group.
- Essex and Suffolk Water (ESW) Chelmsford ecoBETA (2007) (Scobie, 2007)
  - Provided good data on a single device. No disaggregation required. Key device used frequently by companies.
- Yorkshire Water (YW) Water Saving Trial (2008) (Yorkshire Water, 2008)
  - Included control group. Visit and fix. Some information on longevity of savings. Statistics described in detail identified non-normal distribution.
- United Utilities (UU) Home audit study (2008) (Waylen et al, 2008)
  - Data was available to review team. Original analysis includes information reported by device.
- Thames Water (TW) Measured visit and fix trials (2010) (Artesia, 2007)
  - Included a control group, measured data, a reasonable sample size and a good mix of commonly used devices.
- Severn Trent Water (STW) Domestic water efficiency trial (2008) (Artesia, 2008)
  - Included a good mix of commonly used devices, a reasonable sample size, quantitative data on savings and a control group.
- TW Self-audit rateable value trial (2010) (Artesia, 2010)
  - Results could be influenced by metering also being implemented.
- ESW H2Eco (2008)[2] (Artesia, 2010)
  - All data available to review team. Large sample includes occupancy and socio-economic information.

[2] This trial has not been included in the Waterwise Evidence Base, but has been included to complement the review.

5 Review of the Evidence Base

5.1 Introduction

Through the selection process described in Section 4, seven studies from Phase II of the Waterwise Evidence Base were identified for further detailed analysis. The raw data behind the selected projects was requested from Waterwise. Supplementary data was requested from the individual water companies that carried out the trial where necessary. Complete data were provided for the following projects included in the evidence base:

- SWW Water Efficiency Trial;
- ESW Chelmsford ecoBETA;
- YW Water saving trial;
- UU Home audit study;
- TW Measured visit and fix trials;
- STW Domestic water efficiency trial, and;
- TW Self audit rateable value;

In addition a review was also carried out of the H_2Eco study reported in Section 6.3 and in Appendix E, Section E8.

The review was carried out by and under the guidance of two senior experienced statisticians in the consultants' project team. The main issues explored by the review are listed in the table below.

Table 5.1 Main issues explored in this review

Issue	Points for review
Calculation of water consumption	How many meter readings before and after? How long after the intervention was consumption measured?
Control group	Is there a control group? If yes, how many households? Does it provide a good basis for comparison?
Statistical distribution of consumption change	Are the household water consumption changes normally distributed? If this was tested, was it before or after excluding data?
Decisions on inclusion / exclusion of data	How have outliers been identified? Which data were excluded and why?
How to test for significant changes in consumption?	What test(s) were used? Are they appropriate, given the distribution of the data?
What parameters to present in the results?	Mean and/or median? Confidence intervals.

5.2 Results and findings from the review

A short report for each of the studies reviewed is included in Appendix E. Each report summarises the findings from the original water company project (where available), the findings presented in the Waterwise Phase I and Phase II Evidence Bases and the findings from the statistical review carried out as part of this study.

A summary of the analysis is presented in Table 5.2, illustrating the summary statistics from the Waterwise Phase II Evidence Base report and the comparable statistics derived from the present review, using the full dataset and a subset with outliers removed.

The review highlighted a number of areas that relate to the data and findings reported in the evidence base, and these are presented below. The findings suggest a need for normalising statistical approaches applied to the review of evidence base data, to strengthen the robustness and reliability of the findings.

5.2.1 Sample sizes and data exclusion

A number of the studies reviewed had excluded certain data sets prior to results presentation. The data exclusion rules applied had been agreed by the Steering Group for the Waterwise Evidence Base project. Data exclusion is a common procedure, to remove what may appear as inappropriate input (e.g. negative meter readings, or excessive water consumption). However, it is essential to report how much data has been excluded and the reasons for the exclusion. Incorrect readings may occur in more than one direction, and may equalise each other if all are left within the dataset analysed.

Overall this is a complex problem and needs to be given prominence in evidence base reporting, as removing data can have significant impacts on the results. In particular, the methods used, the amount of data excluded and the reasons for excluding data must be presented. This will increase the reader's confidence in the data.

Any explanation for data removal should preferably be backed up by an assessment of the impact on the conclusions. It would be useful to derive some default guidance on the most appropriate data exclusion rules through review of evidence base studies, based on factors such as sample size, how the data was collected and period of consumption analysis.

For some of the studies analysed during the present review, the consultants' team were able to apply the same data exclusion rules used in the Phase II evidence base. Where these were applied, the sample sizes obtained differed from the evidence base report, and the reasons for the different sample sizes were not determined. This again points to the importance of defining the reasons and techniques for data exclusion.

Table 5.2 Summary results from statistical review - effect of data exclusion

	Waterwise Phase 2 Evidence Base			Evidence base review project findings			
Study	Sample size	Mean reduction in consumption (l/prop/day)	Quoted confidence limits	Sample size	Mean reduction in consumption (l/prop/day)	90% confidence limits	Comments
STW domestic water efficiency trial	717	28.4	+149.8 to -92.9	810	11.7	-2.92, 26.3	Using all data
				717	25.8	21.4, 30.1	Excludes data where %change >67.5%
TW measured visit and fix trial	727	29.1	+153.9 to -95.7	885	19.8	13.4, 26.2	Using all data
				823	16.0	11.7, 20.2	Using Phase 2 report screening rules
TW self audit rateable value trial	525	21.5[3]	+265.2 to -221.5	635	15.6	2.63, 28.5	Using all data (300 days post audit)
				489	0.32	-7.11, 7.74	Using Phase 2 report screening rules
YW Water saving trial	378	27.6	+124.3 to -69.0	370[4]	26.2	16.0, 36.4	Using all data

[3] The TW self-audit RV trial results presented in the evidence base suggest that the post intervention data covered 3 months. However, the raw data supplied to the project team covered 30 days and 300 days, there was no data covering the 3 months post intervention. This may be a typographical error in the evidence base or different raw data was used.

[4] The review team were unable to replicate the size of sample used by Waterwise. A full explanation is given in the review report in Appendix D (to check).

	Waterwise Phase 2 Evidence Base			Evidence base review project findings			
Study	Sample size	Mean reduction in consumption (l/prop/day)	Quoted confidence limits	Sample size	Mean reduction in consumption (l/prop/day)	90% confidence limits	Comments
				359	34.5	25.2, 43.7	Excludes data where %change >100%
SWW Water efficiency trial	152	9.1	+40.0 to -21.8	348	7.46	-7.0, 22.0	Using all data
				341	16.6	3.49, 29.7	Excludes data where %change >100%
ESW EcoBETA study	169	31.38 (Phase 1 evidence base)	-	169	40.0	34.4, 45.7	Using all data
UU Home audit study trial	211	20.6	+169.4 to -128.1	260	21.8	11.4, 32.1	Using all data
				246	20.4	13.0, 27.9	Using Phase 2 report screening rules

5.2.2 Impacts of Excluding Data

For the studies reviewed, the rules for excluding data that were used in the Phase II evidence base were obtained from Waterwise. Data was excluded for:

- Incomplete site data.
- Negative consumption.
- Pre and post consumption >800 litres/prop/day.
- Changes in consumption > ± 70%.

The rules were agreed by the Steering Group for the Waterwise Evidence Base.

It is logical to consider excluding data. Water consumption data is nearly always bounded at zero (as negative consumption due to meter read errors is often excluded). However, there are no natural bounds at the upper end of consumption, and hence meter read errors in the upper direction are often included, as are meter read errors that result in a neutral consumption figure. It is also tempting to screen out large changes in consumption during the course of a study that could be due to changes in occupancy, or leaks on supply pipes breaking out or being repaired. However, changes in occupancy or leaks that cancel out reductions in consumption from water efficiency will remain in the sample, thus potentially skewing results. Since there is no industry-wide standard for excluded data, every approach will have limitations, and clear explanation of any data exclusion should be provided.

The impact of removing data from the original dataset can have a significant impact on the results. Table 5.3 shows some analysis carried out by applying different rules for removing 'outliers'. The resulting range of reductions in water consumption is from 11.7 to 39.4 l/prop/day.

Table 5.3 Impact of sample size on results from the STW study

Dataset	No of households	Mean phc pre-installation	Mean phc post-installation	Mean reduction in consumption	90% confidence limits	
All households with complete data	810	249.7	238	11.7	-2.9	26.3
Exclude households where % change >100	774	254.5	215.1	39.4	33.2	45.5
Exclude households where % change > 67.5	717	247.1	221.3	25.8	21.4	30.1
Exclude upper and lower 2.5 percentile	768	242.6	218.4	24.2	19.1	29.2
Exclude upper and lower 5 percentile	728	236.1	212	24.1	20.2	28.0

Conversation with Waterwise highlighted that the Evidence Base Steering Group, which included several water companies, signed off the exclusion criteria after discussing them at length. The criteria were set such that each of the trials would be treated in a consistent way and would be comparable. All properties that were excluded were excluded for objective reasons and in a consistent way.

5.2.3 Confidence limits

The evidence base studies reviewed used confidence limits calculated from standard deviations. However, the confidence limits should be calculated using the standard error of mean (Quantification of the savings, costs and benefits of water efficiency, UKWIR Report 03/WR/25/1, 2003). Calculated correctly, the confidence limits relate to the mean savings (providing a 90% confidence that the mean lies between the limits).

The industry is interested in the overall impact of interventions in multiple properties, and it is therefore important to have an understanding of the confidence in the mean of the results. As an example using the UU study: the quoted 90% confidence limit in the evidence base is -128.1 to +169.4 around a mean of 20.6.This may give the impression that the reduction in consumption is not significant as the confidence limits straddle zero; whereas the review team's calculations give a 90% confidence limit of 13.03 to 27.86 around a mean of 20.4, which shows the mean reduction is significant.

The analysis carried out for this review shows (in Table 5.2) significant savings for six of the trials, with their confidence limits well above the zero point. For one study (the TW self audit rateable value study) the savings are only marginally significant if all the data is used (although there are concerns over the normality of the data), and are not significant if the data screening rules are applied.

We recommend therefore that, for future reporting in the water efficiency evidence base, confidence limits calculated using the standard error of the mean.

5.2.4 Linear regression of pre and post intervention consumption

The Waterwise Evidence Base studies reviewed place great weight on the use of linear regression modelling of pre and post intervention water consumption, for the forecasting of water savings achievable in similar types of project carried out elsewhere.

The review conducted has highlighted that studying water efficiency effects using pre and post audit water consumption linear regression models can be misleading and should not be used as a first order prediction of savings. The apparent indication of higher savings being associated with high pre audit consumption is likely to arise from the imperfect relationship between pre and post audit consumption, and is known as regression towards the mean (see for example Hays, 1991, section 14.7). There is also no information within the model about the nature of the intervention or the area to which the model is being applied or any other factors.

The risk in applying the model can be demonstrated using data from the four phases of ESW's H2Eco trials reported in section Appendix G, Section G2 Four phases of trials were carried out in successive years; each trial was essentially the same in nature (similar interventions, devices and customer engagement) but carried out in different geographic areas in Essex and at similar times of year. A linear model can be constructed using the pre and post intervention data from phase 1, and this model can

then be applied to the pre intervention consumptions in the phase 2, 3 and 4 areas; this should then forecast the savings achievable in the other phases.

The phase 1 model is in the form:

Post cons = 0.73 * Pre cons + 51 (r2 = 0.61)

Table 5.4 below shows the results of carrying out this exercise.

Table 5.4 Predicted savings from linear regression

Phase	Sample size	Measured mean water saving (l/property/day)	90% conf limits	Predicted mean water saving (l/property/day)
Phase 1	663	20.3	15,27	-
Phase 2	622	6.7	0.4,13	23.7
Phase 3	155	4.9	-1,11	14.4
Phase 4	416	27.8	19,36	10.9

The table shows that the predicted savings based on a pre and post audit water consumption model from the phase 1 study are about 3 times more than the measured savings in phases 2 and 3; and just over a third of the measured savings in phase 4.

This study did however manage to explain the differences between the water savings achieved in phases 1 and 4 compared with phases 2 and 3; and the influencing factors are the high intensity of ecoBETA fittings in phases 1 and 4, and the low proportion of ACORN 5 (the Hard Pressed) in phases 1 and 4.

5.2.5 Multiple regression

Whilst outside of the scope of the evidence base itself, the consultants' review team carried out a quick investigation to explore whether more information could be obtained about water savings from the raw data provided if alternative statistical techniques are deployed.

One recognised statistical method is to use multi-regression to help look at how device type and installation quantities influence and explain metered measured savings at households. The multi-regression results shown below (Table 5.5) are using different device types simultaneously as predictor variables and measured pre and post audit consumptions as the response variable.

Whilst each device type will have its own story to tell, the dual flush device (most commonly the ecoBETA) shows the most consistent statistically significant results.

The project team undertook four sets of multi-regression analyses, which are reported here (Table 5.5).

Table 5.5 Results from multiple regression analysis

Study	Sample Size	Saving l/device/day	Statistically Significant	Water Company	Location
H2Eco	1800	16.9	highly	ESW	Chelmsford
TW MVF	885	17.7	highly	Thames	Swindon/Bromley
EcoBETA	169	19.5	highly	ESW	Chelmsford
UU Home Audit	260	15.8	highly	UU	Warrington

On average these four studies showed remarkably consistent results. EcoBETAs installed as part of a multi device water efficiency audit were shown to save between 16 and 18 litres/device/day. A single device ecoBETA installation may save a little more at 19 to 20 litres/device/day.

The other interesting inference is that an ecoBETA installed in Chelmsford in a multi-device setting saves a very similar amount of water as one installed in Swindon, Bromley or Warrington. Therefore, there may not be as much difference in regional response to water efficiency studies as some people may fear.

The results suggest that application of multiple regression to other Phase II studies could provide further statistical robustness to the results obtained, and help allay concerns regarding differences in regional responses.

5.2.6 Data aggregation

There were a number of points made by the industry during interviews conducted, relating to the difficulty of aggregating data from the various trials; reasons given were differences in geographic area, varying amounts of pre and post intervention data, differences in the types of products installed, or differences in the level of engagement of customers.

The seven studies analysed as part of this review have between them nearly 3,500 pairs of pre and post intervention measured consumptions. The H2Eco study described in Section 6.3 below has nearly 1,800 pairs of data. In total, a database of just over 5,200 pairs of data points could be assembled relatively quickly; these data points also have associated with them other information such as numbers and types of devices fitted, type of study (plumber assisted, self audit, etc.). Many also have socio-demographic information such as ACORN, property type, location. Statistical techniques generally produce improved results with increasing dataset sample sizes, even if there is more variability.

Larger datasets are more likely to reveal more reliable water savings numbers for each device type. One way to increase datasets is to collate several study results provided that they are compatible. Therefore, the project review team suggested that there would be merit in aggregating the data and applying a range of statistical techniques to shed light on the factors that influence reductions in consumption from water efficiency. This should help in identifying the device or socio-economic factors which influence water efficiency. In turn this should allow data from one study to be transferred to another area, and could improve the targeting of water efficiency activities.

5.2.7 Monitoring small groups of properties

One of the projects reviewed initially, the Preston Water Efficiency Initiative, used data collected where consumption in small blocks of flats was measured through a single meter. Monitoring blocks of flats or small groups of houses has two drawbacks, from a statistical point of view:

- The number of independent measurements is likely to be small and therefore results will be less reliable.
- Different water efficiency measures may be adopted at different properties within a group, making it more difficult to separate their effects.

On the other hand, there are situations in which it is the better or only option. Blocks of flats where it would be expensive or impossible to meter each flat is one example. Trials at unmetered properties face the issue of how to measure pre-audit consumption, and monitoring small groups of such properties may be one solution.

Such an approach must however take into consideration additional factors that may influence the results, for example the risk of leakage downstream of the meter; or of non-household water use.

5.2.8 Customer feedback and attitudes

Effective use of customer feedback seems to be absent from many of the trials covered in this review An exception to this, and perhaps a pointer to the future, is in the UU Project Report on Water and Energy Efficient Showers (Critchley and Phipps, 2007). This describes a trial in 18 homes, nine of which had an aerated shower head fitted and nine with a flow regulator. Both devices achieved a similar reduction in flow rate, but while the aerators were kept in eight out of nine homes, only three out of nine kept the flow restrictors.

Customer feedback can provide information that measurement of water consumption may not be able to do. It should be considered as an important component of future evidence base studies.

Waterwise has explained that feedback has not been included in the Evidence Base to date in part because the trials collated seldom included this information. Moreover, often when such information is available it is not suitable for comparisons because survey methods and question wording differ, making comparisons invalid. The evaluation guidance being developed during Phase III of the Evidence Base will seek to work with companies to enable customer feedback to be gathered in such a way as to enable trial-to-trial comparison.

5.3 Water Efficiency Trial Design

It is clear from analysing the trial reports and the raw data,that not all the trials or studies collated within the Waterwise Evidence Base have been designed or carried out using good practice; for example most of the studies do not appear to have used control groups. There is an UKWIR good practice report covering these issues (Quantification of the savings, costs and benefits of water efficiency, UKWIR Report 03/WR/25/1, 2003).

Having reviewed the data and the analysis of the data within this study the review team think it important to highlight some of the key good practice points that should be considered in the future. These are listed below.

5.3.1 Setting Trial objectives

- What water uses, appliances, devices and/or campaigns to change attitudes will be tried?
- At which types of property? Socio-economic demographics, dwelling types, numbers of occupants, methods of payment for water, possibly property age.
- What information on customer feedback and attitudes will be obtained?
- What degree of confidence in the measured water efficiency savings is desired?

5.3.2 Determining Trial design and method of selection

- Numbers and types of household
    - Both doing the audit and the control group
    - If there are alternative types of audit/intervention being tried, consider having separate groups of households for each one
    - Properties paying by meter or by RV
    - Dwelling type
    - Numbers of occupants
    - Socio-economic classification
    - Target numbers in trial, expected response rate and number to invite
    - There are recognised methods of calculating required sample sizes.
- How to motivate people to take part?
- Monitoring
    - Equipment & data logging
    - Time period of monitoring, both pre- and post- audit
    - Seasons, include the summer?
    - How many meter readings to take during the monitoring periods?
- Water user questionnaires

5.3.3 Data and analysis

- Screening data and decisions on exclusions
- Statistical distributions of household consumption and changes in household consumption
- State water savings as the mean with 90% confidence limits, estimated from the standard error of the mean (Assuming the mean to be normally distributed, Central Limit Theorem)
- Compare the audit group (or groups if the trial has been designed in this way), with the control group

- Assess the influence of household factors (dwelling type, occupancy etc)
- With multi-appliance trials, assess the relative effectiveness of the different appliances; using multiple regression or alternative techniques
- Use customer feedback to help explain the observed successes & failures
- Compare the water savings actually obtained with theoretical values (useful for the water resource planner)
- Make appropriate use of non-parametric statistics relating to household numbers (median, percentiles, chi-squared tables, correspondence analysis).

6 Additional information to support the Evidence Base

6.1 Introduction

During the review study conducted, a number of additional trials or studies that were comparable in size or nature (i.e. measured savings) to those in the existing evidence base have been identified. These are summarised briefly in this section, and included more fully in Appendixes F and G. The additional studies include:

- the collection of trials contained in the UKWIR WR25 water efficiency database;
- a large collaborative study carried out by WRc;
- a large study carried out by Artesia Consulting for Northumbrian Water; and
- a study undertaken by South East Water.

The last three studies were performed or results published after the release of the most recent Waterwise reports, and are therefore not included in the current Waterwise Evidence Base. They are reviewed briefly here (sections 6.2-6.4), and in detail in Appendix G.

A review of the UKWIR WR25 evidence base was also undertaken, to identify any studies that may be suitable for inclusion within the water efficiency evidence base. In undertaking the review, the criteria used by the consultants when shortlisting evidence base studies for further analysis (see Section 4) were employed to assess if a study was likely to offer results that could strengthen the existing evidence base.

A summary of UKWIR WR25 studies identified as having good results available are provided in Appendix F. The majority of studies identified are from non-household locations. Hence, they would not provide evidence relevant to the household water efficiency evidence base, but should not be forgotten as sources of information on the effectiveness of non-household intervention. No study has yet been carried out to pull the non-household water efficiency data together (excluding the Evidence Base schools report (Waterwise, December 2010)) and identify if there is any consistency amongst savings values.

If water companies are proposing high levels of non-household water efficiency work then this would be a sensible step to take prior to implementation of schemes.

6.2 WRc Collaborative Research project CP359

In 2009 a group of UK Water Companies, Defra and the Environment Agency collaborated to look at the impact of water audit activities in household properties at the micro-component level (Glennie, et al, 2010).

The three key messages from the study were:

- The greatest savings were achieved through retrofitting toilets. Toilet devices should be installed as a priority in older properties where toilet volumes are still likely to be high. Installing a combination of devices, for example 'ecoBETA' and 'Save-a-Flush' can be very effective in reducing the total volume used by toilets in a property.
- The installation of water-efficient shower heads should be targeted at showers with a mean flow rate (prior to the water audit) of more than 8 litres per minute. A reduction in mean flow rate of approximately 25% is likely for these showers and the duration of each shower is unlikely to change.
- Care should be taken when disaggregating savings achieved from implementing a basket of measures to individual water-saving devices. The use of other appliances, those to which no water-saving devices are retrofitted, may also change following a water audit and can account for a high proportion of total savings seen. These might be behavioural changes associated with the audit but this was not confirmed as part of this study.

Further details on this study, and a table of summary results, are presented in Appendix G.

6.3 Analysis of water saving data from H2Eco studies

In 2009/10, Artesia Consulting were asked to examine the data from the four H2Eco project phases carried out by Esssex and Suffolk Water (ESW), to help get further value from the data and examine some of the assumptions and conclusions arising from the projects (Artesia, 2010).

ESW's H2Eco projects are household water efficiency audits and retrofits. Four separate projects (phases 1 to 4) have been completed to date covering different areas of Chelmsford. The phases have varied a little in approach, but have all involved an audit and the provision of and installation of devices including ecoBETAs, "Save a Flush", aerated showerhead, tap inserts, tap re-washering, hose guns, garden crystals, water butts, and water efficiency advice. In each phase, three estimates of the water savings were made: from meter readings, from logger data, or from calculations based on the point-of-use measurements.

This study has enabled the analysis of a significant volume of data collected in a consistent way from a series of water efficiencies studies. The amount of measured data (1787 pairs of readings representing before and after intervention consumptions) has allowed a range of statistical techniques to be used to analyse the data, which has enabled water savings to be determined with a high degree of confidence. It was possible to estimate the volumetric savings from a range of devices. The volume of water saving and socio-demographic data along with good quality records of each audit has allowed the project to draw conclusions on why there are differences in water savings between studies. Further details of the study and the key conclusions are set out in Appendix G.

6.4 South East Water studies in Highland Park

A new residential development in Kent installed efficient fittings and tested a seasonal water tariff.

The development is located in South East Water's area (and in Mid Kent Water's areas previously) and the company worked in partnership with Hillreed Homes at the Highland Park Development, Singleton Hill, Ashford. South East Water (SEW) sponsored the installation of water efficient plumbing and appliances in each of 200 homes. A further 60 homes (already completed) did not feature the water efficient plumbing or appliances and were used as 'control' group properties.

Homes which have been fitted with water efficient devices are known to contain:

- Dual flush (4/2.5 litre or 4.3/3 litre) WCs.
- An aerated shower head (maximum 10 litres per minute).
- Spray or low flow taps (maximum 5 litres per minute) in the downstairs bathroom.
- An efficient washing machine (39 litres per cycle specification).
- A flow limiter to 10 litres per minute on outdoor taps.
- The purpose of this water efficiency and seasonal tariff trial project was to investigate consumers' behaviour in terms of water usage in respect of:
- The presence of water efficient plumbing and appliances; and
- The application of a seasonal tariff to 50% of homeowners.

Headline results of the study are presented in Appendix G.

7 Conclusions

The analysis carried out during this study confirms that most water efficiency projects reviewed lead to reductions in water consumption. The study has also identified a number of improvements that could be made to the existing water efficiency evidence base which should lead to a greater confidence in its use.

7.1 The evidence being reviewed

This review was commissioned by the Environment Agency and overseen by a steering group consisting of the Environment Agency, Defra, Ofwat and water companies. The review was conducted by WRc and Artesia, two consultancies with significant experience in demand management and in the application of statistical analysis.

The review has concentrated on the domestic water efficiency evidence base known as the 'Waterwise Evidence Base: Phase I and Phase II'. The review has also considered other sources of information and evidence, including the Ofwat estimated savings and uptake rate tables in the water efficiency target guidance notes; the UKWIR WR25 database and other projects carried out by individual companies.

7.2 The survey of water companies

The review has canvassed views from a wide range of water companies and determined that:

- There is a general consensus that the water efficiency evidence base provides a useful reference point for best practice guidelines and for drawing together experience on the effectiveness of water saving devices and measures; and experiences from carrying out the trials or studies.
- There are people who make extensive use of the background information on the trials and studies in the evidence base, there are also those who do not use it at all. Many use the Ofwat assumed water savings and uptake rate tables, in particular to calculate water savings and adherence to the Ofwat Water Efficiency Targets.
- In talking to those in the water companies who use water efficiency study data for water efficiency targets or for water resource planning, the need was identified to access different types of information, namely:
    - A comprehensive list of trials, studies and projects that had been carried out, with details of where to access the reports or contact those who had carried out the trials.
    - Summary of statistical analysis of the water savings which are robust, and which include summary information about the trials and guidance on how the results could be applied and used.
    - Detailed information about the experiences from those who conducted the trials in setting up and carrying out water efficiency activities, the logistics, level of engagement with customers and stakeholders and information on what worked well and what did not.

- The views of the water companies suggest that the evidence base, as it stands, is most useful (and most used) to get information relating to this last point.
- Responses also suggested that some concerns existed over the data analysis and presentation of water savings in the Waterwise Evidence Base, which this review has aimed to address.

7.3 The detailed statistical review

7.3.1 General points

The statistical review carried out by the consultants team, identified a number of issues related to the analyses presented in the Waterwise Evidence Base. Resolution of these issues will provide users with greater confidence in the water saving data.

- Where data is excluded from the analysis (under agreed rules), it is essential to report how much data has been excluded and the reasons why it has been excluded. The review has demonstrated that the impact from excluding data can be significant in influencing the result produced.
- The evidence base places great weight on the use of linear regression modelling for providing insights into water efficiency studies. However the review suggests that linear regression may not be appropriate in the analysis of results or as a first order prediction of savings.
- The confidence limits for the evidence base studies have been calculated using the standard deviation. When the limits were calculated using the standard error of the mean in the present review, the water savings were shown to be statistically significant in most cases. This would give the reader more confidence in using the results.

7.3.2 Summary results

The review team has re-analysed seven of the studies in the Waterwise Phase II Evidence Base in detail using raw data. Some of the results are similar; some show lower water savings, and some higher. All have confidence limits applied using standard error, and as a result six of the studies demonstrate reductions in water consumption that are statistically significant, and one study shows no significant savings. The estimates of the mean reduction in consumption derived from the raw data by the review team are shown in Table 7.1 below. These have been derived using data exclusion rules similar to those used in the original analysis and are reported in full in the body of the report and the appendices.

Table 7.1 Estimated mean reduction in consumption

	Waterwise Evidence Base		Present Review project findings	
Study	Mean reduction in consumption (l/prop/day)	Quoted confidence limits	Mean reduction in consumption (l/prop/day)	90% confidence limits
STW domestic water efficiency trial	28.4	+149.8 -92.9	25.8	21.4, 30.2
TW measured visit and fix trial	29.1	+153.9 -95.7	16.0	11.7, 20.2
TW self audit rateable value trial	21.5	+265.2 -221.5	0.32	-7.11, 7.74
YW Water saving trial	27.6	+124.3 -69.0	34.5	25.2, 43.7
SWW Water efficiency trial	9.1	+40.0 -21.8	16.6	3.49, 29.7
ESW ecoBETA study	31.38	-	40.0	34.4, 45.7
UU Home audit study trial	20.6	+169.4 -128.1	20.4	13.0, 27.9

Based on the analysis of the seven studies undertaken in this review, some of the water efficiency savings estimates presented in the Waterwise Evidence Base are likely to be smaller than initially predicted, but have significantly narrower confidence limits, indicating the values to be more reliable for supporting the water resource management plans.

7.3.3 Statistical modelling and factors influencing water savings

The evidence base places great weight on the use of linear regression modelling of pre and post water consumption for providing insights into water efficiency studies, and for the forecasting of water savings achievable in similar types of project carried out elsewhere. The review team conclude that the use of pre and post audit water consumption linear regression models is misleading and should not be used in the analysis of results or as a first order prediction of savings. Worked examples are presented in the review, illustrating the significant difference in measured savings against savings predicted by this method.

Throughout the evidence base reporting, a standard set of analyses has been presented for each study. This has the merits that it allows consistent reporting and comparison. However the application of alternative or additional statistical methods may provide additional useful information. For example, the review team applied multiple regression methods to two of the multi device studies included in the evidence base. This analysis has demonstrated consistent results with two other 'ecoBETA' studies, demonstrating a consistent saving of between 16 and 18 litres/device/day, even though the trials were carried out in different geographic areas and mixes of device type.

The review team suggest there would also be benefit in aggregating the data from most of the studies to create a single large data set and then applying a range of statistical techniques to shed light on the factors that influence reductions in consumption from water efficiency. Statistical techniques generally produce improved results with

increasing dataset sample sizes, even if there is more variability. This should help in targeting activities to different areas, or demonstrating the actual savings made by different types of device or intervention.

Effective use of customer feedback is absent from many of the trials. The review team believe that customer feedback can provide information that measurement of water consumption may not be able to do, and so help explain and understand the factors that lead to reductions in consumption.

7.4 Ofwat water savings tables and the WRMPs

The Ofwat tables of assumed water savings tabulate savings for a wider range of devices than are currently included in the evidence base. The intended purpose of the Ofwat tables is to assess performance against water efficiency targets. Ideally the Ofwat table would be consistent with the Evidence Base. However, these savings values have not been scrutinised to the same level of detail as those reported in the Waterwise Evidence Base, and as a result water company users have expressed concern over whether they can be used for water resource planning purposes.

Based on the work done in this review, Ofwat assumed water saving tables should not be used for planning demand reductions in the Water Resource Management Plans, as they would probably result in an over-estimate of the impact of water efficiency measures.

8 Recommendations

8.1 Improving the confidence in the existing evidence

Based on the review conducted, the confidence in the studies that have been reported in the Phase II Evidence Base could be improved by carrying out the following:

- Confirming the data exclusion rules and the reasons for applying them, applying the rules consistently and reporting the sample sizes pre and post data exclusion.
- Reporting the mean reduction in consumption of the sample post data exclusion.
- Reporting the 90% confidence intervals using the standard error of the mean; i.e. using the following equation:
  - 90% confidence interval = mean $\pm$ 1.645*(SD/$\sqrt{n}$)
  - where: SD – standard deviation and n = sample size
  - Carrying out normality tests on the data.
- Commenting on the statistical significance of the mean taking into account the 90% confidence limits and the normality of the data sets.

This should provide companies with greater confidence in the reductions in consumption from the different studies.

8.2 Increasing the value from the existing data sets

Using the data that has already been collated as part of the Phase II Evidence Base, it should be possible to extract additional value and provide insight into the application of evidence base findings. The individual trial data sets could be aggregated into a single large data set, to which a range of statistical techniques could be applied, to:

- Identify device specific factors that effect water savings.
- Identify socio-economic factors that effect water savings.

These explanatory factors could then be used to provide guidance on how water savings from the studies can be applied to future studies, and hence be used in developing water resource management plans.

8.3 Using the evidence in WRMPs

Water companies should be using the best available evidence in planning how to meet their base water efficiency targets and in water resource planning. The recommendations outlined above provide data that is useful and more robust to support the water resource management plans. Other information contained in the existing evidence base, such as the experiences of carrying out the trials, the description of the devices, and engagement and approaches used, should also be

used to support the planning of water efficiency options within the water resource plans.

8.4 Improving the value of future evidence base work

Future evidence base reporting would benefit from a simpler structure. The two main existing sources of evidence, namely the Waterwise Evidence Base and the UKWIR 25 data base, should be consolidated, and should include:

- A comprehensive list of trials, studies and projects that had been carried out, with details of where to access the reports or contact those who had carried out the trials.
- Summary of statistical analysis of the water savings which are robust, and which include summary information about the trials and guidance on how the results could be applied and used.
- Detailed information about the experiences from those who conducted the trials in setting up and carrying out water efficiency activities, the logistics, level of engagement with customers and stakeholders and information on what worked well and what did not.

The Ofwat water savings tables values should be regularly reviewed to confirm consistency with the available evidence base.

Evidence base reports should state clearly how much data has been excluded and the reasons why it has been excluded. Given the impact of data exclusion, the sensitivity of the data exclusion rules on the data analysis should be explored in more detail. Future evidence base work should give this complex area more detailed analysis and consideration; and investigate the feasibility of providing a default set of data exclusion rules.

Confidence limits on reductions in water consumption should be calculated using the standard error of the mean.

Models of pre and post intervention water consumption should not be used for the forecasting of water savings achievable in similar types of project carried out elsewhere. Future evidence base work should explore alternative and innovative statistical methods, to derive more meaningful relationships.

Future evidence base work should include the use of senior statisticians and expert peer review to ensure that the most appropriate statistical techniques are employed and that the application of those techniques can be challenged.

Future evidence base studies should include customer feedback, which can potentially provide information that measurement of water consumption may not be able to do, and so help explain and understand the factors that lead to reductions in consumption.

The following areas have been identified as gaps to be addressed in future evidence base work:

- Guidance on how to project water savings forward in time, taking into account risks and uncertainties.
- Quantifying the impact of education and behavioural messages on water consumption.
- Evaluating the water savings from new measures being developed by suppliers.

- Guidance on the planning and execution of water efficiency studies to increase the robustness of the data collected and the subsequent analysis. Guidance on this is provided in Section 5.3 of this report for study objectives, study design and data analysis.

Future evidence base work should routinely capture data from water efficiency studies (from water companies and other sources) so that the evidence base can be kept up to date.

8.5 The way forward

To implement these recommendations, collaborative work should be led by water companies to review the available data, update, re-analyse, consolidate and publish summary information from the evidence base. This data should be published so it is widely available.

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10. List of abbreviations

Abbreviation	Definition
ACORN	A Classification Of Residential Neighbourhoods (a geodemographic information system categorising some UK postcodes into various types, based upon census data and other information such as lifestyle surveys)
CCWater	Consumer Council for Water
DCLG	Department for Communities and Local Government
DECC	Department for Energy and Climate Change
ESW	Essex and Suffolk Water
MDC	Mean daily consumption
PCC	Per Capita Consumption
PR	Periodic Review
RV	Rateable value
SD	Standard Deviation
SE	Standard Error
SELWE	Sustainable Economic Leave of Water Efficiency
SESW	Sutton and East Surrey Water
STW	Severn Trent Water
SWW	South West Water
TW	Thames Water
UKWIR	UK Water Industry Research
UU	United Utilities
WRAP	Waste and Resources Action Programme
WRMP	Water Resource Management Plan

Appendix A - Questionnaire for water company discussions

We are carrying out a review, on behalf of the Environment Agency, of the water efficiency evidence base. We will be providing an independent assessment of the robustness and reliability of the evidence base to date, and considering if, for instance, the results are statistically valid. To assist us in targeting the study, we are interested in your opinion of any specific issues, strengths or weaknesses you believe are evident. We have prepared a few short questions that we'd be very grateful if you could take the time to talk to us about, we will be keeping all answers anonymous except for in relation to new trials and data.
To what extent did you rely upon the conclusions and savings values for devices or measures that are derived from the evidence base within your last Water Resource Management Plan or Ofwat water efficiency targets?
Has <company> carried out any trials that you are aware of that are not included within the evidence base?
If yes, would you be willing to provide data on these for use within this study for the EA?
If yes, when would you be able to send the data through?
For any of <company>'s trials that are within the evidence base, are you able to and would you be willing to collate and send through the raw data from the trial for further assessment? Also, are you comfortable with the analysis and reporting of the data from the trials within the waterwise evidence base?
If yes, when would you be able to send the data through?
Were you ever asked, or did you ever provide any follow up data for any trials, for instance meter reads from participants, at a later stage for longevity of savings to be assessed? Did you receive any feedback on this - such as results?
Are there other water efficiency devices or measures that you think should be included within the evidence base? And are you aware of any other evidence that exists for these measures already (e.g. within you own company or elsewhere)?
Do you have any concerns about the water efficiency evidence base, if so, what are they?
What would you say is the single biggest concern and the single greatest strength of evidence base?
Finally, have you any comments on how the water efficiency evidence base should develop?
If the company has a Phase II project: Are you willing to confirm in writing that you are happy for data submitted to the Phase II evidence base can be shared with WRc for the purposes of this study? If you are we will send you through a prepared document that we'd be grateful if you could sign and return.

Appendix B - Water company representatives contacted

Company	Contact (area of expertise)
Anglian Water	Steve Moncaster (Water resources planning)
SembCorp Bournemouth Water	Greg Pienaar (Water Efficiency)
Bristol Water	Patric Bulmer (Water Efficiency)
Northumbrian Water[5]	Tom Andrewartha (Water Efficiency)
Portsmouth Water	Paul Sansby (Water Efficiency)
Scottish Water	Donna McInnes (Water Efficiency)
Severn Trent Water	Doug Clarke (Water Efficiency)
South East Water	Gemma Avory (Water Efficiency)
South West Water	Jon Wood (Water Efficiency)
Sutton & East Surrey Water	Alison Murphy (Water Efficiency)
South Staffordshire Water	Steve Collela (Water Efficiency)
Thames Water	Heather Aitken (Water Efficiency)
United Utilities	Maxine Stiller (Water Efficiency)
Veolia Water Central (formerly Three Valleys Water)[6]	Nic Gilbert (Water Efficiency)
Wessex Water	Kathy Thorton (Water Efficiency)
Yorkshire Water	Suzanne Dunn (Water Efficiency)

[5] Representing views from both Northumbrian Water North and South.
[6] Representing views from Veolia Central, South East and East.

Appendix C - Details of process for short-listing of trial reports

C1 Criteria for short-listing

In addition to the evidence from the review activities, a number of specific points have been taken into account when undertaking the shortlisting. These are:

- Consideration of trials that attempt to quantify longevity of savings versus 'snap shot' trials. It is desirable to include a mixture of these types.
- Consideration of trials where the potential exists for later follow-up to assess longevity of savings. It is desirable to ensure some projects shortlisted have the potential for this.
- Consideration of devices that offer true long term reductions in demand, versus devices that bring forward a saving that would otherwise occur at a later date. It is desirable to focus on devices that offer true long term reductions, although longevity of savings from other devices is of interest.
- Consideration of any trials where we know that data definitely is, or is not, available. It will desirable to select trials with the highest chance of having data available.
- Consideration of whether cost data is available, or information on long run marginal costs (LRMCs) provided. It is desirable to analyse trials where cost data is available.
- Consideration of the potential significance of conclusions drawn from a trial in relation to its use within demand forecasting and water resources planning activities. It is desirable to focus on trials that have devices most widely used within the industry as changes to these results could have the largest impact.

C2 Initial review of trial reports

For trials included within the Waterwise Phase I evidence base report, a review was carried out on both the original trial report, and then on the summary of the trial provided within the Waterwise report. This enabled trials to be identified that initially had, for instance, only household level savings figures quoted, but which were subsequently disaggregated for the evidence base.

For trials included within the Waterwise Phase II evidence base reports, the short-listing review was carried out based on the information within the evidence base report only. This is because Waterwise completed data analysis of trials for Phase II.

The following pro-forma was used to extract key information:

Title of trial
Water Company(s) involved
Name of contractor carrying out work
Name of contractor evaluating work
Location(s) of trial
Date of trial(s)
Stated objective(s) of trial
Type of customer (e.g. Domestic / commercial / School etc.)
Measures being tested e.g. devices and/or any behavioural aspects
Was the trial carried out at the same time as other influencing factors e.g. alongside metering / behaviour campaign etc. How much customer engagement was there?
Number of properties targeted
Number of properties having device(s) installed
Were devices installed by professional, or self-install by households?
"Visit and fix (or plumber assisted audit)", Visit and self audit (i.e. company representative visits, explains need and leaves a self audit pack), Self audit without visit (i.e. postal, or download from web, etc.).
Metered or unmetered customers?
Was any occupancy data collected?
Method used to quantify water savings?
- Property measurements:
- "Logger" (include logging period - pre and post intervention),
- "Meter reads carried out as part of the study" (include period covered by meter reads - pre and post intervention),
- "Meter reads from billing system" (include period covered by meter reads - pre and post intervention),
- "Calculated" (from vol & freq per use), and then sub questions: from questionnaire and flow/vol measurements in each prop, from 'standard or average values', or a combination of these.
- Area measurements: e.g. "DMA", "Supply zone", "Resource zone" (include period covered by meter reads - pre and post intervention),
- "No quantification carried out".
What data has been collected over time and what analysis methods have been applied ?
Was any socio-economic information collected (e.g. income, ACORN group, council tax band, property type)
Are there any details of how the success of the project has been assessed e.g. Statistical tests / assumptions used?

Did the study quantify the savings before and after the intervention (for the study and control group).
Time period (approximate which months/season). Were there any repeat visits over time to indicate longevity of savings
Is the degree and method of data cleansing reported: e.g. identification and removal of 'outliers' or 'data errors'.
What statistical techniques were used (e.g. Simple mean or median, or state other types of tests used (e.g. Normality, t-tests, non-parametric tests, etc))
Were any statistical models used to establish causal links with factors such as: each device, pre and post water consumption, etc.
Are any confidence limits reported with the results?
Did the study include a control group? - If so provide brief explanation (e.g. Company's domestic consumption monitor, separate area with similar demographics, etc)
'Is there any reference to customer opinions, feedback, attitudes or behaviour?'
Headline savings by household, per person, & by device (as reported in the trial report)
Headline savings by household, per person, & by device (as reported in the evidence base report)
Is there any information regarding £/Ml saved? If yes, what is the value given?
Do the conclusions indicate any issues that were raised about the study that might be of relevance?
What are the key conclusions drawn?
Qualitative R/A/G regarding quality of analysis/stats/conclusions? (Only fill in if sure of your thoughts)

C3 Initial statistical review of core 'pre-post' data, and headline statistics within Phase II reports

The studies that have been subject to an initial statistical reviewed (representing all those within the report where data have been plotted) are presented in Tables C.1 to C.3 below.

Table C.1 Phase II Interim Report, February 2010

Section/study/page	Table/Fig ref
7.1 Preston Water Efficiency Initiative (p57)	Table 16 / Fig 6
7.2 Wessex Water - Water Efficiency Trial	Table 17
7.3 South West Water - Water Efficiency Trial	Table 18/Fig 11, 12
7.4 United Utilities Home Audit Study	Tbl 20, Figs 16&17

7.5 Anglian Water Ipswich Area WEM trial	Tbl 22, fig 20, 21
7.6 Thames Water Measured Visit and Fix Trial	Tbl 23, figs 24, 25
7.7 Yorkshire Water – Water Saving Trial	Tbl: 25, Figs 28, 29
7.8 Severn Trent – Domestic Water Efficiency Trial	Tbl 26, figs 32, 33
7.9 Thames Water Self Audit Rateable Value Trial	Tbl 27, figs 36, 37

Table C.2 Phase II Final Report, April 2011

Section/study/page	Table/Fig ref
3.3.1 Sutton and East Surrey Water's Preston Water Efficiency (p43)	Tbl 8
3.3.2 Severn Trent Water – Water Efficiency Trial	Tbl 10, fig 6
3.3.3 United Utilities Home Audit Study	Tbl 12, fig 9
3.3.4 Yorkshire Water – Water Saving Trial	Tbl 13, fig 12

Table C.3 Phase II Second Report, Water Efficiency Retrofitting in Schools

Section/study/page	Table/Fig ref
5.1.1 Severn Trent Water – Schools Water Efficiency Programme (p35)	Tbl 5, 6 (logger data)
	Tbl 9, 10 (meter data)
5.1.2 Thames Water - Water Makeover Project	Tbl 12, 13
5.1.3 Case Study: Business Stream	Tbl 15, 16

Table C.4 Results of review to short-list trials for further detailed assessment

Company	Name of Trial	Original report reference	Single device?	Data available?	Project team involved in original data analysis?	Rank	Statistical review comments
SWW	Water Efficiency Trial 2006	Jacobs (2007)	N	Y	N	1	It is not clear how control group numbers influenced the final answers. No normality test results. Uncertain about the correct use of Confidence intervals.
ESW	Water Saving Toolkit 2006-07	Mouchel Parkman (2007) "Water Saving Toolkit"	N	Contact indicates it could be	N	3	
ESW	Chelmsford EcoBETA	Mouchel Parkman (2007) "Chelmsford EcoBETA"	Y	Y	N	1	
EA	Retrofitting variable flush mechanisms to existing toilets	EA (2005)	Y		N		
ESW	Retrofitting of variable flush devices to existing toilets - follow up report		Y		N	R	

Company	Name of Trial	Original report reference	Single device?	Data available?	Project team involved in original data analysis?	Rank	Statistical review comments
SW	Retrofitting of variable flush devices to existing toilets - analysis of sustained savings		Y		N		
ESW	Sustainable water audit research	Ewan Group plc (2006)	N		N		
ESW	Sustainable audits - progress in 2007	Sustainable audits: progress in 2006/7 WE/0006/06	N		N		
ESW	Thurrock Home Surveys	Essex and Suffolk Water (2006)	N		N		
TW	Domestic water audit and retrofit study report (Liquid assets)	Mouchel Parkman (2007) "Domestic water audit and retrofit study report", final draft	N	Y	N	3	
SW	Dual flush pilot project		N		N		

Company	Name of Trial	Original report reference	Single device?	Data available?	Project team involved in original data analysis?	Rank	Statistical review comments
ESW	Home surveys in Brentwood	H20 Water Services Ltd (2004)	N		N		
ESW	Home surveys in Witham	H20 Water Services Ltd (2002)	N	Contact indicates it could be	N	R	
ESW	Moulsham and silver end	Watersmart (1998) Utilities Project Management (2002)	N	Contact indicates it could be	N	R	
ESW	Quantification of the savings and benefits of water efficiency 2001		N		N		
YW	Water Saving Trial	Yorkshire Water (2008)	N	Contact indicates it could be	N	1	CI's need to be reviewed. Results look reasonable in relation to other studies, but cannot say whether they are optimistic or not.
SESW	Preston Water Efficiency	Waterwise (2008)	N	Contact indicates it would be	N	2	Evidence of subjective data selection Subjective disallowing control group, control data not considered reliable enough by the study.

Company	Name of Trial	Original report reference	Single device?	Data available?	Project team involved in original data analysis?	Rank	Statistical review comments
	Initiative						
ESW	H2ECO	Mouchel Parkman (2008) "H2Eco"	N	Y	N	2	
WW	Water Efficiency Trial 2008-09		N		N		Data cleansing may or may not be valid. Uncertain about the correct use of confidence intervals.
UU	Home audit study	WRc (2008)	N	Y	Y	2	CI's are OK from a symmetry point of view. Uncertain about the comparison with Waterwise CI(?).
TW			N	Y	Y	2	Uncertainty about the correct definition of CI's. Some data points have been excluded from the results.
STW		Artesia Consulting (2008)	N	Y	Y	2	Only 717 made to results page. Results look consistent with others but still could be optimistic if others are also. CI's require calculating. Subjectively questions normality but this can be tested.
TW			N	Y	Y	3	Data excluded from final analysis. Results look consistent with other studies. CI's require calculating.
AW		Anglian Water (2008)	N		N		CI's are symmetrical. Uptake at 10% is of correct order but may only be 6ish %.

Company	Name of Trial	Original report reference	Single device?	Data available?	Project team involved in original data analysis?	Rank	Statistical review comments
UU		United Utilities (2008)	Y	Not yet known	N	3	

Appendix D - Views from Waterwise on the Evidence Base

An interview was conducted with Waterwise early in the development of the project, to obtain feedback on the approach applied during the evidence base review. The interview is presented verbatim below.

Q. The phase I and II reports contain a range of studies from Water Companies; do you hold or have you published a definitive list of all water efficiency projects carried out in the UK?

A. No. There were some projects which Waterwise wanted to include, but could not due to timing (results not available in time for analysis and reporting), and water companies not wishing to share the data. But there is no 'definitive' list of projects carried out in the UK. The UKWIR WR25 database was designed to take on this role.

Q. What was the basis for the selection of projects that went into the Phase I and Phase II reports?

A. Phase I selection was based largely on what data and reports companies already had and were willing to contribute. WRc did this study and made these determinations.

Phase II selection was more targeted. The Evidence Base Steering Group (see Section 3.2.1 for details) decided that projects which were metered (i.e. measured pre and post consumption data) and which were large-scale (although this constraint was not actually applied in the end) would be included.

Q. In the studies in the Phase II reports, properties or sites have been excluded from the analysis or report results. What is the basis or rationale for excluding properties?

A. Data would have been excluded for a number of reasons: some properties/sites had incomplete data, some companies were concerned that leakage had impacted the results, there were some large shifts in consumption during some trials which were assumed to be due to changes in occupancy, and negative consumption from meters.

Therefore the Steering Group agreed to apply a set of criteria to screen out data across all trials as follows:

- Incomplete site data
- Negative consumption
- Pre and post consumption >800 litres/prop/day
- Changes in consumption > ± 70%

These criteria were not put in the report, but the final report was a balance between reporting the information about how the trials were carried out, the analysis and including all the technical detail.

Q. What does the pre/post consumption tell us about water efficiency? Why is the relationship important and how can it be used to predict the result of future studies?

A. The data tells us that targeting those properties with high consumption and using a 'whole' house approach to water efficiency will provide a higher level of reduction in consumption.

It also gives an indication of what level different households can reduce their consumption by, but it is recognized that there is no control data.

Q. Were any other factors such as house type/socio-economic group/location etc. identified as having any impact on water efficiency?

A. That was never part of the project scope. We had no idea what kind of data we were going to obtain. Time was limited for the analysis of the data due to a large amount of time spent chasing the data delivery. Hence to meet report publication deadlines, it was decided to focus on producing a consistent dataset of results, using standard analysis of reduction in consumptions across all datasets.

Q. How are the reported confidence intervals calculated? And how should they be used?

A. The method used to calculate the confidence limits was: mean ± 1.645 x SD.

The confidence intervals were calculated using both Standard Deviation (SD) and Standard Error (SE). We chose to use the intervals using SD in the report. In hindsight a SE derived figure should have been included. This would provide a more traditional estimation of the uncertainty and would, in fact, reduce the apparent level of uncertainty in the results. We would fully expect your report to make recommendations in this area.

Q. Were any normality tests carried out?

A. Some normality tests were carried out and it was found that the consumption data and the changes in consumption were not always normally distributed.

Q. Were any tests carried out to quantify the statistical significance of the findings or changes in water consumption?

A. No. A huge amount of time was spent collating the information in the report. An approach which could be applied to across the board was adopted in discussion with the Steering Group and this scope did not include any other tests than were included in the reports.

We have continually been trying to improve the dataset, for example, through obtaining control data which would enable us to compare trials on a level footing and be as certain as possible that what we were measuring was due to the intervention. The quality of the data was the primary concern and we have been striving to improve this and move beyond it.

Q. Were any attempts made to aggregate the studies, to create datasets with larger numbers?

A. No. This was not part of the agreed scope. However, this is something that has been discussed and could be interesting to do in the future. There would be a number of limitations, particularly because the data from different trials has been collected in different ways. For example:

- some trials have control groups and some do not,
- trials had varying amounts of pre and post intervention data,
- including the types of products installed and
- some trials would have actively engaged customers while other would not.

Q. Is there any plan to include customer feedback in the reported studies?

A. There is not currently a plan to do this but water companies can request for this to be done in the future if they deem it to be a priority. In Phase III, for example, an entire study is focusing on feedback from customers regarding retrofit devices. It remains to be explored how meter data should be looked at alongside customer feedback, and

this is one of the key areas a proposed Phase III guide on evaluation would explore. Some of the latest trials currently underway are collating this type of information, which will also be reported in future reports.

Q. How can the evidence base be used to inform water companies? Are some results more reliable than others (e.g. sample size, length of measurements etc.)? Have differences between studies been explored?

A. Each study can tell us something about future projects that are similar in nature (e.g. the results from the Preston and Wessex studies should inform users planning other social housing projects), i.e. predicted savings, take-up rates, what products were used, the level of engagement, the buy-in from other stakeholders such as local councils. However some trials could be considered more reliable than others based on:

- Whether they have control data to account for background changes in demand.
- Length of monitoring periods pre and post intervention.
- Sample size.
- Frequency of meter readings.

Q. In your view have water companies undertaken proper pre-study designs, such as including control groups? If not, why not?

A. Waterwise had no influence over how the projects were carried out for the phase II study. Control groups were used if they were received from the company.

Waterwise can assist water companies determine sample sizes and on how to design trials, in terms of control groups and data collection.

During Phase III Waterwise will be developing an evaluation guide for companies which will address this area.

Other issued raised during the interview:

In Phase II, the evidence base project was overseen by a steering group made up of water companies, Environment Agency, Defra, Ofwat, Consumer Council for Water (CCWater), Water Industry Commission for Scotland, Department for Energy and Climate Change (DECC), Department for Communities and Local Government (DCLG) and Waste and Resources Action Plan (WRAP). During the programme meetings were held every 3 months and that these provided direction to the project and peer review of the methods applied and results. Every effort was made to ensure that the results were objective and not biased. The approaches used for the analysis evolved over the period of the study, and had to deal with different amounts and quality of data. In addition to the numeric savings there is also a great deal of background data on each trial, identifying what products were used, how the customers were recruited, and costs of delivery.

The consultants' review suggests that some companies were not engaged in the process of identifying what should be reported in the evidence base, as there were different users of the data who were not always represented on the steering group. This is something which has been remedied following discussion with stakeholders at the end of Phase II. For each project in Phase III, Working Groups and a Peer Review Group which are made up of relevant representatives from water companies, selected by the Water Efficiency Network, have been formed. There should also an independent expert, who could be an academic or a consultant, for each project of the Evidence Base Phase III programme.

Appendix E - Detailed review of short-listed trials

The detailed statistical reviews of the short-listed trials are presented below. Each trial has been presented as a separate report. Please note that these reports are records of the technical work that was undertaken.

E1. South West Water (SWW) Water Efficiency Trial (2006)

E1.1 Information available to the reviewer

Three reports were available:

- The original report: South West Water Water Efficiency Trial. August 2007 (Jacobs, 2007)
- Evidence base for large scale water efficiency in homes. Waterwise. Oct 2008 (Waterwise, 2008).
- Evidence base for large scale water efficiency in home Phase II Interim report. Feb 2010 (Waterwise, 2010).

E1.2 Summary of the Trial

Purpose

The trial aimed to:

- Assess the acceptability of water saving devices to customers
- Quantify the water savings that could be achieved
- Assess how well the devices performed
- Cost the provision and fittings of the devices
- Assess the viability of a wider scale programme of installation

Households were offered a variety of devices, with most households opting for a combination of different devices. There were only a small number of households in which only a single device was fitted.

Water saving devices tested

The devices tested were:

- Toilets
- Dudley Turbo 88 retrofit replacement siphon
- Hippo bag

- Save-a-flush bag
- Showers
- Challis aerated showerhead
- Mira low flow showerhead
- Ripple Shower Timer (3 types –Sand/Star/digital)
- Taps
- Miracle tap sprayer (kitchen mixer)
- Challis aerated tap inserts
- Tap magic spray tap insert (version 1 – single flow)
- Tap magic spray tap insert (version 3 – dual flow)
- Outside use
- Spray gun for hose
- Other devices
- Restrictor valve
- Leak alarm

Households taking part in the trial

A sample of 6000 metered households was selected, 3000 each from 2 urban areas, Barnstaple and Newton Abbott. This was done to reduce the travel time between households. Of the 6000 households, 1338 responded positively to a letter and questionnaire. A sub-sample of 600 households was selected to be representative in term of (i) meter optants and non-optants, (ii) Council Tax band and (iii) number of occupants.

One hundred of the 600 sample households were placed in a control group where no water audit was done. The split between 'audit' and 'control' groups ensured similar representation in terms of 5 factors: council tax band, property type, and garden, car and hosepipe usage.

This provided a database of 535 (or 538) audit customers and 109 control customers. Out of these, 42 dropped out, 10 left incorrect contact details and a further 53 proved difficult to contact in the final two weeks of the trial; therefore the original database was reduced to 430 sample customers and 109 control customers. The effect of these households not being used in the trial was not considered to introduce bias into the dataset.

The authors state that a critical influence on water consumption is the state of household occupancy. The results were displayed as Per Capita Consumption (PCC) accounting for household water consumption per person. Therefore, to eliminate potential problems, only households where the same number of occupants were present in the initial and final questionnaires were used. Consequently 349 audit customers and 205 control customers were used for analysis.

Outliers were removed by identifying average PCC values over the sample intervals and removing data that was missing, or unacceptable. This further reduced the sample set to 319 households and 162 control households.

Meter readings

The data indicate that meter readings were taken:

- Two months prior to the audit, in November and December 2005;
- On the day of water audit and device installation, between January and April 2006;
- Approximately 2 months post audit, in May 2006;
- At the end of the summer, in late August and early September.

Consumption during both post audit time periods might be influenced by the weather.

From these data, household water consumption can be calculated for one time period before, and for 2 time periods after the audit: up to ~3 months, and 3 to 6 months. These were referred to as 'before' (B), after (A) and 'after+' (A+) in the SWW report.

E1.3 Report & conclusions drawn

The SWW Report concluded that overall an initial water saving of 5% per household could be made with water saving devices, dropping to 4% six/seven months after installation. On the other hand, table 5 of the statistical analysis appendix (P) shows smaller savings when the audit group is compared to the control group (Table E.1). Similar savings were made across houses in different council bands.

Table E.1 Table 5 of Appendix P in SWW report

Post audit period	Audit properties	Control properties	Saving
Up to 3 months: A vs B	-7.89%	-4.39%	3.5%
3 to 6 months: A+ vs B	4.17%	6.45%	2.3%

E1.4 Evidence presented in Waterwise report(s)

2008 report

The water savings for 293 properties with more than one device were disaggregated to determine an estimated water saving and compared to the actual measured water saving from the study. The estimated water saving was determined to be 48.02 (l/prop/day), however the total measured water saving was actually recorded as 8.74 (l/prop/day). Waterwise attributed the large discrepancy between the estimated and measured savings as a result of behavioural and customer influences.

2010 report

The WaterWise analysis acknowledges that the data set was 535 customers and that 430 customers were actually used for the study. However, only 198 properties were used in its analysis. No information only how this number was derived was reported.

The Waterwise report also states that a control group of 152 properties were used and ran alongside this study.

Waterwise determined the overall water saving after three months to be 3.5% (equivalent to 9.1 litres/property/day) with 90% confidence levels of 30.2% (40 l/prop/day) and -23.2% (-21.8 l/prop/day). After 6 months the water savings were measured as 2.3% (equivalent to 6 litres/property/day) with the maximum and minimum 90% confidence levels reported as 38% (46.6 l/prop/day) and -33.4%(-34.7 l/prop/day).

Histograms describing the distribution of water savings per property per day were plotted (both as a % reduction and in l/prop/day). The histograms were used to demonstrate that 71% of properties had reduced their water consumption after three months. However, after 6 months only 58% of properties were still analysed as saving money. Waterwise state that a such a sharp reduction in savings is not typical of retrofitting, although the results may be explained by a drought which occurred between the first and second measurements leading to increased water use.

A scatterplot of post-trial vs pre-trial mean daily consumption was used to generalise the water saving results for both post trial time periods. Linear regression of the data generated the following equation:

3 Months: Post MDC = 0.88 pre MDC + 6 $r^2 = 0.844$

6 months: Post MDC = 0.96 pre MDC + 3 $r^2 = 0.773$

where Post MDC and Pre MDC stand for post and pre mean daily consumption, respectively.

Analysis of water consumption for a control group (n = 152) associated with the trial showed a decrease in consumption over the first 3 months. However, at 6 months, water consumption had increased by 6.45% It is not clear from the report whether the results from the control group were used to deduce a net change in consumption for the households in the trial.

Using assumptions about the water saving capacity for each device, and the installation rate an estimated water saving value was derived and compared to the actual measured values.

Post-trial water consumption was plotted against calculated theoretical water savings (using assumed water saving volumes for individual device). Waterwise state that the theoretical water savings on average overestimate the water savings by about 15 l/prop/day.

Where only one device was fitted in households and the number of households exceeded 10, Waterwise were able to determine the individual water saving % for the each respective device. The Dudley Turbo device was shown to reduce water consumption by 10 and 13% for 3 and 6 months, respectively. However cistern-displacement devices (such as Save-a-Flush and Hippo Bags) showed no change in consumption at 3 months and an increase at 6 months.

E1.5 The Review

Data preparation

No data for the control households was available.

The excel file provided included data from 430 households. All the meter readings (raw data) that were missing or made no sense (i.e. subsequent meter readings were lower than previous meter readings) were eliminated. Furthermore, any PCC cells that were coloured either red or yellow (no explanation provided for colouring) were also discounted. Any PCC value that was negative was also discounted. This provided 348 households for analysis.

Per household consumption in litres/day was calculated (as opposed to the PCC in litres/person/day used by SWW) and the differences between B, A and A+ consumption were used to estimate savings.

Calculations

The change in water consumption from post- to pre- installation period for 3 and 6 months were calculated (Table E.2) and outliers removed by:

- If the change in consumption was greater than 100%
- Excluding 2.5% upper and lower percentiles
- Excluding 5% upper and lower percentiles

Table E.2 Change in Water Consumption

A: up to 3 months								
	N	Mean phc pre-	Mean phc post-	Mean change per prop	Standard deviation	Standard Error of Mean	% change	What % of props save water
total households	348	260.9	253.4	-7.46	164.33	8.81	-2.86	66.67
Exclude %change greater than 100	341	262.6	246.0	-16.59	147.25	7.97	-6.31	68.04
Exclude upper and lower 2.5 percentile	330	238.4	224.5	-13.90	51.30	2.82	-5.83	67.58
Exclude upper and lower 5 percentile	312	236.3	222.5	-13.81	40.72	2.31	-5.85	68.59

A+: 3 to 6 months								
	N	Mean phc pre-	Mean phc post-	Mean change per prop	Standard deviation	Standard Error of Mean	% change	What % of props save water
total households	348	260.9	275.3	14.44	194.40	10.42	5.54	54.89
Exclude %change greater than 100	324	267.3	252.9	-14.41	131.69	7.32	-5.39	58.95
Exclude upper and lower 2.5 percentile	330	238.0	245.8	7.801	73.87	4.07	3.28	55.15
Exclude upper and lower 5 percentile	312	236.0	240.0	3.97	56.043	3.17	1.68	55.49

Test for normality

The phc data was tested for normality with a Shapiro-Wilks test in R (Appendix A). The results showed that neither set of data is normally distributed. The skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution) were calculated in Excel (Table E.3). Appendix E.1 contains histograms of the data.

Table E.3 Results of normality test

A: up to 3 months			
	N	Skewness	Kurtosis
Total households	348	5.35	84.10
Exclude %change greater than 100	341	6.40	128.89
Exclude upper and lower 2.5 percentile	330	-0.05	1.51
Exclude upper and lower 5 percentile	312	-0.08	0.54
A+: 3 to 6 months			
	N	Skewness	Kurtosis
Total households	348	1.22	38.78
Exclude %change greater than 100	324	-6.90	74.60
Exclude upper and lower 2.5 percentile	330	0.96	4.71
Exclude upper and lower 5 percentile	312	1.11	1.93

Note: the normal distribution has zero skewness and kurtosis. The definition of kurtosis used is the excess kurtosis (see http://mathworld.wolfram.com/Kurtosis.html for more detail).

From this, we concluded that household consumption values tend to be concentrated quite tightly about a central value, with a small proportion of very low and very high values.

E1.6 Findings

Trial report

The initial trial included a control group of 152 households and a sample size of 293 households for statistical analysis. The statistical properties of this group were not included in the report so the adequacy of the sample size cannot be properly deduced.

The 90 day installation period finished in April indicating that there should have been no summer seasonal peaks. Follow up consumption data was provided for 689 households for up to 2.6 years later therefore allowing long term changes from the water saving devices to be monitored.

The original trial result reported the water saving percentage as -7.89% for the first three months. Our analysis of the water saving, excluding only the households where the data was clearly not valid, provided a result of -2.86%. However, by removing just seven outliers the water saving increased to between -6.31%. This illustrates how

important a small number of households can be to the overall savings. A similar conclusion is suggested by the 3 to 6 month phc data.

Waterwise Evidence (compared to the original report)

The 2008 and 2010 Waterwise report used considerably smaller datasets than the original trial. No clear indication of how this data was screened was included in the report. Without knowing how data was excluded from further statistical analysis it would be inappropriate to conclude on the validity of the screening method to clean the data and whether unnecessary household data had been removed.

Waterwise estimated the water savings to be 3.5% and 2.3% for three and sixmonths, respectively. In our analysis when all the households with adequate data were analysed for water, 2.86% was saved at three months. However at six months there was no saving (5.54%). When outliers were removed the values of water saving at 3 months ranged from -5.83 to 6.31; at 6 months the values ranged from 1.68 to- 5.39.

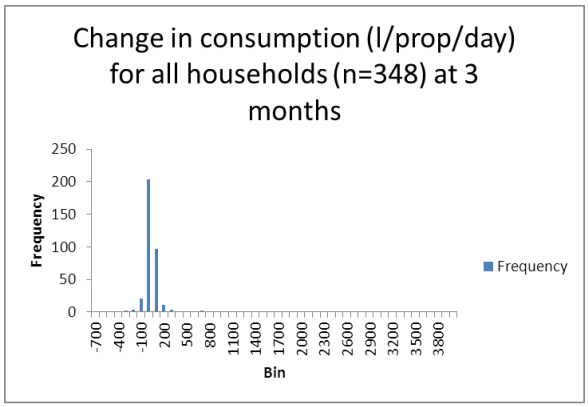
Our analysis of the change in water consumption indicate that it is not normally distributed. Waterwise do not account for this in their analysis of the data or in subsequent calculations for water saving.

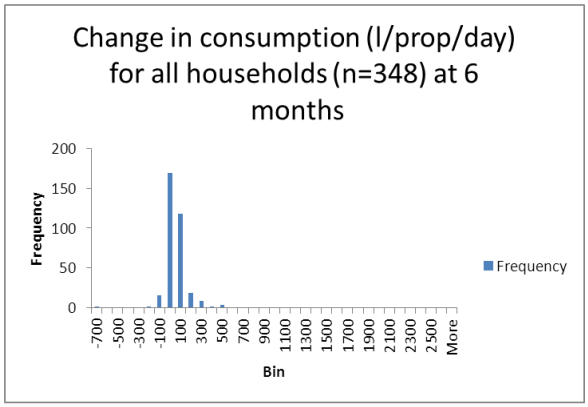
The confidence intervals presented by waterwise are considerably larger than those calculated in the review here indicating that they may have calculated the sample standard deviation, not the standard error of the mean.

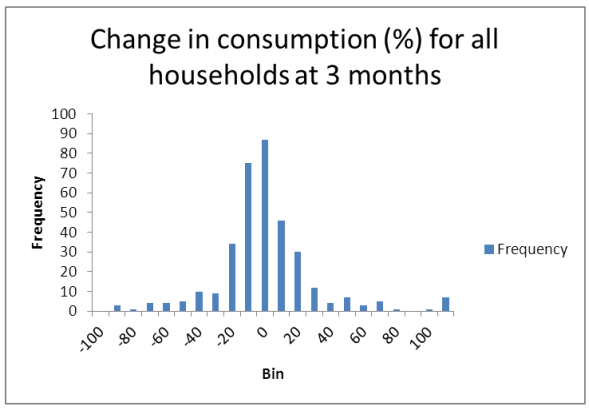
The calculated linear regression from Waterwise for the change at three and sixmonths has a similar gradient to the calculated equations here when outliers are removed from the sample.

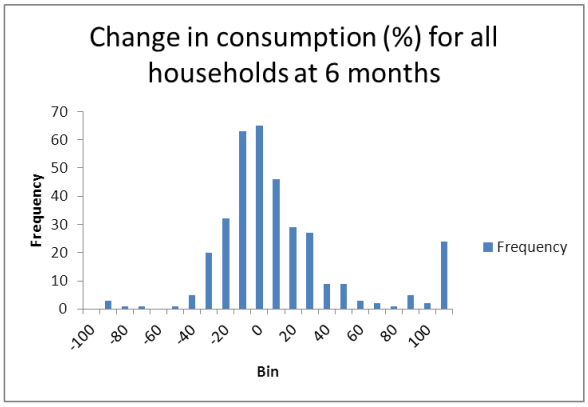
Appendix E.1

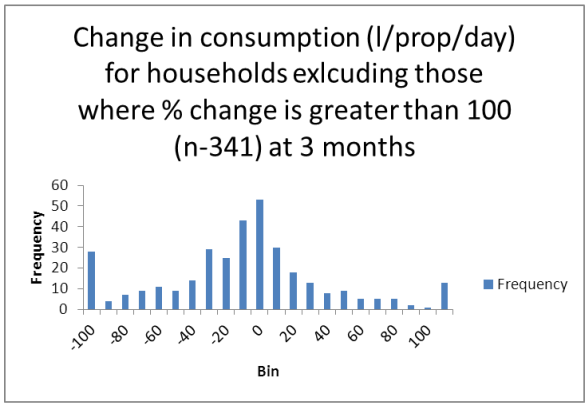
Figure E.1 Histograms of water saving for 3 and 6 months

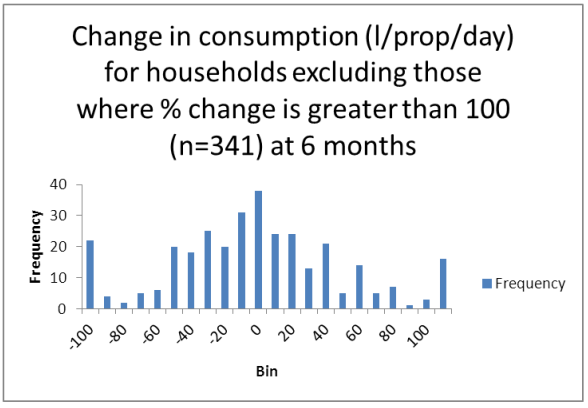


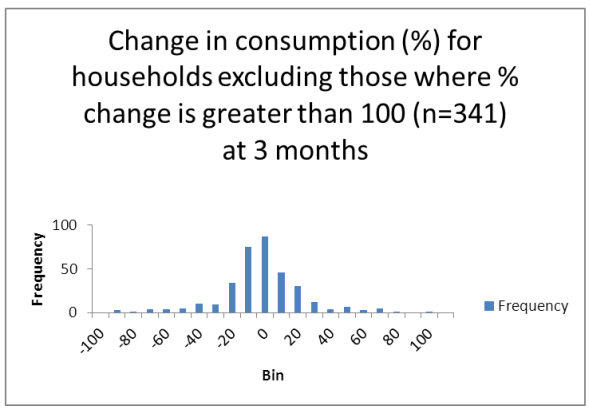


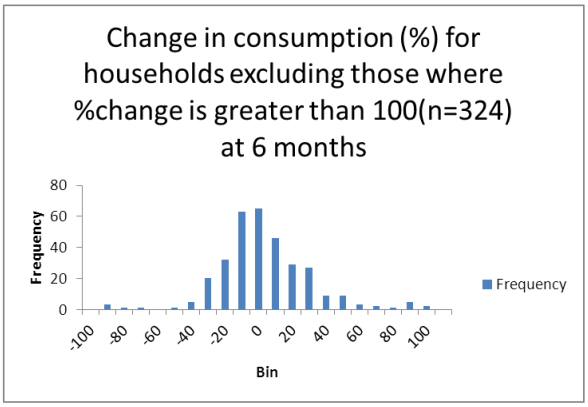


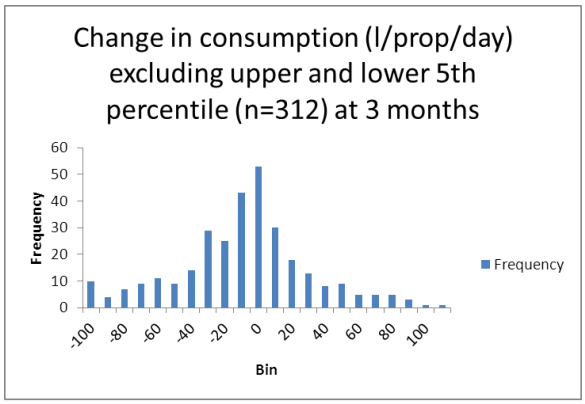


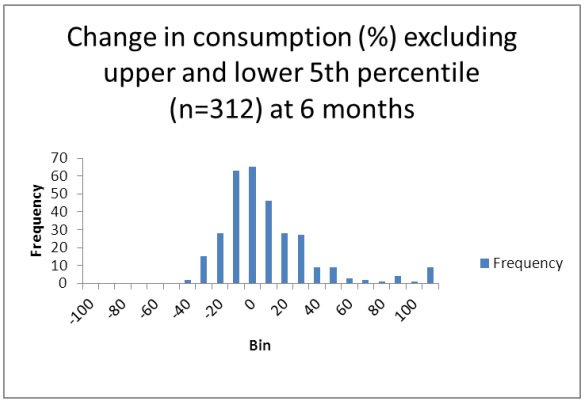


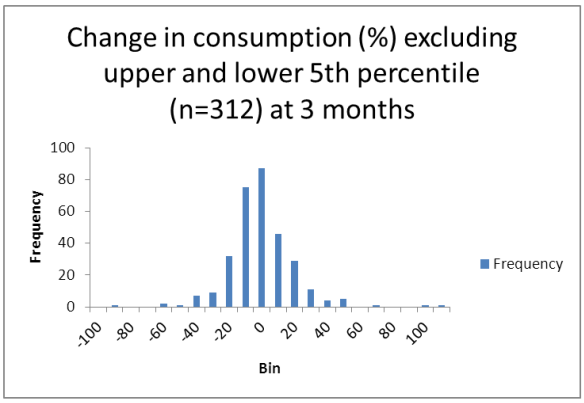







Change in consumption (l/prop/day) excluding upper and lower 5th percentile (n=312) at 3 months
Frequency
Bin
Frequency


Change in consumption (%) excluding upper and lower 5th percentile (n=312) at 6 months
Frequency
Bin
Frequency


Change in consumption (%) excluding upper and lower 5th percentile (n=312) at 3 months
Frequency
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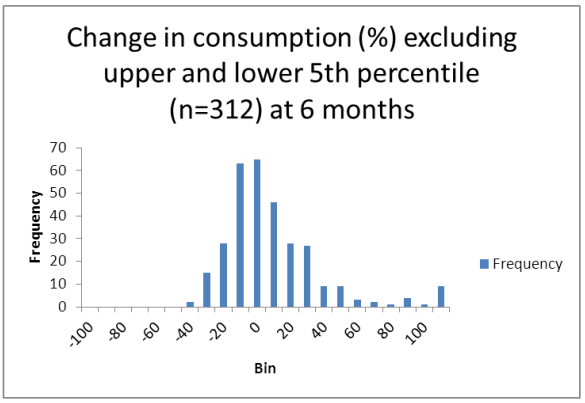
Change in consumption (%) excluding upper and lower 5th percentile (n=312) at 6 months
Frequency
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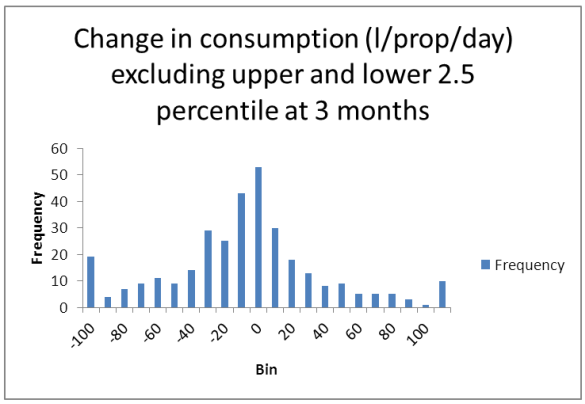
Change in consumption (l/prop/day) excluding upper and lower 2.5 percentile at 3 months
Frequency
Bin
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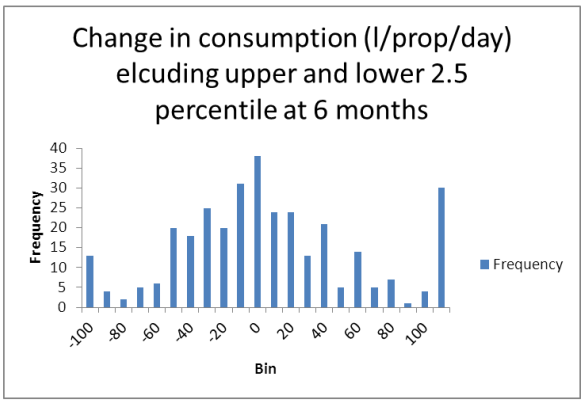
Change in consumption (l/prop/day) elcuding upper and lower 2.5 percentile at 6 months
Frequency
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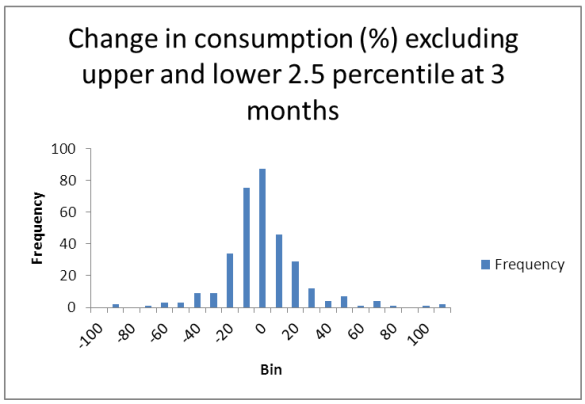
Change in consumption (%) excluding upper and lower 2.5 percentile at 3 months
Frequency
Bin
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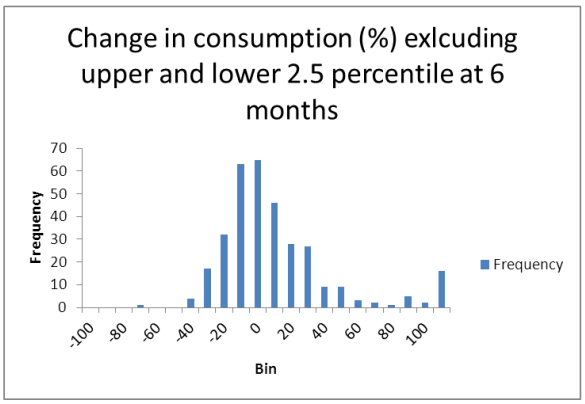
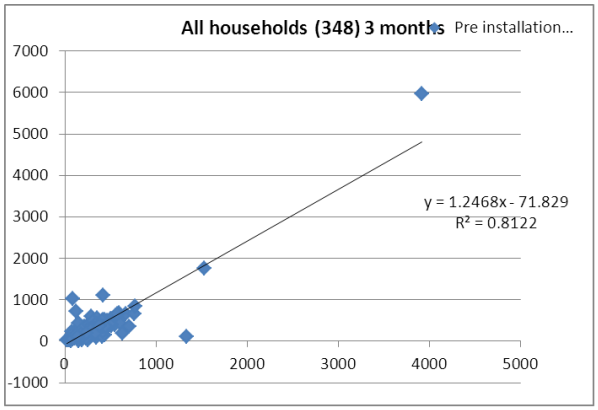
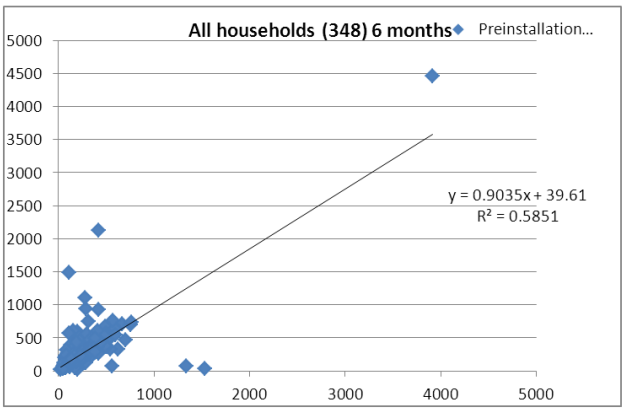
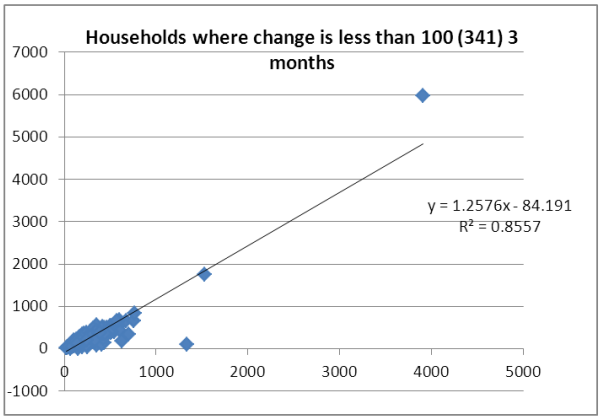

Change in consumption (%) exlcuding upper and lower 2.5 percentile at 6 months
Frequency
Bin
Frequency

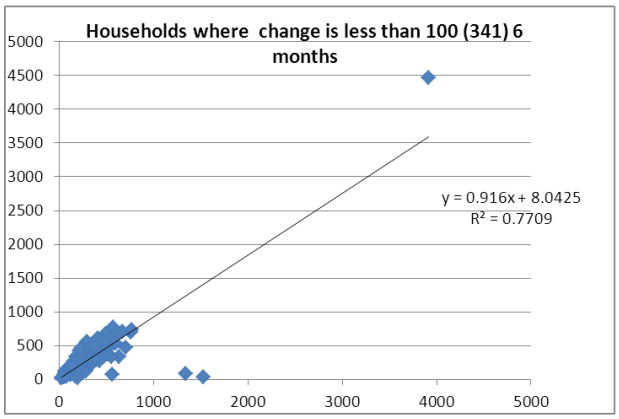
Appendix E.2

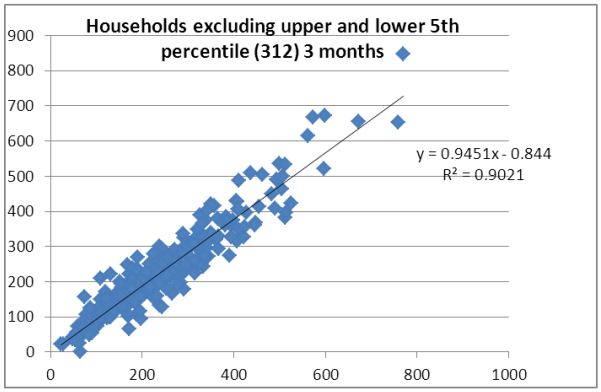
Figure E.2 Scatter plots of linear regression of the change in water consumption

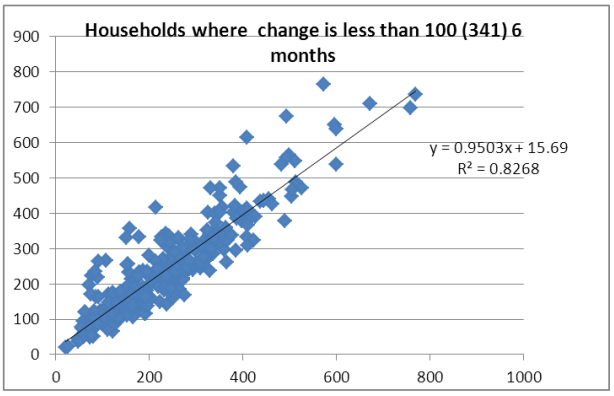


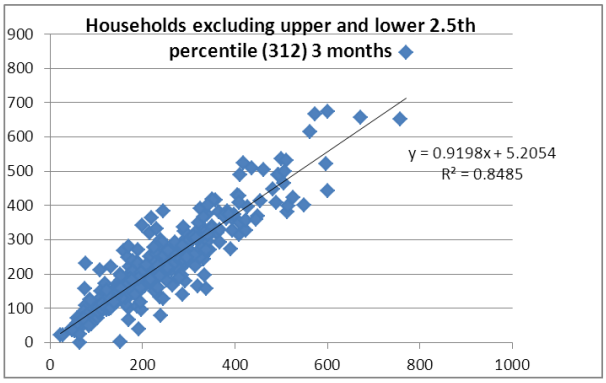


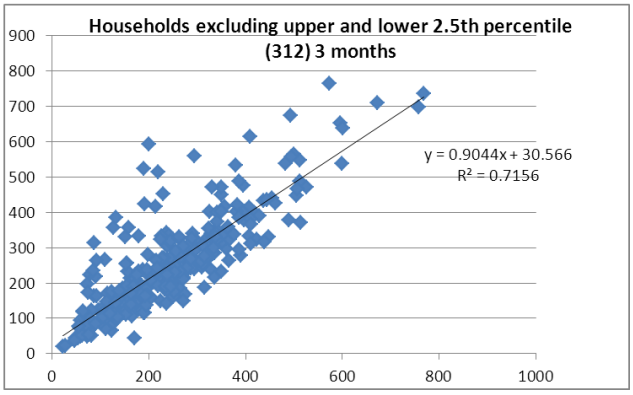












E2. Essex & Suffolk Water (ESW) Chelmsford ecoBETA (2007)

E2.1 Information available to the reviewer

Two reports were available:

- Evidence base for large scale water efficiency in home report Oct 2008 (Waterwise, 2008).
- Report Analysis of ESW Chelmsford ecoBETA October 2007 Mouchel Parkman Consulting (Scobie, 2007).

E2.3 Summary of the trial

Purpose

The project presented involved mailing customers to invite them to have a toilet dual flush retrofit device called ecoBETA installed.

Of the 4,866 customers who were mailed, 910 customers applied to take part, representing a take-up rate of 18.7%. There were 1,012 ecoBETA devices installed in 555 properties between 17 April and the 7 July 2007. 187 customers completed and returned their home water audit form. Meter reading data was collected from those properties that had an externally accessible water meter, and 56 flow loggers were installed to collect detailed water use information.

Water saving devices tested

ecoBETA dual flush devices.

Households taking part in the trial

169 households had meter readings or logger readings taken and the number of ecoBETA fitted recorded.

Meter readings

The meter readings were taken:

- approximately 30 days pre-installation
- approximately 30 days post installation

E2.4 Mouchel Parkman Report & conclusions drawn

The project resulted in each participating property saving on average 31.38 l/prop/day.

Table 1: Summary of key results:

- Total customers mailed 4,866
- Applications received 911
- Of those that applied
- 33% were Metered
- 67% were Unmeasured
- Audits completed 708

E2.5 Evidence presented in Waterwise report

2008 review

Measured saving 31.38 litres per prop per day

Confidence High

E2.6 The Review

Data preparation

The data received provided information on 169 households displaying water use pre and post-installation as litres/property/day. All 169 households had positive believable pre and post audit consumptions

Calculations

All 169 households the change in water consumption from post- to pre- installation period was a mean saving of 40.03 l/p/d [34.38, 45.68] and a median value of 36.52 l/p/d with 90% CI [28.95, 45.13].

Using Waterwise stated screening rules all 169 properties remained in the sample and therefore identical results to those stated above.

Test for normality

The change in consumption data for the 30 day pre and post change was tested for normality using a Ryan Joiner technique (Shapiro-Wilks equivalent), which it passed.

Although the normality test was passed, for consistency with other analysis the data was also tested for measures of skewness (a measure of lack of symmetry) and

kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution). Table E.4 contains the results.

Table E.4 Normality test results

Dataset		No of households	Skewness	Kurtosis
All households with complete data	30 days	169	-0.25	-0.47

Using kurtosis value greater than |3| (absolute value of 3) and Skewness of greater than |2| indicating a normality test pass.

Estimation of savings and confidence bands

Having passed all normality tests there is no reason to question the parametric mean and CI. Using only parametric results, there was a mean saving of 40.03 l/p/d [34.38, 45.68].

Waterwise stated 31.38 l/prop/day.

Disaggregation of savings per device

At the 169 measured properties there was either 1, 2 or 3 ecoBETAs fitted with a mean installation of 2.05 ecoBETAs per property. Using the mean saving value of 40.03 l/p/d produces a mean saving of 19.53 litres/device/day.

Using regression with change in consumption as the response and the number of ecoBETAs fitted as the predictor both the constant and ecoBETA coefficients return significant values to 10% significance.

The model is change in consumption is 26.5 +6.6*number of ecoBETAs.

This implies that installation of:

- 1 ecoBETA saves 33 l/device/day.
- 2 ecoBETAs saves 39.6 l/prop/day giving 19.8 l/device/day
- 3 ecoBETAs saves 46.2 l/prop/day giving 15.4 l/device/day

This result is based upon a sample of only 169 properties with only short term pre and post period measurements and therefore the scale of the numbers should be treated with caution but it may be more useful as an indication that savings per device does reduce as the number of ecoBETA installations increase within any property.

Regression Analysis: Change lpd versus No_ecobetas

The regression equation is:

Change lpd = - 26.5 - 6.60 No_ecobetas

Predictor Coef SE Coef T P

Constant	-26.531	8.365	-3.17	0.002
No_ecobetas	-6.595	3.734	-1.77	0.079

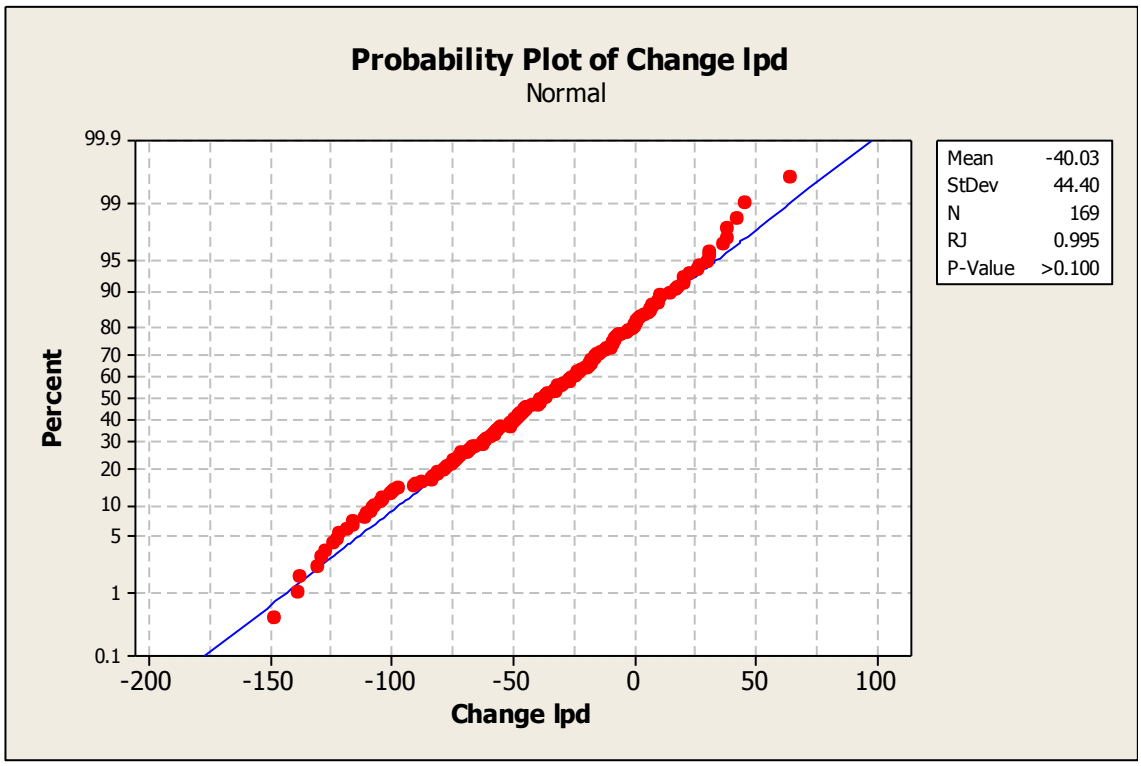
E2.7 Findings

Trial report

Waterwise report savings on average 31.38 l/prop/day. In October 2008 but do not use the opportunity to further analyse the data in their February 2010 Interim report Phase II. This is surprising particular because it provides a unique opportunity to look in detail at a single device study.

Appendix E.3: Normality testing

Figure E.3 Ryan Joiner (equivalent to Shapiro-Wilk) normality test



P-value indicates data is not significantly different to normally distributed.

E3. Yorkshire Water (YW) Water Saving Trial (2008)

E3.1 Information available to the reviewer

Three reports were available:

- Evidence base for large scale water efficiency in homes. Waterwise. Oct 2008 (Waterwise, 2008)
- Evidence base for large scale water efficiency in home Phase II Interim report. Feb 2010 (Waterwise, 2010).
- Waterwise Evidence Base for large scale water efficiency Phase II final report. (Waterwise, 2011)

E3.2 Summary of Trial

Purpose

The YW Water Saving Trial was designed to assess the reduction in water supply through the installation of retro-fit devices into customers' properties. Specifically the aims of the trial were to establish:

- The performance of selected water saving devices
- The acceptability of water saving devices to customers
- Customers attitudes to water efficiency
- The volume of water saved through these devices
- The cost of installation of these devices
- The cost-effectiveness of installation water-efficient products on a larger scale

Water saving devices tested

The water saving devices available were:

- Toilets
- Showers
- Challis silver shower head
- Mira adjustable shower head (white)
- Digital shower timer
- Duck shower timer
- Star sand shower timer
- Taps
- Dart valley flow restrictor

- Challis water saving tap aerator SALSP415
- Challis water saving tap aerator SALSP416
- Female connector
- Tap magic M22 cartridge
- Tap magic M22 Spraymagic single flow
- Tap magic M24 cartridge
- Tap magic M24 spraymagic single flow
- Tap magic spraymagic 15-19 mm unfit round outlets
- Tap magic M22 unfit
- Outside use
- 7 Patter spray gun
- Other devices
- Universal tap connector
- EcoSave leakage Alarm

However no EcoSave leakage alarms, dart valley flow restrictors or close-coupling kits were actually fitted.

Households taking part in the trial

The trial aimed to include 500 properties. Two areas, Wakefield and Scarborough, were chosen within YW, that were thought to provide a range in types of households. 2500 letters were sent within each area to properties which were already metered and included a questionnaire requesting information on occupancy rate, age of occupants, council tax band and type of house. A total of 986 households replied, a return rate of 19.72%, consequently 500 properties were selected, 250 from each area, using the information from the questionnaires to provide a good variation in property types, occupancy rates and age groups.

A control group of 100 properties, 50 from each area was also set up. The control group were not made aware that they were part of the trial. Meter readings were also collected from an additional 20 properties to act as a reserve group. The occupants were only made aware that they were part of the trial if they were selected to replace a property.

Installations were carried out between October 2007 and April 2008. During the trial 444 households were visited (WW 2008).

Meter readings

The data indicate that meter readings were taken:

- 90 days (estimated mean) prior to the audit
- On the day of installation
- 180 days (estimated mean) post installation
- 780 days (estimated mean) post installation

E3.4 Report and conclusions drawn

The original report was not available

E3.5 Evidence presented in Waterwise report

2008 Report

Overall estimated water savings were 31.68 litres/property/day. However accounting for changes in the control group, the actual savings were 14.62 litres/property/day. Only meter readings from 290 of the 444 properties visited during the trial were actually used to calculate the average saving per household/day.

"…the overall estimate of the water savings due to installation of water efficiency devices ranged from 19.20 to 31.68 litres per property per day, depending upon the definition of exclusions (i.e. both extreme values and outliers or just extreme values). Alternatively, an estimate of the water savings was either seven or ten percent from a sample of 278 or 290 properties, respectively."

Total measured savings were 14.62 l/prop/day compared to an estimated water savings of 29.39 l/prop/day. Waterwise suggest that this difference is due to the wide range of products offered and the high degree of behavioural influence with products like tap inserts and shower timers.

2010 report

From the 378 properties used for this assessment, a water saving of 27.6 l/property/day (8.4% reduction) was achieved. The 90% confidence level was 124.3 and -69.0 l/property/day (41.6% and -24.8%).

The control group of 83 properties had a similar pre-trial consumption to the study group (271 l/p/day and 267 l/p/d, respectively). Over the same period as the study group, the control group also showed a reduction of 9.5 l/pd. Waterwise therefore conclude "It can be stated with some confidence that this trial achieved water savings of at least 18 l/p/d, and importantly that the water savings reported in this trial have occurred because of Yorkshire Water's water efficiency intervention, and have not just occurred by chance."

The distribution of the water savings (both as % reduction and l/prop/day) were plotted as a histogram, Waterwise state "There is a clear majority saving water and this in confirmed by further analysis of the data that revealing that [sic] 74% of properties involved in this trial saved water following retrofitting"

A scatterplot of post-trial Vs pre-trial mean daily consumption was used to generalise the water saving results in this trial. Linear regression of the data generated the following equation:

Post MDC = 0.81 pre MDC +23 r2= 0.801

Where Post MDC and Pre MDC stand for post and pre mean daily consumption, respectively.

Using assumptions about the water saving capacity for each device, and the installation rate an estimated water saving value was derived and compared to the actual measured values. The difference between the theoretical saving and the actual

saving was plotted. Waterwise state that from the graph indicates the high degree of variability in individual household savings, but that if the sample is taken as a whole "the theoretical savings values seem to characterise quite well the mean response that can be expected from a large sample of properties."

2011 report

Yorkshire water provided Waterwise with follow-up meter readings for 780 (mean) days post-installation. Of the original 378 properties, data was included for 337 properties. After 2.6 years the water saving was 26.3 l/prop/day. The control properties (88 households) also showed a decrease in water consumption of 11.4 l/prop/day therefore the net water savings were 14.9 l/prop/day. The 90% confidence level after 2.6 years was 348.4 and -295.8 l/prop/day

The distribution of water saving (l/prop/day) were displayed as a histogram. After 2.6 years monitoring, 62% of properties involved in the trial saved water following retrofitting compared to 74% at 6 months.

Waterwise include in the report a graph comparing Yorkshire Waters measured household consumption for several years prior to the study compared with the trial households to provide an indication of how domestic demand has changed. Waterwise acknowledge that the trial households may not be representative of domestic use in their area because of a self-selection bias, whereby households who agreed to take part were more likely to be more conscious of their water use.

E3.6 The Review

Data preparation

Only data relating to the 6 month installation period was provided.

Data was only provided for 406 households and 88 control households. Out of these 406 households, from the excel spreadsheet, 36 had no devices fitted according to column E of the Excel sheet. Column AU contains the number of devices fitted per household, of which 49 are listed as 0 despite 13 of these households being listed as having devices fitted from column E (assume this is a transcription error and that column E is correct). Therefore 370 households of the main study were used for further analysis.

Calculations

The change in water consumption from post- to pre- installation period for 3 and 6 months were calculated (Table E.4) and outliers removed by:

- If the change in consumption was greater than 100%
- Excluding 2.5% upper and lower percentiles
- Excluding 5% upper and lower percentiles

The overall net change in consumption (%) was calculated (Table E.5)

Table E.5 Overall net change in consumption

	N	Mean phc pre	Mean phc post.	Mean change	St Dev of mean change	Standard Error of mean change	% change	What % of households save water
Sample Households								
total households	370	273.87	247.68	-26.20	119.31	6.20	-9.57	70.81
excluding those with greater than 100% change	359	279.18	244.73	-34.45	107.09	5.65	-12.34	72.98
excluding 5th percentile	332	259.6	236.78	-22.82	44.00	2.41	-8.79	72.89
excluding 2.5th percentile	350	262.76	239.35	-23.41	54.19	2.90	-8.91	72.00
Control Households								
Total households	88	262.29	257.05	-5.23	76.29	8.13	-2.00	59.09
excluding those with greater than 100% change	87	264.78	258.94	-5.84		8.20	-2.21	59.77
excluding 5th percentile	78	247.96	242.36	-5.60		5.39	-2.26	60.26
excluding 2.5th percentile	82	255.26	249.51	-5.75		6.21	-2.25	59.76

Test for normality

The change in consumption data for the original 370 properties and the four groups of data where outliers were removed were tested for normality with a Shapiro-Wilks test in R (result in Appendix E.4). The data that failed this test for normality were consequently tested for measures of skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution) in Excel (Table E.6). Appendix E.5 contains histograms of the data.

Table E.6 Normality test results

	N	skewness	Kurtosis
Sample Households			
total households	370	-3.54	43.70
excluding those with greater than 100% change	359	-6.06	62.67
excluding 5th percentile	332	-0.17	0.36
excluding 2.5th percentile	350	-0.31	1.34
Control Households			
total households	88	0.07	1.90
excluding those with greater than 100% change	87	0.09	1.90
excluding 5th percentile	78	-0.24	0.36
excluding 2.5th percentile	82	-0.18	0.78

Estimation of savings and confidence bands

The estimated savings were calculated (Table E.5). The net change in water consumption is presented in Table E.7.

Table E.7 Net change in water consumption

	Net change (%)	Net change (l/prop/day)
All households in sample	-7.57	-20.96
excluding those with greater than 100% change	-10.13	-28.61
excluding 5th percentile	-6.53	-17.22
excluding 2.5th percentile	-6.65	-17.66

E3.7 Findings

Trial report

The initial trial report was not available for review

Waterwise's summary of the results

Waterwise provided no clear explanation of why 290 households were used out of 444 households that were visited in the trial. Our analysis of the data, and subsequent removal of potential outliers left between 359 and 332 properties. Without knowing how data was excluded from further statistical analysis it would be inappropriate to conclude on the validity of the screening method to clean the data and whether unnecessary household data had been removed.

Waterwise estimated savings at 6 months to be 18.1 l/prop/day, this is similar to our estimations of 20.96 l/prop/day which was calculated using all the suitable household data. When the data was screened for outliers, net water savings were between 17.22 and 28.61 l/prop/day.

The net water savings calculated by Waterwise were estimated to be 74%, this value is similar to the range of values calculated here (70.81 to 72.98).

Our analysis of the change in water consumption indicate that it is not normally distributed. Waterwise do not account for this in their analysis of the data or in subsequent calculations for water saving.

The confidence intervals presented by Waterwise are considerably larger than those calculated in the review here, indicating that the calculation may not have been correct.

The equation of the linear regression presented by Waterwise is similar to the equation calculated here for the data when the upper and lower 5% percentile of household data was removed.

Appendix E.4

Sample with all data

Shapiro-Wilk normality test

data: rawdata$samplealldata

W = 0.6287, p-value < 2.2e-16

Sample households with data excluded where % change was greater than 100

Shapiro-Wilk normality test

data: rawdata$sample100

W = 0.5797, p-value < 2.2e-16

Sample households with data excluded from upper and lower 2.5 percentile

Shapiro-Wilk normality test

data: rawdata$sample2.5percentile

W = 0.9891, p-value = 0.01378

Sample households with data excluded from upper and lower 5th percentile

Shapiro-Wilk normality test

data: rawdata$sample5percentile

W = 0.9712, p-value = 1.959e-06

Control households with all data

Shapiro-Wilk normality test

data: rawdata$controlalldata

W = 0.9511, p-value = 0.002246

Control households with data excluded where % change was greater than 100

Shapiro-Wilk normality test

data: rawdata$control100

W = 0.9502, p-value = 0.002138

Control households with data excluded from upper and lower 2.5 percentile

Shapiro-Wilk normality test

data: rawdata$control2.5percentile

W = 0.9833, p-value = 0.3986

Control households with data excluded from upper and lower 5th percentile

Shapiro-Wilk normality test

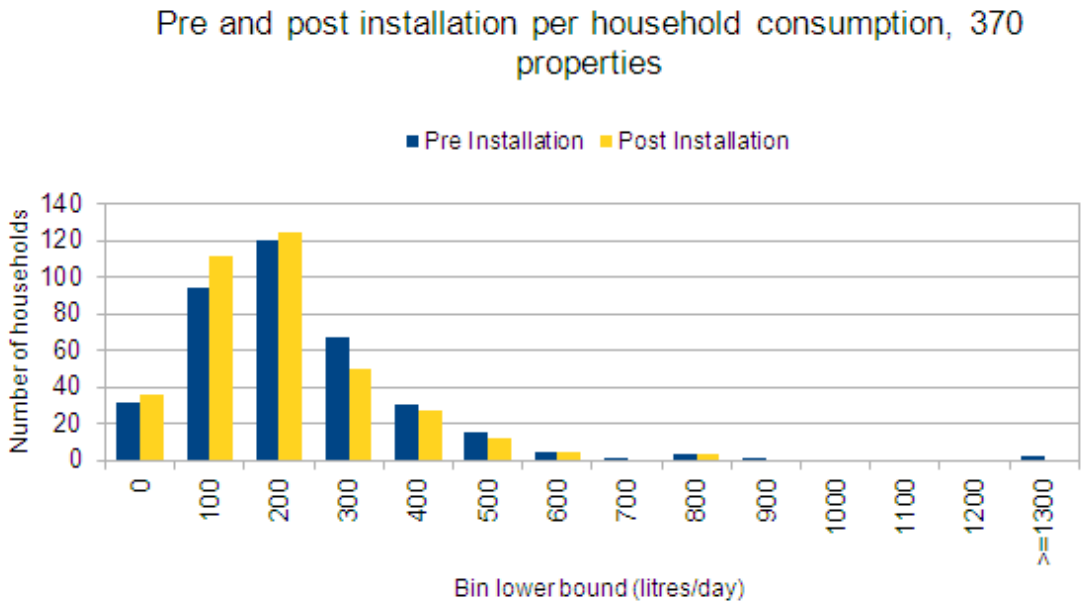
data: rawdata$control5percentile

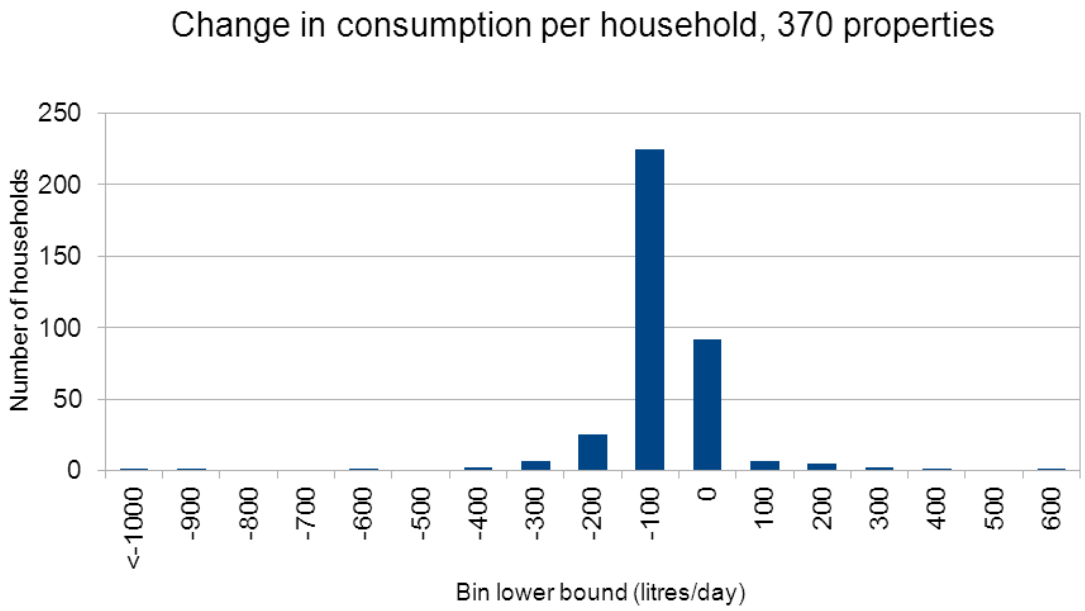
W = 0.9836, p-value = 0.3788

Appendix E.5: Histograms of the change in consumption

Table E.8 Change in consumption

Bin lower bound (litres/day)	Number of properties	
	Pre Installation	Post Installation
0	32	36
100	94	112
200	120	125
300	67	50
400	30	27
500	15	12
600	5	5
700	1	0
800	3	3
900	1	0
1000	0	0
1100	0	0
1200	0	0
>=1300	2	0
Total	370	370


Pre and post installation per household consumption, 370 properties
Pre Installation
Post Installation
Number of households
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
>=1300
Bin lower bound (litres/day)


Change in consumption per household, 370 properties
Number of households
250
200
150
100
50
0
<-1000
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
Bin lower bound (litres/day)

E4. United Utilities (UU) Home Audit Study (2008)

E4.1 Information available to the reviewer

Three reports were available:

- Evidence base for large scale water efficiency in home report Oct 2008.
- Evidence base for large scale water efficiency in home Phase II Interim report Feb 2010
- Evidence base for large scale water efficiency in home Phase II Final report April 2011.

E4.2 Summary of the trial

Purpose

The objectives of the project were to determine the practicality of fitting and promoting a selection of WEMs, to gain a better understanding of the likely costs of fitting these devices and to determine associated savings of these devices through property and DMA metering.

Water saving devices tested

The devices fitted were:

- Toilets
- Dual Flush ecoBETA
- Save-a-flush Cistern bag
- Showers
- Aerated Showerhead

Households taking part in the trial

A total of 4,642 customers in two DMAs in the Great Sankey area of Warrington were invited to participate in the United Utilities Home Audit Trial. Of the 509 households that originally volunteered to take part in the project, 393 audits were successfully completed.

Of the 393 customers who underwent an audit, 313 were metered and 70 were unmetered.

Meter readings

The meter readings were taken:

- approximately 40 days pre-installation
- On the day of installation
- 90 days post installation (

E4.3 Evidence presented in Waterwise report

2008 review

Total measured water saved is reported as 61 l/prop/day.

2010 review

Summary table

- No. of properties 211
- Water savings 20.6 (l/prop/day) Water savings 6.8 (% reduction)
- 90% Confidence interval 47.3 -33. (% water saved) 6
- 90% Confidence interval 169.4 -128.1 (litres saved/prop/day)
- Probability of water savings 0.67 Uptake rate (%) 8.5

2011 review

Waterwise reported long term savings from this study (up to 3 years post measure) as 28.7 litres/prop/day. We cannot check these numbers as Waterwise have not sent this data to us at the time of writing this report.

E4.5 The Review

Data preparation

The data received provided information on 260 households displaying water use pre and post-installation as litres/property/day. All 260 households had positive believable pre and post audit consumptions.

Calculations

All 260 households the change in water consumption from post- to pre- installation period was a mean saving of 21.78 l/p/d with a 90% CI [11.43, 32.12] and a median value of 21.75 l/p/d with 90% CI [10.60, 27.76].

Using Waterwise stated screening rules 246 properties remained in the sample and have a mean saving of 20.44 l/p/d with 90% CI [13.03, 27.86] and a median value of 21.75 l/p/d with 90% CI [10.85, 27.63].

Test for normality

The change in consumption data for the original 260 properties, and the screened 246 were tested for normality using a Ryan Joiner technique (Shapiro-Wilks equivalent) Both sets of data failed this test for normality and consequently was tested for measures of skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution) (Table E.9) contains the results.

Table E.9 Results of test for normality

Dataset	No of households	Skewness	Kurtosis
All households with complete data	260	0.87	9.91
Waterwise screen rule properties	246	-0.26	3.16

Using kurtosis value greater than |3| (absolute value of 3) and Skewness of greater than |2| indicating a normality test fail, the all household sample of 260 fails completely but the very good result for skew and the very small fail for Kurtosis indicate that the 246 screened households are borderline.

Estimation of savings and confidence bands

The following savings were calculated:

- 21.75 l/p/d with 90% CI [10.60, 27.76], using only non-parametric results for the 260 households;
- 20.44 l/p/d with 90% CI [13.03, 27.86], using non-parametric for the screened 246 households, and;
- 21.75 l/p/d with 90% CI [10.85, 27.63], using parametric results for the screened 246 households.

There is very little difference between these results and all three lie well within each other's CI range.

Waterwise stated 20.6.litres savings which is entirely consistent and in agreement with this analysis.

Disaggregation of savings per device

Waterwise made no attempt to disaggregate savings for this study. Using multi-regression techniques, on the unscreened sample it can be shown that both dual flush ecoBETA and showerheads are significant terms, although showerheads are marginal. Dual flush ecoBETA saved 15.4 l/device/day and Showerheads saved 16.7 l/device/day. As shown below.

Regression Analysis: Saving versus No_ecobeta, No_SAF, No_Shwrhead

The regression equation is

Saving = 2.4 + 15.4 No_ecobeta + 1.37 No_SAF + 16.7 No_Shwrhead

Predictor	Coef	SE Coef	T	P
Constant	2.40	11.18	0.21	0.830
ecobeta	15.388	7.815	1.97	0.050
SAF	1.375	5.692	0.24	0.809
Shwrhead	16.68	10.28	1.62	0.106

E4.6 Findings

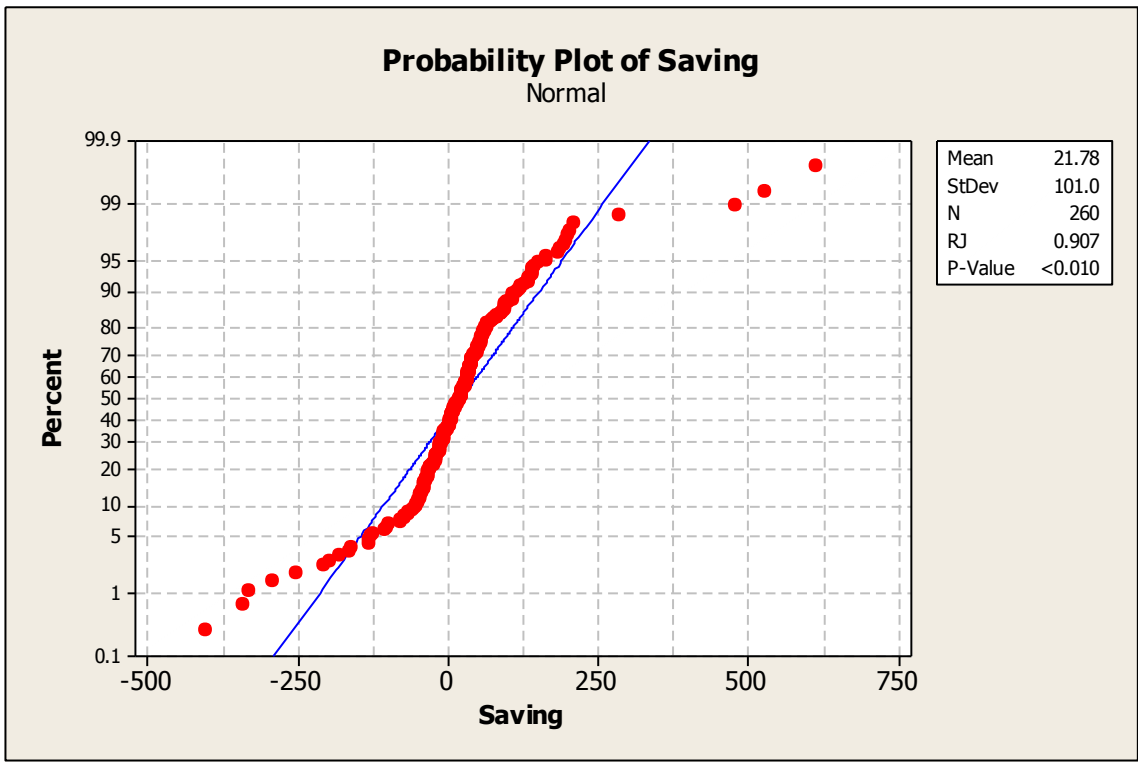
Trial report

In the initial report (October 2008) the claimed of savings of 61 litres/prop/day are extremely optimistic. However, when Waterwise were given the opportunity to analyse the supplied data themselves (Feb 2010 interim Phase II report) savings of 20.6 litres/prop/day are reported. The analysis in this report verifies that savings of this scale are reliable and robust for this study. However, Waterwise go on to claim a larger 28.7 litres/prop/day for long term savings which unfortunately could not been either confirmed or refuted as the supporting data were available for review at the time of writing.

Appendix E.6: Normality testing

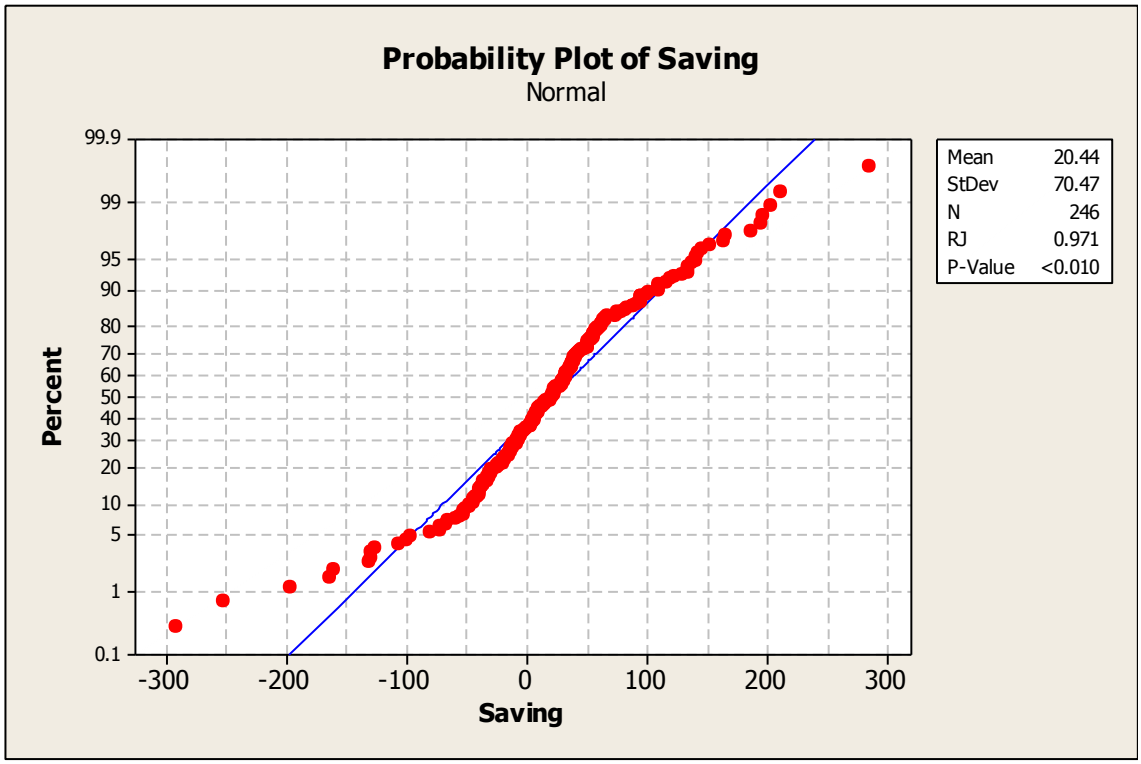
Ryan Joiner (equivalent to Shapiro-Wilk) normality test

FigureE.4 260 unscreened data



P-value indicates data is highly significantly different to normally distributed.

Figure E.5 246 screened properties



P-value indicates data is highly significantly different to normally distributed.

E5. Thames Water (TW) Measured visit and fix trials (2010)

E5.1 Information available to the reviewer

Two reports were available:

- Evidence base for large scale water efficiency in home Phase II Interim report Feb 2010.
- Report Analysis of Thames Water's water efficiency trial data Jan 2010. Artesia Consulting.

E5.2 Summary of the trial

Purpose

The trial targeted metered households in Wiltshire and Bromley, aimed to evaluate the effectiveness of the retrofit-style water efficiency devices in houses from the two areas within the Thames water area. Trained plumbers were used to install devices within each property.

Water saving devices tested

The devices fitted were:

- Toilets
- Dual Flush
- Save-a-flush Cistern bag
- Showers
- Aerated Showerhead
- Taps

Households taking part in the trial

10,454 metered domestic customers within Bromley and Swindon were sent an invitation letter inviting them to take part in the project, a total of 1,307 households responded positively and 885 audits were completed where credible meter readings were taken and recorded

Meter readings

The meter readings were taken:

- approximately 400 days pre-installation
- On the day of installation

- 500 days post installation

E5.3 Artesia Report & conclusions drawn

The average water saved on the MVF trial was 22.2 l/prop/day which, based on an average pre water consumption of 287 l/prop/day, is approximately a 7.7% saving. This is based on a sample of 879 properties whose savings are averaged over nearly 2 years of post audit data, indicating that this average saving is sustained for nearly 2 years.

E5.4 Evidence presented in Waterwise report

2010 review

Summary table

- 727 Properties Water savings 29.1 (l/prop/day) Water savings 7.9 (% reduction)
- 90% Confidence interval (% water saved) 45.7 -29.9
- 90% Confidence interval (litres saved/prop/day) 153.9 -95.7
- Probability of water savings 0.69
- Uptake rate (%) 9.2

Graph immediately below table shows a mean % saving of 6.88 NOT 7.9 using 833 properties.

Waterwise claim to compare results with a control group of 109 properties. Data provided to them did not contain any control groups or any control group results.

Comparison of actual and theoretical water savings

The Thames Water MVF trial achieved mean savings of about 29 litres per property per day. This compares with the average theoretical savings of 31 lpd using the estimates for dual-flush conversion, cistern displacement devices, showerhead and tap insert retrofit given in the table below. Hence on average the assumed values which might be used to estimate the impact of water efficiency retrofitting overestimate savings by 2 lpd on average in the case of this trial.

E5.5 The Review

Data preparation

The data received provided information on 885 households displaying water use pre and post-installation as litres/property/day. All 885 households had positive believable pre and post audit consumptions.

Calculations

Using all 885 households the change in water consumption from post- to pre-installation period gave a mean saving of 19.8/1 l/p/d with 90% CI [13.44, 26.17] and a median value of 15.10 l/p/d with 90% CI [11.41, 18.11].

Using Waterwise stated screening rules, 823 properties remained in the sample, giving a mean saving of 15.97 l/p/d with 90% CI [11.70, 20.24] and a median value of 13.54 l/p/d with 90% CI [10.19, 16.17].

Test for normality

The change in consumption data for the original 885 properties, and the screened 823 were tested for normality using a Ryan Joiner technique (Shapiro-Wilks equivalent) Both sets of data failed this test for normality and consequently was tested for measures of skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution). Table E.10 contains the results.

Table E.10 Results of normality test

Dataset	No of households	Skewness	Kurtosis
All households with complete data	885	-5.59	98.13
Waterwise screen rule properties	823	0.08	4.21

Using kurtosis value greater than |3| (absolute value of 3) and Skewness of greater than |2| indicating a normality test fail, the all household sample of 885 fails completely but the very good result for skew and the small fail for Kurtosis indicate that the 823 screened households are borderline.

Estimation of savings and confidence bands

The following savings were calculated:

- 15.10 l/p/d with 90% CI [11.41, 18.11], using only non-parametric results for the 885 households;
- 15.97 l/p/d with 90% CI [11.70, 20.24], using non-parametric for the screened 823 households, and;
- 13.54 l/p/d with 90% CI [10.19, 16.17], using parametric results for the screened 823 households.

The 29 l/p/d saving stated by Waterwise lies a long way outside all 3 CI ranges.

Disaggregation of savings per device

Waterwise made no attempt to disaggregate savings for this study. Using multi-regression techniques. on the screened sample it can be shown that both dual flush

and showerheads are significant terms. Dual flush saved 17.7 l/device/day and Showerheads saved 14.1 l/device/day. As shown below.

Predictor	Coef	SE Coef	T	P
Constant	-1.752	5.679	-0.31	0.758
Dual flush	-17.652	5.531	-3.19	0.001
Save a flush	-3.382	5.466	-0.62	0.536
Tap device	5.105	5.234	0.98	0.330
Shower head	-14.137	5.473	-2.58	0.010
Shower timer	-4.558	5.737	-0.79	0.427

E5.6 Findings

Trial report

The original report suggested the savings were 22.2 litres/prop/day.

Waterwise reported the savings to be 29 litres/prop/day.

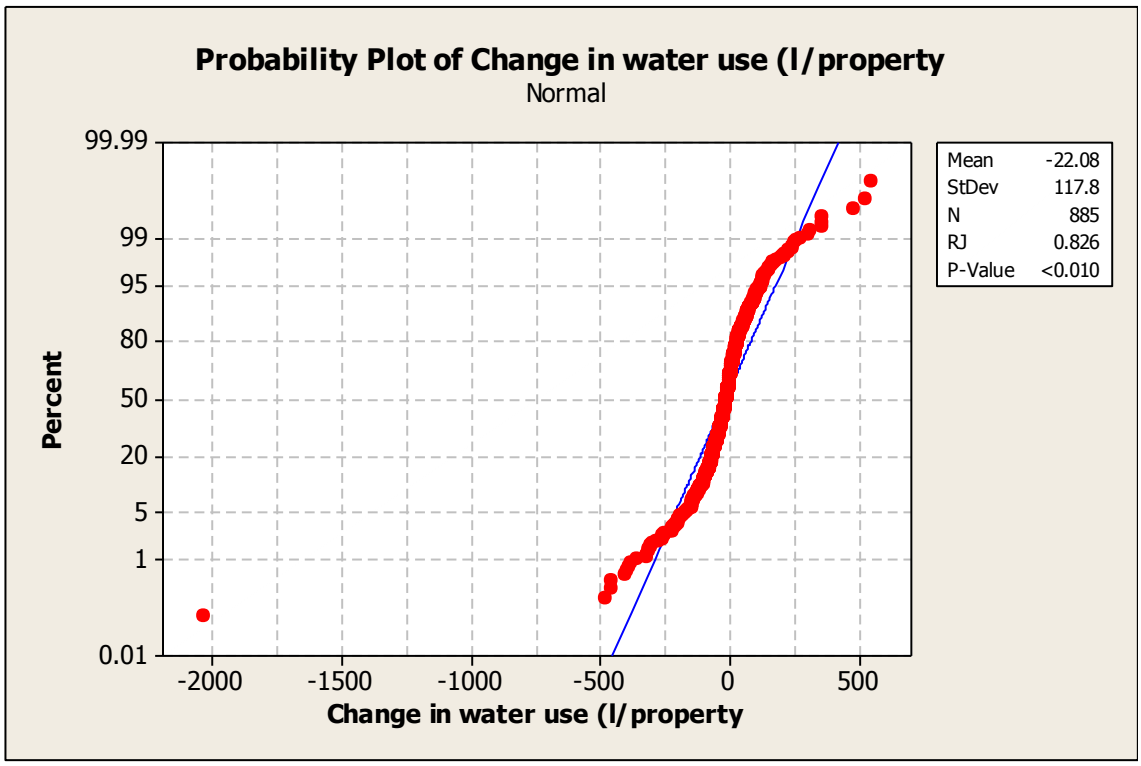
The analysis undertaken for this current review indicates that the most likely overall saving was 15 litres/prop/day [12,18] 90%CI.

Waterwise claim to compare results with a control group of 109 properties. Data provided to them did not contain any control groups or any control group results.

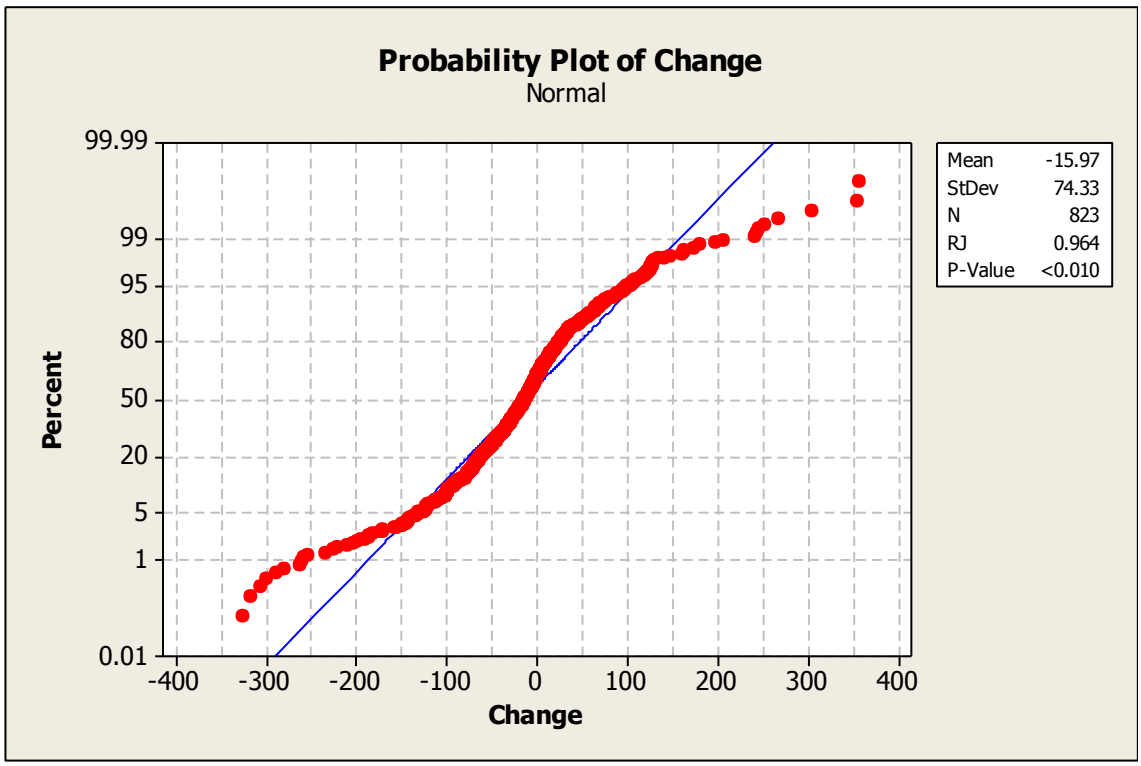
Using multi-regression techniques the analysis within this current review showed that Dual flush saved 17.7 l/device/day and Showerheads saved 14.1 l/device/day. This type of analysis was not attempted by Waterwise.

Appendix E.7: Normality testing

Ryan Joiner (equivalent to Shapiro-Wilk) normality test



P-value indicates data is highly significantly different to normally distributed. The larger outlier (bottom left) shown in the above graph was removed prior to analysis.



P-value indicates data is highly significantly different to normally distributed.

E6. Severn Trent Water (STW) Domestic water efficiency trial (2008)

E6.1 Information available to the reviewer

Four reports were available:

- Evidence base for large scale water efficiency in homes. Waterwise Oct 2008
- Evidence base for large scale water efficiency in home Phase II Interim report Feb 2010.
- Waterwise Evidence Base for large scale water efficiency Phase II final report. Waterwise. April 2011
- Additional analysis of the STW domestic efficiency trial. Final report. Artesia Consulting.

E6.2 Summary of the trial

Purpose

The trial aimed to evaluate the effectiveness of the retrofit-style water efficiency devices in houses from two areas within the Severn Trent area.

Water saving devices tested

The devices fitted were:

- Toilets
- Dudley Turbo
- Save-a-flush Cistern bag
- ecoBETA
- Showers
- Challis Aerated Showerhead 412
- Aqualogic Aerated Showerhead Fixed 310
- Taps
- Tapmagic Kitchen Spray Magic
- Tapmagic Dual Flow
- Aqualogic PCA 5 lpm
- Aqualogic 8lpm

Households taking part in the trial

Initially a sample of 9446 metered households were selected from the Nottingham and Worcester areas. A further 2500 properties in Worcester were contacted, as uptake rates were initially overestimated.

From the 11,946 households contacted, 932 metered households took part, an uptake rate of 7.8 %.

Properties were selected from the Nottingham and Worcester areas. The areas were divided according to a DMA map and the sites selected to provide geographically adjacent locations as well as adequate diversity to satisfy ACORN groupings. From both Nottingham and Worcester, the selected DMAs were assembled to form 10 groups of approximately 1000 properties. An equal number of properties from each group were selected.

The households used in the study were predominantly single occupancy (70%, Artesia Consulting, 2008)

A control group (2010 Waterwise report) was included in the trial although the details were not provided to Waterwise for either the 2008 or 2010 report.

Meter readings

The Waterwise reports indicate that the meter readings were taken:

- 960 (mean estimated monitoring period) pre-installation days based on historical bills
- Approximately 180 days pre-installation
- On the day of installation
- 90 days post installation (April 2008).
- 2.6 years post installation (only for 689 properties)

E6.3 Report & conclusions drawn

The original report was not available.

E6.4 Evidence presented in Waterwise report

2008 review

Water savings were estimated by comparing pre- and post-trial meter reading for each individual property. The 935 participating households were screened to exclude unreliable data resulting from errors in the meter reading process, transcribing the data or where new meters were installed, leaving 805 properties. Analysis of pre- and post-trial water meter readings for these properties provide a post-trial saving of 25.5 l/property/day (10.2 % of pre-installation water use).This value was compared against an estimated water saving value of 26.18 l/property/day generated from disaggregation of individual savings from each device and installation rate.

2010 review

Based on 717 households, Waterwise estimated a water saving of 28.4 l/property/day, equivalent to an 8.7% reduction in water consumption after retrofitting of water saving devices. The 90% confidence intervals for the water saving were 149.8 to -92.9 l/proper/day or 51.1% to -33.8% water saved. Waterwise stated that "This shows fairly standard variability in water savings, compared with many other trials."

Commenting on the large degree of variability on the distribution of percentage reduction in mean daily water consumption, Waterwise state that "It cannot be stated that the water savings are normally distributed but the water savings distribution alongside the curve of normal distribution reveals more than a passing resemblance" From the report it is not apparent if any actual statistical analysis of the distribution was determined.

Using assumptions about the water saving capacity for each device, and the installation rate an estimated water saving value was derived and compared to the actual measured values. The estimated theoretical savings overestimated the actual measured savings by 17 l/property/day. By plotting the difference between actual and theoretical water savings, Waterwise stated that there was a high degree of variability between savings in individual households making it difficult to "…predict how an individual property will respond to retrofitting". Although they later state that "if the sample is taken as a whole, the theoretical savings values seem to characterise quite well the mean response that can be expected from a large sample of properties".

2011 report

Additional data were provided to Waterwise from Severn Trent Water giving the post-installation metering information for 689 of the properties that were originally used in the trial for mean of 963 days following installation. Analysis of 689 properties indicated a water saving of 20.3 l/property/day which was stated as a 8.2 percentage reduction in water saving The 90% confidence levels were 247.4 to -206.8 litres/property/day. The percentage of households who made savings in their water consumption was calculated to be 56% after 2.6 years of post-installation (after 90 days it had been estimated to be 65%)

E6.5 The Review

Data preparation

The data received provided information on 910 households displaying water use pre and post-installation as litres/property/day. Of these households, 100 had incomplete information (missing or negative figures) and were therefore excluded from further analysis leaving 810 households.

Calculations

The change in water consumption from post- to pre- installation period was calculated (Table E.11) and outliers removed by:

- If the change in consumption was greater than 100%
- If the change in consumption was greater than 67.5% (this left 717 households, similar to the waterwise report)
- Excluding 2.5% upper and lower percentiles
- Excluding 5% upper and lower percentiles

Table E.11 Change in water consumption

Dataset	No of props	Mean phc pre-	Mean phc post-	Mean change per prop	Standard deviation of mean	Standard error of mean	% change in water use	What % of prop save water
All households with complete data	810	249.7	238.0	-11.68	253.03	8.89	-4.68	62.84
Exclude households where % change >100	774	254.5	215.1	-39.35	104.69	3.76	-15.47	65.76
Exclude households where % change > 67.5	717	247.1	221.3	-25.76	71.00	2.65	-10.43	64.57
Exclude upper and lower 2.5 percentile	768	242.6	218.4	-24.16	85.21	3.07	-9.96	63.54
Exclude upper and lower 5 percentile	728	236.1	212.0	-24.12	64.34	2.38	-10.22	64.29

Test for normality

The change in consumption data for the original 810 properties, and after removing the four groups of outliers, were tested for normality with a Shapiro-Wilks test in R (result in Appendix E.8). The data failed this test for normality and consequently was tested for measures of skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution) in Excel (Table E.12). Appendix E.9 contains histograms of the data presented both as change in consumption in l/prop/day and % change.

Table E.12 Results of normality test

Dataset	No of households	Skewness	Kurtosis
All households with complete data	810	10.56	149.42
Exclude households where % change >100	774	-1.87	6.97
Exclude households where % change > 67.5	717	-1.16	3.91
Exclude upper and lower 2.5 percentile	768	-0.29	2.67
Exclude upper and lower 5 percentile	728	-0.75	1.24

From this, we concluded that household consumption values tend to be concentrated quite tightly about a central value, with a small proportion of very low and very high values.

Estimation of savings and confidence bands

The estimated savings were calculated (Table E.12).

E6.6 Findings

Trial report

The original report was not available for review

Although a control group was stated to be included in the trial no data was provided for this review, or to Waterwise.

The 90 day installation period finished in April indicating that there should have been no summer seasonal peaks. Follow up consumption data was provided for 689 households for up to 2.6 years later therefore allowing long term changes from the water saving devices to be monitored.

No customer feedback on the use and implementation of the water saving devices were sought.

Waterwise evidence

In the 2010 waterwise report, 810 households were used for analysis, data was stated to be excluded from analysis if it was deemed unreliable and incomplete. The 2010 waterwise report only used 717 households for analysis although no indication as to how households were excluded from analysis was included.

The water savings estimated by Waterwise was 8.7%. Our analysis of the data provided a range of results; when all the data for the households were include saving were estimated as 4.68%. When outliers were removed, water saving increased to between 9.96 and 15.47%

The change in consumption pre and post installation was not statistically checked for normality, although the authors state that the distribution showed a resemblance to normally distributed data.

The confidence intervals presented by Waterwise are considerably larger than those calculated in the review here, indicating that they may represent the standard deviation of the sample, not the standard error of the mean.

Appendix E.8: Normality testing

From R:

For all data (810 households)

Shapiro-Wilk normality test

data: rawdata$changealldata

W = 0.371, p-value < 2.2e-16

Data excluded where % change was greater than 100

Shapiro-Wilk normality test

data: rawdata$change100

W = 0.8257, p-value < 2.2e-16

Data excluded where % change was greater than 67.5

Shapiro-Wilk normality test

data: rawdata$change67.5

W = 0.9089, p-value < 2.2e-16

Data from upper and lower 2.5 percentile excluded

Shapiro-Wilk normality test

data: rawdata$change2.5percentile

W = 0.9232, p-value < 2.2e-16

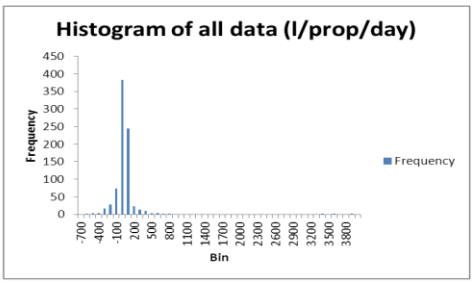
Data from upper and lower 5 percentile excluded

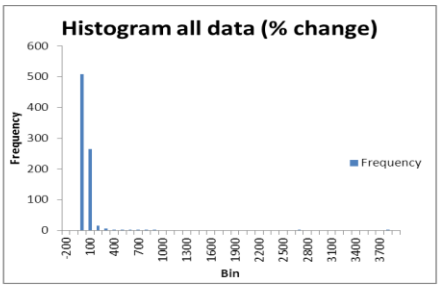
Shapiro-Wilk normality test

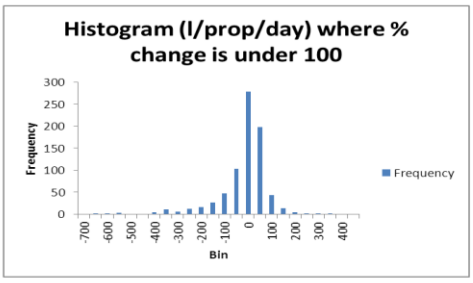
data: rawdata$change5percentile

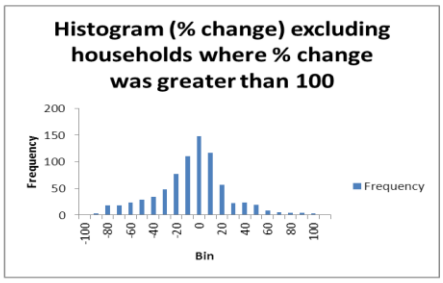
W = 0.9525, p-value = 1.425e-14

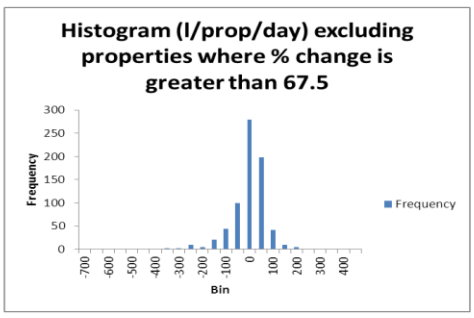
Appendix E.9: Histograms of the change in consumption presented as % change and litres/property/day.

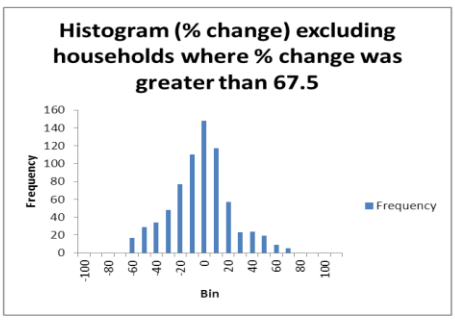


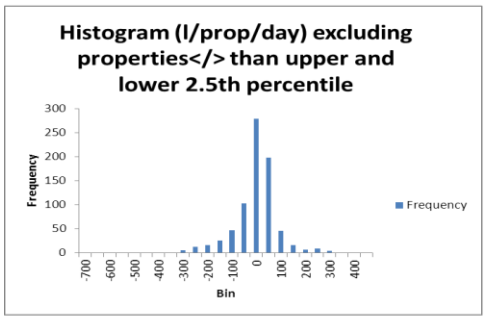


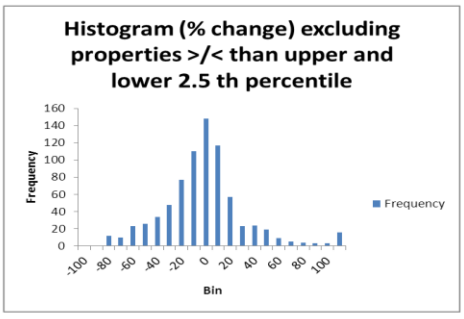


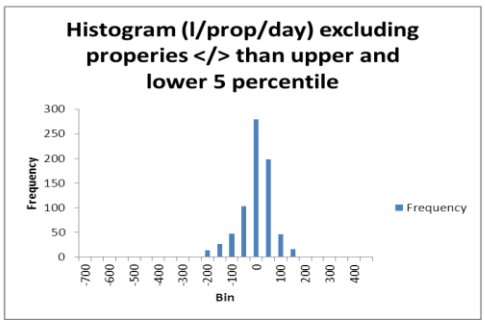


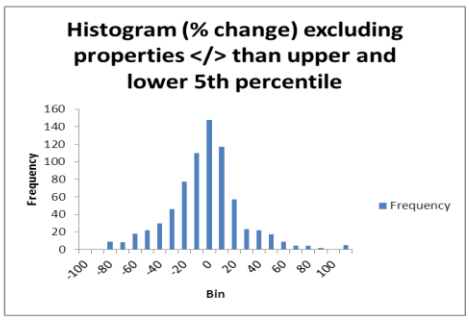












E7. TW Self-audit rateable value trial (2010)

E7.1 Information available to the reviewer

Two reports were available:

- Evidence base for large scale water efficiency in home Phase II Interim report Feb 2010.
- Report Analysis of Thames Water's water efficiency trial data Jan 2010. Artesia Consulting.

E7.2 Summary of the trial

Purpose

Thames Water distributed 1,754 water saving packs to London households between December 2007 and March 2008 to help reduce domestic properties' water consumption. The customers were billed the rateable value (RV) method but many had sleeping meters which were read and available for subsequent analysis.

Water saving devices tested

The devices fitted were:

- Spray swivel Tap (for the kitchen tap)
- Digital shower timer
- Save-a-flush
- Tap washers (with instructions to help repair leaky taps)
- Shower and tap flow bag
- Bathroom beaker with water saving messages
- Tea towel with water saving messages
- Watering can with water saving message
- Trigger hose gun (available as an option)
- Aerating Showerhead (available as an option)

The 'Self audit' trial delivered one of 4 different self audit packs to each property.

- Pack 1: Basic self audit pack (tap insert, taps washers, save-a-flush, watering can, drip gauge, shower flow bag, bathroom beaker, digital shower timer, tea towel).
- Pack 2: Basic self audit pack plus aerated shower head.
- Pack 3: Basic self audit pack plus hose trigger nozzle.

- Pack 4: Basic self audit pack plus aerated shower head plus hose trigger nozzle.

Households taking part in the trial

645 households had meter readings taken and the type of pack sent was recorded.

Meter readings

The meter readings were taken:

- 30 days in the post pack delivery period
- 300 days in the post pack delivery period

E7.3 Artesia Report & conclusions drawn

For the SA-RV trial, there was an average saving in water consumption of 23.2 l/prop/day which, based on an average pre water consumption of 507 l/prop/day, is approximately a saving of 4.6%. This is based on a sample of 640 properties whose savings are averaged over 300 days of post audit data.

Period after the audit packs were delivered	Water saving (l/property/day)	Number in sample
30 days	10.9	645
300 days	23.2	640

E7.4 Evidence presented in Waterwise report

2010 review

Summary table

- No. of properties 525
- Overall - After 3 months Water savings 21.9 (l/prop/day)
- Water savings 1.2 (% reduction)
- 90% Confidence interval 44.2 -41.8 (% water saved) after 10 months
- 90% Confidence interval 265.2 -221.5 (litres saved /prop/day) after 10 months
- Overall - After 3 months Probability of water savings 0.54
- Overall Uptake rate (%) 6.2

There wasn't any 3 month meter reads sent to Waterwise.

Waterwise correctly state that no control groups were used.

No comparison of actual and theoretical water savings as the data wasn't provided, again correctly reported.

E7.5 The Review

Data preparation

The data received provided information on 638 households displaying water use pre and post-installation as litres/property/day. All 638 households had positive believable pre and post audit consumptions

Calculations

30 day data

All 638 households the change in water consumption from post- to pre- installation period was a mean saving of 0.59 l/p/d with 90% CI [-10.38, 11.57] and a median value of 1.50 l/p/d with 90% CI [-4.21, 7.53].

Using Waterwise stated screening rules 505 properties remained in the sample and have a mean increase of 3.05 l/p/d with 90% CI [-9.85, 3.75] and a median saving value of 1.55 l/p/d with 90% CI [-4.73, 6.95].

300 day data

All 635 households the change in water consumption from post- to pre- installation period was a mean saving of 15.56 l/p/d with 90% CI [2.63, 28.48] and a median value of 7.05 l/p/d with 90% CI [1.69, 15.95].

Using Waterwise stated screening rules 489 properties remained in the sample and have a mean saving of 0.32 l/p/d with 90% CI [-7.11, 7.74] and a median saving value of 3.36 l/p/d with 90% CI [-1.41, 10.25].

Test for normality

The change in consumption data for the 30 day and 300 day screened and unscreened were tested for normality using a Ryan Joiner technique (Shapiro-Wilks equivalent). All sets of data failed this test for normality and consequently was tested for measures of skewness (a measure of lack of symmetry) and kurtosis (a measure of whether the data is flat or peaked relative to a normal distribution). Table E.13 contains the results.

Table E.13 Results of normality test

Dataset		No of households	Skewness	Kurtosis
All households with complete data	30 days	638	0.37	9.97
Waterwise screen rule properties	30 days	505	0.38	1.36
All households with complete data	300 days	635	-0.99	6.71
Waterwise screen rule properties	300 days	489	0.08	0.75

Using kurtosis value greater than |3| (absolute value of 3) and Skewness of greater than |2| indicating a normality test fail. Both unscreened sets fail and both screened sets pass.

Estimation of savings and confidence bands

Using only non-parametric results for the unscreened sets and both non-parametric and parametric results for the screened the following results were obtained.

30 day data unscreened.

Water saving median of 1.50 l/p/d with 90% CI [-4.21, 7.53]. The CI spans 0 therefore the result is not statistically significant.

30 day data screened

Parametric mean INCREASE of 3.05 l/p/d with 90% CI [-9.85, 3.75] and a median SAVING value of 1.55 l/p/d with 90% CI [-4.73, 6.95] again both CI's span 0 therefore the reported numbers are not statistically significant.

300 day data, unscreened

Water saving median of 7.05 l/p/d with 90% CI [1.69, 15.95] a statistically significant saving of 7 l/p/d.

300 day data. screened

Parametric mean saving of 0.32 l/p/d with 90% CI [-7.74, 7.11] and a median saving value of 3.36 l/p/d with 90% CI [-1.41, 10.25]. Again both sets not statistically significant.

Overall the results are inconsistent and unconvincing.

Waterwise stated 21.9.litres/prop/day savings after three months but there weren't any three month reads available.

Disaggregation of savings per device

It was not possible to disaggregate savings for this study as the results (shown in previous section) were inconclusive.

E7.6 Findings

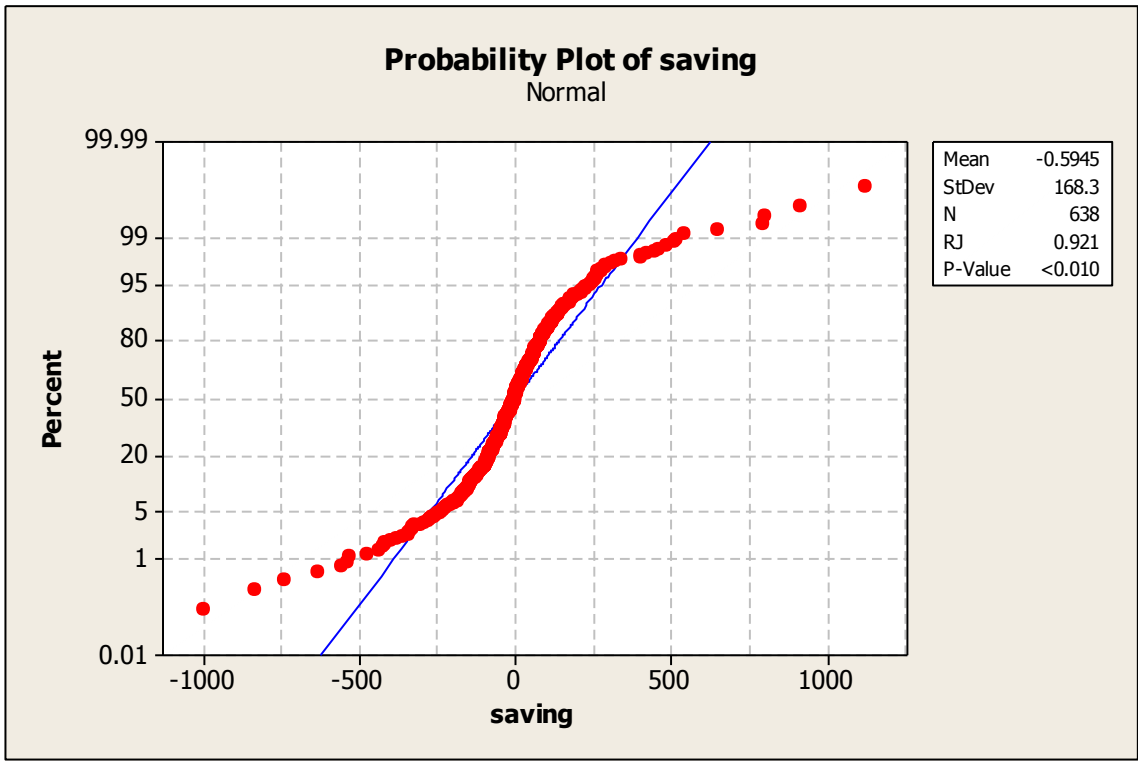
Trial report

It has not been possible to substantiate the 21.9 litres/prop/day after threemonths, as claimed be Waterwise.

Appendix E.10: Normality testing

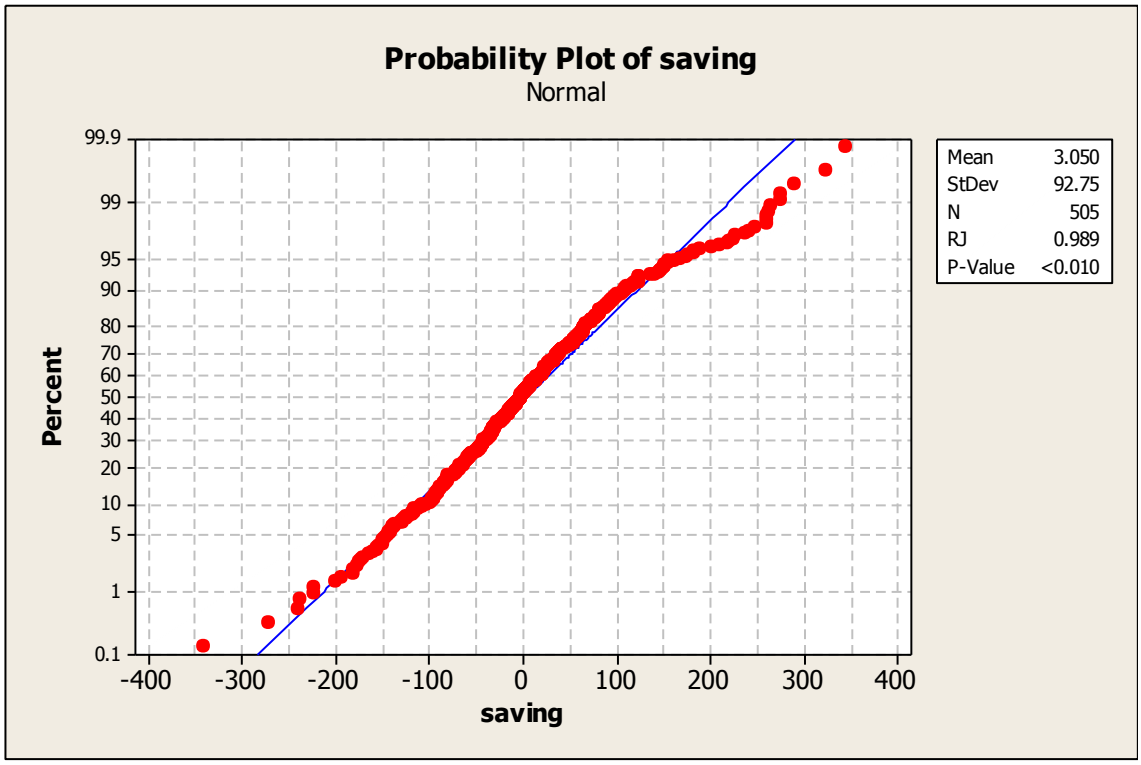
Ryan Joiner (equivalent to Shapiro-Wilk) normality test

Figure E.6 30 day unscreened



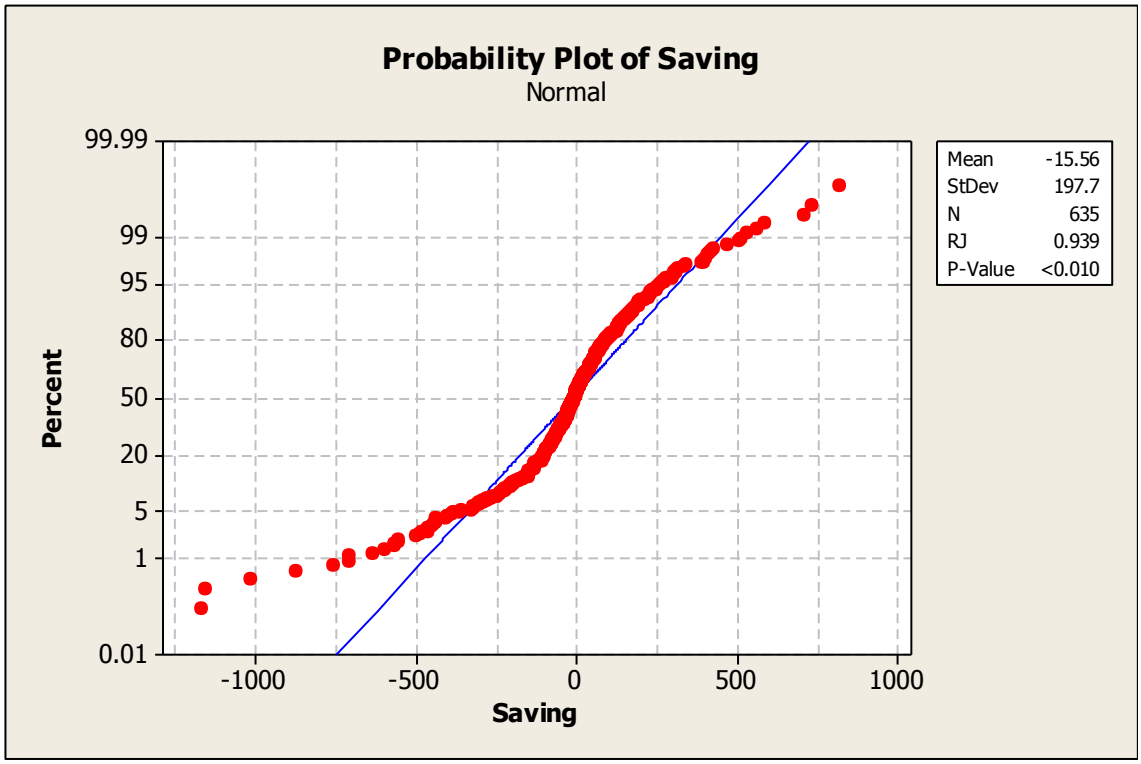
P-value indicates data is highly significantly different to normally distributed.

Figure E.7 30 day screened



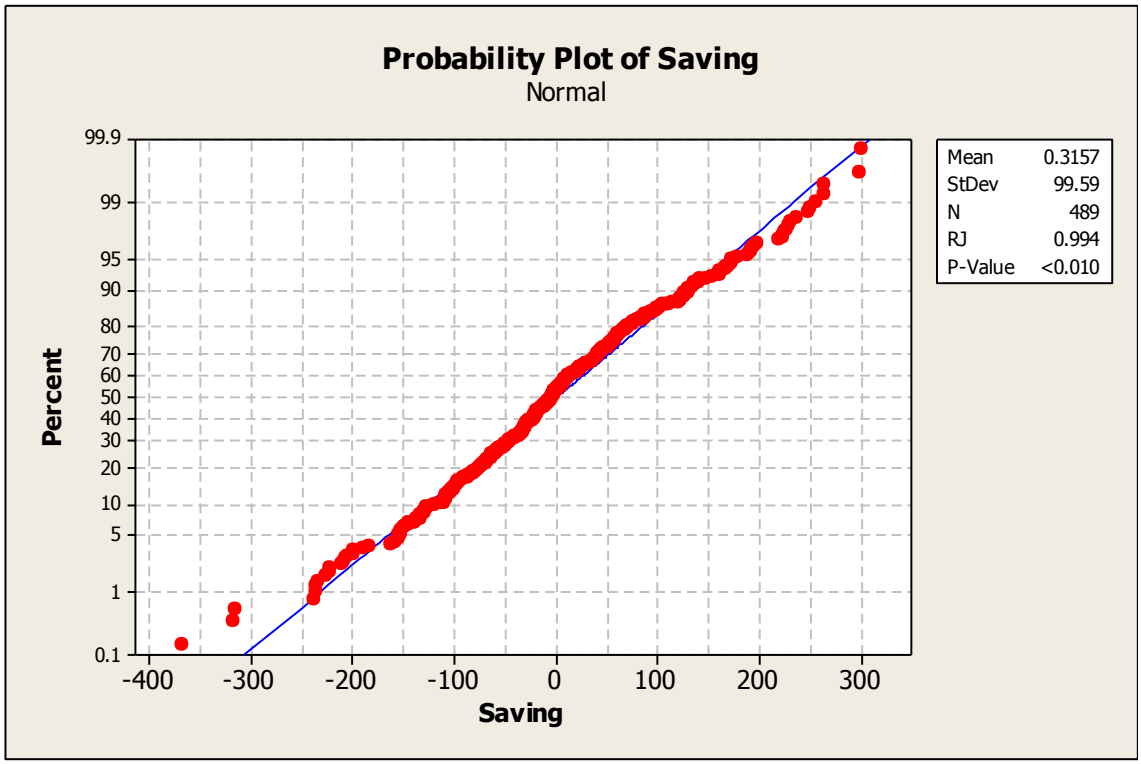
P-value indicates data is highly significantly different to normally distributed.

Figure E.8 300 day unscreened



P-value indicates data is highly significantly different to normally distributed.

Figure E.9 300 day screened



P-value indicates data is highly significantly different to normally distributed.

E8. ESW H2Eco (2008)

E8.1 Information available to the reviewer

One report was available:

- Mouchel Parkman (2008) "H2Eco"

E8.2 Summary of the trial

This trial was not part of the Waterwise Phase II study, however it has been included in this review as the trial was based on a large sample, including occupancy and socio-economic data. All trail data were available to the review team.

The details of this study are presented in Section 5.4. The following section describes the review of the project report.

E8.3 The Review

Recommendation a: Future studies should not exclude data just because it is greater than 2 standard deviations.

The reviewer agrees with this statement.

Recommendation f and section 5.1: Studying Water Efficiency effects using pre and post audit water consumption linear regression models is unhelpful and misleading and they should not be used to predict savings.

The reviewer agrees with this statement. The apparent indication of higher savings being associated with high 'pre' consumption arises from the imperfect relationship between 'pre' and 'post' consumption, and is known as regression towards the mean (see for example Hays, 1991, section 14.7).

Sections 5.2 to 5.5: Water Efficiency effects are examined using household attributes, such as property type, occupancy and ACORN.

This is legitimate. The large number of properties in the four phases of the study (~2500) means that interesting conclusions are reached.

Section 5.6: Estimating savings at unmetered properties

The formula proposed is probably the best given the data available.

Section 5.8: Multiple regression to estimate the savings from each appliance individually

A useful method when the data set is large (1787 properties)

Confidence intervals are expressed using the standard error of the mean, assuming the mean to be normally distributed.

The reviewer agrees with this statement.. The Central Limit Theorem (Hays, 1991, section 6.7) justifies using a normal distribution for the mean, even if the sample data are not normally distributed, provided the sample size is 'large enough'.

E9. Sutton and East Surry Water (SESW) Preston Water Efficiency Initiative (2008)

E9.1 Information available to the reviewer

The following reports were available:

- Evidence base for large scale water efficiency in homes. Waterwise Oct 2008
- Evidence base for large scale water efficiency in home Phase II Interim report Feb 2010.
- Waterwise Evidence Base for large scale water efficiency Phase II final report. Waterwise. April 2011
- Preston Water Efficiency Initiative, Interim Report – September 2008.
- Excel file 'Block meter readings'

E9.2 Summary of the trial

Purpose

The trial was coordinated by Reigate and Banstead Borough Council, to assess the effect on water consumption of efficiency measures in social housing. 160 dwellings being refurbished as part of a 'Decent Homes' programme, with water efficiency devices being retrofitted into 205 properties.

Water saving devices tested

A shower and new toilets and basins/taps were installed as part of the refurbishment. During the retrofitting a range of devices were offered to householders.

Households taking part in the trial

See above under 'purpose'.

Meter readings and monitoring

A distinctive feature of the trial was the monitoring of water used by groups of households, for example in blocks of flats. Details for five blocks of flats are given in the Excel file and summarised in the following table.

Table E.14 details of multi-occupancy properties included

Block of flats	Nr of dwellings	Nr of dwellings retrofitted
A	9	6
B	12	11
C	9	4
D	12	7
E	9	12

E9.3 Report & conclusions drawn

The interim project report concluded that 'both the refurbished and retrofit programme achieved considerable savings, although not quite as high as predicted in the theoretical calculations'. Statistical confidence limits were not quoted in either the project report or by Waterwise, possibly because of the relatively small number of blocks that were monitored.

E9.4 Monitoring small groups of properties

Monitoring blocks of flats or small groups of houses has two drawbacks, from a statistical point of view:

- The number of independent measurements is likely to be small and therefore results will be less reliable.
- Different water efficiency measures may be adopted at different properties within a group, making it impossible to separate their effects.

On the other hand, there are situations in which it is the better or only option. Blocks of flats where it would be expensive or impossibly to meter each flat is one example. Trials at unmetered houses face the issue of measuring pre-audit consumption, and this may be one solution.

There is the risk of leakage downstream of the meter, or of non-household water use – a building site took water for 3 months from one of the blocks of flats in the SEW trial.

Appendix F - List of useful projects in UKWIR WR25 Database

The Watercycle project: Water efficiency at the Millennium Dome, Thames Water (1998-2001)

Location: Millennium Dome, London

Description: A combination of greywater, rainwater and groundwater was treated on site and used for flushing the 873 WCs and urinals. Treatment technologies included reedbeds for the rainwater, a biological aerated filter (BAF) for the greywater and membranes for the groundwater.

Measure: Rainwater Harvesting, Grey water recycling, Waterless urinals

A study on the effectiveness of Grey Water Recycling Technology, South Staffordshire Water (2001-2002)

Location: West Bromwich

Description: Study the effect of grey water on household consumption, the quality of recycled greywater and the responses and perceptions of customers to greywater systems.

Measure: greywater harvesting

Water Audits for Non-domestic Customers, South West Water (2004 on-going)

Location: Cornwall and Devon

Description: Working with third parties on Energy, Waste and Water, businesses who are particularly interested in making water savings are identified. Water audits are carried out by means of a site visit and a detailed saving report provided back to the Company.

Measure: Water audits, Water Efficiency promotion / publicity.

Poseidon Seawater System, Poseidon Water Limited (Future Planned)

Location: Any coastal area

Description: Poseidon treats seawater to non-potable standard, uses dual plumbing to convey to nearby hotels, developments, etc. for toilet flushing, treats the wastewater and returns it to the sea. Data presented here is modelled on a typical mid-size development.

Measure: Use of seawater for toilet flushing.

SMART project, Severn Trent Water (2005 on-going)

Locations: England

Description: To enable the use of in home technology to see water use through the TV screen.

Measure: Water Efficiency promotion / publicity

Resource savings and Eco Homes, work carried out by Ian Dickie, RSPB (Completed)

Location: England and other Developed Countries

Description: Study resource savings and Eco Homes.

Measure: Domestic customers - new homes

Waterless Urinals, Now2000 (2001-2002)

Location: Portsmouth Water Head Office in Havant

Description: To compare the costs and effectiveness of Waterless Urinals and PIR Controlled flushing urinals.

Measure: Urinal controls

Appendix G - Additional evidence base studies

G1. WRc Collaborative Research project CP359

In 2009 a group of UK Water Companies, Defra and the Environment Agency collaborated to look at the impact of water audit activities in household properties at the micro-component level (Glennie, et al, 2010).

WRc's Identiflow® system was used to measure savings at a micro-component level. Device flow rates, water used per product use and accurate frequency of use information was collected to allow the impact of water efficiency devices to be assessed. This project monitored a sample of 74 homes which were selected by the participating water companies who also organised the water audits.

Table G.1 Summary of main findings from WRc project CP359

	Volume per use (litres)	Volume used by appliance per day (litres)	Mean flow rate of device (litres per minute)	Duration of use of device (seconds)
Shower head	6.51 [2.83,10.2]	With occupancy*	1.33 [0.53,2.12]	-49.4 [-81.7,-17.1]
Shower timer	NS	NS	NS	NS
EcoBETA (at household level)	1.86 [1.15,2.57]*	18.7 [4.78,32.6]	-	-
EcoBETA (at specific device level)	1.89 [1.13,2.65]	-	-	-
Save-a-Flush (at household level)	1.25 [0.55,1.96]	22.4 [11.1,33.6]	-	-
Save-a-Flush (at specific device level)	NS	-	-	-
Cistern displacement device (at household level)	1.09 [0.43,1.74]	NS	-	-
Cistern displacement device (at specific device level)	2.06 [1.46,2.65]	-	-	-
Combination of toilet devices (at household level)	1.64 [0.89,2.39]	41.3 [17.8,64.8]	-	-
Tap inserts	NS	NS	NS	NS

* The impact of these devices was found to be influenced by the household occupancy. Lower occupancy households saw a larger saving than higher occupancy households.

The results from the trial were analysed using tests of statistical significance. The table above summarises the main findings, indicating the value of any statistically significant differences by parameter investigated (positive values indicate savings). Note that 'NS' indicates where the parameter investigated is not statistically significant at the 10% significance level.

In two cases (asterisked), the statistical relationship is strengthened by including the effect of occupancy (i.e. the impact of the water-saving device is also dependent upon the occupancy of the household). Confidence intervals (90%) are provided in square brackets where appropriate to indicate the uncertainty around the best estimate.

Savings from Save-a-Flush and other cistern displacement devices (excluding EcoBETA) were found to be broadly in line with the savings assumed by Ofwat. For all other devices tested, smaller savings than those assumed by Ofwat were found.

G2. Analysis of water saving data from H2Eco studies

In 2009/10, Artesia Consulting were asked to examine the data from the four H2Eco project phases carried out by Esssex and Suffolk Water (ESW), to help get further value from the data and examine some of the assumptions and conclusions arising from the projects (Artesia, 2010).

ESW's H2Eco projects are household water efficiency audits and retrofits. Four separate projects (phases 1 to 4) have been completed to date covering different areas of Chelmsford. The phases have varied a little in approach, but have all involved an audit and the provision of and installation of devices including ecoBETAs, Save a Flush, aerated showerhead, tap inserts, tap re-washering, hose guns, garden crystals, water butts, and water efficiency advice. In each phase, three estimates of the water savings were made: from meter readings, from logger data, or from calculations based on the point-of-use measurements.

This study has enabled the analysis of a significant volume of data collected in a consistent way from a series of water efficiencies studies. This amount of measured data (1787 pairs of readings representing before and after intervention consumptions) has allowed a range of statistical techniques to be used to analyse the data, which has enabled water savings from measured data to be determined with a high degree of confidence, despite the inherent volatility in household consumption data. It was possible to estimate the volumetric savings from a range of devices. The study has also revealed that despite the four phases being very similar the water savings results are very different. The volume of water saving and socio-demographic data along with good quality records of each audit has allowed the project to draw conclusions on why there are differences in water savings between studies. The key conclusions from the study are set out below.

The project found that the original study reports excluded data which was greater than 2 standard deviations (SDs) when calculating pre and post intervention water consumption. The project concluded that this was not justified, and excludes potentially valid data. The reason for this is that knowledge of the nature of the underlying distribution is required before attempting to apply predetermined exclusion rules. If this is not done exclusion rules are more likely to introduce bias.

The original studies included ‘theoretical’ water savings for each property which were calculated based on water behaviour assumptions and measurements of appliance data taken during the audits. The project made some modifications to the theoretical calculations. The theoretical calculations can be used to illustrate the potential water saving which should be achieved from each property if the occupants use the water saving devices as expected.

The headline findings on water savings from each phase are shown in the following table (mean values and confidence intervals).

Table G.2 Water saving from each phase of H2Eco studies

	Water savings (L/prop/day)			
Phase	Measured	90% CI	Theoretical	90% CI
Phase 1	20.3	[14.9, 27.0]	31.1	[26.5, 35.7]
Phase 2	6.7	[0.4, 13.0]	18.8	[15.9, 21.7]
Phase 3	4.9	[-1.2, 10.9]	22.7	[14.2, 31.2]
Phase 4	27.8	[18.9,36.6]	33.7	[27.6, 39.8]
All phases	15.6	[12.0, 19.2]	26.9	[22.8, 31.0]

The water savings for phases 1 and 4 are similar in nature and not statistically significantly different. The same is true for the water savings from phases 2 and 3. However, as a collective the water saving results from phases 1 and 4 are both statistically significantly different to phases 2 and 3.

The confidence interval on the measured water savings from phase 4 overlaps the theoretical water savings, indicating that the phase 4 trial was most successful in delivering the potential water savings. In order to understand what is driving these differences, a number of one and multi dimensional analysis techniques were used.

The difficulty in measuring water savings after water efficiency interventions is due to the underlying day to day volatility in property water consumption data.

Single occupancy properties show measured savings equal to the theoretical savings; therefore they met their savings expectation, whereas for all other occupancies the measured water savings fall short of their savings expectation. This may be because of behaviour and due to the fact that for single occupancy properties the sole occupier is present and engaged during the audit, whereas in multiple occupancy dwellings there is a reliance on all occupiers being fully engaged in the audit and understanding how to use the water saving devices. Or it may be due to the way in which theoretical calculations are scaled up as the occupancy increases leading to an overestimate of the theoretical saving for multi occupancy dwellings.

Using the top level ACORN[7] classification; ACORN 1, 3 and 4 delivered a similar level of water saving against the theoretical water saving value. ACORN 5 returned the lowest value both in absolute terms and in comparison to the expected value.

The project combined occupancy and ACORN data and there are three groups that can be defined whose water savings following the audit are significantly different, these are:

The “wealthy and settled” with a high occupancy (3 to 4) show the highest savings (41.6 l/property/day) and meet their savings expectation (44 l/property/day).

The “hard pressed” and “prudent pensioners” save the least (4 l/property/day against an expectation of 21 l/property/day).

The “rest of the population” (15.7 l/property/day against an expectation of 29.5 l/property/day).

From analysis of the water saving device groups and water savings (from the complete measured dataset), the consultants' best estimates for water savings from each device are:

[7] **ACORN** is a geodemographic segmentation of the UK’s population which segments small neighbourhoods, postcodes, or consumer households into 5 categories, 17 groups and 56 types. The categories range from Category 1 "Wealthy Achievers" to Category 5 "Hard Pressed".

Table G.3 best estimates for water saving per device

Device	Typical Values	
ecoBETA:	17 l/device/day	23 l/prop/day
Save-A-Flush:	6 l/device/day	8 l/prop/day
Showerhead:	12 l/device/day	14 l/prop/day
Tap inserts:	5 l/device/day	7 l/prop/day
Miracle tap	5 l/device/day	5 l/prop/day

The detailed analysis looking at the performance of ecoBETAs revealed that the above water saving numbers are means for each device. Furthermore, the saving obtained from each device was dependent upon the installation context. Properties with saturated (or 100%) fits (e.g. the number of ecoBETAs fitted is the same as the number of toilets in the property) save more water per device than less than saturated fits. A single saturated ecoBETA saves more per device than a saturated fit comprising 3 ecoBETAs. This result is not entirely surprising.
Correspondence analysis was also carried out on the devices, which showed that ecoBETAs and Save-A-Flushes were associated with high water savings. However, showerheads and tap inserts are most closely associated with two types of user: those that behave as expected and save water, and those who do not save water. This may be an indication that behaviour plays a large part in the water savings realised from shower and tap devices, and behaviour is much less of a factor for the WC devices. Correspondence analysis also revealed that single occupancy households consistently deliver reasonably high water savings reinforcing the notion that this group consistently realise their water saving potential. In contrast properties with occupancy of 2 are equally split between poor savings and good savings. This group either performs well or poorly resulting in an overall modest water saving return.
The best explanation for the differences between the water savings achieved in phases 1 and 4 compared with phases 2 and 3 are: the high intensity of ecoBETA fittings in phases 1 and 4, and the low proportion of ACORN 5 (the Hard Pressed) in phases 1 and 4.

G3. South East Water studies in Highland Park

A new residential development in Kent installed efficient fittings and tested a seasonal water tariff.

The development is located in South East Water's area (and in Mid Kent Water's areas previously) and the company worked in partnership with Hillreed Homes at the Highland Park Development, Singleton Hill, Ashford. South East Water (SEW) sponsored the installation of water efficient plumbing and appliances in each of 200 homes. These homes began to be completed in May 2006, and were being sold in phases of approximately 25 units until 2010. A further 60 homes (already completed) did not feature the water efficient plumbing or appliances and were used as 'control' group properties.

Homes which have been fitted with water efficient devices are known to contain:

- Dual flush (4/2.5 litre or 4.3/3 litre) WCs.
- An aerated shower head (maximum 10 litres per minute).
- Spray or low flow taps (maximum 5 litres per minute) in the downstairs bathroom.
- An efficient washing machine (39 litres per cycle specification).
- A flow limiter to 10 litres per minute on outdoor taps.
- The purpose of this water efficiency and seasonal tariff trial project was to investigate consumers' behaviour in terms of water usage in respect of:
- The presence of water efficient plumbing and appliances; and
- The application of a seasonal tariff to 50% of homeowners.

The monitoring study was carried out in five phases between autumn 2006 and summer 2009 and included three groups of properties: containing water efficient plumbing and appliances, containing water efficient plumbing and on seasonal tariff with 'control' properties.

The headline findings on water savings from each phase are shown in the following table.

Table G.4 Results from all 5 phases of logging

	Ownership			Volume per use (litres)						Frequency of use (per household per day					
	Control	Water efficient	Tariff	Control		Water efficient		Tariff		Control		Water efficient		Tariff	
				Mean	St. dev.	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Toilet	100.0%	100.0%	100.0%	6.1	1.4	4.2	0.7	4.3	0.6	11.1	6.2	10.4	3.5	9.8	4.3
Bath	56.8%	54.1%	53.8%	72.4	21.6	63.3	17.1	59.7	14.5	0.9	0.7	0.7	0.5	0.7	0.6
Shower	97.5%	92.7%	100.0%	43.0	25.3	35.7	16.9	42.2	14.9	1.8	2.1	1.6	1.3	1.5	1.0
Washing Machine	96.0%	100.0%	97.2%	43.1	12.4	48.5	13.1	51.4	12.0	0.7	0.6	0.8	0.5	0.9	0.5
Dishwasher	68.8%	54.7%	63.9%	14.0	5.8	17.1	2.4	16.6	5.6	0.7	0.5	0.6	0.4	0.5	0.3
Internal tap	100.0%	100.0%	100.0%	1.9	0.5	1.6	0.5	1.6	0.6	53.1	47.9	45.4	22.3	45.9	22.2
Outside tap	38.3%	46.2%	38.0%	40.7	21.2	21.4	28.7	30.9	67.1	1.4	1.4	2.9	1.8	1.9	1.2

Note, the sample size within each phase of logging varies. Sample sizes were:

- Phase 1 – 12 properties (6 control and 6 water efficient).
- Phase 2 – 14 properties (5 control, 5 water efficient and 4 tariff and water efficient).
- Phase 3 – 23 properties (10 control, 5 water efficient and 8 tariff and water efficient).
- Phase 4 – 22 properties (6 control, 7 water efficient and 9 tariff and water efficient).
- Phase 5 – 25 properties (8 control, 8 water efficient and 9 tariff and water efficient).

In a separate project, SEW worked with the EA on the analysis of the tariff trial data, along with 3 other companies and they showed that between 2007 and 2011 there was no statistical evidence to show the tariffs were having an impact.

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