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Greenhouse gas emissions of water supply and demand management options

Science Report – SC070010

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Steve Killeen

Head of Science

Executive summary

Reducing greenhouse gas emissions is one of the key challenges of our generation. The UK Government has recognised the necessity for significant reductions. The Stern Report, Energy White Paper and Climate Change Bill provide the scientific and legislative impetus to mitigate and adapt to the effect of emissions across all sectors of the UK.

The water industry must play its part and reduce its greenhouse gas footprint. Water typically requires treatment prior to use and on its return to our environment. It is pumped and pressurised to reach our homes. All of these activities require energy and therefore result in greenhouse gas emissions.

The water industry contributes 0.8 per cent of annual UK greenhouse gas emissions. However, the emissions that result from heating water in the home increases this figure to 5.5 per cent.

This project examines the difference in greenhouse gas emissions associated with a variety of options for supplying water and using it more efficiently. We assess options for new supplies of water, working with an existing water supply network, plus methods and products to reduce and manage households' water demand. This study does not include any assessment of other environmental, social or economic costs and benefits.

We provide an evidence base and framework to inform our understanding of water resource and carbon impacts, underpinning one of five modules of our new water resource strategy for England and Wales, planned to be published in December 2008. This is also one report in a wider two-year project looking at the potential for energy efficiency and carbon reduction across the entire water industry.

Throughout the report we refer to greenhouse gas emissions as carbon dioxide equivalent (CO_2e). The cost of CO_2e follows the Defra Shadow Price of Carbon guidance; £26 per tonne in 2008, thereafter rising by two per cent each year. This report does not include any assessment of other environmental, social or economic factors. We recognise that quantifying greenhouse gas emissions is just one factor to be considered in the overall decision-making process.

Our key findings

1. 89 per cent of carbon emissions in the water supply - use - disposal system is attributed to "water in the home" and includes the energy for heating water (excludes space heating), which compares with public water supply and treatment emissions of 11 per cent.

2. Simple demand management measures, particularly those which reduce hot water use, have significant potential to not only promote water and energy efficiency but also to reduce the carbon footprint of the water supply - use - disposal system. For example, moving to full water metering across England and Wales could reduce annual emissions by 1.1 - 1.6 million tonnes of carbon dioxide per year. Moving to full metering in areas of serious water stress could potentially reduce annual emissions by between 0.5 - 0.75 million tonnes CO_2e per year.

3. All supply side measures result in an increase in carbon emissions (we assume new schemes are implemented to meet rising demand rather than replacing existing assets). There is often a wide range in carbon emissions associated with water supply schemes of a similar type, and therefore overlap between different types of schemes is common. For example, medium to large reservoirs and indirect effluent re-use can have similar carbon emissions per volume of water supplied, dependant on scheme design. To select the lowest carbon solution requires a scheme by scheme assessment.

4. Most demand management options, for example water metering, have low operational carbon emissions, the exception being retrofitting of household rainwater harvesting and greywater recycling to existing homes. Data concerning the energy use of these two techniques is scarce and requires further research.

5. Combinations of demand management options, even those including rainwater harvesting in new homes, offer larger water savings compared to individual water efficiency options and still compare favourably to supply side options in terms of overall lower carbon emissions.

6. Current legislation continues to require the sustainable management of rivers and groundwater. In some cases this will mean that water abstraction will need to be reduced to ensure a sustainable water environment, resulting in a reduction in the water available for supply. To offset this effect, companies are investigating alternative sources of water. Our work indicates this will increase carbon emissions overall. We believe that widespread implementation of demand management measures can offset or further reduce overall emissions, as well as reducing the need for some of these new supplies in the first place..

   For example an initial assessment using South East data indicates that the lowest carbon cost is delivered by the scenario which includes both demand management for two million homes and 18 new supply schemes, delivering a 14 per cent carbon cost saving compared to business as usual.

7. We acknowledge that future technological developments may offer greater energy and carbon savings to both water supply and demand management options. The extent of these savings has not been looked at in this study due to the level of uncertainties involved.

8. In future, policies need to consider the greenhouse gas emissions across the whole of the water system, i.e. emissions arising from both the water industry and the use of water by consumers. Policy-makers also need to recognise the potential overlap with the aims of energy efficiency initiatives and ensure there is no double counting of carbon reductions.

9. Water Resource Management Plans require water companies to assess their carbon footprint related to water supply only and not the whole life cycle costs. Water companies planning future water resources options through the 25 year planning period are required to build-in the shadow price of carbon to the economic analysis. However, this typically relates to the direct energy costs of water production and embedded carbon for construction activities.

   This current approach constrains the options appraisal as it fails to take full account of the life cycle costs of carbon and particularly the positive impact of demand management related to water use in the home as well as wastewater activities. This approach has therefore been unable, to date, to incorporate the largest and most significant aspects of carbon accounting within assessments between building new resources and managing demand.

The life-cycle emission model

We assessed new water supply options and demand management options working with an existing water supply network. The options considered included:

- **Supply options -** storage reservoirs; regional water grids via transfer pipelines; desalination plant to make seawater and brackish water drinkable; effluent re-use; groundwater and river abstractions.
- **Demand management options -** water saving devices for toilets, showers and baths; water meters; water efficient domestic appliances; rainwater collection systems; grey-water recycling (i.e. water from showers, baths and sinks used for toilet flushing); water mains leakage reduction.

We developed our methodology in line with Defra guidance on the Shadow Price of Carbon and our guidance on water resources planning. Present value techniques are used to compare options in terms of their carbon cost as CO_2e versus water delivered or saved over a planning horizon of 60 years.

We model the life-cycle impact of individual options by calculating the greenhouse gas emissions associated with construction, manufacture, installation, maintenance and operation.

- For a unit of water we evaluate the current carbon emissions and cost of carbon.
- For water supply options we calculate the scheme carbon cost, e.g. new reservoir, new treatment facilities - clean and wastewater, and increased capacity in the distribution network.
- For demand management options we calculate the carbon cost to introduce and operate the measure and the carbon savings from lower water demand.

The model, built in MS Excel® for ease of use, is intended for high-level carbon cost appraisal in advance of more detailed study. It can be easily tailored to suit regional and scheme specific data as appropriate, and should help in our review of water company PR09 plans.

Conclusions

Our study, as part of a broader project on energy efficiency and carbon emission reductions across the water and wastewater sector, provides a first evidence base for water supply and demand management options. To create this evidence, we developed at a strategic level an initial methodology for carbon cost assessment, producing results that can be built on.

The model framework can be used to compare the carbon impacts of individual supply and demand options. Key details of construction and operation are adjustable to reflect actual schemes, or to explore the carbon implications of different designs.

Our results show that simple demand management measures, such as metering, have the potential for significant carbon reduction through reducing energy usage associated with heating water in the home. Water efficiency measures could provide a significant reduction in UK carbon emissions, and reduce our individual energy and water bills.

Successfully implementing the right balance of low carbon supply side solutions and wider implementation of water demand management activities now can begin the process of moving towards a lower carbon water industry. Getting it wrong will leave a legacy of carbon intensive water management which will remain with us for decades to come.

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Contents

1 Introduction

1.1 Background

Recent publications such as the Stern Report, the Climate Change Bill and the Energy White Paper highlight the ever increasing focus on climate change and greenhouse gases. The Government programme for tackling these issues will have implications for the Environment Agency's responsibilities as regulator of the environment in England and Wales.

Our study forms part of a broader project examining the potential for increased energy efficiency and carbon emission reductions across the water and wastewater sector. This study explores the link between water resources, energy and carbon emissions. Both water supply and demand management options are considered, consistent with the twin-track approach to water resources planning.

The carbon footprint specific to water resources planning options and the emerging price review 2009 (PR09) is a new area of work, with knowledge as to how the proposed options to meet future water demand and efficiency compare in carbon cost terms beginning to emerge.

As a first step in carbon cost assessment, the study delivers: (a) an evidence base derived from energy and carbon emission datasets related to water supply and demand management options; (b) a carbon cost assessment model (in MS Excel®) developed from these datasets; and (c) results illustrated for options using water company data for the South-East of England (illustrative purposes only).

Decision making in water resources planning encompasses a range of environmental, social and economic factors. This study only examines energy usage and greenhouse gas emissions at a strategic level.

The study output is intended for use in strategic water resources planning to appraise and compare the different water resource options based on their carbon cost. The findings will inform the carbon module which is part of our new water resources strategy for England and Wales, planned to be published in December 2008.

In this report, the term "carbon" is shorthand for greenhouse gases and presented as carbon dioxide equivalent (CO_2e).

1.2 Objectives

The study aims to gather data so that potential investments in different water supply and water demand management options may be appraised more fully, specifically in terms of their carbon costs.

The main objectives of the study are to:

- gather energy and carbon emissions data for common water supply and demand management options.
- examine the carbon impact of options individually, and in combination
- develop a carbon cost assessment model to assist in the evaluation of different water supply and demand options.
- illustrate the carbon assessment based on worked examples for water resource planning scenarios for the south east of England.

The high-level results from this study will inform our technical review of water company plans. There is scope for further study and development of the carbon cost model. At this stage, we propose to make the model freely available to academics/practitioners so that the work can be interrogated and to help in developing best practice. The model is built in MS Excel® for ease of use.

1.3 Report outline

This study report is organised in the following sections:

- **Chapter 2** outlines legislation and guidance relating to carbon and the water sector;
- **Chapter 3** examines the various options for water supply and demand management;
- **Chapter 4** explains the carbon "footprint" concept and methodology for this study;
- **Chapter 5** presents the carbon cost assessment model;
- **Chapter 6** presents the carbon cost of standard supply/demand management options;
- **Chapter 7** illustrates the carbon costs for some example South East options;
- **Chapter 8** sets out the conclusions and recommendations of this study.

2 Carbon reduction

2.1 Overview

The Stern Review calls for global action on climate change and suggests reduction targets for global carbon emissions. This chapter explains the UK strategy to address climate change, stemming from the Stern report and set in legislation. We explain the current Defra guidance on carbon cost assessment, and how this relates to the Environment Agency's guidance on water resources planning. This study adopts Defra's guidance in carbon cost assessment within its methodology.

In subsequent chapters we evaluate how different water supply and demand management options compare in terms of total greenhouse gas (GHG) emissions. This focus on both demand management and supply side options is consistent with the Environment Agency's twin-track approach to water resources planning.

2.2 Carbon and energy use in water resources

As carbon dioxide is a major contributor to climate change, the need to offset or reduce carbon production has risen high in national and international political agendas.

The Government has identified a significant potential to reduce carbon cost-effectively, and to promote energy efficiency. There are a number of initiatives to this work, such as the Climate Change Bill and the proposed Carbon Reduction Commitment. The Bill proposes five-yearly targets to reduce carbon dioxide and at least a 60 per cent reduction by 2050 compared to 1990 levels.

The water and wastewater sectors fall within these initiatives. Many large scale resource development options such as desalination, pumped storage reservoirs and effluent re-use are recognised as relatively energy intensive both in terms of operation and construction. Demand management may result in lower energy use, which could offset future energy pressures and reduce carbon emissions. However, the evidence base for GHG associated with different strategies is fairly poor; this study seeks to clarify the relative carbon impact between new water resources and demand management.

2.3 Stern Review

The Stern Review stated that the risks of the worst impacts of climate change can be substantially reduced if GHG levels in the atmosphere can be stabilised between 450 and 550 parts per million (ppm) CO_2 equivalent (CO_2e). The current level is 430ppm CO_2e, rising at more than 2ppm each year.

Total emissions are predicted to continue to rise for the next 10 to 20 years, but then they need to fall by at least 1 per cent to 3 per cent per year. Stabilisation will require global emissions to be at least 25 per cent below current levels by 2050. Any delay in reducing emissions will miss the opportunity to stabilise at even between 500 and 550ppm CO_2e.

2.4 Climate Change Bill

Climate change legislation will form a fundamental part of the UK's strategy to tackle climate change and address the issues raised by the Stern Review. The Climate Change Bill sets the UK's target to reduce carbon dioxide emissions through domestic and international action by 26-32 per cent by 2020 and at least 60 per cent by 2050, against a 1990 baseline.

The Bill contains enabling powers to introduce new trading schemes, such as the Carbon Reduction Commitment (CRC), through secondary legislation. The CRC will target emissions from energy use by large organisations whose annual mandatory half hourly metered electricity use is above 6,000 MWh. This scheme focuses on those emissions outside the Climate Change Agreements (CCAs) and outside the direct emissions covered by the EU Emissions Trading Scheme (EU ETS).

The CRC, which is likely to be introduced in 2010, will cover the water sector and require all water companies to participate in a cap and trade scheme for carbon emissions. It will provide an additional driver for water companies to put a price on their carbon emissions for planning purposes.

Our study is based on the Shadow Price of Carbon (SPC) methodology set by Defra for carbon cost assessment. Given the CRC is still being developed at this time we have not attempted to capture the implications of this scheme for water companies - this is an area for future study as more guidance comes to light.

2.5 The Government's water strategy for England

Future Water published in February 2008 sets out the Government's vision for sustainable delivery of secure water supplies and an improved and protected environment.

The water strategy emphasises the key role of the water sector in mitigating climate change by taking action to reduce their GHG emissions wherever possible. These emissions arise primarily from water treatment, supply and wastewater disposal activities, and from water use by customers.

The strategy document provides the following data on water industry GHGs:

- emissions arise from abstracting, pumping, treating and heating water and treating and pumping wastewater in the water sector;
- In 2006/07 the water industry used almost 7,900 GWh of energy for its operations with emissions (CO_2e) of over five million tonnes;
- around 56 per cent of these emissions derive from wastewater, 39 per cent from water supply and five per cent from administration/transport by the water industry (2005/06).

The strategy further highlights that the use of hot water in homes for such things as personal and household washing, cooking and cleaning, but excluding that for heating the home, contributes roughly 35 million tonnes of GHGs (CO_2e). This is seven times as much as that emitted by the water industry, and amounts to over five per cent of total UK emissions.

Water efficiency measures are cited as a real "win-win solution" as they reduce energy use and water use, thereby reducing GHG emissions. Those measures that focus on reducing hot water would result in much larger energy savings.

The strategy concludes that the need for adaptation to climate change as well as its mitigation is unquestionable. The impact of climate change must be fully considered and integrated in all water policy and management.

2.6 Placing a value on greenhouse gas emissions

Defra guidance sets out how to value GHG emissions based on the concept of the Shadow Price of Carbon (SPC), which supersedes the Social Cost of Carbon (SCC). The SPC captures the estimated damage costs of climate change caused by each additional tonne of GHG emission, expressed as CO_2e.

The Defra guidance defines the following approach:

- Step 1: quantify the impact on GHG emissions - in tonnes of CO_2e;
- Step 2: calculate the SPC schedule over the planning appraisal period set alongside the GHG quantities saved, as illustrated in Figure 2.1 (extract from Defra interim guidance document);
- Step 3: multiply each year's GHG quantities abated/emitted (CO_2e) by SPC;
- Step 4: use these monetised GHG values in cost-benefit analysis.

The SPC thus depends on the year the carbon is abated/emitted. In 2007 the SPC is £25.5 (per tCO_2e), rising at two per cent per annum to £26.0 in 2008 and £50 in 2040. We use only this uplift in our carbon-cost assessment and exclude others such as the Retail Price Index (general purpose domestic measure of inflations). The cost-benefit analysis follows Treasury Green Book guidance.

Table 2: SPC from 2007 to 2050 (in 2007 prices)

Shadow Price of Carbon in 2007 prices (£/tCO2)

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
SPC in 2007 prices and with 2% pa increase	25.5	26.0	26.5	27.0	27.6	28.1	28.7	29.2	29.8	30.4	31.0	31.6

2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
32.3	32.9	33.6	34.3	34.9	35.6	36.4	37.1	37.8	38.6	39.4	40.1	40.9	41.8	42.6	43.4

2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
44.3	45.2	46.1	47.0	48.0	48.9	49.9	50.9	51.9	53.0	54.0	55.1	56.2	57.3	58.5	59.6

Figure 2.1 Schedule of Shadow Price of Carbon (CO_2e)

The SPC captures the damage costs of climate change caused by each additional tonne of GHG (CO_2e) emitted, i.e. it reflects the adaptation costs under a 'business as usual' scenario assuming society does nothing to mitigate the climate change effects. However there remains great uncertainty about the damage and adaptation costs for climate change and rising sea levels, and the costs of failing to take early action.

Sensitivity analysis around key variables is fundamental to any appraisal. It is important to test the vulnerability of options to unavoidable future uncertainties. Defra guidance requires that sensitivity analysis consider a +/-5 per cent change in the SPC.

There are considerable uncertainties surrounding estimates of the impacts of climate change and the value of the SPC[13]. Research continues, e.g. by the Meteorological Office Hadley Centre (Integrated Climate Change Programme), Intergovernmental Panel on Climate Change and the wider academic community.

SPC is one of a number of ways to value carbon, and is currently recommended for the assessment of policy by Defra. One alternative method of calculating SPC, based on the global marginal abatement costs (MAC) required to meet a given stabilisation goal, is under assessment by the Government[13]. The initial indications are that the current SPC is consistent with meeting global stabilisation and goals for reducing national emissions.

2.7 Water resources planning - Environment Agency guidance

Environment Agency guidance on water resource planning, updated in September 2007, explains how to include the SPC (for capital and operating costs) in the appraisal of options. The guidance requires that water companies should:

- include the cost of carbon in option evaluation;
- base this cost on calculations of average incremental social costs (AISCs, defined below and in Section 2.10);
- present the total carbon (tCO_2e) of water supply activities per year.

The average incremental social cost (AISC) is the standard term used for assessing water resource options as defined in the Economics of Balancing Supply and Demand[5].

This study presents our preliminary investigations of water supply and demand options by calculating the total carbon:

- specific to an option;
- specific to the option, but combined with other water supply, use and disposal activities (expressed as AISC for the carbon component only).

2.8 UKWIR carbon accounting guidelines

UKWIR are developing guidelines[20] (draft, March 2008) to assist water companies in CO_2e costing for asset planning. While its first use is expected to be in justifying investment for PR09, the guidelines are also intended for water resources planning and options appraisal at a project level.

The guidelines cover:

- embodied carbon estimating and emissions values;
- whole life carbon costing;
- worked examples and case studies.

One objective of the UKWIR guidelines is to ensure that water companies present plans to Ofwat based on the same core data and assumptions so that like-for-like comparisons can then be made.

The guidelines are aimed at detailed CO_2e costing of supply-side options, whereas our 'high level' study presents a strategic framework with which to compare the full range of water resource options, including demand management, across the water supply-use-disposal system.

Thus there are hierarchical (detailed versus strategic) and boundary (supply side versus water system) differences between the UKWIR guidelines and our study. The approach to whole life costing is the same, following Defra guidance (Section 2.6).

2.9 Ofwat's carbon accounting requirements

Ofwat recently introduced a new carbon accounting requirement; water companies must report operational GHG emissions associated with the provision of water, wastewater and sludge disposal - to be reported in their 2008 June return. The UKWIR Phase 1 carbon accounting methodology (2008), based on the Water UK methodology (2007), is to be used.

Total emissions calculated according to the CRC and the Defra guidance (Section 2.6) are required (i.e. two outputs), should include direct sources owned or controlled by water companies, and indirect sources arising from a water companies activities. The figures are to exclude supply chain emissions from manufacture/transport of consumables (e.g. chemicals) and embedded carbon emissions (e.g. manufacture/transport of construction materials).

There is a further requirement for water companies: '…to make informed judgements about the validity of the emission estimates…', and to advise the reasons behind any omissions.

Ofwat has also obliged companies to report, in their business plans for 2010 to 2015, their projected carbon emissions (both operational and embedded) and the associated net present value (NPV) of these emissions as part of a cost benefit analysis (CBA) to demonstrate cost beneficial solutions.

2.10 Comparing carbon costs of different options

It is difficult to compare directly the carbon costs of different options (water supply and demand management) as calculations must use a common basis that takes into account different water yields or savings, asset life, total carbon emissions, and an annual rising SPC.

The use of NPV techniques is a standard method used in water resources planning to determine a least social cost solution. The discounted unit cost for both supply and demand options can be defined as the present value of the option cost over a time horizon divided by the present worth of water actually delivered over that time. The same principle can be applied when comparing the carbon costs of different options.

The AISC is the standard term used for options appraisal in water resources planning.

The AISC is the ratio of total capital and operating costs for a scheme, including one off and annual social and environmental costs, per volume of additional water supplied or reduced demand, discounted over a defined period of time. The unit of measure is pence per metre cubed (p/m^3). The ratio represents the net present value of social costs over the net present value of additional water supplied or reduced demand. A low value represents a low social cost.

For this study the average incremental ratio is referred to as the average incremental carbon cost (AICC), in the same way as AISC used in water resources planning but based only on carbon costs (calculated using SPC) and excluding other social costs. Thus AICC is the ratio of total capital and operating carbon costs for a scheme, calculated based on net present value (NPV) as follows:

$$\text{AICC (p/m}^3\text{)} = \frac{\text{CAPEX + OPEX - Saving}}{\text{Water x 10}}$$

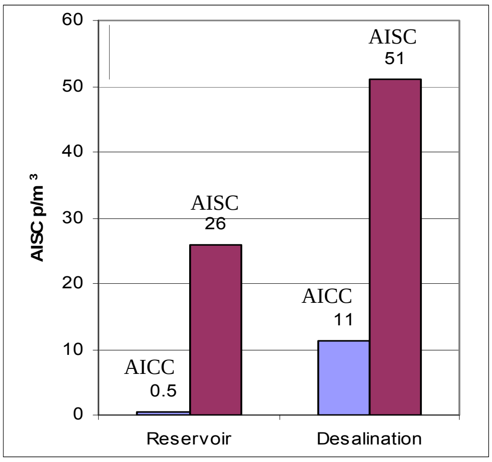
where

CAPEX:	NPV capital expenditure as carbon cost (£)
OPEX:	NPV operating expenditure as carbon cost (£)
Saving:	NPV water saving as carbon cost if demand management (£)
Water:	NPV water delivered or saved (mega-litres, Ml)

The NPV sums the annual carbon costs/savings over the planning period, with future costs/savings discounted using discount rates from the Treasury Green Book. This requires that for projects with very long-term impacts, over thirty years, a declining schedule of discount rates should be used rather than the standard discount rate (3.5 per cent).

Our study adopts a planning period of 60 years, with the discount rate set at 3.5 per cent for years 1 to 30 and 3.0 per cent for years 31 to 60, based on the schedule of long-term discount rates recommended in the Treasury Green Book (Annex 6).

For illustration, Figure 2.2 compares the AISC and AICC calculated for two supply-side options, a new reservoir scheme and a new desalination plant. The carbon cost for desalination is relatively high due mainly to operational costs.



Note: AICC is a subset of the AISC. The values shown represent the carbon footprint to construct and operate the supply-side option only, and exclude the carbon for other components of the water system, as assessed later in this report.

Figure 2.2 Average Incremental Social Cost compared with CO_2e Cost

As well as AISC, the development of marginal abatement cost curves (MACC) is another useful tool used in developing policy. Such an approach could be trialled in further study.

2.11 Related international studies

The energy and associated carbon impact of the water sector has been investigated in a number of international research projects. Of particular note is the Natural Resource Defence Council "Energy Down the Drain" research that concerns California's water supply[25] and the Australian university research (Monash University, Melbourne)[24] that examines the potential of water demand strategies to reduce the GHGs associated with urban water systems. We have reviewed these and other studies and include appropriate cross-references in this report.

3 Water supply & demand management options

3.1 Overview

This chapter identifies the individual options for water supply and demand management (including water-use efficiency). We calculate the GHG emissions of these options following the methodology explained in Chapter 4 and the assessment framework described in Chapter 5. The carbon footprints of these options are presented in Chapters 6 and 7.

3.2 Options considered

Water supply and demand management options were identified through a literature review. A key reference is the UKWIR (02/WR/27/4) Economics of Balancing Supply and Demand[5] .

The options considered include:

- Supply options - storage reservoirs; regional water grids via transfer pipelines; desalination plant to make seawater and brackish water drinkable; effluent re-use (indirect); groundwater and river abstractions;
- Demand management options - water saving devices for toilets, showers and baths; water meters; water efficient domestic appliances; rainwater collection systems; grey-water recycling (i.e. water from showers, baths and sinks used for toilet flushing); reductions in water mains leakage.

Table 3.1 lists the supply options and Table 3.2 the demand management options.

Table 3.1 Water supply options

Options	Sub-types	Details relevant to energy use and carbon emission
Reservoir	- bankside - bunded - raising existing - pumped - quarry area	- high capital investment involved - medium operating cost - long development period, say 15 to 20 years - potential for major impact on local environment
Desalination plant	- reverse osmosis - electrodialysis - nanofiltration - offshore	- treatment of brackish or saltwater to produce drinking water - costs and energy usage depend on water salinity - generates highly saline waste to be disposed of - treated water needs hardening
Effluent reuse - assessed only indirect schemes	- conventional - reverse osmosis - reed bed - nanofiltration	- sewage treatment works discharges treated water into rivers for re-abstraction downstream - main concern over protecting public health - unplanned effluent re-use commonplace in UK - cost and energy usage depend on effluent quality
Groundwater	- boreholes - aquifer storage recovery - river/stream augmentation	- accounts for large proportion of public supply - can be used to augment flow in rivers/streams - energy consumption depends on borehole depth - treatment cost depends on aquifer type but generally lower than for surface water source
River abstraction	- to water treatment works or reservoir	- relatively low cost to construct/operate - treatment normally multi stage
Transfer	- pipelines	- transfer of supply from surplus, to deficit areas - energy depends on pumping length/head/capacity

Table 3.2 Demand reduction options

Options	Sub-types	Details relevant to energy use and carbon emission
Leakage management	- supply - distribution	- active leakage control to find/fix leakages - pressure management for optimal pumping - water (mains) distribution pipeline replacement - monitoring to identify leakage problems
Metering	- voluntary - compulsory - occupancy change - smart and tariffs	Implementation of various metering and tariff (rising/seasonal) schemes in order to change water usage habits.
Water audits	- domestic, - commercial - publicity campaign	Individual household, community-level and commercial water audits by a professional team and wide-scale publicity campaigns.
Water saving devices	- toilet - bath - showers*	Retrofit devices such as low/variable/dual flush devices, cistern displacement devices, low-flow taps, low flow shower heads, flow regulators, lower volume baths.
Domestic appliances	- water efficient white goods*	Water efficient dish washers and clothes washing machines.
Garden appliances	- water butt - hose timer - trigger hose nozzle	Water-saving products in the garden to store water for plant watering and reducing hose usage.
Harvesting/ reuse technologies	- rain water - grey water - black water	Individual household and community level systems to store/treat/re-use rainwater or wastewater from showers/ basins and toilet.
Non-households and non public water supply - not assessed		

*energy efficiency savings of these products were not assessed for this study

3.3 Options for water supply

We examine water supply options based on data from water companies held by the Environment Agency. The schemes have a deployable output ranging from 2-350 Ml/d.

We use the information on proposed and actual schemes as input to the carbon life-cycle model. Using a variety of schemes enables understanding of the range of carbon associated with building and operating, for example, new reservoirs, as well as comparing the carbon impact of different scheme types.

- Reservoir: impounded storage of surplus water during the winter/spring, with run-of-river or bankside (bunded) storage options. Alternatives include raising the level of existing bunded storage sites or using quarry sites.
- Desalination: treatment of brackish or saltwater for water supply, with the lower salinity of brackish water requiring considerably less energy in the treatment process. This process can include water hardening.
- Effluent reuse (we assessed only indirect schemes): treatment of wastewater effluent to a sufficiently high standard for it to be transferred via pipeline and discharged to a river or reservoir for indirect reuse downstream.
- Aquifer storage and recovery: recharging of aquifers via boreholes using surplus (treated) winter/spring water which can then be re-abstracted in the peak summer months.
- River augmentation: involves groundwater abstraction from borehole(s) ideally located close to the river, with the abstracted water requiring some basic treatment before discharge into a river.
- Direct run-of-river abstractions: river offtake works and pipeline.
- Transfer pipeline and pump station(s): water transfer across river catchments.

3.4 Options for water demand reduction

In the last ten years there has been moderate progress in reducing the demand for water. Water companies have reduced their levels of leakage and the importance of metering, water efficiency devices within households and other options is now widely accepted. However, there remains much scope for greater water efficiency within households and non-households (i.e. industrial, commercial and public sector premises).

Structural and non-structural approaches to reduce water demand are examined.

- Structural measures improve the efficiency of the end uses of water. Examples of structural measures include the replacement of inefficient toilets, showers (or showerheads), dishwashers and washing machines with more efficient models.
- Non-structural measures require behavioural change to reduce water demand. Examples of non-structural measures include shorter shower times, reduced toilet flushing (e.g. by increased use of the half-flush facility on toilet cisterns) and garden watering using non-potable water.

This study considers how water demand can be reduced through leakage management and water efficiency measures within households. Non-households (i.e industry and agriculture) have not been considered because data are too limited. We therefore consider the greenhouse gas impacts of water savings on 70 per cent of the public water supply (22 per cent leakage and 48 per cent household)[7].

The subject of water demand reduction has been widely studied. Our focus is on the more common options listed in Table 3.2 and their carbon implications, rather than detailed appraisal for every circumstance.

Any estimate of water savings will be uncertain, and as higher water efficiency standards are introduced it will limit the opportunity for further efficiency. We recognise that there is no 'standard' household, and no single 'package' of options for optimal water efficiency. Different options are appropriate for different situations, but for the purpose of this strategic appraisal we have adopted a set of average parameters.

Research continues to improve the understanding of how effective managing demand can be. Examples include the recently completed Water Cycle Management for New Developments (WaND) project that examines water cycle management for new developments, and the metering tariff trials by Folkestone and Dover Water Services. Performance data on new technologies are also held by suppliers of bespoke recycling systems.

The water savings that can be achieved and sustained over the longer term rely on effective awareness raising and behavioural change - these are important non-structural elements. Our baseline simply assumes that options for water demand reduction are effective, as any assessment of sensitivities is outside the scope of this study.

One adverse effect of reduced water demand is the possibility that reduced flow in sewerage systems can lead to blockage problems, extra costs to maintain, etc. In contrast, the impact downstream on the sewage treatment works can be beneficial, with extended life of treatment components due to reduced (hydraulic) loading.

The following sections set the baseline parameters we have adopted for leakage management, water savings from metering, household products, water audits of households, and the more innovative technologies of rainwater harvesting and greywater recycling for household supply.

3.4.1 Water savings - leakage management

Leakage occurs in all distribution and supply systems, and is governed by the condition of the pipes, the operating pressure and how well leakage problems are monitored and addressed. From an economic perspective, the cost of any measures to reduce leakage must be less than the cost to produce the water from another source. Target levels for reducing leakage are set that balance the needs of water users and the environment.

The current leakage target for the water sector, set by Ofwat, will see leakage fall by eight per cent in 2010 (to 3,320 Ml/d) from the 2004/05 baseline level of leakage (3,608 Ml/d).

Ofwat's reported leakage data for 2006/07[16] identify:

- 2,545 Ml/d distribution losses from the water companies' system
- 873 Ml/d supply losses from property owners' underground pipes

Ofwat data reported for 2005/06[17] gives a further breakdown:

- Distribution losses of 149 l/d per property and 11 m^3/d per kilometre of pipeline
- Supply losses of 43 l/d per property
- 335,000 km of distribution pipeline and 24 million property connections

Options for leakage control from water mains and service pipelines include:

- Customer reporting of leaks
- Water company detection
- Pipeline renewal as part of a planned asset renewal programme
- Pressure management initiatives

Leakage data, including data specific to carbon emissions, are taken from Ofwat's guidance on the economic level of leakage[15]. This guidance includes example data on carbon emissions connected with different leakage control activities. Water company data (Wessex Water) are also referenced in this study's analyses.

3.4.2 Water savings - metering

Water metering plays an important part in decreasing the demand for water, by reducing general water use in the home and also helping to detect leaks. An increasing number of households receive a metered supply (i.e. they pay for water in relation to the amount they use). All new properties are now metered.

The number of houses with a water meter has increased since 2000. Over 6.5 million households (29 per cent) now have a metered supply compared to 3.5 million (16.5 per cent) in 2000[7].

Meter penetration is highest in the east and south west England. Tendring Hundred Water, Anglian Water, Cambridge Water and South West Water all meter over half of households. Portsmouth Water has the lowest meter penetration in England and Wales at less than eight per cent.

Metering offers households a financial incentive to reduce their water use. Not only can households cut their water bills, but by using less hot water, they benefit from energy savings as well.

Water metering can achieve an average water saving of 10 – 15 per cent per household (35-52 l/d assuming 147.8 per capita consumption[21] and a 2.36 occupancy rate (Office of National Statistics), and possibly more. This water efficiency saving could be further increased with the introduction of "smart" metering and structured tariffs, for example rising block and seasonal tariffs.

3.4.3 Water savings - household products

There are several options for reducing domestic water demand. Significant water savings at point of use are possible by retrofitting existing homes with water efficient products.

Water companies offer advice about ways to use water wisely. Many issue free toilet cistern devices and have other initiatives to cut the amount of water used in the home and garden. Choosing water efficient appliances when replacing old machines (such as dishwashers and washing machines) also helps to reduce the amount of water used in the home.

For a "standard" home, a breakdown of average household water use into micro components is given in Table 3.3, taken from Defra's Future Water[4] (page 39). This table includes a breakdown of a standard home and the same home fitted with the best available water saving products. Based on these figures, water use in the home can be reduced by 28 per cent (from 150 to 108 l/d per capita). Since 2000, water consumption per person has not changed significantly in almost all areas of England and Wales[7].

One of Defra's Future Water[4] targets is for average water consumption to fall to 130 l/d per capita by 2030, or possibly 120 l/d depending on technological innovation. These targets represent water savings of 12 per cent and 19 per cent respectively. The current average water consumption is about 147.8 l/d per capita[21], which means the average in the home is about 350 l/d per property (based on a 2.36 occupancy rate - Office of National Statistics).

Future technological innovation could further improve water savings and some household products on the market (for example waterless compost and vacuum toilets) could provide even greater efficiency gains. They are excluded from this study, however, as they currently have very limited uptake.

Water efficiency rates for new homes are specified in the Code of Sustainable Homes (CSH)[1]. Table 3.3 summarises usage rates for a standard home (as defined in Defra's Future Water[4]) and water efficient homes defined by CSH levels. Figures for this table are taken from our Thames Gateway study[12].

This study uses this baseline data to assess water savings at a micro component level. (i.e. individual items within a home).

Table 3.3 Targets for water use in new homes

Micro component	**Water use** (l/d/capita)			
	Standard home	CSH Level 1/2 (120 l/d/capita)	CSH Level 3/4 (105 l/d/capita)	CSH Level 5 (80 l/d/capita)
Toilet flushing	28.8	19.2[(b)]	16.8[(d)]	8.4 (8.4)[(f)]
Taps[(a)]	42.3	31.8	24.9	18
Shower	30.0	24	18	18
Bath	28.8	25.6[(c)]	25.6[(c)]	22.4[(e)]
Washing machine	16.7	15.3	15.3	7.65 (7.65)[(f)]
Dishwasher	3.9	3.6	3.6	3.6
Recycled water[(f)]	-	-	-	-16.1
Total per capita	**151**	**120**	**104**	**78**
Outdoor (garden)	11.5 – assumed	11.5	11.5	11.5
Total per home	**367**	**294**	**257**	**196**

Notes: [(a)] combines kitchen sink and wash hand basin [(b)] 6/3 litre dual-flush toilet
[(c)] 160 litre bath filled to 40% capacity, frequency of use 0.4/day
[(d)] 4.5/3 litre dual-flush toilet [(e)] 120 litre bath
[(f)] recycled water by rainwater harvesting (figures in brackets)

3.5.4 Water savings from variable tariffs - household level

Variable tariffs offer a financial incentive to use less water. Variable tariffs include rising-block tariffs that apply higher unit rates for each unit of water above a certain threshold, or seasonal tariffs, where water costs change depending on the time of year, typically becoming more expensive during summer when demand is higher. Our Thames Gateway study[12] assumed (for modelling purposes) that variable tariffs could reduce demand by 5 per cent, additional to 10 per cent from metering, at relatively low costs.

3.5.5 Water savings from audits - household level

Only limited data are available regarding the water savings that arise following household water audits. We found reference to a study by Essex and Suffolk Water (2004) that estimated water savings of just 11 l/d per household following the distribution of self audit packs. This saving is just over three per cent of total household water use. Whether this moderate level of water saving can be sustained into the future is not known.

3.5.6 Rainwater harvesting & greywater recycling

Rainwater harvesting systems collect, store and use rainwater for non-potable use. They require large tanks, normally underground, for storing intercepted rainwater, coupled with a treatment unit (filter) and pump, header tank (in loft) and separate pipework to allow the use of rainwater for toilet flushing, washing clothes and external uses of water (e.g. gardening, car washing). The header tank draws on the mains water as a supplementary supply.

Although not common in the UK, household rainwater collection systems are becoming more proven technology in countries such as Germany and Holland. But only limited data are available on community scale systems. The general view is that their overall impact can be less than household systems.

Rainwater requires only basic filtration treatment before use in toilets and for washing clothes. Rainfall frequency dictates the size of storage tank, which should typically hold at least two weeks supply. Storage tanks underground are preferred as the low and fairly constant water temperature limits algal growth and other water quality problems. For this reason, treated rainwater should be pumped direct for use, without a header tank.

Greywater systems collect, store and treat water from domestic appliances (not toilets or bidets), and delivers non-potable water for toilet flushing and external use. They require large tanks, normally underground, for storing greywater (filtered), coupled with a pump, treatment unit (filter, disinfection), header tank and separate pipework. The header tank draws on the potable mains water as a supplementary supply.

Greywater requires additional treatment (filtration, biological and ultra-violet) compared with rainwater systems and this increases the energy usage. One manufacturer suggested about one third higher, quoting 0.6 kWh per day for a standard home. Storage tanks can be sited within the home, ideally in a cellar or garage, for ease of access. One manufacturer advised of new technology that can recycle the heat of bath/shower wastewater for heating the home. This is not assessed for this study.

Rainwater and greywater systems require energy to operate pumps, although data is scarce and actual energy usage depends on the configuration. Public acceptability over recycling water non-potable use in the home is a potential issue, although rainwater harvesting systems are becoming more widespread in commercial premises, and achievement of the Code for Sustainable Homes (CSH) level 5/6 criteria does require harvesting.

One supplier claims very limited energy needs for the latest technology in greywater system - minimal energy for treatment of greywater prior to reuse, and to pump water to the first floor level (toilet filling), with gravity feed to the ground floor level (toilet and washing machine). The same supplier advised that systems can recycle heat from shower/bath wastewater, reducing the energy for space heating in the home.

A more basic greywater system can be used for external water use. An example is the DroughtBuster that reuses bath, shower or sink water - the system has no mechanical parts, and simply delivers water via a hosepipe into the garden. Water savings of 25 per cent of external use are claimed by the manufacturer.

3.5.7 Publicity campaigns by water companies

Not considered in this study as no reliable evidence was found.

3.5.8 Non-household & non-public water supply

Not considered in this study because of a lack of available data, but should be explored in future study.

3.5 Scale issues

This study assesses a number of demand reduction options at the level of households and wider community. We do this because we believe there are potential benefits for reducing energy usage and lowering carbon emissions by operating innovative technologies, such as rainwater harvesting or effluent recycling at a scale wider than individual households.

Installing and operating the harvesting and/or water recycling measures individually in new homes may increase energy demand. But economies of scale may exist if these technologies are incorporated into new developments of several hundred homes or more. These technologies offer greater potential for new homes rather than as retrofit solutions on existing homes.

4 Methodology

4.1 Overview

This chapter explains the carbon footprint concept and life-cycle analysis we apply to estimate the carbon emitted by water supply and demand management options. The boundaries adopted in the carbon cost calculation are discussed, as are the inter-relationships between them. The assessment framework is then described in Chapter 5 and the calculated carbon footprints of the options are presented in Chapter 6.

Our study only considers the carbon costs associated with different options; no other scheme costs are considered and this should be borne in mind when interpreting the results presented in subsequent chapters of this report. Results from this study should be considered in conjunction with other inputs to the planning process such as economic, environmental and social costs.

4.2 Outline methodology

Our methodology first estimates greenhouse gas (GHG) emissions and then expresses them as carbon dioxide equivalent emissions (CO_2e). The calculation for the different water supply and demand management options considered are based on life-cycle analysis, using published data on water efficiency measures, energy usage, GHG emissions and water supply options. In this analysis we treat water as the 'product' and calculate the carbon footprint of the main input, output and unit processes.

This study assesses the carbon 'footprint' for each of these options outlined in Chapter 3 and then places a value on them by using the Shadow Price of Carbon (SPC). We assess:

- individual water supply options;
- individual demand reduction options;
- commonly combined demand reduction options;
- illustrative planning scenarios for the South East of England.

We take a strategic look at the carbon implications of the above, and focus on new water supply options and the introduction of demand management measures within an existing water supply network. Our main assessment work was completed over a four month period - by necessity we took a broad-scale approach as it can take many months of detailed appraisal to accurately assess the carbon emissions for a single option.

4.3 Carbon footprinting

A carbon footprint is a measure of the impact that human activities have on the environment in terms of the amount of greenhouse gases (GHG) emitted over the full life cycle of a process or product measured in units of carbon dioxide (CO_2). Non-carbon GHG (e.g. methane) are converted to CO_2-equivalent (CO_2e).

The carbon footprint specific to water resources planning and the emerging price review 2009 (PR09) options is a new area of work, with knowledge as to how the proposed options to meet future water demand and efficiency compare in carbon cost terms beginning to emerge.

Water UK reports energy and climate change data for water companies, including the carbon emissions data for the last three years, summarised in Table 4.1. Over the longer term, the water sector typically reports energy use has doubled since the early 1990s. Such data are useful to identify general trends for the water sector, but do not enable understanding of optimum future options from a carbon perspective.

Table 4.1 Water UK GHG Emissions Data

GHG emissions (tonnes)[1]	2004/05	2005/06	2006/07
Total CO_2e (million)	4.14	4.15	5.03
In supplying 1 Ml water	0.249	0.289	0.271
In treating 1 ML sewage	0.641	0.406	0.476

[1]Figures taken from Water UK Sustainability Indicators 2006/07 report

Given the growing drivers on pricing carbon outlined in Section 2, information on the carbon footprint of different elements of the water supply chain will be increasingly useful.

The Carbon Trust, in conjunction with 14 water companies, assessed in 2007 the contribution of greenhouse gases to total water industry emissions as:

- carbon dioxide – 74 per cent
- nitrous oxides – 14 per cent
- methane – 12 per cent

Carbon 'footprint' calculation tools are available. The Environment Agency, for example, developed a carbon-wise construction project tool that aims to promote resource efficiency and reduce carbon emissions for construction projects.

However, such tools are not designed for life-cycle assessment. The energy to operate rather than construct is consistently the most significant source of GHGs when taken over the life-cycle[24]. For this purpose our study developed a carbon cost model of water supply and demand options.

Figure 4.1 illustrates carbon footprinting for a water supply scheme in construction and operation.

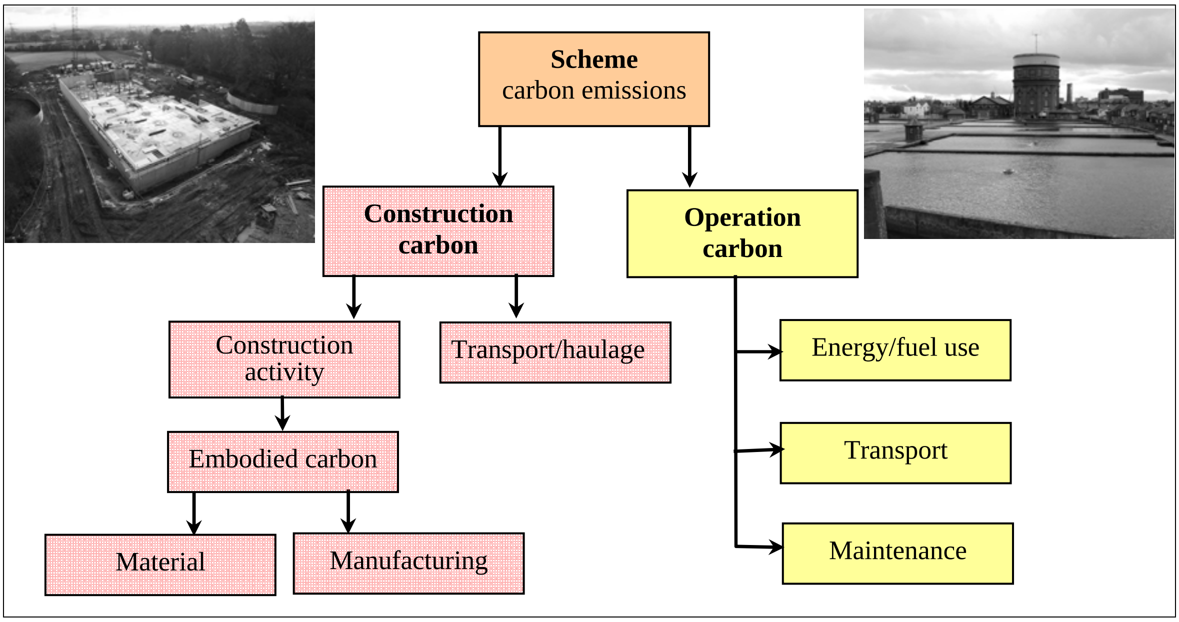


Figure 4.1 Illustration of carbon footprinting for a scheme

4.4 Life-cycle carbon emissions

The life-cycle approach examines the carbon emissions associated with different phases in construction, manufacture, installation, maintenance and operation. In this study we focus on:

- **Water supply** – key emissions from construction, including transport and embodied energy, maintenance, operation and distribution, and the emissions from water use in the home and in wastewater treatment.
- **Demand reduction** – key emissions from manufacture, installation, maintenance and operation, and the net benefit of avoided abstraction, distribution, use in the home and wastewater.

The embodied GHG of a product can be defined as the total CO_2e emitted during its life-cycle, including for example, emissions from the extraction and processing of raw materials, manufacturing and secondary processing (e.g. factory lighting, transport, etc), packaging, energy consumption during use and maintenance. The deconstruction, recycling and/or disposal of assets can also be included, but these are not considered in this study due to the lack of available information - this is an area for future study.

Water supply options include high capital investment to build new reservoirs and high energy costs to operate desalination. Apart from leakage control, demand management primarily impacts at household level, such as metering and low water use devices such as toilets and showers, but in some cases can extend to a community scale, such as rainwater harvesting, grey-water and effluent reuse.

Estimates are made of the carbon emissions and carbon cost relating to the capital works for water supply options (Figure 4.1), and the manufacture and installation of demand reduction options. In addition, the life-cycle assessment covers the operational energy usage across the water supply-use-disposal system for both supply and demand options (Figures 4.1 and 4.2).

The estimates are based only on the main option components that are likely to have the most (carbon) impact, namely:

- the manufacture of construction materials
- energy usage during the capital works
- energy usage during operation

We consider only one energy source - power supply (electricity). The operational energy usage is based on the number of days a year that the option is used, which is determined by whether the scheme is designed for peak demand use only or throughout the year.

No attempt is made to consider different fuel types, such as renewable energy, or carbon efficient construction/production methods, as these are outside the scope of this study.

4.5 Boundaries

Defining the boundaries for assessing GHG emissions is an essential first step to this study. The abstraction, treatment, distribution and household use of water, treatment of wastewater and the disposal of sludge all use energy and contribute to GHG emissions. A broad picture of water sector emissions and energy use is presented in Defra's Future Water[4] and reproduced in Figure 4.2. The shading represents areas investigated in more detail in this study.

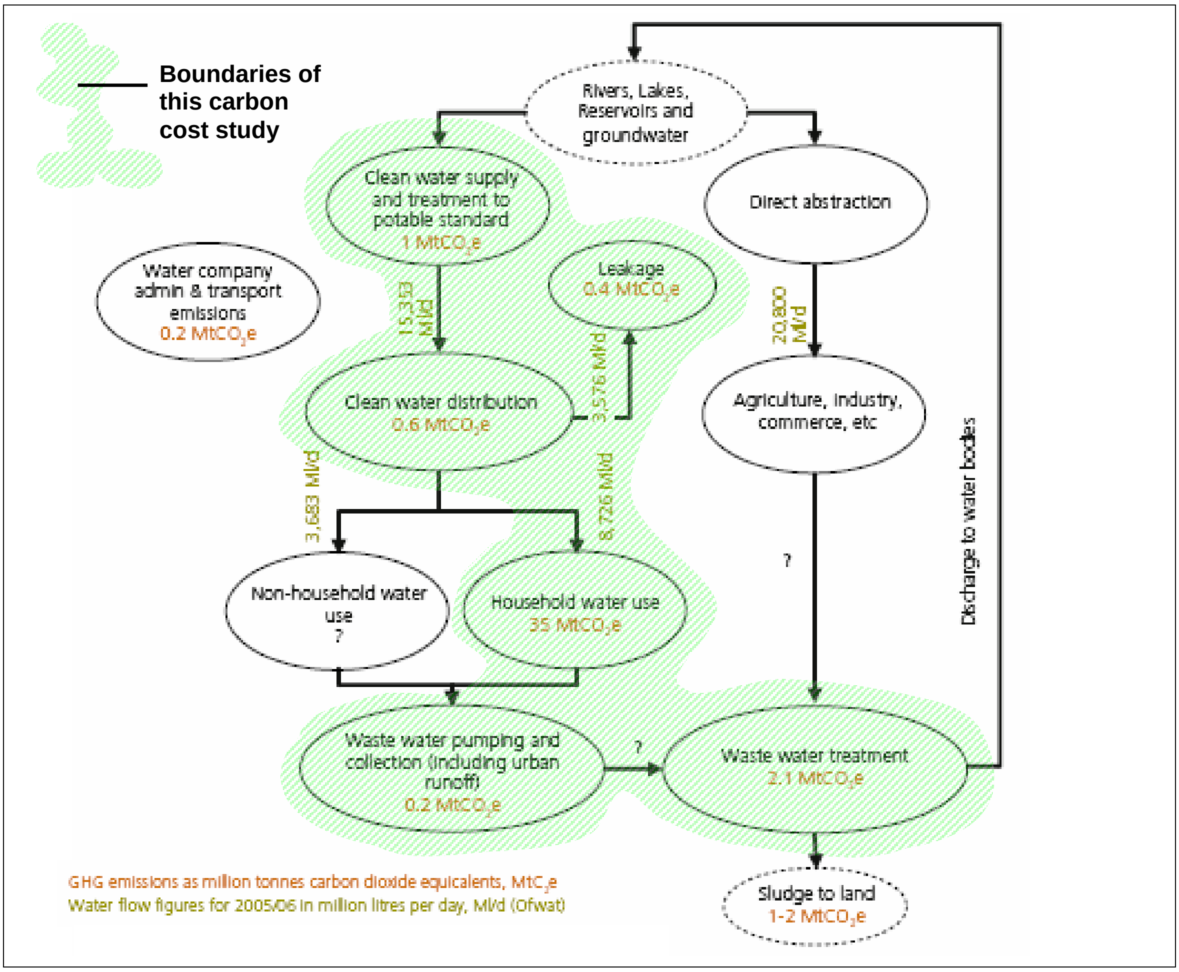


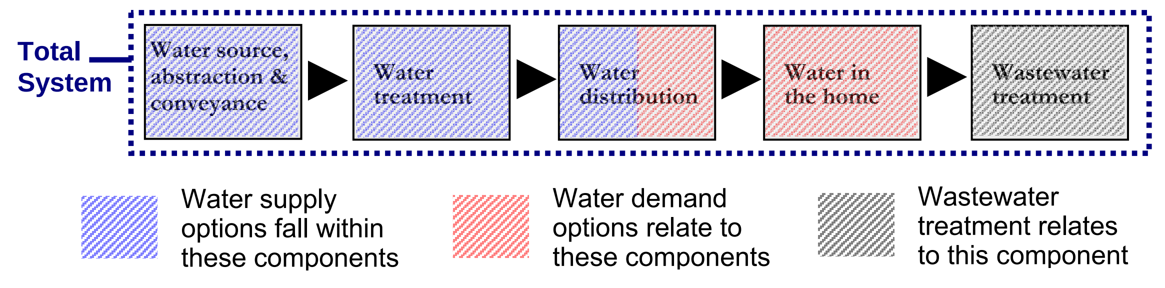
Figure 4.2 Water sector greenhouse gas emissions, 2005/06
(Source: Defra Future Water[4], Figure 12 reproduced above)

Our study identified five key activity areas that encompass the water supply-use-disposal system for public water use (Figure 4.3). Defining energy use and from there, carbon emissions, for each component allows us to examine the impacts of different water supply and demand management options on total carbon.

While the study focuses on the carbon associated with water supply and demand options, we cannot ignore the impact that changes in these will have on other components, such as the amount of treatment, distribution and wastewater treatment.

The carbon implications of using less water are widespread. As an example, lower water use in the home potentially results in carbon reduction benefits from less water heated and less volume of sewage treated (although this will be more concentrated).

The five key components of the water system are defined in more detail below, including the water supply and demand reduction options that are relevant for each component, and the key assumptions made in this study.



Energy usage (synonymous with carbon emissions) in this system:

- **Water source, abstraction and conveyance:** energy to abstract water, mainly diverted from rivers or pumped from groundwater, and with conveyance by pumping into reservoirs or via transfer pipelines to water treatment facilities.
- **Water treatment:** energy to pump and process water to potable standards, with the amount of energy required dependent on the source water quality. Water abstracted from rivers that have upstream discharges of wastewater may require significant treatment, whereas groundwater is often high quality and requires minimal treatment.
- **Water distribution:** energy to pump to households and businesses.
- **Water in the home:** energy to pump, heat and other processes.
- **Wastewater treatment:** Energy to collect, pump, aerate and other processes to treat to final effluent quality - wastewater treatment is shown as a water supply component as increases in water supply require increases in wastewater treatment

Figure 4.3 Water supply-use-disposal system

4.5.1 Water supply options

We use published data on carbon emissions associated with the existing water supply system. For example, the "water source, abstraction and conveyance" component includes the carbon emitted by abstracting water from rivers and groundwater, and the carbon associated with pumping it into reservoirs or via transfer pipelines to water treatment facilities.

We assume that if a new water supply option is constructed, we need to consider the carbon associated with the construction, in terms of materials used, the buildings and plant (pumps, etc) and earthworks. In addition, we need to account for the carbon associated with operating the resource over its lifetime. Thus we consider the capital carbon and operational carbon to determine the total carbon.

We consider the carbon cost of:

- water to treatment works – groundwater/surface water, reservoir storage, transfer pipelines, etc;
- water treatment – includes simple groundwater treatment through to complex filtration and reverse osmosis technology;
- water distribution – includes network maintenance and operation, maintaining leakage levels and all other activities, e.g. pumping.

Leakage management related to water distribution can reduce leakage, thereby saving energy and reducing carbon. These options include pressure management to minimise leakage, and network management to minimise pumping across the distribution network.

4.5.2 Water demand options

We use published data on carbon emissions associated with leakage and the "water in the home" component of the total water system (Figure 4.3), i.e. toilet, taps, bath, shower and white goods (washing machine, dishwasher).

We assume that if a demand management option is introduced, we need to consider the carbon to manufacture, install and operate the option over its lifetime. As with water supply options, we consider the capital and operational carbon to determine the total carbon.

We consider the carbon cost of:

- water efficiency options in the home – metering; tariffs; toilet retrofit and low-flush alternatives; water efficient sink; bath/shower products; white appliances (washing machines and dishwashers);
- water efficiency options at household and community scale - rainwater harvesting, greywater re-use;
- leakage reduction.

The demand management options reduce water demand, thereby saving energy and therefore carbon. As discussed in Section 5.3, heating water in the home (excluding heating the home) is by far the most significant contributor to carbon emissions in the total water system; many of the water demand options can reduce this. We take account of the possible savings in the carbon cost assessment.

The savings adopted for demand management options in this study are based on published data, including Environment Agency figures and the 2008 Three Regions Climate Change Group report[18] "Your home in a changing climate". Where a range of savings are published, we use the mid range value. Water saving values can vary within the carbon cost assessment model (Chapter 5).

4.5.3 Wastewater pumping and treatment

Additional supply into the total water system (Figure 4.3) will require additional wastewater pumping and treatment. Conversely, water savings due to demand management options are likely to reduce the volume of water to sewer, thereby reducing the wastewater pumping, but not reducing the end treatment necessary to achieve water quality standards. We take this into account in calculating the carbon footprint of both water supply (i.e. additional carbon) and demand options (i.e. reduction in carbon).

We use published data on carbon emissions associated with operating existing wastewater treatment systems, for pumping and treating wastewater and disposal of sludge. As the focus of this study is on water supply and demand options, the carbon footprint to build new treatment facilities is not directly assessed. As a proxy, we assume the same carbon footprint to build new water treatment facilities - in terms of materials used, the buildings and plant (pumps, etc) and earthworks.

4.6 Life-cycle Approach

Our life-cycle approach to the carbon cost assessment is illustrated as conceptual models for two options - desalination as a water supply option (Figure 4.4) and metering as a demand management option (Figure 4.5). Further qualification of the boundaries adopted for this study is presented in the next chapter on the carbon cost model.

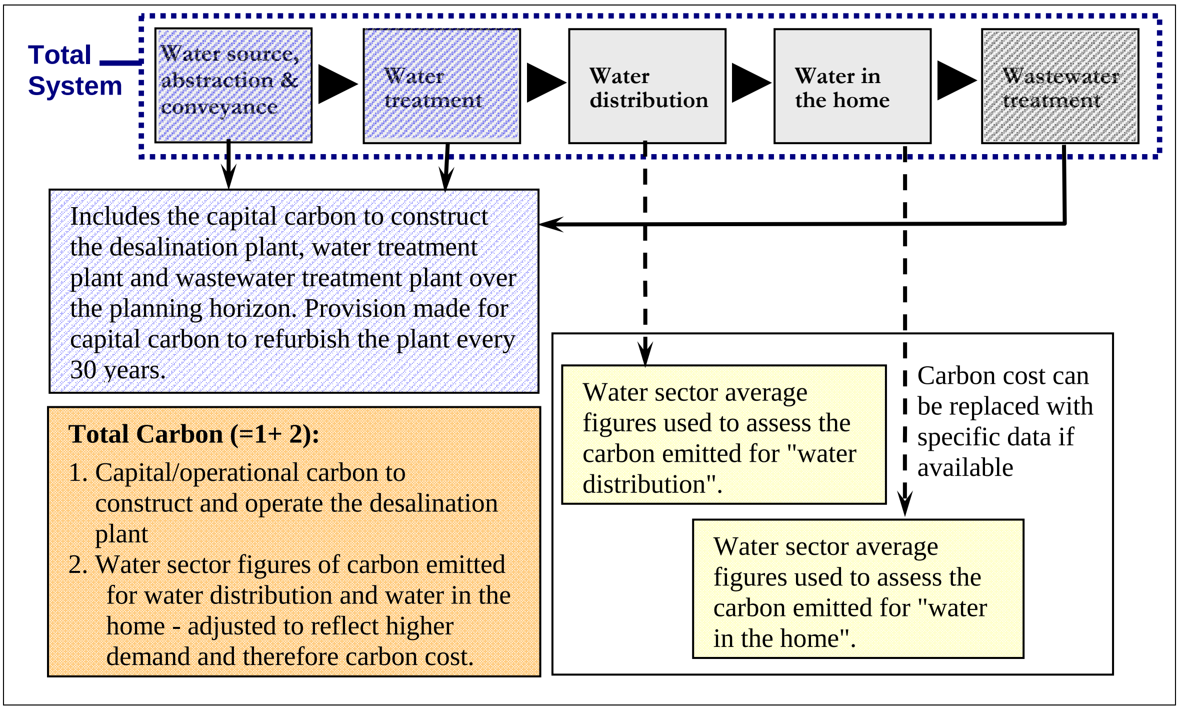


Figure 4.4 Conceptual model of water supply option – desalination

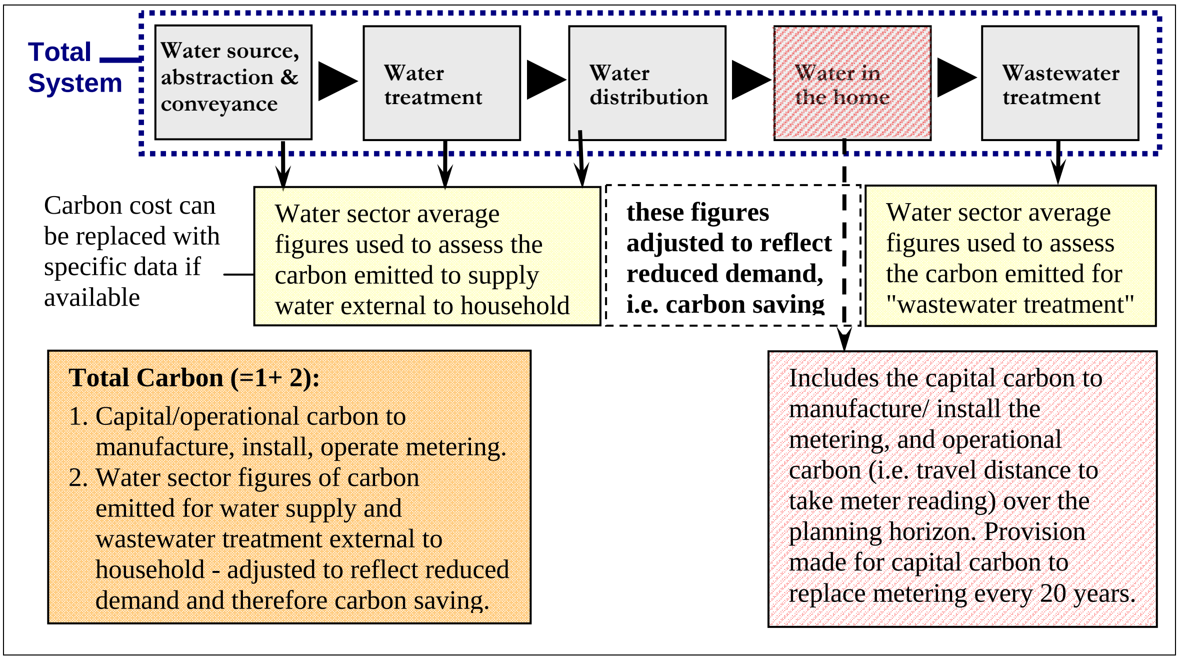


Figure 4.5 Conceptual model of demand management - metering

5 Carbon cost assessment model

5.1 Overview

This study aims to develop a robust, practical and easy-to-use carbon life-cycle/footprint model as an initial framework to enable more informed decision making in evaluating water resource plans.

The model is used to examine generic options for water supply and demand management (Chapter 6), benchmarked against options for the south east of England (Chapter 7). The model has wider application to other regions.

5.2 Model structure

The model, built in MS Excel with a modular structure (see Figure 5.1) for ease of use, is intended for high-level carbon cost appraisal in advance of more detailed study. It can be easily tailored to suit regional and scheme specific data as appropriate, and should help in our review of water company PR09 plans.

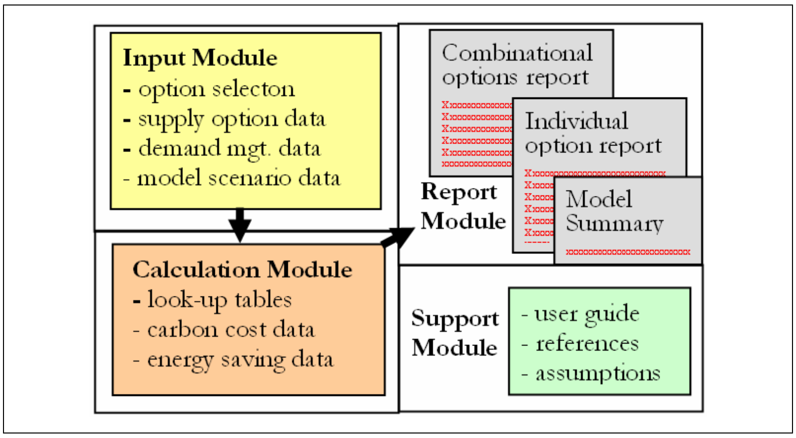


Figure 5.1 Carbon cost assessment model: modular structure

Separate worksheets define each water supply and demand management option. Within each worksheet data are entered for the option to be evaluated.

For water supply options, input data are consistent with those typically presented in water company plans. For water demand management options, input data can be simply defined as the number of households to be considered. Other base data used in the carbon cost calculation can be revised by the user if necessary, including:

- Shadow Price of Carbon (Figure 2.1);
- CO_2e emission factors for embodied carbon in materials (e.g. concrete, steel);
- water sector average figures applied in the model for energy usage and carbon emissions in the water system (Figure 4.3).

The output data include graphical plots to illustrate carbon costs, presented separately for construction (CAPEX) and operational (OPEX) carbon, over the selected planning period as well as in terms of the average incremental carbon cost (AICC).

5.3 Model principles

The carbon cost model calculates the carbon footprint specific to water supply and demand management options defined by the user. It combines these costs with those derived for the other water system components (defined in Section 4.5 and Figure 4.3) using average figures from the water industry.

Three key principles of this approach are:

i. Average GHG emissions per mega-litre (Ml) of water are estimated for each of the five components. This establishes the baseline for CO_2e that new supply and demand options are assessed against (Figure 4.3).

ii. Emissions resulting from new supply schemes are primarily allocated to the first component (source, abstraction, and conveyance), but with consideration of the impact on emissions of supplying additional water on the treatment, distribution and wastewater treatment model components.

iii. Emissions resulting from new demand management measures are primarily allocated to the household water use area (except for leakage control), but also consider water savings and therefore emission reductions from reduced water supply and pumping of wastewater.

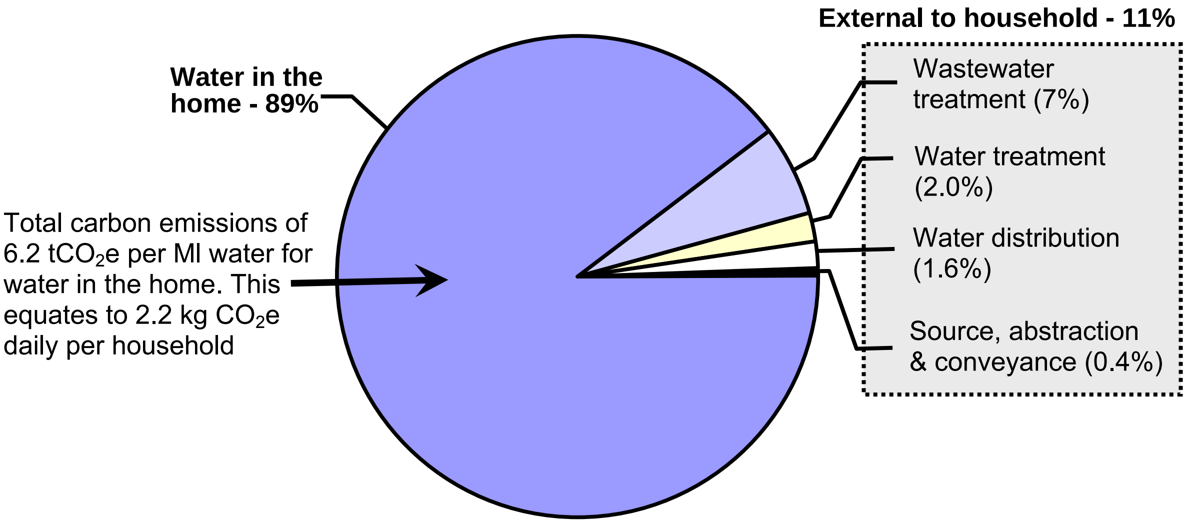
The model incorporates published data and information on industry average energy use and carbon emissions for water supply and demand options. The key sources and their relevance to this study are listed in Table 5.1.

Table 5.1 Key sources of data

Data	Key source	Relevance
Water efficiency	Environment Agency	Published ranges for water efficiency saving options presented in: Water efficiency savings data for a range of water-saving technologies[42] (2007), Water efficiency in the South East of England[11] (2007), Thames Gateway water neutrality study[12] (2007)
	Water Companies	Data on water conservation guidelines[46,61]
	Others	Published data by manufacturers - toilet[41,49,50,52,53], tap[59], bath[39,54,60], and shower products, white appliances, rainwater harvester systems[45,56,63], meters[33], others
Energy use	Environment Agency	Environment Agency: Water infrastructure technological options science report[10]
	Others	Published data by manufacturers[38] and other organisations[32]
Carbon emissions	Government	Defra's GHG conversion factors[2] and SPC guidelines[3], Water UK[11]
(incl. materials)	Academic research	Data sources for embodied energy and carbon of materials include the database by Bath University - International Centre for the Environment[14], and published work by others[18,38]
	Others	Published data by manufacturers and others[3,6,8,13,26,30,32,35,37,40, 42]

Using data reported by Water UK, BRE and WRc, a breakdown of carbon emissions across the water supply-use-disposal system is illustrated in Figure 5.2. This picture is indicative only, and serves to highlight the high proportion attributed to "water in the home", including energy used to heat water for use (not for heating the home), compared with public water supply and treatment "external to household".

No corresponding figures are available for non-household use.



Note: Sub-division of carbon emissions between "water in the home" and those "external to household" consistent with data published in Defra's Future Water strategy (Section 2.5).

Data sources used for this breakdown:

(a) Water UK reported water company average carbon emissions (Table 3.1):

- 0.271 tCO_2e in supplying 1ML water - figure adopted for "source, abstraction & conveyance", "water treatment" and "water distribution".
- 0.476 tCO_2e in treating 1ML sewage - figure adopted for "wastewater treatment"

(b) Environment Agency breakdown of water company emissions by end use:

- Water supply - 36% based on abstraction (4%), treatment (18%) and distribution (14%) (percentages appied to the Water UK data - supplying 1ML water)
- Wastewater - 59% based on treatment (54%) and collection (5%)
- Administration and transport - 5%

From recent research (by Environment Agency - D. Calderbank, unpublished), these figures should be: "*…treated with caution as the differing reporting methods by different companies make end use allocation difficult. Additionally, individual companies can vary significantly from this, e.g. due to terrain or ratios of supply to waste water…*".

The percentage breakdown between water supply, wastewater and administration and transport components is very similar to results presented by the Carbon Trust working with 18 water companies in 2007.

(c) WRc (for Defra) estimated annual carbon emissions of 0.792 tCO_2e at the household scale, resulting from energy usage by domestic appliances. This figure, adopted for the "water in the home" component, takes account of water heating (boiler) inefficiencies but is considered an under-estimate as it excludes any heat loss factor, e.g. for unused hot water, unlagged pipes or long pipe runs (from recent research unpublished as referenced above).

Figure 5.2 Carbon emissions for total water system - UK average (2006/07)

A 2007 Australian study[24] investigated a similar sub-division of carbon emissions, reporting 90 per cent and 97 per cent carbon emissions associated with "water in the home" that derive mainly from operating household appliances. This figure compares favourably with the 89 per cent based on average UK figures (Figure 5.2).

A similar result is reported in a Californian case study for San Diego County[25] in terms of energy usage in the total water system (energy usage closely reflects the carbon emissions). The energy estimated for "end use" of water dominates the water system, and that for "source, abstraction and conveyance" is also significant due to the large quantity of water imported into the region (very high energy cost for pumping).

5.4 Model assumptions

Key assumptions of the carbon cost assessment model are outlined below:

5.4.1 Water supply options

Assumptions in the model for water supply options are:

- a standard carbon cost dataset derived for each water supply option using actual scheme data taken from previous water resource plan submissions and recent studies;
- the model configured for assessment of standard schemes with the facility for users to adopt scheme-specific data where available in order to improve the accuracy of the modelled carbon costs.

Assumptions for individual options are further detailed in Section 5.6.

5.4.2 Water efficiency savings

Assumptions in the model for levels of water efficiency savings:

- savings determined by reference to published data (Section 3.4);
- existing homes assumed to be inefficient in water use, e.g. no metering, poor efficiency rating of household products (toilets, shower, bath, taps, washing machine, dishwasher).

Assumptions for individual options are further detailed in Section 5.7.

5.4.3 Water demand

- Water demand is based on average daily per capita consumption of 147.8 litres (Water UK, 2006/07 data) and an average household occupancy of 2.36 persons (Office of National Statistics). These model input data can be modified to be region-specific.

5.4.4 Carbon assessment

Assumptions in the assessment of carbon include:

- carbon cost for each stage of the water-use-disposal system is modelled as either scheme or product-specific, as defined below (in terms of CAPEX and OPEX), or based on average water sector figures for carbon emissions (Figure 5.2);
- embedded carbon costs are derived from principal quantities of material (e.g. concrete, steel) and Defra GHG conversion factors and related SPC guidance[2,3];

- main components of each option are first identified, with material/mass of each component then assessed based on previous similar schemes and/or information published by suppliers/manufacturers;
- embedded "cradle to site" carbon costs of each material (per unit mass) based on published reports where available. If data are not available, as is the case for the manufacture of many products for example, then per centage allowances are applied;
- carbon cost of manufacture, for example the metals to manufacture pump equipment is calculated as a per centage of the embedded carbon costs of material. Up to 30 per cent may be deemed appropriate (personal communication with a carbon researcher at the University of Bath[14]);
- embedded carbon cost of each option is calculated using the material, mass and embedded carbon/mass data (as tCO_2e). The energy consumed during construction/installation of each scheme is also converted to tCO_2e;
- embedded and construction energy usage in CO_2e is then converted to carbon cost using Defra's £/tCO_2 conversion table (£25.5 in 2007 then a two per cent per year increase) to give the capital or construction (CAPEX) carbon cost;
- construction energy usage (as referenced above) is estimated for earthworks, e.g. for bunded reservoir construction; and for other scheme components the embedded carbon cost of principal construction items is assessed, e.g. quantities of concrete/steel in buildings;
- energy involved in operating an option is converted to tCO_2e, assuming for power supply the electricity conversion factor of 0.43 kg CO_2e per kWh (as quoted by Defra[2]) gives the operating carbon cost; no other types of energy (gas, oil, solid fuel) was assessed for operational carbon;
- a single set of unit carbon costs is applied to all options irrespective of location, i.e. no account taken of regional variation, local source of materials, etc;
- carbon cost profile for each year in the planning period assessed then results generated and plotted as a cumulative total, along with capital and operational carbon costs.

5.4.5 Economic appraisal

Assumptions for economic appraisals include:

- planning horizon is assessed over 60 years, based on the longest lived asset (e.g. reservoir). This timeframe is standard for water resources planning[7] (note: default of 40 years to be adopted in PR09). The replacement cost for shorter lived assets is included, for example water meters with an assumed 'life' of 20 years require replacement in Years 20 and 40.
- no residual scheme costs are taken into account, i.e. the model assumes that assets are fully replaced at the end of their design life, which tends to inflate the estimate of construction carbon. Operational carbon is unaffected.
- life-cycle cost (construction, operation, replacement and repair) assessed over this planning horizon is based on the average incremental carbon cost (AICC) as an economic indicator (defined in Sections 2.7 and 6.5).
- life-cycle cost for the total water system assessed over this planning horizon is again based on AICC, combining carbon costs as modelled for a

specific option and using water sector average data (defined in Section 5.2).

- annual carbon cost is assessed per mega-litre of water supplied/yield (supply option) or saved (demand management option).

5.4.6 Other factors

Other factors that would benefit from further study include:

- in the absence of clear projections on water use in the home, the efficiency gains to be achieved and resulting water savings, the water demand is assessed based on current water demand;
- progressively over time, renewable energy and new construction/ production methods will lead to lower GHG emissions in line with the Climate Change Bill (current 60 per cent reduction target by 2050);
- in the absence of clear projections on future carbon reduction the carbon costs are assessed and compared based on current carbon. The carbon cost results therefore represent a worst case, particularly for options with significant future carbon costs such as desalination, although this assumption has similar effects on all future measures including water demand management options;
- the UKWIR guidance[20] adopts a similar line, recognising that there is potential for future reductions in carbon emissions as a result of technology improvements, but because this is not yet quantifiable, no guidance is given.

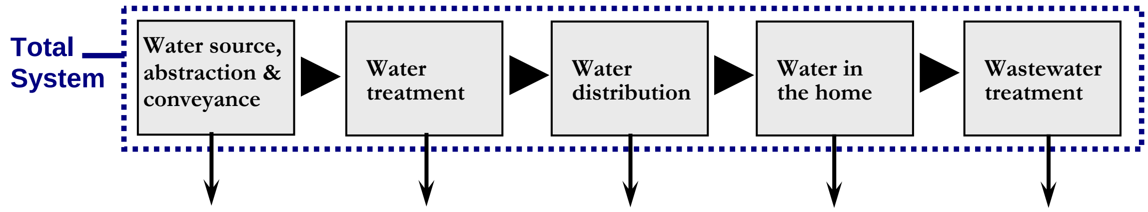
5.5 Total system carbon cost

Figure 5.3 presents the UK average carbon footprint for each component of the water supply-use-disposal system (see also Figure 4.3). This carbon cost assessment is in line with the model assumptions outlined in Section 5.4, and uses the industry average data detailed in Section 5.3. This total carbon cost of the water system (average incremental cost of carbon: 28.31 p/m^3) provides the benchmark against which new water supply and demand management options can be assessed.

We present the carbon costs in terms of tonnes of CO_2e/ Ml supplied or saved to show the direct carbon impact across the total water system.

We also present results as AICC (defined in Section 2.10). This enables comparison between the carbon costs of different supply and water efficiency options, taking into account different water yields or savings, asset life, total carbon emissions and annual rising SPC over the planning horizon (60 years adopted).

Figure 5.3 Carbon footprint for the current water supply - use - disposal system



tCO_2e/Ml	0.03	0.14	0.11	6.22	0.48
AICC (p/m^3)	0.12	0.56	0.43	25.52	1.95

Total system: **6.97 tCO_2e/Ml**

28.58 p/m^3 as AICC

To place the carbon emissions in a UK wide context it is useful to consider that:

- total UK carbon emissions were 639 $MtCO_2e$ in 2007;
- total UK water consumption is 17,531 Ml/d (Water UK data for 2006/07[21]);
- carbon emissions from domestic and non-domestic supply by water companies are 5.03 $MtCO_2e$ (Water UK data for 2006/07[21]), i.e. 0.8 per cent of total UK emissions;
- carbon emissions lost to leakage by UK water companies are 0.45 $MtCO_2e$, based on 4,520 Ml/d leakage and 0.271 kg CO2e/Ml for water supply (Water UK data for 2006/07[21]);
- carbon emissions from household water use are 35 $MtCO_2e$ (Defra[4], and Figure 4.2 in this report), i.e. 5.5 per cent of total UK emissions.

5.6 Modelling water supply options

A standard carbon cost dataset for each water supply option is modelled using scheme data taken from previous submissions of water resource plans and recent studies[6,11]. The standard carbon cost for each option type is taken as the average carbon cost. The results (both averages and ranges) are given later in this report (Chapter 6).

The model calculates the carbon footprint for the whole life-cycle of water supply options (excluding decommissioning and recycling at end of life) in terms of the carbon cost of capital works (CAPEX) and in operation (OPEX).

Previous submissions of water resource plans by water companies include technical details for the water supply options listed in Table 3.1. Typically, the following "common" data for all option types, with carbon implications, are available:

- deployable output of source or capacity of pipeline transfer (CAPEX);
- associated building for plant, for example floor area, height (CAPEX);
- total duty pump or plant capacity (CAPEX / OPEX);
- annual frequency of operation (OPEX);
- operational hours per day and days per year (OPEX).

The model incorporates a unit carbon cost rate schedule that converts these "common" data for each option, defining the overall scale of the construction works and operation, into carbon (as tCO_2e), and including the embodied carbon for the main components of the construction works. The carbon footprint is presented as CAPEX and OPEX.

An outline assessment for a reservoir scheme is illustrated in Figure 5.4.

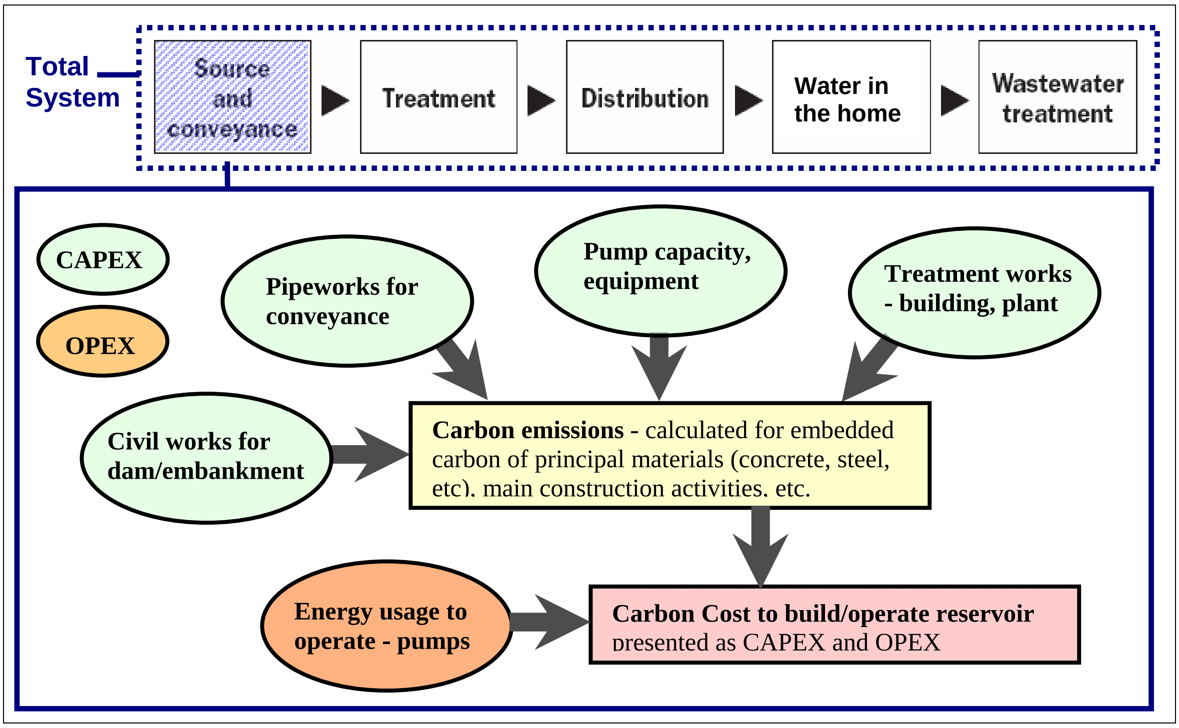


Figure 5.4 Outline carbon cost assessment of water supply option – reservoir

The model calculates the carbon cost following Defra's interim guidance[2,3] and the AICC (average incremental carbon cost) based on deployable output over the planning horizon following our guidance on water resources planning.

The carbon cost model of a standard reservoir is illustrated in Figure 5.5.

Model input data include:

- data based on water resource plans (default values can be "user" defined);
- data common to all water supply options include operational frequency, discount rate (for AICC calculation), etc;
- data entry specific to reservoirs (as shown) include dam or embankment type/length/height; pump capacity; conveyance pipeline length/diameter, etc.

Model output data include:

- modelled carbon footprint presented in tCO_2e and tCO_2e/Ml (based on water yield over the planning period);
- corresponding carbon costs (broken down as CAPEX and OPEX) and AICC.

The model output plots include:

- carbon cost plot to show cumulative CAPEX and OPEX, and total carbon cost;
- AICC plot to show CAPEX and OPEX over the planning period;
- plot of carbon cost per unit mega-litre of water yield (not shown in Figure 5.5).

For the reservoir example, the carbon footprint for building and operating the resource falls within the "water source, abstraction and conveyance" component of the water system. For other system components, the model adopts the industry average figures for AICC (Figure 5.3). Alternatively, the results can be combined with modelled data for other options so that the full carbon footprint is modelled - reservoir, transfer pipeline, water treatment, etc.

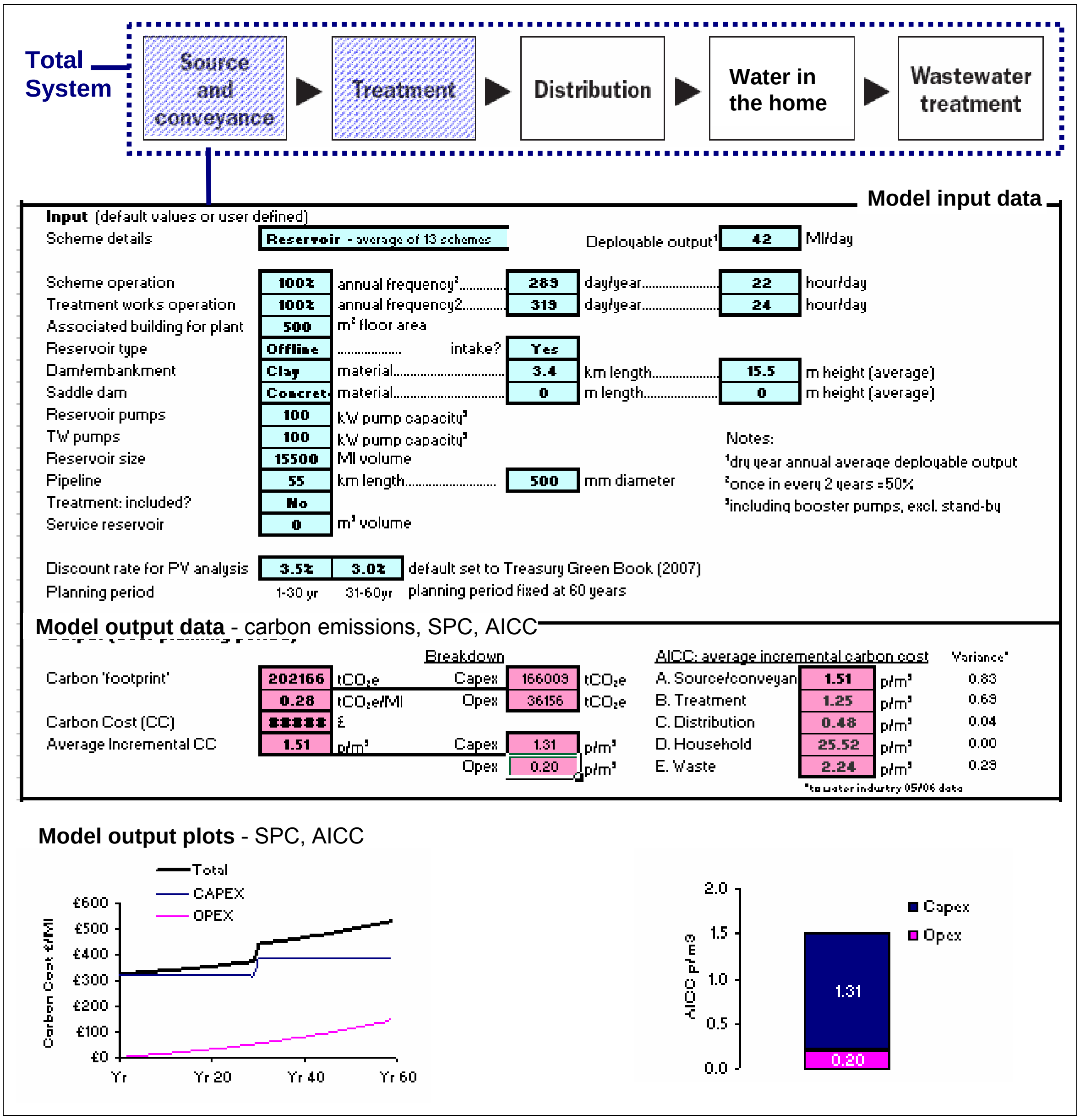


Figure 5.5 Example carbon footprint model of water supply option

5.7 Modelling water efficiency options

The carbon cost assessment model calculates the carbon footprint in terms of capital and operational works for the whole life-cycle of water efficiency options (excluding decommissioning/recycling). Table 5.2 identifies the data source referenced by the model to assess this footprint.

The reduced carbon emissions that result from water efficiency options across the total water system will always be specific to a locality. But the aim of this study is to provide an initial appraisal framework, recognising that in subsequent work more locally specific data could be used if available.

The carbon cost of each water efficiency option is assessed on an individual basis, and as combinations of options (Section 5.7). The full range of technological options is examined, namely:

- metering;
- toilet retrofit and low-flush options;
- bathroom/shower/tap water saving products;
- water-efficient white appliances (washing machine, dishwasher);
- rainwater harvesting;
- greywater reuse;
- leakage reduction methods.

Base data used to assess CAPEX and OPEX of each water efficiency option include:

- main components i.e. their weight (mass) and fabrication material based on technical specifications published by suppliers (CAPEX);
- embodied carbon for materials from published data (CAPEX);
- travel/haulage distance of these components from factory to site (CAPEX);
- like-for-like replacement at end of design life (CAPEX);
- operational costs such as visits to read water meters (OPEX);
- energy usage – for rainwater harvesting and greywater recycling (OPEX).

The carbon cost model of a standard reservoir is illustrated in Figure 5.6.

The model calculates the full carbon footprint over the planning horizon (60 years adopted) from the above base data, presented as tCO_2e and carbon cost based on SPC in accordance with DEFRA guidance[2,3]. For the life-cycle analysis, water savings for each option are assessed over the planning horizon, using published data.

AICC is also calculated so options can be more easily compared. AICC is the ratio of present value carbon cost versus the volume of water supplied or saved (Section 2.10). For comparison purposes, we include only the initial CAPEX cost to manufacture/install water saving replacement products as a one-off retrofit cost for existing homes, e.g. shower, washing machine, dishwasher. In new homes these products would be installed new (i.e. they are not a replacement) and are treated as a "sunk" cost. The CAPEX cost for metering is included for both existing and new homes.

For the water efficiency options, we assume that reduced water demand will correspondingly reduce carbon emissions across the total water system (Figure 5.3), i.e. 10 per cent water saving gives 10 per cent reduced emissions. There are some exceptions to this assumption, however. Water savings will not reduce the amount of solids to be treated during wastewater treatment, and rainwater harvesting reduces public water supply, not wastewater.

The energy (and carbon) used in wastewater treatment, very approximately, is assumed as 40 per cent pumping and 60 per cent treatment processes. The high proportion of energy used for pumping is confirmed in recent work by the Carbon Trust. The carbon cost model calculates the carbon saving of each water efficiency option by reducing (linearly) only the pumping fraction (40 per cent) of wastewater treatment by an amount corresponding with the water saving. The wastewater treatment fraction (60 per cent) is held constant.

For water audits, we assume a three per cent water saving and exclude any CAPEX/OPEX (minimal).

For leakage control, the range of carbon cost will vary widely, depending on each circumstance (e.g. locate and repair of leaks in water mains and household pipeline, pressure management to reduce leakage by lowering the operating pressure in water mains whenever possible without adversely affecting supply in the home, etc). For this option the model takes the example carbon cost data presented in Ofwat's guidance on the economic level of leakage, plus some additional, but limited water company data.

The leakage model is developed from the example leakage levels and carbon emissions reported as "externalities" in Ofwat's guidance* and water company data (Wessex Water) as follows:

- leaks detected - 386 leak repairs per year resulting in a 4.1 Ml/d water saving (406 tCO_2e);
- leaks detected - 700 leak repairs per year resulting in a 1Ml/d saving (86 tCO_2e);
- leaks reported - 1206 leak repairs per year, resulting in a 15.7 Ml/d saving (1203 tCO_2e);
- asset renewal - 33.6 km of mains pipeline giving a 1 Ml/d saving (4475 to 11,082 tCO_2e);
- asset renewal - service pipes gives a 1Ml/d saving (16,221 tCO_2e);
- control pressure for 162,000 properties results in a 17 Ml/d saving (based on current pressure management schemes; no carbon estimate).

The levels of leakage reduction that can be achieved through the above activities are uncertain, with a "mixed record" claimed by one water company.

Table 5.2 Water efficiency options

Option	Water saving*	Details (including sub-types)
Metering	10%[(a)] 15%[(b)]	• Conventional • Conventional with variable tariffs
Toilets - compare with "traditional" toilets: 6, 7.5 or 9 litres per flush		
- retrofit	10%[(c)] 10% 3%	• Variable flush device retrofitted to existing WCs • Cistern displacement: "hippo" saves 3 litres per flush • Cistern displacement: "save-a-flush" saves 1 litre (water savings quoted assume 7.5 litre toilet)
- low flush	6.4-8%	• Dual flush: 4/2.6 litres (incl. in Defra's Future Water) • Ultra-low flush units: 4.5 litres per flush • Sub ultra low flush units: 1.5 litres/flush or less (flush booster collects several toilet flushes for discharge together - not commercially available)
Bath	2.1%	• Low volume bath: 120 litre (standard home: 180 litre)
Shower	8%	• Low flow: 7.75 litres/minute (standard home: 10 l/min)
Taps	7-11.6%	• Flow restrictors on tap, e.g. tap magic: 7 litres/minute • Flow regulators (stop cock) to reduce water pressure
Water efficient white goods	0.9% 0.2%	• Washing machine: 40 litre (standard home: 49 litre) Dishwasher: 10 litre (standard home: 13 litre)
Rainwater harvesting	10.7% 20-50%[(d)]	• Individual household: - retrofitting difficult but possible - requires collectors, mechanical filters, small storage tank, pipework within household, water pump - chemical and UV treatment unit if for potable water use • Community scale (for 10s or 100s of houses) - for new housing developments - bigger community level storage tank - distribution system and pumping system
Greywater recycling for non-potable use	5-35%[(e)]	• Individual household: - similar constraints to rainwater harvesting - retrofitting difficult (requires non-standard toilet cistern that takes reused water) - chemical disinfectant for non-potable use • Community scale - suitable for new housing developments - depending on the size of the community – biological aerators, chemical filters (e.g. GAC), membranes or reed beds can be used for filtration/treatment

*expressed as percentage of total water use in a standard home (Table 3.3)

(a) 10% quoted in various Environment Agency reports[9,11,12] and at conservative end of 10-15% range reported by UKWIR 2006

(b) adopted as conservative estimate based on UKWIR 2006[18] and the Thames Gateway study[12]

(c) http://www.environment-agency.gov.uk/subjects/waterres/286587/286911/548861/862159/?version=1&lang=_e

(d) Water savings quoted by various sources: 27 to 88% savings or 25-100 l/c/d[9] and up to 50% from http://www.constructionresources.com/products/services/water_saving.asp?PageCategoryID=6; and 50 to 60% from http://www.titanpc.co.uk/env_faq.htm

(e) Water savings quoted by various sources: 5 to 36%[8] and 33% from http://www.environment-agency.gov.uk/subjects/waterres/286587/286911/548861/565687/?version=1&lang=_e, http://www.environment-agency.gov.uk/commondata/105385/greywater_880769.pdf

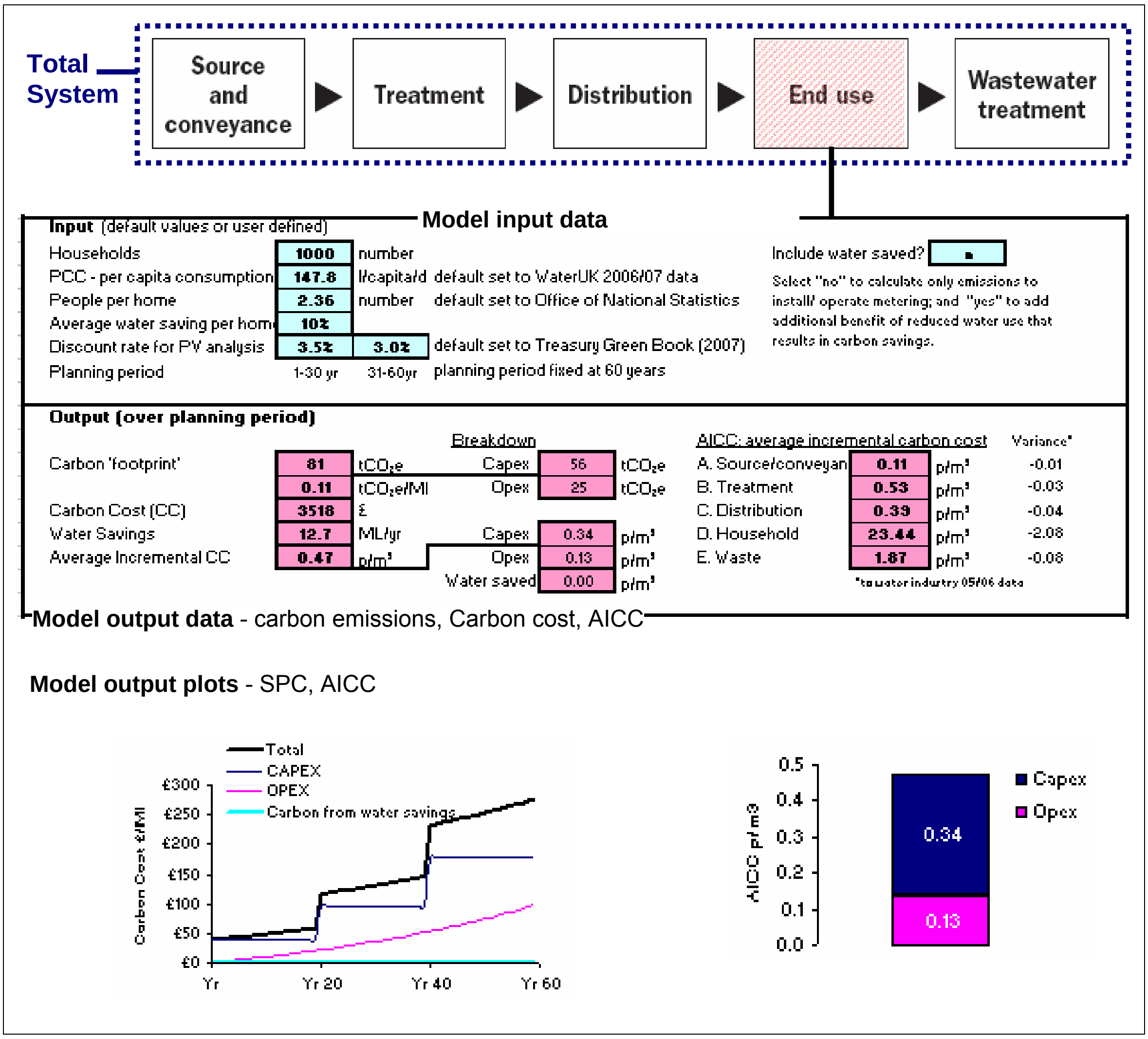


Figure 5.6 Example carbon footprint of demand management - metering option

5.8 Modelling combinations of water efficiency options

Demand management options are often installed in combination, not individually. For illustrative purposes, we assess the carbon cost of water efficiency options based on the following combinations (reflecting the target water savings for homes advised in the Code for Sustainable Homes (CSH)[1] and summarised in Table 5.3):

- Combination A for new homes: CSH Level 1/2 to achieve 120 litres per capita consumption rates, i.e. approximately 21 per cent water savings against UK average;
- Combination B for new homes: CSH Level 3/4 to achieve 110 litres per capita consumption rates, i.e. approximately 31 per cent water savings against UK average;
- Combination C for new homes: CSH Level 5/6 to achieve 80 litres per capita consumption rates, i.e. approximately 48 per cent water savings against the UK average.

These combinations include the “micro components” defined by CSH: metering, toilet cistern device, shower/ bathroom/ taps water saving products and water efficient white goods (washing machine and dishwasher). The CSH Level 5/6 option also adopts rainwater harvesting to further increase water efficiency.

Table 5.3 Demand Management Combinations

Micro component	Standard home (l/d) see Table 3.3	Water savings – as per cent of total per capita (for standard home)		
		CSH Level 1/2 (120 l/d/capita)	CSH Level 3/4 (105 l/d/capita)	CSH Level 5 (80 l/d/capita)
Toilet flushing	28.8	6.4%	8.0%	8.0%[(a)]
Taps	42.3	7.0%	11.6%	16.1%
Shower	30.0	4.0%	8.0%	8.0%
Bath	28.8	2.1%	2.1%	4.3%
Washing machine	16.7	0.9%	0.9%	0.9%[(a)]
Dishwasher	3.9	0.2%	0.2%	0.2%
Total per capita	**151**	**21%**	**31%**	**48%**
Outdoor (garden)	11.5	0%	0%	0%
Total per home	**367**	**20%**	**30%**	**47%**

[(a)] 50% recycled water by rainwater harvesting

Table 5.3 further details the three options with a breakdown of their water efficiency savings for each component. We configured the carbon cost model to reflect these water savings, and show water savings as a percentage of the total "water in the home" which serves as the basis for the calculation of carbon savings (illustrated later in Table 6.1).

We exclude greywater recycling schemes as a high cost option to install and maintain. Previous studies[11] of this technology found that until such schemes become more reliable (so called 'fit and forget') they are unlikely to appeal to the general public.

5.9 Carbon footprint examples

In order to further illustrate the modelling concept, carbon footprint examples are outlined and initial results presented below for two water efficiency options - metering and low flush toilet.

- Table 5.4 shows the reduced carbon emissions resulting from water savings - this example assumes 10 per cent water saving by metering and 9.4 per cent water saving by low flush toilet (Table 3.3).
- Tables 5.5 and 5.6 show the carbon cost model results for both options in terms of their tCO_2e and carbon costs (CAPEX/OPEX) calculated using the SPC over 10 years, compared with reduced emissions from Table 5.4.

Higher carbon reduction can be achieved by metering as this option reduces household emissions associated with hot and cold water. Low flush toilets reduce carbon as a result of water savings, but have no hot water associated carbon reductions. The toilet example indicates a five-year 'payback' period before the carbon saving offsets the carbon cost of toilet replacement (values shaded in Table 5.6). The carbon costs of metering are offset by carbon savings within the first year.

This concept can be assessed in different ways. For example, water metering of the average household saves one tonne of carbon every 8 to 12 years. For a town the size of Swindon this reduces emissions by 6,000 to 10,000 tonnes every year. In carbon cost terms this amounts to between £2-3 million over 10 years and £14-21 million over 50 years.

More detailed results for all options are presented in Section 6.

Table 5.4 Example carbon emissions calculation - metering & toilet

Water system components (see Figure 5.3)	Carbon emissions - baseline		Reduced emissions - 1000 homes	
	Water system tCO_2e /Ml	1000 homes[1] tCO_2e/year	Meter, tCO_2e/yr (10% water saved)	Toilet, tCO_2e/yr (9.4% water saved)
A. Source/conveyance	0.030	3.8	-0.4	-0.4
B. Treatment	0.136	17.4	-1.7	-1.6
C. Distribution	0.105	13.4	-1.3	-1.3
D. Household	6.221	794.7	-79.5	0 [2]
E. Wastewater	0.476	60.8	-2.4 [3]	-2.3 [3]
Total carbon	**6.968**	**890**	-85	-5.5

[1] average household demand of 350 l/d
[2] household emissions mainly for water heating (excl. space heating)
[3] assumes only emissions associated with pumping (not treatment) can be reduced

Table 5.5 Example carbon footprint calculation - metering

1000 homes		Option carbon footprint			Water saved carbon		Total
Year	SPC[1]	tCO_2e (model)	Capex £CO_2e (A)	Opex £CO_2e (B)	tCO_2e (Table 5.4)	£CO_2e (C)	cumulative (A+B+C)
2008	26.0	19	£483	£11	-85	-£2,204	-£1,710
2009	26.5	0.4	-	£11	-85	-£2,248	-£3,947
2010	27.1	0.4	-	£11	-85	-£2,293	-£6,229
2011	27.6	0.4	-	£11	-85	-£2,339	-£8,556
2012	28.2	0.4	-	£12	-85	-£2,386	-£10,931
2013	28.7	0.4	-	£12	-85	-£2,434	-£13,352
2014	29.3	0.4	-	£12	-85	-£2,482	-£15,822
2015	29.9	0.4	-	£12	-85	-£2,532	-£18,341
2016	30.5	0.4	-	£13	-85	-£2,582	-£20,911
2017	31.1	0.4	-	£13	-85	-£2,634	-£23,532
Totals		22.8	£602		-851	-£24,134	

Table 5.6 Example carbon footprint calculation - low flush toilet

1000 homes		Option carbon footprint			Water saved carbon		Total
Year	SPC[1]	tCO_2e (model)	Capex £CO_2e (A)	Opex £CO_2e (B)	tCO_2e (Table 5.4)	£CO_2e (C)	cumulative (A+B+C)
2008	26.0	32	£829	-	-5.5	-143	718
2009	26.5	-	-	-	-5.5	-146	571
2010	27.1	-	-	-	-5.5	-150	422
2011	27.6	-	-	-	-5.5	-152	269
2012	28.2	-	-	-	-5.5	-155	114
2013	28.7	-	-	-	-5.5	-158	-44
2014	29.3	-	-	-	-5.5	-162	-206
2015	29.9	-	-	-	-5.5	-165	-371
2016	30.5	-	-	-	-5.5	-168	-539
2017	31.1	-	-	-	-5.5	-172	-711
Totals		32	£829	-	-55	-£1,572	

[1] SPC as per Defra guidance

5.10 AICC calculation examples

AICC is the unit carbon cost for water either supplied (water supply options) or saved (demand management options). The unit of measure is pence per cubic metre (p/m^3) which is standard for water resources planning.

The carbon cost (OPEX and CAPEX) and volume of water supplied or saved are calculated as present net values. Table 5.7 shows the benchmark AICC calculation based on average figures (total AICC of 28.2 p/m^3) for the water sector (Figure 5.3).

Table 5.7 Example AICC calculation - benchmark AICC for water sector

Year	PV Factor[1]	SPC[2] Table 2.2	Water supplied PV - m^3	Carbon cost PV - p/m^3 for water system components[3] (Figure 5.3)					
				A	**B**	**C**	**D**	**E**	**Total**
2008	1.00	26.0	1.00	0.08	0.35	0.27	16.18	1.24	**18.1**
2009	0.97	26.5	0.97	0.08	0.35	0.27	15.95	1.22	**17.9**
2010	0.93	27.1	0.93	0.08	0.34	0.27	15.71	1.20	**17.6**
2011	0.90	27.6	0.90	0.07	0.34	0.26	15.49	1.19	**17.4**
2012	0.87	28.2	0.87	0.07	0.33	0.26	15.26	1.17	**17.1**
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
2058	0.16	82.0	0.16	0.04	0.17	0.12	7.98	0.61	**8.9**
2059	0.15	83.7	0.15	0.04	0.17	0.12	7.91	0.61	**8.9**
Total - present value			**26.3**	**3.2**	**14.6**	**11.4**	**670.2**	**51.3**	**750.7**
AICC - p/m^3				**0.12**	**0.56**	**0.43**	**25.52**	**1.95**	**28.6**

[1] PV factor as per Treasury Green Book rates
[2] SPC rising at 2% per annum as per Defra guidance[3]
[3] see Figure 5.3 for carbon emission values (as tCO_2e/Ml)

In this table the water supplied and carbon cost are presented as present values, i.e. with discount factor applied.

Present values are the values on a given date of a future cost or saving, discounted to reflect the time value of money and other factors. These values are widely used in economics to provide a means to compare cash flows at different times on a meaningful "like for like" basis.

Two examples are presented that show the impact of water supply (reservoir scheme) and demand management (metering) options on the benchmark AICC - see Table 5.8 and Table 5.9 respectively.

i. the metering option in this illustration assumes 10 per cent water savings, and includes the CAPEX to manufacture, install and replace the meter (20 year life span assumed), and the OPEX for meter reading (distance travelled);
ii. the reservoir scheme includes the CAPEX to construct the reservoir and treatment facility, plus the CAPEX to increase the capacity of the supply distribution network and wastewater treatment. The calculation also includes the OPEX to operate the reservoir scheme.

The benchmark AICC of 28.2p/m^3 reflects the total water system carbon cost of water supplied. By developing a new supply option this AICC increases by 7 per cent for the reservoir example (Table 5.8) and decreases by 8 per cent for metering (Table 5.9).

The above results suggest that increased carbon from a new reservoir scheme (+7 per cent) could be offset by reduced carbon from metering (-8 per cent). For example, if a new reservoir supply of 14 Ml/d (average of the schemes assessed) can service 40,000 properties, then metering (assumed water saving of 10 per cent) of over 400,000 homes is required to offset this carbon.

Table 5.8 Example AICC calculation - water supply reservoir option

Water system components (Figure 5.3)	Benchmark AICC - p/m³ (Table 6.5)	Option impact on benchmark AICC	
		AICC - p/m³	Basis for carbon cost model results
A. Source/conveyance	0.12	+0.83	reservoir scheme[1] (Figure 5.5)
B. Treatment	0.56	+0.69	- combines A and B components
C. Distribution	0.43	+0.04	increase capacity[2]
D. Household	25.52	-	No change
E. Wastewater	1.95	+0.29	increase capacity[3]
Total system carbon	**28.6**	**1.9**	**+7%**

[1] taken as average of 13 reservoir schemes
[2] assumes 10 per cent uplift in carbon costs as not modelled (common to all supply options)
[3] based on new treatment facility

Table 5.9 Example AICC calculation - demand management metering option

Water system components (Figure 5.3)	Benchmark AICC - p/m³ (Table 6.5)	Option impact on benchmark AICC	
		AICC - p/m³	Basis for carbon cost model results
A. Source/conveyance	0.12	-0.01	-10% for water savings
B. Treatment	0.56	-0.03	-10%
C. Distribution	0.43	-0.04	-10%
D. Household	25.52	-2.08	-10%
			+0.47 p/m³ for metering as CAPEX/OPEX per m³ water saved
E. Wastewater	1.95	-0.08[1]	- 4%
Total system carbon	**28.6**	**-2.2**	**-8%**

[1] assumes only emissions associated with wastewater pumping (not treatment) reduced

6 Model results

6.1 Overview

This chapter presents the model results as follows:

- water supply options - carbon footprint for scheme only;
- water efficiency options - carbon footprint to install/operate options on individual basis and taking into account water savings;
- demand management options - carbon footprint to install/operate for combinational options and taking into account water savings;
- comparing supply and demand options - total water system carbon footprint;

The model output is presented in terms of the carbon cost, based on SPC, per unit mega-litre (Ml) of water supplied (supply options) or saved (water efficiency options).

6.2 Carbon footprint of water supply options

We first assess the carbon footprint of water supply options and compare individual options in terms of their carbon cost to construct and operate them. The results presented in this report are option specific, e.g. reservoir options include treatment works but no capacity upgrade in the distribution network or wastewater treatment. We account for this in calculating the AICC later (Section 6.5).

We set a 60-year planning horizon to account for asset replacement and its carbon cost over the longer term. For example, the assessment assumes asset replacement every 30 years for the transfer pipeline option and 60 years for reservoirs (option with longest life).

The model results for water supply options are summarised in Figure 6.1 based on:

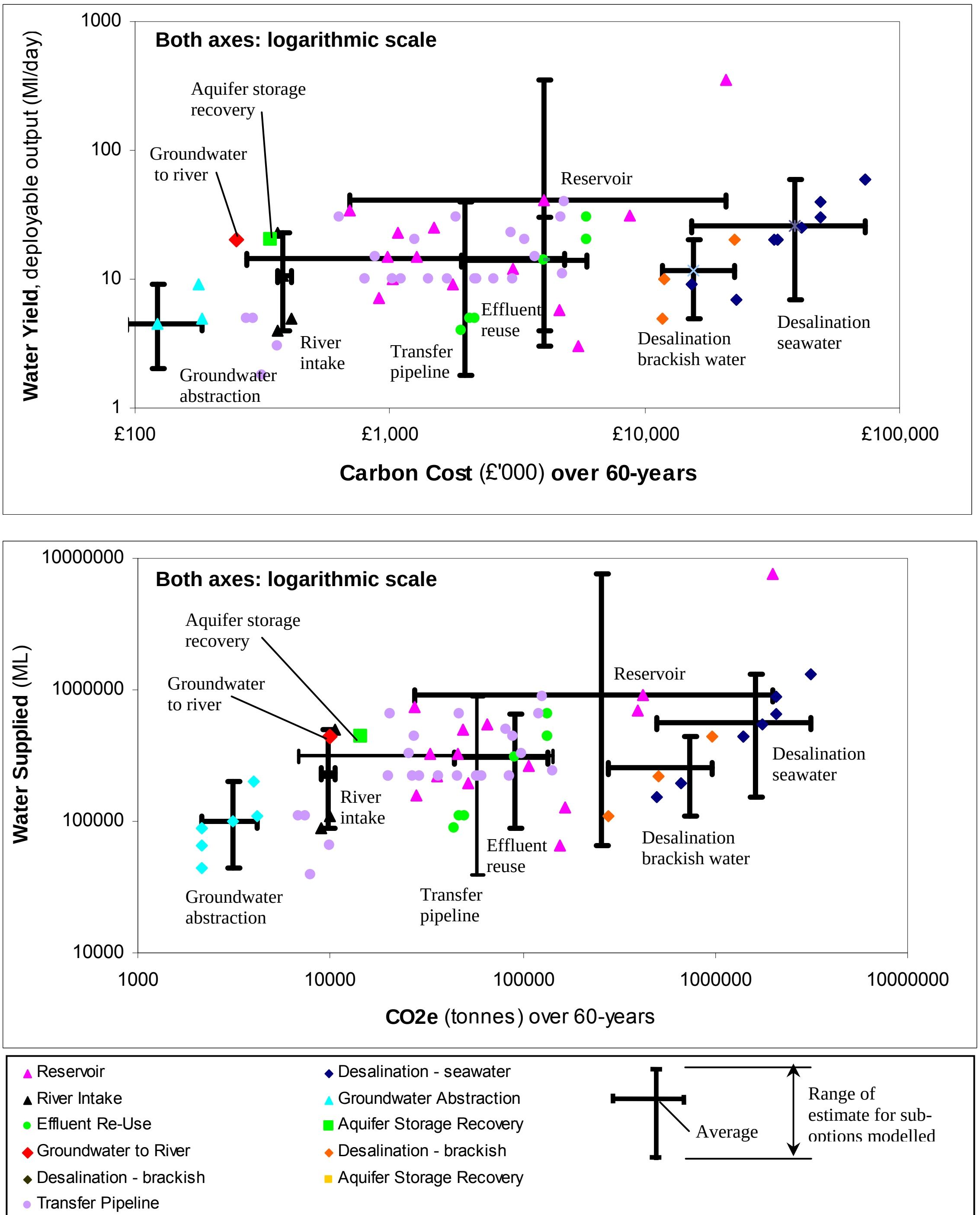
i. total carbon cost versus yield (Ml/day);
ii. total CO_2e versus water supplied (Ml) over 60 years.

Results are indicative only. Result "bars" are drawn to indicate the average (where the bands intersect) and range of carbon costs (see figure legend).

These scatter plots (Figure 6.1) show where the supply options fall relative to each other, and also the wide range of the results based on the scheme proposals investigated. The figures quoted for carbon costs are not discounted. A further assessment of options based on AICC (present values) is presented in Section 6.5.

Differences between options are not clear cut. Based on the model results the water supply options can be classified in terms of carbon as:

- Low carbon cost relative to other options with limited capital works and operational carbon costs <£0.5 million, (river intake, groundwater abstraction, aquifer storage recovery and local transfer pipeline schemes);
- Medium carbon cost with carbon cost ranging from £0.5 to £10 million, (small to medium size reservoirs, transfer pipelines and indirect effluent reuse schemes);
- Medium to high cost with carbon cost ranging from £10 to £15 million, (desalination of brackish water source);
- High carbon cost with a carbon cost between £15 to £75 million (one major reservoir scheme, desalination of brackish water for larger plants and of seawater requiring significant energy to operate).



Note: The plotted water supply results based on scheme specific proposals cannot be directly compared with water demand results based only on uptake by 1000 households.

Figure 6.1 Carbon Cost Model Results - Water Supply Options

Table 6.1 summarises the model results for each water supply option, in terms of the schemes investigated, range in water yield and carbon footprint. Further interpretation of results is given below.

Table 6.1 Carbon cost model results - water supply options

Option	No. of schemes assessed	Yield (Ml/d)	Carbon Footprint		
			tCO_2e/Ml	million tCO_2e over 60 years	million £ over 60 years
Reservoir	13	3 to 350	<0.1 to 2.4	<0.1 to 2.0	0.7 to 21
Desalination	12	5 to 60	2.2 to 3.4	0.3 to 3.1	12 to 75
River intake	5	4 to 23	up to 0.1	0.01	0.3 to 0.4
Groundwater abstraction	6	2 to 9	<0.1	<0.01	0.1 to 0.2
Effluent Reuse - indirect	6	4 to 30	up to 0.5	0.04 to 0.15	2 to 6
Aquifer storage recovery	1	20	<0.1	0.02	0.3
Groundwater to river augmentation	1	20	<0.1	0.01	0.3
Pipeline transfer	24	2 to 40	up to 0.6	0.01 to 0.15	0.2 to 5

The carbon costs are also considered below in terms of capital (CAPEX) and operational (OPEX) costs. This break down helps in highlighting how sensitive the results are to the model assumptions (Section 5.4).

- CAPEX: capital cost combining the embodied carbon in materials, which is typically the dominant capital component, with manufacture and construction and including construction energy usage.
- OPEX: operational cost of the energy involved in operation based on power supply (electricity conversion factor of 0.43 kgCO2e per kWh quoted by Defra[2]) but no other types of energy.

For example, an option that is skewed heavily to OPEX will be sensitive to the above assumption on power supply (e.g. desalination). The uncertainty in the key assumptions and parameters of this assessment is discussed later (Section 6.6), and is recognised as an area for further study.

Reservoir schemes
Schemes include river take-off, reservoirs (dam or bunded), pipeline and treatment facilities. The highest yield scheme at 350 Ml/d is an outlier, with 150,000 Ml storage, bunded height up to 25m and 15km of pipeline. This compares with the lowest yield scheme (3 Ml/d) for 2,000 Ml storage. As these results are so widespread (Figure 6.1), even based on the Ml/d yield, it is difficult to define a standard scheme. Carbon costs typically range from £0.7 to £21 million. Carbon costs over 60 years break down as 80 per cent CAPEX and 20 per cent OPEX.

Desalination schemes
Schemes include take-off works, service reservoirs, desalination plants, pipeline and treatment facilities (for water hardening). The water source is either brackish or seawater, as reflected in the energy costs, with treatment of seawater claimed to be twice as energy intensive. The water yield data in Figure 6.1 is based on peak operating. Carbon costs typically range from £12 to £75 million over 60 years.

The calculated carbon cost takes into account a varying water yield for each scheme based on the available data for average and peak operation. The period and type of operation can impact on the model results in a significant way, for example the carbon generated during operation to meet peak demand over a 10 week period can be double the average operating carbon cost over the remaining 42 weeks. The reason is that carbon costs over 60 years are divided typically less than 5 per cent CAPEX and greater than 95 per cent OPEX (for brackish water this figure can be 85 per cent).

The desalination carbon footprint is calculated based on new technologies, i.e. reverse osmosis and nano-filtration, which typically require less energy than earlier desalination methods that heated water for distillation (multi-effect and multi-stage flash distillation). The carbon footprint of these older technologies has not been assessed, but would be higher cost than newer methods.

River intake
Carbon costs (£0.3 to £0.4 million over 60 years) reflect the scope of the five river intake schemes assessed. River intake schemes include new pipeline (up to 5 km length), pump capacity (20 to 80 kW) and ancillary buildings (500 to 1,500 m^2 plan area). This option is relatively low carbon cost, though higher than the groundwater abstraction option because the scope of the capital works and operational requirements are greater for the schemes assessed. Carbon costs over 60 years average about 40 per cent CAPEX and 60 per cent OPEX.

Groundwater abstraction
Carbon costs (£0.1 to £0.2 million over 60 years) reflect the scope of the six borehole schemes assessed - yield (5 to 18 Ml/d), pipeline length (up to 2 km), pump capacity (25 to 50 kW) and ancillary buildings (300 m^2 plan area). This option is least cost compared with the other water supply options. Carbon costs over 60 years average about 15 per cent CAPEX and 85 per cent OPEX.

Effluent reuse - indirect
Carbon costs (£2 to £6 million over 60 years) reflect the scope of the six schemes assessed - yield (5 to 130 Ml/d), pipeline (up to 2 km length), pump capacity (100 to 500 kW) and ancillary buildings (500 to 2000 m^2 plan area). This option is relatively high cost compared with all options except the reservoir and desalination options due to its high energy demand in operation. Carbon costs over 60 years average about 30 per cent CAPEX and 70 per cent OPEX.

Aquifer storage recovery
Carbon costs (£0.3 million over 60 years) reflect the scope of the one scheme assessed - yield (20 Ml/d), pump capacity (100 kW), service reservoir (500 m^3 storage volume) and ancillary buildings (300 m^2 plan area). This option falls within the range of estimate of the river intake option. Carbon costs over 60 years break down as 50 per cent CAPEX and 50 per cent OPEX.

Groundwater to river augmentation
Carbon costs (£0.3 million over 60 years) reflect the scope of the one scheme assessed - yield (20 Ml/d), pipeline (2 km length), pump capacity (50 kW), service reservoir (500 m^3 storage volume) and ancillary buildings (300 m^2 plan area). This option falls within the range of estimate of the river intake option. Carbon costs over 60 years break down as 65 per cent CAPEX and 35 per cent OPEX.

Pipeline transfer
Carbon costs (£0.2 to £5 million over 60 years) reflect the scope of the 24 schemes assessed - yield (20 Ml/d), pipeline (up to 85 km) and pump capacity (up to 440 kW). As these schemes are so varied in scope there is a wide range of cost estimate. These pipeline options typically transfer water between adjacent water resource zones. Carbon costs over 60 years average about 45 per cent CAPEX and 55 per cent OPEX.

6.3 Carbon footprint of water efficiency options

The carbon footprint of the different water efficiency options is assessed and compared in terms of the carbon cost over 60 years for 1,000 homes, although the model results can be scaled to cover a larger or smaller number of homes as required.

These initial results indicate that the reduction in emissions from water saved far outweigh carbon costs to implement these options. But this positive outcome does not apply to all options. The model results for the different water efficiency options are shown in Figure 6.2 as a scatter plot based on total carbon cost to implement each option versus water saved as Ml/year (both axes logarithmic scale). The results are indicative only.

The results presented represent the full carbon footprint of each option, including the carbon embedded in materials and during the manufacturing of the product; the carbon emitted during installation of the product; and the carbon associated each time the option is replaced at the end of its life span over the 60-year time frame (every 20 years for metering, 25 years for toilets).

Figure 6.2 shows where the different options for demand management fall relative to each other. The figures quoted for carbon costs are not discounted. A further assessment of options based on AICC (present values) is presented in Section 6.5.

Water savings (Ml/d) for household products are based on CSH Level 3/4 (Table 5.3), and savings for recycled water are set at 30 per cent for rainwater harvesting and 20 per cent for greywater reuse (within the ranges quoted in Table 5.2). The preferential position on this scatter plot is for low carbon cost and high water saved, e.g. installing the toilet "hippo" is low carbon cost and average in water saved, in contrast with replacement white goods that return high carbon cost and low water saved.

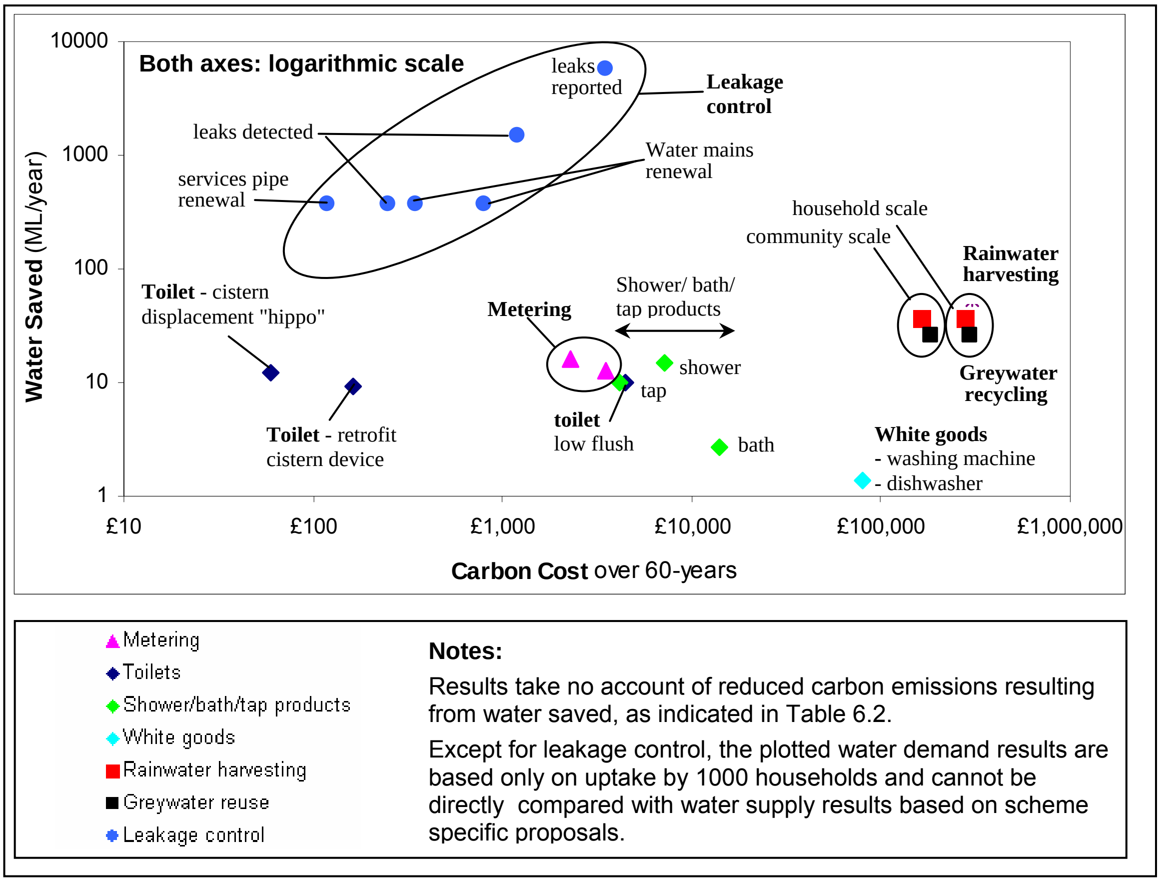


Figure 6.2 Carbon Cost Model Results - Water Efficiency Options

Our appraisal includes the carbon cost to manufacture/install the option with like-for-like replacement at the end of the option's design life (CAPEX), and any operational costs (OPEX). It could be argued that household products represent "sunk" costs, except in the case of one-off retrofit costs to bring water efficiency into existing homes. We assume "sunk" costs in calculating AICC (Section 6.5).

For new home builds, the preference is for energy/water efficient products, as there is no real premium over inefficient alternatives. The product efficiency relies on good design and proper use. The need to promote this via branding is recognised in Defra's Future Water strategy[4].

Based on the model results the water efficiency options can be classified as:

- low carbon cost relative to other options, with carbon cost ranging from less than £1000 (toilet cistern devices) to below £5000 (low flush toilet, metering, low flow taps and shower), with moderate (5-10 per cent) to high (>10 per cent) water savings;
- medium carbon cost of below £15,000, moderate to low water savings of less than five per cent (low volume bath);
- medium to high carbon cost of up to £100,000 and low water savings of less than five per cent (white goods);
- high carbon cost of over £100,000 and high water savings greater than 10 per cent (rainwater harvesting and greywater reuse).

Table 6.5 summarises the water savings, carbon costs and savings and net carbon emitted for each water efficiency measure and leakage control options, based on model results. Further interpretation of results is provided below, with a similar breakdown of the carbon footprint to that presented above for water supply options.

Table 6.2 Carbon Cost Model Results - Water Efficiency Options

Water efficiency option	**Water Savings** Ml per year	**Carbon costs** £ '000	**Carbon savings** £ '000	**Net carbon emitted** tCO_2e '000
Water efficiency measures - model results for 1000 households over 60 years				
Metering	13 to 16	2 to 4	250 to 320	-5 to -6
Low flush toilet	9 to 12	<1 to 5	10 to 20	-0.2 to -0.3
Bath/shower/tap	3 to 15	4 to 15	50 to 200	-0.8 to -4
White goods	1	80	30	1.8
Rainwater harvesting	40	160 to 280	50	2.4 to 4.8
Greywater recycling	25	180 to 295	35	3.0 to 5.4
Variable tariffs	7	0	125	-1.5
Water audits	4	0	125	-2.5
Leakage Control - model results based on available data				
Repair leaks detected	365 to 1500	250 to 1200	300 to 1300	-1 to 2
Repair leaks reported	5730	3500	4900	-21
Water mains renewal	365	345 to 800	310	3 to 16
Service pipes renewal	365	120	310	-3
Control pressure	6200	no data	5300	-110

Metering

Metering options modelled include conventional and smart metering, and metering in conjunction with variable tariffs. These options show limited variation in the calculated carbon cost and water savings (see cluster in Figure 6.2). The water savings on household use are 10 to 15 per cent, with operational carbon for meter reading minimal (no visits are required for smart metering, which therefore returns the lowest carbon cost). Net emission savings are high because metering is assumed to reduce household hot water related energy emissions by similar reductions to water savings.

Toilet - low flush options

Options were modelled for retrofit cistern displacement device ("hippo" and flush unit), retrofit cistern device and low flush toilet (can be fitted as a retrofit option, or as the preferred choice in new build homes), and show wide variation in carbon cost. Similar water savings are calculated, with the "hippo" clearly the most effective least cost option. The carbon cost of the low flush toilet is relatively high due to embedded carbon costs in manufacture. Net emissions are still negative however, but far less than those for water metering because there are no household energy benefits from low flush toilets.

Bath/shower/tap products
Options modelled for low flow taps (or flow regulator), low flow shower unit and low volume bath, and all show similar results. The main difference in carbon cost can be attributed to product manufacturing, with large items such as a bath unit having higher embodied carbon emissions. A low flow showerhead as an alternative to a retrofit shower unit would give similar water savings, but with a lower carbon cost. Our appraisal excludes any energy savings offered by the most efficient shower units. Carbon savings are relatively high due to reduced household emissions from water heating.

White goods
Options modelled for water-efficient white goods include the cost of manufacture, which is significant given the complexity and size of these machines. White goods are thus the most carbon costly of the household products examined. For this option the carbon costs exceed the savings calculated over 60 years. But our appraisal excludes any energy savings offered by the most efficient machines, i.e. technological improvements mean they use less energy to heat the same amount of water when compared with inefficient machines.

Rainwater harvesting
Options were modelled at household and community scales to supply non-potable water. Our assessment includes the carbon cost to manufacture, install and operate the systems. They return high carbon costs relative to the other options due to the energy required to pump and treat (filtration) water for non-potable use throughout the asset lifetime. The potential water saving (30 per cent) is assumed to be higher than for grey-water recycling (20 per cent), though carbon costs are comparable. Both rain water harvesting and greywater systems are similar in scope, with storage tanks, pumps, pipework, etc. For a lower water saving the carbon cost increases.

Greywater recycling
Options modelled at household and community scales for non-potable water. Modelling included the carbon cost to manufacture, install and operate the systems. They return high carbon costs relative to the other options due to the energy required to pump and treat water for non-potable use. The potential water saved is assumed lower than for rainwater harvesting, but carbon costs are comparable as both systems are similar in scope with storage tanks, pumps, pipework, etc.

Variable tariffs
Option modelled in combination with metering. Costs and savings assume that variable tariffs for metered homes can reduce water demand by an additional five per cent. This option gives a moderate water saving and relatively high carbon savings (assumes reduced household emissions from heating less water). The net carbon savings are added to that for metering to give an overall benefit of the two options combined.

Water audits
Option not modelled. Our literature review suggests that water audits can reduce water demand by three per cent (although there is much uncertainty over this figure), which gives the moderate water savings quoted in Table 6.5, and relatively high carbon savings (assumes lower household emissions from reduced water heating). We assume that water audits can be carried out using self audit packs as explained in Section 3.5.5, and for this reason the assessment excludes any transport emissions.

Leakage control
Options modelled based on example leakage and carbon emissions data in Section 5.7. For this assessment, leak repairs are assumed to take place year-on-year

as part of an ongoing programme to maintain the level of leakage control, i.e. the carbon emission values quoted in Section 5.7 are accounted for every year of the 60 year appraisal period. Asset renewals (water mains and service pipes) are assumed to last 30 years before replacement.

The following example sets out our assessment for leaks reported, based on the figures quoted in Section 5.7 for this leakage control option with 15.7Ml/d water saving; 1203 tCO_2e.

- 15.7 Ml/d or 5370 Ml/year water saved
- water saved equivalent to 1550 tCO_2e/year (based on figures for water source, treatment and distribution in Figure 5.3) or 93 ktCO2e saved over 60 years
- 1203 tCO2e or 72 $ktCO_2e$ over 60 years
- net carbon 21 ktCO2e saved over 60 years (93 - 72 $ktCO_2e$)

The results, based on limited data, are interpreted below to give a first indication of carbon impacts. They indicate that with the exception of water mains renewal, leakage control activities can reduce carbon overall (refer to net values in Table 6.5). However, such generalisations may not carry when other factors are considered such as leakage reduction targets, since in practice, water company leakage reduction targets are met through a combination of leakage control activities.

Pressure control activities are most effective, in part because no carbon cost is included for which no data are available - this requires further study. For other leakage options, the repair of reported leaks return a higher water saving and carbon reduction than leak detection and repair.

The renewal of service pipes is more effective in carbon terms than renewing water mains. The high carbon cost of water mains renewal makes this option less attractive relative to the other options. The high cost is mainly due to the embedded carbon in pipe materials and during the renewal works, including traffic disruption (increased journey time of diversions).

Our assessment, limited to available data (Section 5.7), indicates a higher water saving and reduced carbon impact from service pipes repair, presumably because only basic repair is required.

6.4 Carbon footprint of water efficiency options in combination

Water efficiency measures are typically installed in combination, particularly in new homes.

We assess the carbon cost of three combinations of water efficiency options which reflect the three different CSH levels related to water, as detailed in Section 5.8 (21, 31 and 48 per cent water savings). The model results are again based on 1,000 homes, taking account of the carbon footprint of the option and savings in energy and reduced emissions from reduced water demand that the combined schemes achieve over 60 years.

Model results are calculated following the same principles used for the modelling of individual water efficiency options. The results are based on the water savings listed in Table 5.3 and including all CAPEX/OPEX carbon costs. We further assume that all combinations include metering, but do not claim any additional water savings above the figures quoted in Table 5.3.

The model results for the different combinations of water efficiency options are shown in Figure 6.3 as a scatter plot against the results for individual options (both axes logarithmic scale. This scatter plot shows where the demand options fall relative to each other. Table 6.3 summarises the model results, which are indicative only.

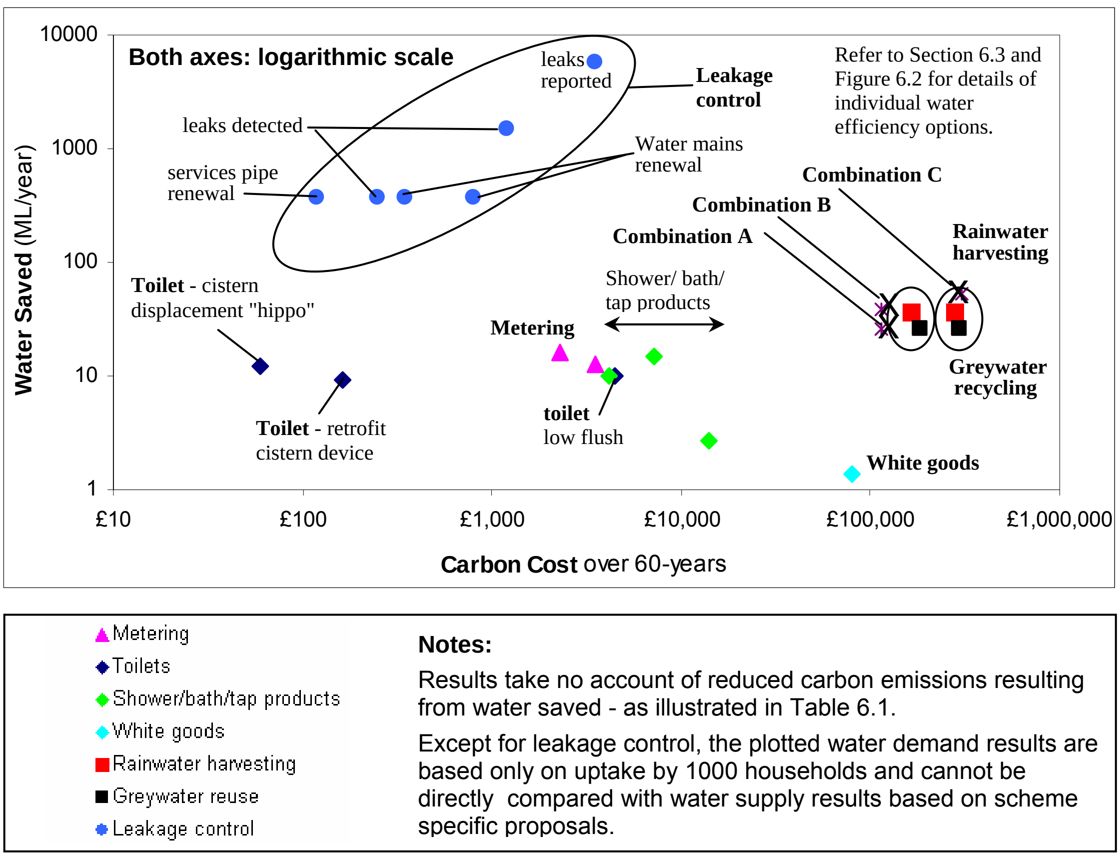
The model results for the three option combinations are skewed towards high carbon cost as they each include high carbon cost options, such as white goods and, in the case of Combination C, rainwater harvesting. The combinations also reflect the increased water saved from low flush toilets and other water saving products.

Greater insight of how these option combinations compare is given in Section 6.5.

Table 6.3 Demand Management Combinations - model results for 1000 homes

	Standard home (l/d)	**Water savings** - % of total A	B	C[a]
Water use – litres per capita	151	120	104	78
Water savings - %	-	21%	31%	48%
Water savings - Ml/yr	-	26	39	53
Carbon costs - £'000 over 60 years	-	160	160	325
Carbon savings - £'000 over 60 years	-	-240	-370	-455
Net carbon emitted - tCO_2e '000	-	-1.2	-3.8	-2.2

[a] combination includes recycled water by rainwater harvesting (50% for toilet/washing machine)



Notes:

Results take no account of reduced carbon emissions resulting from water saved - as illustrated in Table 6.1.

Except for leakage control, the plotted water demand results are based only on uptake by 1000 households and cannot be directly compared with water supply results based on scheme specific proposals.

Figure 6.3 Carbon cost model results for combined water efficiency options

6.5 Comparing supply and demand options

So far in this chapter we present the carbon footprint for:

- water supply options (carbon cost for scheme only);
- water efficiency options (carbon cost to install/operate on individual basis);
- combinations of water efficiency options (carbon cost on combined basis).

It is difficult to compare directly the carbon costs of different options as calculations must use a common basis that takes into account different water yields or savings, asset life, total carbon emissions, and an annual rising Shadow Price of Carbon.

The preliminary results presented below are average values, based on our high level assessment (note: we continue to refine the results for water supply options in our separate studies for the South-East region). The range of life-cycle emissions associated with new supply schemes in particular is large. To select the lowest carbon solution requires a scheme by scheme assessment.

A first comparison is made based on carbon associated with the water supply-use-disposal system on a household basis. Figures 5.2 and 5.3 illustrate the carbon emissions calculated using UK average data (6.97 tCO_2e/Ml), which equates to the average household emitting 2.43 kg CO_2e daily (assumes 149 l/d per capita and 2.36 occupancy).

Table 6.4 shows the relative change in household emissions (from kg CO_2e) for individual options. Metering as a demand management option is shown to be carbon efficient, and the water supply option of desalination returns the highest carbon emitted.

Table 6.4 Model results - relative impact of options at household level

Demand management option	**Household net carbon emitted** kg CO_2e/day	**Water supply option**	**Household net carbon emitted** kg CO_2e/day
Metering and tariffs	2.08	Direct ground water abstraction	2.46
Smart metering	2.14	Aquifer storage and recharge	2.47
Conventional metering	2.20	River intake	2.48
Efficient showers	2.25	Indirect effluent reuse	2.57
Water audits	2.36	Reservoir	2.61
Efficient baths	2.30	Desalination (brackish water)	2.91
Spray taps	2.38	Desalination (saline water)	3.77
Low flush toilets	2.42		

Notes:

(a) Water supply options: figures represent the increase in emissions to develop a new scheme for abstraction/conveyance (Figure 5.2), and include 10 per cent increase in capacity in water treatment, distribution and wastewater system.

(b) Demand management options: figures represent the net increase in carbon, e.g. to manufacture and install, and decrease in carbon from water savings.

In order to make a direct carbon cost comparison between water supply, individual water efficiency options and combined water efficiency options we calculate the AICC (average incremental carbon cost) for the water supply-use-disposal system.

We define AICC in Section 2.10 and explain the calculation in Section 5.10.

Our preliminary options appraisal compares the option impact on benchmark AICC for all water supply and demand management options (see Figure 6.4). All water supply and demand management options are included, except leakage control as the available leakage data are limited and estimates of water savings at the level of households cannot be made.

In the AICC calculation for household products - shower, bath, taps and white goods - the option carbon cost (CAPEX/OPEX) are included as one-off retrofit costs only for existing homes. No costs are included for new homes; they are treated as "sunk" costs and considered to be installed in every new home, given that there is no real premium between water efficient and inefficient products.

Higher water savings are also assumed for some household products as one-off retrofit in existing homes. White goods (4 per cent) and bath products (6 per cent) are increased from estimates previously quoted (Table 5.3) that relate to new homes.

The headline results are:

i) all water supply options result in increased carbon emissions above current baseline;

ii) all forms of water metering result in reduced carbon emissions, with smart metering and metering with tariffs the most effective options for carbon mitigation.

For existing homes:

iii) retrofitting white goods, rainwater harvesting or greywater recycling options increase carbon emissions;

iv) but retrofitting of low flush toilets, low flow showers and spray taps to existing homes results in reduced carbon emissions.

For new homes:

v) all other water efficiency options show an overall reduction in carbon;

vi) installation of rainwater harvesting (or greywater recycling) as part of a new development and alongside other water efficiency measures (i.e. as required to meet CSH level 5/6) shows a net carbon benefit.

The relative differences against the benchmark AICC are summarised below:

- Water supply options: AICC increases by five per cent or less for groundwater and river intake options; and by 5-10 per cent for the indirect effluent reuse and reservoir options. Desalination increases AICC by 20 per cent for brackish water and by over 50 per cent for seawater.
- Water efficiency options (metering, tariffs and audits): AICC decreases by 3-15 per cent for metering, which is high relative to other options because the option has low carbon CAPEX and OPEX, and water savings are assumed to give corresponding lower emissions due to less hot water use in the home.
- Water efficiency option (toilets): AICC decreases by almost 7 per cent for displacement devices and 1 per cent for low flush toilets in existing homes (retrofit). Reductions of 8 per cent are achieved for this latter option in new homes (the carbon footprint ignores the "sunk" carbon costs because the devices are installed in every home not for water efficiency purposes).
- Water efficiency option (shower, bath, taps): AICC decreases by 2-12 per cent in new homes. This excludes the option carbon, and water savings are assumed to give lower emissions due to less hot water use in the home. This range falls to 1-7 per cent if the option carbon footprint is included for existing homes as a one-off retrofit cost. An increase in AICC for bath products is indicated because the one-off retrofit cost for a replacement is high.

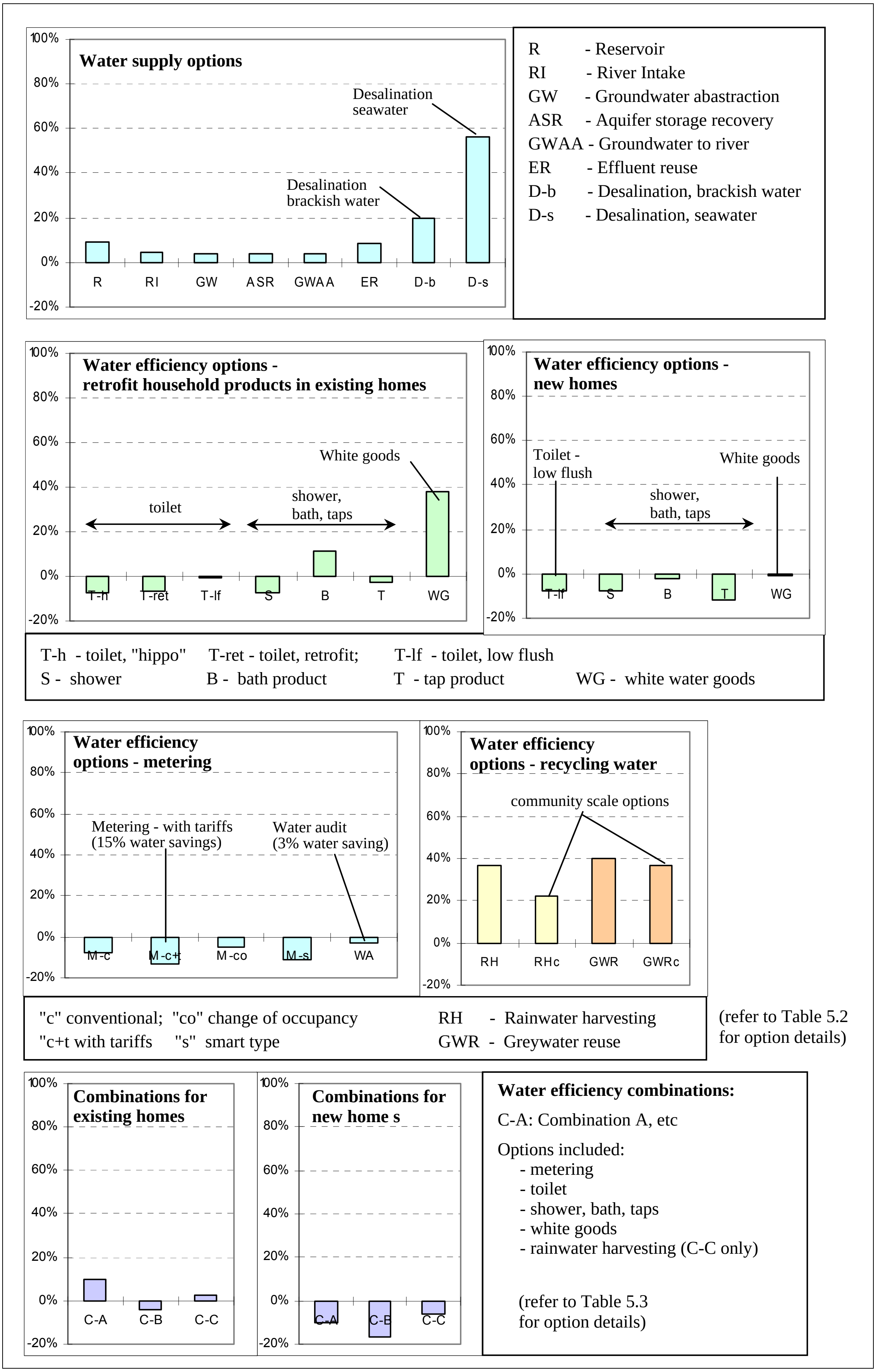


Figure 6.4 Model results - relative impacts of options

- Water efficiency option (white goods): AICC decreases by three per cent in new homes and rises above 30 per cent if this option's carbon is included for existing homes as a one-off retrofit cost. However, the model calculation does not capture the full energy efficiency gains that new washing machines and dishwashers can offer.
- This last point is based on manufacturer data for water savings, the associated heating of this water (in the home), and also the greater efficiency in heating water (i.e. extra benefit).
- Water efficiency option (rainwater harvesting): AICC increases by 20-40 per cent based on 30 per cent water savings. Community scale harvesting is more carbon-efficient. A higher range of 50-70 per cent is modelled for 10.7 per cent water savings, in line with the CSH Level 5/6 demand management combination (Section 3.3).
- Water efficiency option (greywater recycling): AICC increases by 30-60 per cent based on 20 per cent water savings, with community scale systems more carbon-efficient.

All water efficiency combinations (A, B and C) indicate overall carbon savings for new homes and one combination (B) for existing homes. The two other combinations (A and C) for existing homes return carbon savings if white goods are excluded from the combination (white goods - high carbon for limited water saving). Even rainwater harvesting as an option combined with other water efficiency measures is net carbon positive (C for new homes).

The following points should be noted:

- Bath and white goods options for existing homes assume greater water savings (6 per cent and 4 per cent, respectively) than claimed for new homes in Section 3.4 (up to 4.3 per cent and 1.1 per cent). This higher figure is justified in view of claims made by manufacturers about water efficiency gains if old products are replaced.
- Household products - shower, bath, taps and white goods - for existing homes are included as one-off retrofit costs. The costs are not applied to new homes as they are treated as a "sunk" cost.
- The carbon impact of rainwater harvesting in combination is reduced as this option provides only 10.7 per cent of water in the home, not the 30 per cent when harvesting is treated as a standalone product - higher savings lead to increases in operational carbon.

On the above basis, AICC for combinations A, B and C for existing homes increases by 10 per cent, decreases by 4 per cent and increases by 2 per cent, respectively, and for new homes decreases by 10 per cent, 17 per cent and 6 per cent, respectively.

6.6 Uncertainty

Inevitably there is uncertainty in the study findings, arising from the reliability of the input data, the adopted boundaries in the life-cycle analysis and the key assumptions that underpin the carbon cost model.

Uncertainty in the key assumptions is a subject for further study, to assess for example:

- different material types, fuels and construction/manufacture techniques;
- future replacement of options at full carbon cost with no account of any cost/saving from re-use, recovery, recycling and disposal;
- step changes in improvement of operational efficiency in the future.

Another key parameter is the SPC, currently set at £26/tCO_2e, but this figure could potentially increase before 2009[12]. The uncertainties and sensitivity of the SPC, and how it should be used in policy making, are addressed in the commentary in Section 2. If the SPC doubles, the carbon cost calculated by the model for each option will correspondingly double.

In order to compare directly the various water supply and demand management options, this study looked beyond the more conventional approach to carbon footprinting on a scheme by scheme basis. We formulated an innovative approach to carbon cost modelling, involving life-cycle analysis across the entire water system. However, this added complexity leads to greater uncertainty.

The datasets used for the carbon cost assessment are gathered from many sources, including water company's plans for water resources, related water resources projects (some unpublished), and Defra and Environment Agency guidance. The worked example (next chapter) is based on scenarios for the South East region, as presented in related projects – we have not questioned the basis for these scenarios.

This work is intended to catalyse further research and refinement of carbon cost assessments. The model developed for this study provides broad-scale assessments that are intended only to highlight carbon impacts at a strategic level. There could be a wide margin of uncertainty, and no attempt has been made to determine confidence limits or error bands.

The carbon cost of water supply options is modelled using water company data for proposed capital and operational works. Consistent with Defra's guidance on project appraisal[13], we assess initial confidence limits around the model results based only on a 60 per cent increase in the scheme (and carbon) costs to reflect optimism bias (applied to both CAPEX and OPEX). No further confidence limits are investigated.

We present carbon costs calculated using national average data to define carbon emissions rather than regional or local data. We also use these averages for the worked examples for the South-East region. Further studies could easily update these costs to reflect regional data if required.

7 Worked Example - South East region

7.1 Overview

This chapter applies the carbon cost assessment model to real world scenarios. The assumptions that back up the worked example presented are taken from recent work for the South East region[6,10]. The model results serve to illustrate the wide variance in carbon impact of water resource planning and demand management scenarios.

We chose the South East region as a case study because it faces many challenges to meet future water demand and is the subject of our recent study[11] that looks at managing water resources in this region as part of the development of our new water resources strategy.

The results presented are not definitive and are intended to provide a first indication of the carbon implications of supply-demand scenarios. The uncertainties over data, boundaries, methodology and assumptions are explained in previous chapters.

7.2 South East region

With acute and growing pressure on scarce water resources in this region, the notable characteristics and challenges include:

- high population density in parts of this region;
- high water use rates compared with other parts of the UK;
- high levels of housing growth planned over the next 25 years (28,900 homes per annum as per SEERA South East Plan Consultation, 2006);
- climate change impacts (i.e. hotter, drier summers and wetter, warmer winters).

The Environment Agency's previously stated position is that we need to act now to secure future water supply to this region, and find the optimal balance in developing supply options and managing water demand. The Environment Agency recently initiated wider debate within the water sector about the larger role that demand management clearly has to play in water resources planning[11].

This worked example on carbon for the South East can help inform the debate.

7.3 Water resource planning scenarios

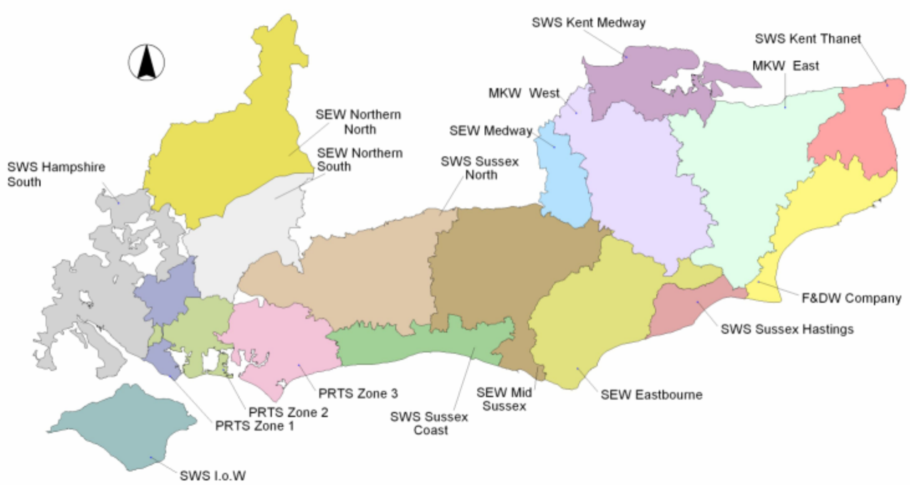
Carbon cost models are developed for three supply-demand scenarios that were assessed in a recent water resources optimisation modelling study (November 2007)[6]. We examine three scenarios as defined in Table 7.1, each allowing for regional housing growth. Figure 7.1 shows the scope of this modelling work of five water company areas.

Table 7.1 Selected South-East water resources planning scenarios

Ref.	Scenario	Description	Implementation Cost Estimate[6]
SE1	Business as usual scenario	Base sustainability reduction in deployable output of schemes/options	£900 million
SE2	Higher sustainability scenario	As SE1, but with higher sustainability reduction to achieve Water Framework Directive targets (upper bound estimate) e.g. for Hampshire SE1 - 35 ML/d reduction from 2010 compares with SE2 - 70 ML/d reduction for WFD	£2,140 million
SE3	Lower demand scenario	As SE1, but with lower overall demand based on 21 per cent water efficiency saving in new homes; 90 per cent overall metering in existing homes by 2020 with each meter achieving 15 per cent savings[*]	£470 million

[*]this upper limit of 15 per cent was adopted in our optimisation modelling study6

Our previous optimisation modelling identified for each scenario the water supply options (from 66 individual options) that satisfy the supply deficit on a regional basis at least cost. These options include indirect effluent reuse, strategic water transfer, desalination, river abstraction, groundwater and reservoir development. We based this work on an updated version of the regional model originally developed for the Water Resources in the South East Group.



Scenarios investigated for:
- Folkestone & Dover Water (F&DW)
- South East Water (SEW)
- Southern Water Services (SWS)
- Portsmouth Water Services (PRTS)
- Mid-Kent Water (MKW)

Figure 7.1 Water Resources in South-East, Regional Model Network Schematic

Implementation (undiscounted) costs[6] for the new water supply options for each scenario over 25 years have been previously estimated, as quoted in Table 7.1.

- SE2 as the highest cost scenario reflects the significant investment to achieve WFD targets and safeguard existing water resources for which new sustainable water supply schemes must be exploited.
- SE3 as the lowest cost scenario assumes that average water demand can be reduced by 40 per cent in new homes and 15 per cent in existing homes, with 90 per cent coverage of metering/tariffs by 2020.

For SE3 the water (and emissions) savings are calculated for both water efficient new homes (28,900 per annum), and existing homes that number more than two million.

7.4 Basis for carbon cost assessment

We use the carbon cost model to assess the new water supply options for the South East region, which include new scheme options as well as options to increase the capacity of existing schemes. For the three scenarios, the options selected by optimisation modelling number 34 schemes for SE1 (red line in Figure 7.1), 51 schemes for SE2 (blue line) and 18 schemes for SE3 (green line).

An attempt is made to model the carbon costs of the total water supply-use-disposal system (Figure 5.3) on a regional basis, covering both existing and new homes and including the carbon cost of the options selected for each scenario. To place this in context, the baseline average water demand for two million homes is 254,630 Ml/year (based on 148 l/capita/d, 2.36 occupancy rate), equating to 1.8 $MtCO_2e$/year (based on 6.97 tCO_2e/Ml).

For SE3 a conservative approach is taken regarding the demand management options that are modelled: only metering is modelled and water savings are set at 15 per cent (i.e. equivalent to the metering with tariffs option assessed in Section 6).

A planning horizon of 25 years is adopted to be consistent with our previous studies.

7.5 Carbon cost assessment model results

The first plot in Figure 7.2 shows the carbon cost model results plotted in terms of the carbon cost for the total system for SE1 (red line), SE2 (blue line) and SE3 (solid green line). The second plot shows the same results except it excludes "water in the home" from the total water system to highlight its dominance in the carbon footprints.

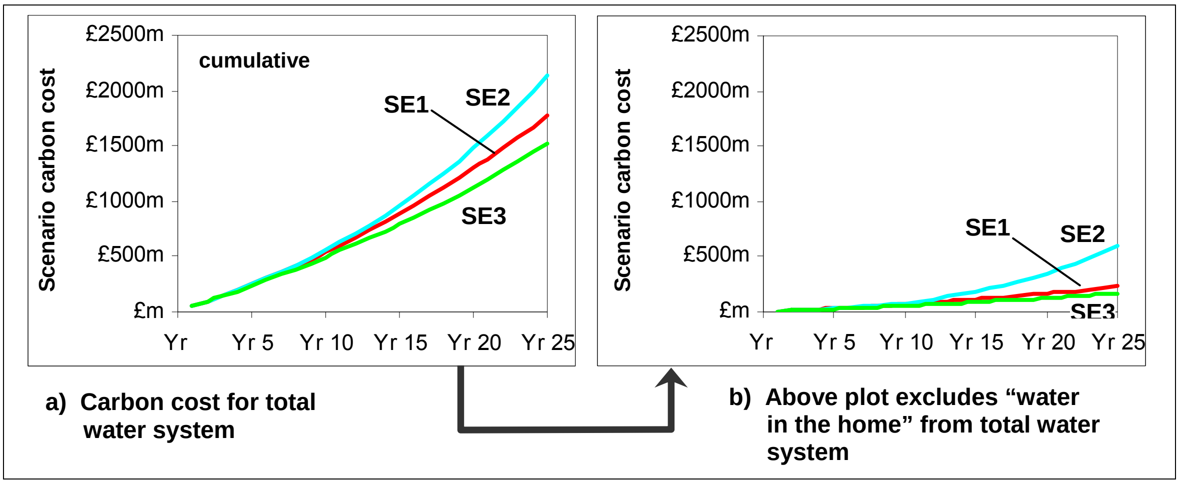


Figure 7.2 Carbon cost for South East region scenarios

The cumulative carbon (undiscounted) cost for the scenarios after 25 years are calculated to be:

- SE1 - business as usual scenario: £1,776m carbon;
- SE2 - higher sustainability scenario: £2,137m carbon;
- SE3 - lower demand scenario: £1,524m carbon.

The model results are indicative, drawing attention to the scale of the carbon cost in a water resources planning context. They are significant when compared with the option implementation costs outlined previously. The carbon costs are mainly due to water use in the home, as highlighted shown by the difference between the two plots in Figure 7.2.

The results are not fully representative of the supply-demand balance, however, because they assume that new water supply options are fully deployed once implemented. In practice this is not the case.

As expected, SE3 is clearly the most carbon-efficient option. This scenario includes only 18 new supply-side options, with reduced water demand in more than two million existing homes. Compared with ‘business as usual’ (SE1), the lower demand scenario (SE3) can achieve a 14 per cent carbon saving, in addition to the 50 per cent saving in implementation cost estimated in the previous study.

Finally, the AICC for the three scenarios is compared with the benchmark AICC (average incremental carbon cost, calculated using water sector average data). We explain the basis for this calculation in Section 2.10.

The benchmark AICC is adjusted to stay consistent with the progressive increase in water demand in line with housing growth and the 25 year planning horizon. A benchmark AICC of 22.6 p/m^3 was calculated. For the three scenarios, the relative differences against the benchmark AICC are:

- SE1 – increase of 2 per cent;
- SE2 – increase of 20 per cent;
- SE3 – reduction of 11 per cent.

By this measure of AICC, SE3 is again shown to be significantly more carbon efficient.

The preliminary results presented above are based on our high level assessment (note: we continue to refine the results for water supply options in our separate studies for the South-East region).

8 Concluding remarks

Our study explores the link between water resources, energy and carbon emissions, with a focus on the carbon cost of different options for supplying water and using water more efficiently.

The study was conceived because carbon footprinting specific to water resources was so poorly understood. For this reason we decided to develop an initial evidence base and framework for the appraisal of carbon impacts at conceptual/strategic level. There remains considerable amount of research and investigation to be carried out in this area.

The following findings, conclusions and recommendations can be drawn:

Headlines

- Climate change presents one of the key challenges of our generation. It is critical to achieve a low carbon water system, whilst still improving wider sustainability and quality of life objectives. This should be implemented through the right balance of options to help customers manage their demand for water as well as considering some new water resource schemes.
- The water industry uses large amounts of energy to supply water and treat wastewater. This activity releases greenhouse gases and accounts for 0.8 per cent of UK emissions.
- Consumers use energy when they use and heat the water (e.g. for baths, showers, washing machines etc). This activity accounts for 5.5 per cent of UK emissions. This figure excludes the impact of energy use for space heating, which is outside the scope of this study.
- By far the highest proportion (89 per cent) of carbon emissions in the water supply-use-disposal system is attributed to "water in the home", which includes energy for heating water (excluding space heating). Carbon emissions from the supply and treatment of public water accounts for 11 per cent of emissions.
- Simple demand management measures such as water metering have the potential to reduce greenhouse gas emissions by reducing the energy use associated with heating water in the home. For example, moving to full water metering across England and Wales could reduce annual emissions by 1.1 - 1.6 million tonnes of carbon dioxide per year. Moving to full metering in areas of serious water stress could potentially reduce annual emissions by between 0.5 - 0.75 million tonnes CO_2e per year.

Water supply

- All supply-side measures result in an increase in carbon emissions (we assume new schemes are implemented to meet rising demand rather than replacing existing assets).
- There is often a wide range in the level of carbon emissions associated with schemes of a similar type, so different types of schemes commonly overlap in their emission levels. For example medium to large reservoirs and indirect effluent re-use can have similar carbon emissions per volume of water supplied, dependant on each scheme's design. To select the lowest carbon solution requires a scheme by scheme assessment.

Demand management

- Most demand management options have low operational carbon emissions, the exception being household rainwater harvesting and greywater recycling. Data concerning the energy use of these latter techniques is scarce and requires further research.

- Combinations of demand management options, even those including rain water harvesting in new homes, offer larger water savings compared to individual water efficiency options and still compare favourably to supply side options in terms of overall lower carbon emissions.

Technological developments

- We acknowledge that future technological developments will offer greater energy and carbon savings to both water supply and demand management options. The extent of these savings has not been looked at in this study due to the level of uncertainties involved.

Legislation

- Current legislation continues to require the sustainable management of rivers and groundwater. In some cases this will mean that water abstraction will need to be reduced to ensure a sustainable water environment, resulting in a reduction in the water available for supply. To offset this effect, companies are investigating alternative sources of water. Our work indicates this will increase carbon emissions overall. We believe that widespread implementation of demand management measures can offset or further reduce overall emissions, as well as reducing the need for some of these new supplies in the first place..

- For example initial assessment using South East data indicates that the lowest carbon cost is delivered by the scenario which includes both demand management for two million homes and 18 new supply schemes, delivering a 14 per cent carbon cost saving compared to business as usual.

Policy implications

- In future, policies need to consider the greenhouse gas emissions across the whole of the water system, i.e. emissions arising from both the water industry and the use of water by consumers. Policy-makers also need to recognise the potential overlap with the aims of energy efficiency initiatives and ensure there is no double counting of carbon reductions.

- Water Resource Management Plans require water companies to assess their carbon footprint related to water supply only and not the whole life cycle costs. Water companies planning future water resources options through the 25 year planning period are required to build-in the shadow price of carbon to the economic analysis. However, this typically relates to the direct energy costs of water production and embedded carbon for construction activities.

  This current approach constrains the options appraisal as it fails to take full account of the life cycle costs of carbon and particularly the positive impact of demand management related to water use in the home as well as wastewater activities. This approach has therefore been unable, to date, to incorporate the largest and most significant aspects of carbon accounting within assessments between building new resources and managing demand.

The Environment Agency is committed to working with the water industry and other partners to deliver a low carbon, high quality environment. We set out below our ongoing partnership and proposed agenda to further explore the link between water resources, energy and carbon emissions:

- Partnership approach: Collaborative working to continue through our wider two-year project looking at the potential of energy efficiency and carbon reduction across the water industry. Our Steering Group for this project is represented by the Carbon Trust, Defra, Ofwat, Water UK, Thames Water and Yorkshire Water.

- Evidence base: Initial evidence base (as presented) to be reviewed against the carbon footprint results reported in water resource plans (2008) - this will further inform our understanding of water resources and carbon impacts.
- Standardise carbon cost assessment: As a strategic tool the model developed for this study provides an initial framework with which to assess water resources and carbon impacts, and can be reconfigured as we gain experience in carbon footprint studies, acquire more scheme specific and regional data, and to model new situations.
- New UKWIR guidelines for carbon estimation: These guidelines will set the water sector standard for detailed carbon footprint studies, and there is scope to incorporate the published data in our model. From our initial review the model already adopts the same base data such as the carbon conversion factors.
- Water resources planning: Review current guidance on carbon impacts, the total water system and how to account for the full benefit of water efficiency options - see issue raised above about policy makers.
- Academic research and related international studies: Establish wider links and share information with universities and international agencies involved in this type of research.

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List of abbreviations

AICC	Average incremental carbon cost
AISC	Average incremental social cost
BRE	Building Research Establishment
CBA	Cost benefit analysis
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CCA	Climate change agreement
CRC	Carbon Reduction Commitment
CSH	Code for Sustainable Homes
EU ETS	European Union Emission Trading Scheme
GHG	Greenhouse gases
MAC	Marginal abatement cost
NPV	Net present value
ppm	parts per million
SEERA	South East England Regional Assembly
SCC	Social cost of carbon
SPC	Shadow price of carbon
WFD	Water Framework Directive

Appendix A
Carbon Cost Model
- water supply options

Water supply/demand management options
Carbon foot-print calculator
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Water supply option: Reservoir

Input (default values or user defined)

Scheme details	Reservoir - average of 13 schemes			Deployable output[1]	42	Ml/day
Scheme operation	100%	annual frequency[2]..........	289	day/year.................	22	hour/day
Treatment works operation	100%	annual frequency2..........	319	day/year.................	24	hour/day
Associated building for plant	500	m^2 floor area				
Reservoir type	Offline	.... intake?	Yes			
Dam/embankment	Clay	material..........................	3.4	km length.................	15.5	m height (average)
Saddle dam	Concrete	material..........................	0	m length..................	0	m height (average)
Reservoir pumps	100	kW pump capacity[3]				
TW pumps	100	kW pump capacity[3]				
Reservoir size	15500	Ml volume				
Pipeline	55	km length........................	500	mm diameter		
Service reservoir	0	m^3 volume				

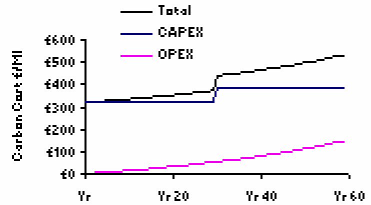
Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]including booster pumps, excl. stand-by

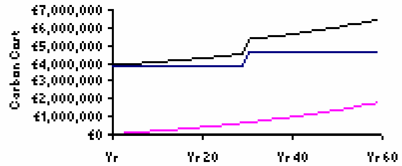
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

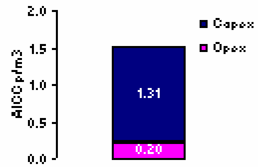
Output (over planning period)

			Breakdown			AICC: average incremental carbon cost			Variance*
Carbon 'footprint'	202166	tCO_2e	Capex	166009	tCO_2e	A. Source/conveyance	1.51	p/m^3	0.83
	0.28	tCO_2e/Ml	Opex	36156	tCO_2e	B. Treatment	1.25	p/m^3	
Carbon Cost (CC)	#####	£				C. Distribution	0.48	p/m^3	0.04
Average Incremental CC	1.51	p/m^3	Capex	1.31	p/m^3	D. Household	25.52	p/m^3	0.00
			Opex	0.20	p/m^3	E. Waste	2.24	p/m^3	0.29

*To water industry 05/06 data







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Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials	see below						91241484	91241	0.02	33.68
Capex: Construction	see below						24889562	24890	0.02	9.19
Capex: Haulage	travel	t	road	522011	63.48		33137246	33137	0.01	9.86
Capex: Travel	travel	km	transit van	1000	0.21		209	0	0.01	0.00
Opex: Operate	energy	kWh	electricity	1401400	0.43		602602	603	1.00	14.35
Capex: Materials	Totals->			-	-		116131047	116131	0.02	42.87
Steel components		t	steel - virgin	81	3313.00	50%	404997	405	0.01	0.12
Concrete components		t	concrete	515732	134	20%	82929690	82930	0.01	24.68
Pipeline		t	steel- Piping	6197	1800	50%	16731000	16731	0.03	13.28
Pumps		t	steel - virgin	1	3313	100%	4970	5	0.04	0.00
Diesel for construction		lt	diesel	4071075	2.63	50%	16060391	16060	0.01	4.78
Annual Opex: Operate	Totals->			-	-		602602	603	-	14.35
Pumping		kWh	electricity	635800	0.43		273394	273	1.00	6.51
Treatment		kWh	electricity	765600	0.43		329208	329	1.00	7.84

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e

Water supply/demand management options
Carbon foot-print calculator
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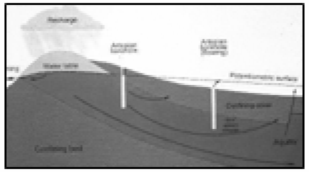


Water supply option **Groundwater abstraction & river augmentation**

Input (default values or user defined)

Scheme details	Scheme - based on 1 scheme proposal			Deployable output[1]	20	Ml/day	
Scheme operations	100%	annual frequency[2]...........	220	day/year..................	8	hour/day	
Associated building for plant	300	m^2 floor area					
Boreholes	1	number..........................	Lined	type........................	20	m depth..	350 mm diameter
Pumps	50	kW total duty capacity[3]					
Pipeline	2	km length........................	200	mm			
Service reservoir	500	m^3 volume					
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)				
Planning period	1-30 yr	31-60 yr	planning period fixed at 60 years				

Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]including booster pumps, excl. stand-by

Output (over planning period)

			Breakdown		
Carbon 'footprint'	5973	tCO_2e	Capex	1843	tCO_2e
	0.02	tCO_2e/M	Opex	2270	tCO_2e
Carbon Cost (CC)	249581	£			
Average Incremental CC	0.10	p/m^3	Capex	0.07	p/m^3
			Opex	0.04	p/m^3

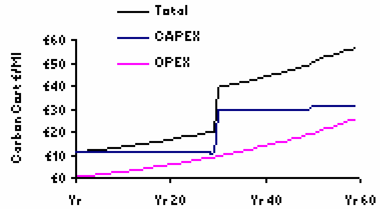
AICC: average incremental carbon cost			Variance*
A. Source/conveyance	0.10	p/m^3	-0.02
B. Treatment	1.25	p/m^3	0.69
C. Distribution	0.48	p/m^3	0.04
D. Household	25.52	p/m^3	0.00
E. Waste	2.24	p/m^3	0.29

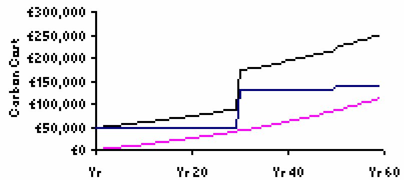
*To water industry 05/06 data

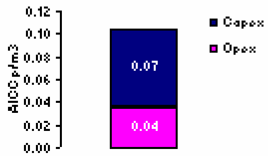
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/M
Capex: Materials		see below					1190168	1190	0.03	1.96
Capex: Construction		see below					579647	580	0.03	0.95
Capex: Haulage	travel	t	road	1155	63.48		73343	73	0.03	0.12
Capex: Travel	travel	km	transit van	1000	0.21		209	0	0.03	0.00
Opex: Operate	energy	kWh	electricity	88000	0.43		37840	38	1.00	1.89
Capex: Materials	Totals->			-	-		1769815	1770	0.03	2.91
Steel		t	steel - virgin	337	3313	50%	1677196	1677	0.03	2.80
Concrete		t	concrete	480	134	20%	77184	77	0.02	0.08
Pipeline		t	steel- piping	0	1.8	50%	0	0	0.03	0.00
Pumps		t	steel - virgin	338	0.375	100%	253	0	0.07	0.00
Diesel for construction		lt	diesel	2886	2.63	100%	15182	15	0.05	0.04
Annual Opex: Operate	Totals->			-	-		37840	38	1.00	1.89
Pumping		kWh	electricity	88000.0	0.43		37840	38	1.00	1.89

Notes: [1] material's embedded CO2e, [2]CO2e from construction (as percentage of embedded CO2e)







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Water supply/demand management options
Carbon foot-print calculator
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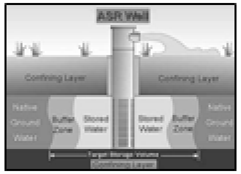


Water supply option **Aquifer Storage Recovery**

Input (default values or user defined)

Scheme details	Scheme - based on 1 scheme proposal			Deployable output[1]	20	Ml/day	
Scheme operations	100%	annual frequency[2]	200	day/year[3]	8	hour/day	
Associated building for plant	300	m^2 floor area					
Boreholes	1	number	Lined	type	20	m depth	350 mm diameter
Pumps	100	kW total duty capacity[4]					
Pipeline	2	km length	200	mm diameter			
Service reservoir	500	m^3 volume					
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)				
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years				

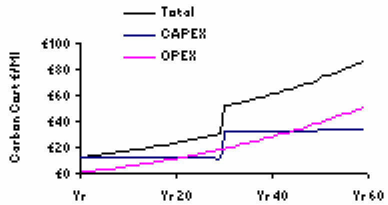
Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]incl. srorage and recharge - day/year
[4]incl. booster pumps, excl. stand-by

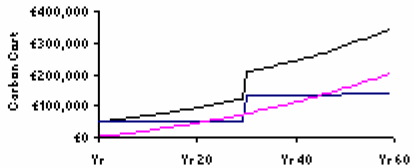
Output (over planning period)

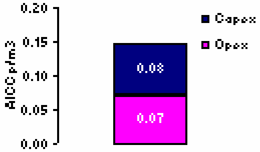
			Breakdown		
Carbon 'footprint'	7040	tCO_2e	Capex	1848	tCO_2e
	0.03	tCO_2e/M	Opex	4128	tCO_2e
Carbon Cost (CC)	341792	£			
Average Incremental CC	0.15	p/m^3	Capex	0.08	p/m^3
			Opex	0.07	p/m^3

AICC: average incremental carbon cost			Variance*
A. Source/conveyance	0.15	p/m^3	0.02
B. Treatment	1.25	p/m^3	0.69
C. Distribution	0.48	p/m^3	0.04
D. Household	25.52	p/m^3	0.00
E. Waste	2.24	p/m^3	0.29

*In water industry 05/06 data







Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/M
Capex: Materials		see below					1190416	1190	0.03	1.96
Capex: Construction		see below					579834	580	0.03	0.95
Capex: Haulage	travel	t	road	1223	63.48		77620	78	0.03	0.13
Capex: Travel	travel	km	transit van	1000	0.21		209	0	0.03	0.00
Opex: Operate	energy	kWh	electricity	160000	0.43		68800	69	1.00	3.44
Capex: Materials	Totals->			-	-		1770250	1770	0.03	2.91
Steel		t	steel - virgin	337	3313	50%	1677196	1677	0.03	2.80
Concrete		t	concrete	480	134	20%	77184	77	0.02	0.08
Pipeline		t	steel- piping	67	1.8	50%	181	0	0.03	0.00
Pumps		t	steel - virgin	338	0.75	100%	507	1	0.07	0.00
Diesel for construction		lt	diesel	2886	2.63	100%	15182	15	0.05	0.04
Annual Opex: Operate	Totals->			-	-		68800	69	1.00	3.44
Pumping		kWh	electricity	160000	0.43		68800	69	1.00	3.44

Notes: [1] material's embedded CO2e, [2] CO2e from construction (as percentage of embedded CO2e)

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Water supply/demand management options
Carbon foot-print calculator
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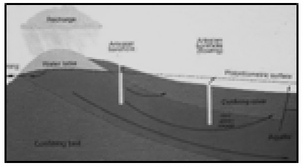


Water supply option **Groundwater abstraction**

Input (default values or user defined)

Reservoir name	Scheme - based on 1 scheme proposal			Deployable output[1]	4.5	Ml/day	
Scheme operations period	100%	annual frequency[2]	329	day/year	8	hour/day	
Associated building for plant	300	m^2 floor area					
Boreholes	1	no. type	Unlined	depth	20	m diameter	350 mm
Pumps	50	kW total duty capacity[4]					
Pipeline	0.2	km length	200	mm diameter			
Service reservoir	0	m^3 volume					
Treatment: included?	No						
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)				
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years				

Notes:
[1] dry year annual average deployable output
[2] once in every 2 years =50%
[3] incl. srorage and recharge - day/year
[4] incl. booster pumps, excl. stand-by

Output (over planning period)

			Breakdown		
Carbon 'footprint'	3632	tCO_2e	Capex	109	tCO_2e
	0.04	tCO_2e/M	Opex	3395	tCO_2e
Carbon Cost (CC)	176810	£			
Average Incremental CC	0.17	p/m^3	Capex	0.01	p/m^3
			Opex	0.16	p/m^3

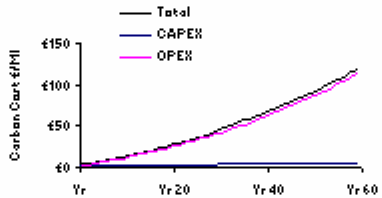
AICC: average incremental carbon cost			Variance*
A. Source/conveyance	0.17	p/m^3	0.04
B. Treatment	1.25	p/m^3	0.69
C. Distribution	0.48	p/m^3	0.04
D. Household	25.52	p/m^3	0.00
E. Waste	2.24	p/m^3	0.29

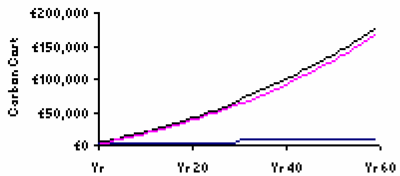
*In water industry 05/06 data

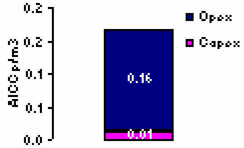
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/M
Capex: Materials	see below						68231	68	0.04	0.54
Capex: Construction	see below						37915	38	0.04	0.30
Capex: Haulage	travel	t	Road	44	63.48		2772	3	0.04	0.02
Capex: Travel	travel	km	Transit van	1000	0.21		209	0	0.04	0.00
Opex: Operate	energy	kWh	electricity	131600	0.43		56588	57	1.00	12.58
Capex: Materials	Totals->			-	-		106146	106	0.04	0.84
Steel		t	Steel - virgin	18	3313	50%	90931	91	0.03	0.67
Concrete		t	Concrete	0	134	20%	0	0	0.02	0.00
Pipeline		t	Steel- Piping	7	1.8	50%	18	0	0.03	0.00
Pumps		t	Steel - virgin	19	0.375	100%	14	0	0.07	0.00
Diesel for construction		lt	Diesel	2886	2.63	100%	15182	15	0.05	0.17
Annual Opex: Operate	Totals->			-	-		56588	57	1.00	12.58
Pumping		kWh	electricity	#####	0.43		56588	57	1.00	12.58

Notes: [1] material's embedded CO2e, [2] CO2e from construction (as percentage of embedded CO2e)







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Water supply/demand management options
Carbon foot-print calculator

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Water supply option **Desalination (seawater)**

Input (default values or user defined)

Desalination plant name	Scheme - based on scheme proposals			Deployable output[1]	25 Ml/day
Water source	Seawater	degree of salinity			
Scheme operations period	100%	annual frequency[2]...........	173 day/year...............		24 hour/day
Associated building for plant	3500	m^2 floor area			
Pumps	3500	kW total duty capacity[3]			
Service reservoir	2600	m^3 volume			
Discount rate for PV analysis	3.5% / 3.0%	default set to Treasury Green Book (2007)			
Planning period	1-30 yr / 31-60yr	planning period fixed at 60 years			

Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]incl. booster pumps, excl. stand-by

Output (over planning period)

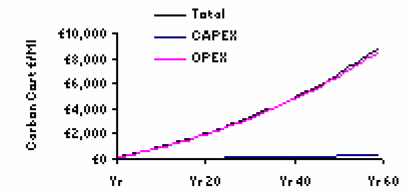
			Breakdown			AICC: average incremental carbon cost			Variance*
Carbon 'footprint'	773270	tCO_2e	Capex	8529	tCO_2e	A. Source/conveyance	12.29	p/m^3	12.17
	2.99	tCO_2e/Ml	Opex	747684	tCO_2e	B. Treatment	1.25	p/m^3	0.69
Carbon Cost (CC)	4E+07	£				C. Distribution	0.48	p/m^3	0.04
Average Incremental CC	12.29	p/m^3	Capex	0.44	p/m^3	D. Household	25.52	p/m^3	0.00
			Opex	11.85	p/m^3	E. Waste	2.24	p/m^3	0.29

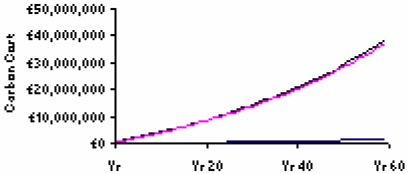
*to water industry 05/06 data

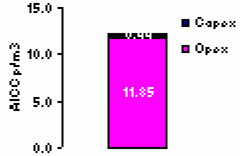
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/Ml
Capex: Materials	see below						5428118	5428	0.04	8.68
Capex: Construction	see below						2291342	2291	0.04	3.67
Capex: Haulage	travel	t	road	12745	63.48		809046	809	0.04	1.29
Capex: Travel	travel	km	transit van	1000	0.21		209	0.21	0.04	0.00
Opex: Operate	energy	kWh	electricity	1E+07	0.43		1.2E+07	12461	1.00	498.46
Capex: Materials	Totals->			-	-		7719460	7719	0.04	12.35
Steel		t	steel - virgin	1122	3313	50%	5573915	5574	0.04	8.92
Concrete		t	concrete	11597	134	20%	1864802	1865	0.04	2.98
Pumps		t	steel - virgin	26	3313	100%	173933	174	0.04	0.28
Diesel for construction		lt	diesel	27075	2.63	50%	106811	107	0.04	0.17
Annual Opex: Operate	Totals->			-	-		6230700	6231	1.00	249.23
Pumping/treatment		kWh	electricity	1E+07	0.43		6230700	6231	1.00	249.23

Notes: [1] material's embedded CO2e, [2] CO2e from construction (as percentage of embedded CO2e)







Halcrow

Water supply/demand management options
Carbon foot-print calculator

Environment Agency

Water supply option — River Intake

Input (default values or user defined)

Reservoir name	Scheme - based on scheme proposals			Deployable output[1]	7.2	Ml/day
Scheme operations period	100%	annual frequency[2]	329	day/year	21	hour/day
Associated building for plant	800	m^2 floor area				
Pumps	41	kW total duty capacity[3]				
Pipeline	4	km length	500	mm diameter		
Service reservoir	0	m^3 volume				
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)			
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years			

Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]incl. booster pumps, excl. stand-by

Output (over planning period)

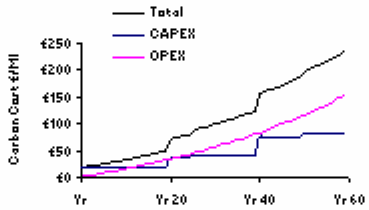
			Breakdown			AICC: average incremental carbon cost			Variance*
Carbon 'footprint'	11928	tCO_2e	Capex	1540	tCO_2e	A. Source/conveyance	0.36	p/m^3	0.24
	0.08	tCO_2e/Ml	Opex	7308	tCO_2e	B. Treatment	1.25	p/m^3	0.69
Carbon Cost (CC)	554143	£				C. Distribution	0.48	p/m^3	0.04
Average Incremental CC	0.36	p/m^3	Capex	0.15	p/m^3	D. Household	25.52	p/m^3	0.00
			Opex	0.21	p/m^3	E. Waste	2.24	p/m^3	0.29

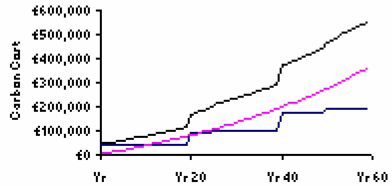
*In water industry 05/06 data

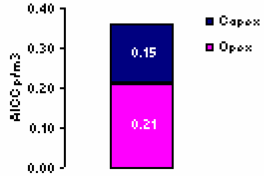
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/Ml
Capex: Materials	see below						1004434	1004	0.05	6.71
Capex: Construction	see below						502262	502	0.05	3.35
Capex: Haulage	travel	t	Road	520	63.48		33027	33	0.05	0.22
Capex: Travel	travel	km	Transit van	1000	0.21		209	0	0.05	0.00
Opex: Operate	energy	kWh	electricity	283269	0.43		121806	122	1.00	16.92
Capex: Materials	Totals->			-	-		1506696	1507	0.05	10.06
Steel		t	Steel - virgin	58	3313	50%	285931	286	0.04	1.59
Concrete		t	Concrete	12	134	20%	1892	2	0.02	0.01
Pipeline		t	Steel- Piping	451	1800	50%	1216800	1217	0.05	8.45
Pumps		t	Steel - virgin	0	3313	100%	2037	2	0.07	0.02
Diesel for construction		lt	Diesel	6.7	2.63	100%	35	0	0.05	0.00
Annual Opex: Operate	Totals->			-	-		121806	122	1.00	16.92
Pumping		kWh	electricity	283269	0.43		121806	122	1.00	16.92
Treatment										

Notes: [1] material's embedded CO2e, [2]CO2e from construction (as percentage of embedded CO2e)







Halcrow

Water supply/demand management options
Carbon foot-print calculator
v1 © Environment Agency

Environment Agency

Water supply option **Effluent Reuse - Indirect**

Input (default values or user defined)

Scheme name	Scheme - based on scheme proposals			Deployable output[1]	10.5	Ml/day
Scheme operations period	100%	annual frequency[2]...........	329	day/year................	24	hour/day
Associated building for plant	1700	m^2 floor area				
Pumps	350	kW total duty capacity[3]				
Pipeline	0	km length........................	200	mm diameter		
Service reservoir	0	m^3 volume				

Notes:
[1] dry year annual average deployable output
[2] once in every 2 years =50%
[3] incl. booster pumps, excl. stand-by

Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Output (over planning period)

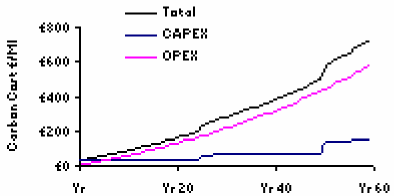
			Breakdown			AICC: average incremental carbon cost			Variance*
Carbon 'footprint'	90460	tCO_2e	Capex	6925	tCO_2e	A. Source/conveyanc	1.03	p/m^3	0.91
	0.25	tCO_2e/M	Opex	71301	tCO_2e	B. Treatment	1.25	p/m^3	0.69
Carbon Cost (CC)	4423816	£				C. Distribution	0.48	p/m^3	0.04
Average Incremental CC	1.03	p/m^3	Capex	0.23	p/m^3	D. Household	25.52	p/m^3	0.00
			Opex	0.80	p/m^3	E. Waste	2.24	p/m^3	0.29

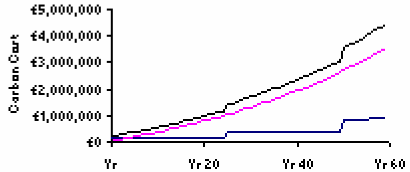
*In water industry 05/06 data

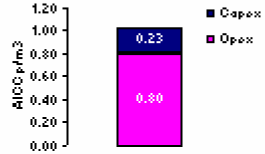
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/M
Capex: Materials	see below						4400093	4400	0.03	8.30
Capex: Construction	see below						1867075	1867	0.03	3.52
Capex: Haulage	travel	t	Road	10366	63.48		658064	658	0.03	1.24
Capex: Travel	travel	km	Transit van	1000	0.21		209	0	0.03	0.00
Opex: Operate	energy	kWh	electricity	3E+06	0.43		1188348	1188	1.00	64.24
Capex: Materials	Totals->			-	-		6267168	6267	0.03	11.82
Steel		t	Steel - virgin	918	3313	50%	4562594	4563	0.04	9.87
Concrete		t	Concrete	9442	134	20%	1518229	1518	0.02	1.64
Pipeline		t	Steel- Piping	0	1800	50%	0	0	0.03	0.00
Pumps		t	Steel - virgin	7	3313	100%	43930	44	0.07	0.16
Diesel for construction		lt	Diesel	27075	2.63	100%	142415	142	0.02	0.15
Annual Opex: Operate	Totals->			-	-		1188348	1188	1.00	64.24
Pumping/Treatment		kWh	electricity	3E+06	0.43		1188348	1188	1.00	64.24

Notes: [1] material's embedded CO2e, [2] CO2e from construction (as percentage of embedded CO2e)







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Water supply/demand management options
Carbon foot-print calculator
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Environment Agency

Demand Management: Bulk transfer pipeline

Input (default values or user defined)

Transfer name	Scheme - based on scheme proposals	Deployable output[1]	14.2	Ml/day	
Scheme operations period	100%	annual frequency[2]...........	329	day/year................	21.3 hour/day
Associated building for plant	10	m^2 floor area			
Pumps	167.4	kW total duty capacity[3]			
Pipeline	1	no. of pipes.....................	Ductile iron	pipe material	
	20	km length.........................	500	mm diameter	
Tunnel	3	km length			
Treatment: included?	No				

Notes:
[1]dry year annual average deployable output
[2]once in every 2 years =50%
[3]incl. booster pumps, excl. stand-by

Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Output (over planning period)

			Breakdown		
Carbon 'footprint'	43081	tCO_2e	Capex	6193	tCO_2e
	0.15	tCO_2e/M	Opex	30266	tCO_2e
Carbon Cost (CC)	#####	£			
Average Incremental CC	0.66	p/m^3	Capex	0.22	p/m^3
			Opex	0.44	p/m^3

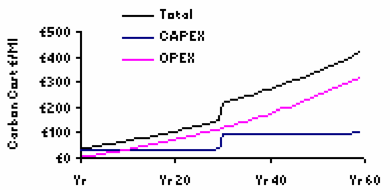
AICC: average incremental carbon cost			Variance*
A. Source/conveyance	0.66	p/m^3	0.54
B. Treatment	1.25	p/m^3	0.81
C. Distribution	0.14	p/m^3	0.01
D. Household	23.70	p/m^3	0.00
E. Waste	2.24	p/m^3	0.65

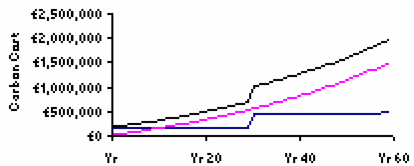
*In water industry 05/06 data

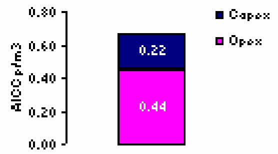
Basis for carbon 'footprint' calculation

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequenc	tCO2/M
Capex: Materials	see below						3956748	3957	0.03	9.30
Capex: Construction	see below						1822353	1822	0.03	4.28
Capex: Haulage	travel	t	Road	6496	63.48		412388	412	0.03	0.97
Capex: Travel	travel	km	Transit van	5000	0.209		1045	1	0.03	0.00
Opex: Operate	energy	kWh	electricity	1E+06	0.43		504428	504	1.00	35.52
Capex: Materials	Totals->			-	-		5779101	5779	0.03	13.59
Steel		t	Steel - virgin	1	3313	50%	3031	3	0.03	0.01
Concrete		t	Concrete	4241	134	20%	681977	682	0.03	1.60
Pipeline		t	Ductile iron	2253	1490	50%	5036200	5036	0.03	11.82
Pumps		t	Steel - virgin	1	3313	100%	8319	8	0.07	0.04
Diesel for construction		lt	Diesel	9425	2.63	100%	49574	50	0.03	0.12
Annual Opex: Operate	Totals->			-	-		504428	504	-	35.52
Pumping		kWh	electricity	1.2E+06	0.43		504428	504	1.00	35.52

Notes: [1] material's embedded CO2e, [2] CO2e from construction (as percentage of embedded CO2e)







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Appendix B
Carbon Cost Model
- demand management options

Water supply/demand management options
Carbon foot-print calculator
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Demand Management: Metering


http://www.westvancouver.ca/upload/images/water_meter.jpg
http://www.pipestock.com/PVC-Pipe-Dimensions.php
http://www.bellflowsystems.co.uk/Single-jet-Cold-Water-Meter-p-16202.
http://assuredautomation.com/flow/index.php
http://www.smartmeter.co.uk/news_details.php?news_id=40

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.8		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	10%		
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Include water saved? y

Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

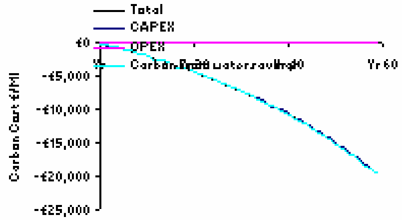
Smart metering? y

Output (over planning period)

			Breakdown		
Carbon 'footprint'	-5048	tCO_2e	Capex	56	tCO_2e
	-6.61	tCO_2e/Ml	Opex	0	tCO_2e
Carbon Cost (CC)	-3E+05	£			
Water Savings	12.7	Ml/yr	Capex	0.34	p/m³
Average Incremental CC	0.34	p/m³	Opex	0.00	p/m³

*per Ml water saved

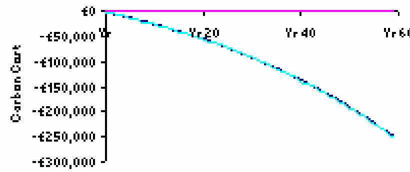
AICC: water-use-disposal system			Variance*	
A. Source/conveyance	0.11	p/m³	-0.01	
B. Treatment	0.50	p/m³	-0.06	
C. Distribution	0.39	p/m³	-0.04	
D. Household	23.30	p/m³	-2.21	
E. Waste	1.87	p/m³	-0.08	
Total	26.18	p/m³	-2.40	-9%

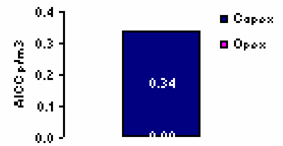


Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					7.9	0.008	0.05	0.03
Capex: Manufacture		see below					10.3	0.010	0.05	0.04
Capex: Distribute	travel	km	transit van	0.1	0.21		0.0	0.000	0.05	0.00
Capex: Install	travel	km	transit van	5	0.21		1	0	0.05	0.00
Opex: Operate		see below					0.0	0.000	4.00	0.00
Capex: Materials	Totals->			-	-		17.6	0.018	0.05	0.07
water meter		kg	brass	1.8	3.71	150%	16.2	0.016	0.05	0.06
civil works		kg	concrete	5.0	0.13	25%	0.7	0.001	0.05	0.00
pipework		kg	PVC	0.2	2.41	50%	0.5	0.001	0.05	0.00
associate PVC components		kg	polypropylene	0.0	3.30	100%	0.2	0.000	0.05	0.00
Annual Opex: Operate	Totals->			-	-		0.0	0.000	4.00	0.00
Meter reading (quarterly)		km	transit van	0.0	0.21		0.0	0.000	4.00	0.00
Annual water savings		Ml	water	-0.013	6682	n/a	-85.07	-0.085	1.00	-6.68

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e





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Water supply/demand management options
Carbon foot-print calculator
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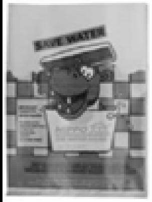


www.hippo4life.co.uk
http://www.hippo-the-watersaver.co.uk/

Demand Management: **Toilet -"hippo"** (retrofit cistern displacement device)

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.8		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	10%		hippo 3l;, 4.8xflush/capita/day, 7.5 l toilet
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30yr	31-60yr	planning period fixed at 60 years

Include water saved? n

Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance[2]	
Carbon 'footprint'	1	tCO_2e	Capex	1	tCO_2e	A. Source/conveyance	0.11	p/m³	-0.01	
	0.00	tCO_2e/Ml	Opex	0	tCO_2e	B. Treatment	0.50	p/m³	-0.05	
Carbon Cost (CC)	61	£				C. Distribution	0.39	p/m³	-0.04	
Water Savings	12.4	Ml/yr	Capex	0.01	p/m³	D. Household	25.52	p/m³	0.01	
Average Incremental CC	0.01	p/m³	Opex	-	p/m³	E. Waste	1.88	p/m³	-0.08	
						Total	28.40	p/m³	-0.18	-1%

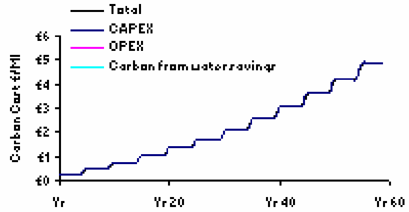
[1]per Ml water saved

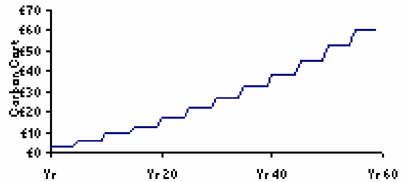
[2]to water industry 05/06 data

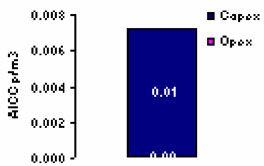
Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					0.0	0.000	0.20	0.00
Capex: Manufacture		see below					0.0	0.000	0.20	0.00
Capex: Distribute	travel	km	transit van	0.1	0.21		0.0	0.000	0.20	0.00
Capex: Install	travel	km	average car	0.1	0.21		0	0	0.20	0.00
Opex: Operate		see below					0.00	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		0.065	0.000	0.20	0.00
bag		g	HDPE	27.0	0.002	50%	0.065	0.000	0.20	0.00
Annual Opex: Operate	Totals->			-	-		0.0	0.000	1.00	0.00
Annual water savings		Ml	water	0.000	461	n/a	0.00	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







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Water supply/demand management options
Carbon foot-print calculator
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https://waterwise.uk.net/Links/Dualflushreport.pdf1Up to 30% saving- http:
http://www.cistermiser.co.uk/products/easyflush.htm

Demand Management: Toilet - retrofit cistern device

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.8		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	7%		7% for 7.5 l toilet, 4.8 flushes/capita/day
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Include water saved? n

Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	4	tCO_2e	Capex	4	tCO_2e	A. Source/conveyance	0.11	p/m³	-0.01	
	0.01	tCO_2e/Ml	Opex	0	tCO_2e	B. Treatment	0.54	p/m³	-0.02	
Carbon Cost (CC)	165	£				C. Distribution	0.40	p/m³	-0.03	
Water Savings	8.9	Ml/yr	Capex	0.03	p/m³	D. Household	25.55	p/m³	0.03	
Average Incremental CC	0.03	p/m³	Opex	-	p/m³	E. Waste	1.90	p/m³	-0.05	
						Total	28.50	p/m³	-0.08	0%

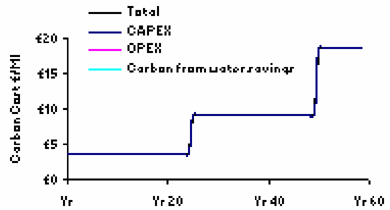
*per Ml water saved

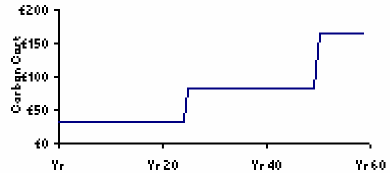
*In water industry 05/06 data

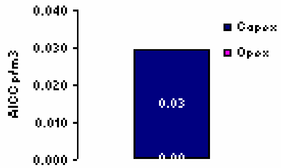
Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials			see below				0.1	0.000	0.04	0.00
Capex: Manufacture			see below				0.0	0.000	0.04	0.00
Capex: Distribute	travel	km	transit van	0.1	0.21		0.0	0.000	0.04	0.00
Capex: Install	travel	km	average car	5	0.21		1	0	0.04	0.00
Opex: Operate			see below				0.00	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		0.1	0.000	0.04	0.00
Plastics		g	plastic	15.0	0.003	50%	0.1	0.000	0.04	0.00
Metals (incl. Brass)		g	brass	10.0	0.004	20%	0.0	0.000	0.04	0.00
Plastic tubing		g	LDPE	12.0	0.002	50%	0.0	0.000	0.04	0.00
Annual Opex: Operate	Totals->			-	-		0.0	0.000	-	0.00
Annual water savings		Ml	water	0.000	461	n/a	0.00	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







Halcrow

Water supply/demand management options
Carbon foot-print calculator
v1 © Environment Agency

Environment Agency

Demand Management: Toilet - replacement cistern

http://waterrave.uk.net/Presentations/Maada.pdf
http://www.sandiego.gov/water/conservation/ultra.shtml
http://www.thebluebook.co.uk/static/5_1_1A.asp?Specifying-&digits-5:1:1

Input (default values or user defined)

Households	1000	number	
PCC - per capita consumption	147.8	l/capita/d	default set to WaterUK 2006/07 data
People per home	2.36	number	default set to Office of National Statistics
Average water saving per home	8%		default set to CSH level 3/4/5 (8%)
Discount rate for PV analysis	3.5% / 3.0%		default set to Treasury Green Book (2007)
Planning period	1-30 yr / 31-60yr		planning period fixed at 60 years

Include water saved? n

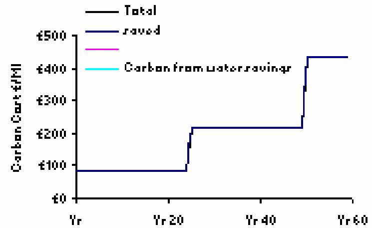
Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

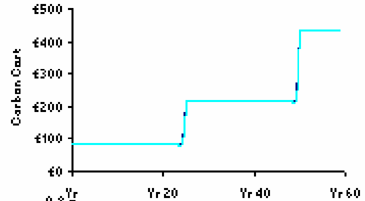
Output (over planning period)

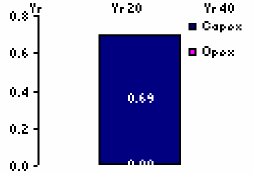
			Breakdown			AICC: water-use-disposal system			Variance*
Carbon 'footprint'	96	tCO_2e	Capex	96	tCO_2e	A. Source/conveyance	0.11	p/m³	-0.01
	0.16	tCO_2e/Ml	Opex	-	tCO_2e	B. Treatment	0.53	p/m³	-0.02
Carbon Cost (CC)	4439	£				C. Distribution	0.40	p/m³	-0.03
Water Savings	10.2	Ml/yr	Capex	0.69	p/m³	D. Household	26.21	p/m³	0.69
Average Incremental CC	0.69	p/m³	Opex	-	p/m³	E. Waste	1.89	p/m³	-0.06
						Total	29.15	p/m³	0.56 2%

*per Ml water saved

*to water industry 05/06 data







Halcrow

Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					6.5	0.006	0.04	0.03
Capex: Manufacture		see below					13.0	0.013	0.04	0.05
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.04	0.04
Capex: Install	travel	km	transit van	10	0.21		2	0	0.04	0.01
Opex: Operate		see below					0.00	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		19.5	0.019	0.04	0.08
Pan		kg	ceramic	11.8	0.55	200%	19.5	0.019	0.04	0.08
Annual Opex: Operate	Totals->			-	-		0.0	0.000	1.00	0.00
Annual water savings		Ml	water	0.000	461	n/a	0.00	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e

Water supply/demand management options
Carbon foot-print calculator

Environment Agency

http://www.environment-agency.gov.uk/subjects/waterres/286587/28691

Demand Management: **Shower** - water saving product

Input (default values or user defined)

Households	1000	number	
PCC - per capita consumption	147.8	l/capita/d	default set to WaterUK 2006/07 data
People per home	2.36	number	default set to Office of National Statistics
Average water saving per home	8%		default set to CSH level 3/4/5 (8%)
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30yr	31-60yr	planning period fixed at 60 years

Include water saved? n
Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Only showerhead? n y/n
Select "yes" if showerhead replaced only

Output (over planning period)

			Breakdown		
Carbon 'footprint'	237	tCO_2e	Capex	237	tCO_2e
	0.39	tCO_2e/Ml	Opex	-	tCO_2e
Carbon Cost (CC)	10684	£			
Water Savings	10.2	Ml/yr	Capex	1.68	p/m³
Average Incremental CC	1.68	p/m³	Opex	-	p/m³

'per Ml water saved

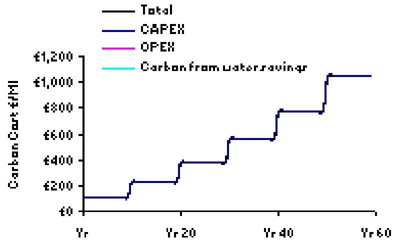
AICC: water-use-disposal system			Variance*	
A. Source/conveyance	0.11	p/m³	-0.01	
B. Treatment	0.53	p/m³	-0.02	
C. Distribution	0.40	p/m³	-0.03	
D. Household	25.16	p/m³	-0.36	
E. Waste	1.89	p/m³	-0.06	
Total	28.09	p/m³	-0.49	-2%

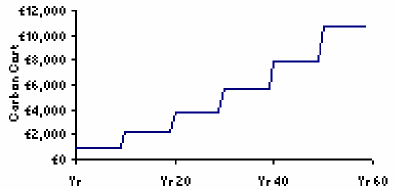
*to water industry 05/06 data

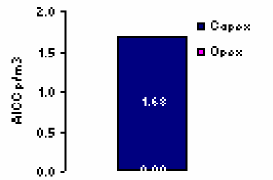
Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					3.62	0.004	0.10	0.04
Capex: Manufacture		see below					1.81	0.002	0.10	0.02
Capex: Distribute	travel	km	transit van	50	0.21	n/a	10.45	0.010	0.10	0.10
Capex: Install	travel	km	transit van	10	0.21	n/a	2.09	0	0.10	0.02
Opex: Operate		see below					0.00	0.000	#REF!	0.00
Capex: Materials	Totals->			-	-		26.90	0.027	0.10	0.26
Shower head		kg	ABS	0.7	3.10	50%	3.02	0.003	0.10	0.03
Pipework		kg	stainless steel	2.0	6.15	50%	18.45	0.018	0.10	0.18
Heater		kg	PVC	1.5	2.41	50%	5.42	0.005	0.10	0.05
Annual Opex: Operate	Totals->			-	-		0.00	0.000	#REF!	0.00
Annual water savings		Ml	water	0.000	6682	n/a	0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







Halcrow

Water supply/demand management options
Carbon foot-print calculator

http://www.greenworks-energy.co.uk/water-conserving-bath.php
http://www.tuxfordbathrooms.com/default.asp?path-1:52:8684.pdf
http://www.water-saving.org.uk/residential/baths_showers.html
http://www.aquater.co.uk/2912_2927.aspx
http://www.environment-agency.gov.uk/subjects/waterres/286587/28691

Demand Management: **Bath** - water saving product

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.8		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	2.1%		default set to CSH level 3/4 & 1/2 (2.1%)
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60 yr	planning period fixed at 60 years

* 147.8litres/day per capita, WaterUK 2006/07 -

Include water saved? n

Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	308	tCO_2e	Capex	308	tCO_2e	A. Source/conveyance	0.12	p/m³	0.00	
	1.92	tCO_2e/Ml	Opex	-	tCO_2e	B. Treatment	0.55	p/m³	-0.01	
Carbon Cost (CC)	14242	£				C. Distribution	0.42	p/m³	-0.01	
Water Savings	2.7	Ml/yr	Capex	8.47	p/m³	D. Household	33.46	p/m³	7.94	
Average Incremental CC	8.47	p/m³	Opex	-	p/m³	E. Waste	1.94	p/m³	-0.02	
						Total	36.49	p/m³	7.90	22%

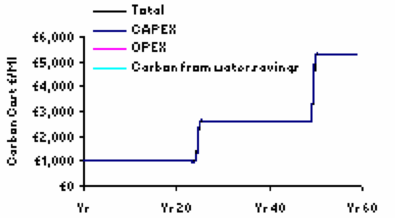
*per Ml water saved

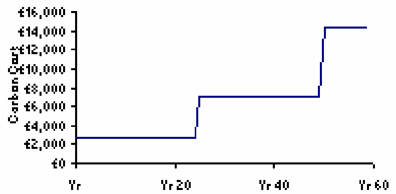
*To water industry 05/06 data

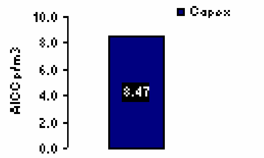
Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					60.1	0.060	0.03	0.75
Capex: Manufacture		see below					30.1	0.030	0.04	0.45
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.04	0.16
Capex: Install	travel	km	transit van	10	0.21		2.1	0.002	0.04	0.03
		see below					uyuuj	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		90.2	0.090	0.04	1.35
		kg	steel- general	30.0	1.82	50%	81.9	0.082	0.04	1.23
		kg	ceramic	10.0	0.55	50%	8.3	0.008	0.04	0.12
Annual Opex: Operate	Totals->			-	-		uyuuj	0.000	1.00	0.00
Annual water savings		Ml	water	0.000	6682	n/a	0.0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







Halcrow

Water supply/demand management options
Carbon foot-print calculator
v1 © Environment Agency

Environment Agency

http://www.environment-agency.gov.uk/subjects/waterres/286587/28691
http://www.tapmagic.co.uk/cartridge.html
http://www.tapmagic.co.uk/products.html

Demand Management: Taps - water saving product

Input (default values or user defined)

Households	1000	number	
PCC - per capita consumption	147.8	l/capita/d	default set to WaterUK 2006/07 data
People per home	2.36	number	default set to Office of National Statistics
Average water saving per home	16.1%		default set to CSH level 3/4 (11.6%)
Discount rate for PV analysis	3.5% / 3.0%		default set to Treasury Green Book (2007)
Planning period	1-30yr / 31-60yr		planning period fixed at 60 years

Include water saved? n

Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

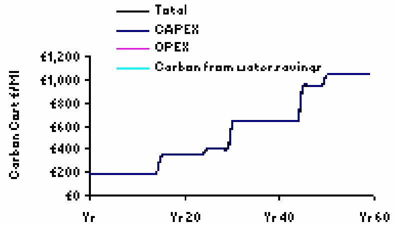
			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	496	tCO_2e	Capex	496	tCO_2e	A. Source/conveyance	0.10	p/m³	-0.02	
	0.40	tCO_2e/Ml	Opex	-	tCO_2e	B. Treatment	0.51	p/m³	-0.04	
Carbon Cost (CC)	21360	£				C. Distribution	0.36	p/m³	-0.07	
Water Savings	20.5	Ml/yr	Capex	1.82	p/m³	D. Household	23.23	p/m³	-2.29	
Average Incremental CC	1.82	p/m³	Opex	-	p/m³	E. Waste	1.83	p/m³	-0.13	
						Total	26.03	p/m³	-2.55	-10%

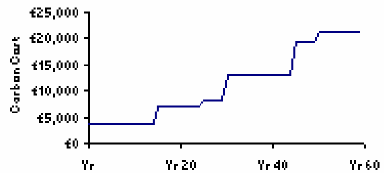
*per Ml water saved
*to water industry 05/06 data

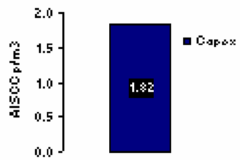
Basis for carbon 'footprint' calculation - for single household — 2 sets of taps

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					69.6	0.070	0.02	0.06
Capex: Manufacture		see below					58.4	0.058	0.02	0.05
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.02	0.01
Capex: Install	travel	km	transit van	10	0.21		2.1	0.002	0.02	0.00
Opex: Operate	energy	see below					0.00	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		128.0	0.128	0.06	0.38
Low-flow tap		kg	brass	5.00	3.71	50%	27.8	0.028	0.04	0.05
Tap cartridge		kg	plastic	0.03	2.53	50%	0.1	0.000	0.02	0.00
Sensor taps	PIR senso	kg	bronze	8.00	6.07	100%	97.1	0.097	0.07	0.32
	Solenoid	kg	stainless steel	0.004	6.15	50%	0.0	0.000	0.07	0.00
	Control b	kg	ABS	0.78	3.10	20%	2.9	0.003	0.07	0.01
Annual Opex: Operate	Totals->			-	-		0.0	0.000	1.00	0.00
Annual water savings		Ml	water	0.000	1706	n/a	0.00	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







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Water supply/demand management options
Carbon footprint calculator

Environment Agency

Demand Management: **White goods** - washing machine & dishwasher

http://www.appliancesmagazine.com/ae/editorial.php?article=1393&zone=
http://www.hylands.tv/Dishwashers.htm
http://www.greenpeace.org/international/campaigns/climate-change/tak

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.0		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	4.0%		default 4% (1.1% at CSH level 3/4 & 1/2)
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

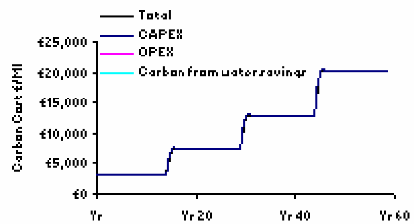
Include water saved? no

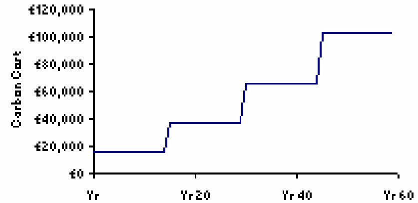
Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	2411	tCO_2e	Capex	2411	tCO_2e	A. Source/conveyance	0.12	p/m³	0.00	
	7.09	tCO_2e/Ml	Opex	-	tCO_2e	B. Treatment	0.54	p/m³	-0.01	
Carbon Cost (CC)	103405	£				C. Distribution	0.42	p/m³	-0.02	
Water Savings	5.1	Ml/yr	Capex	35.31	p/m³	D. Household	59.01	p/m³	34.29	
Average Incremental CC	35.31	p/m³	Opex	-	p/m³	E. Waste	1.92	p/m³	-0.03	
	*per Ml water saved					Total	62.01	p/m³	34.22	54%

*to water industry 05/06 data

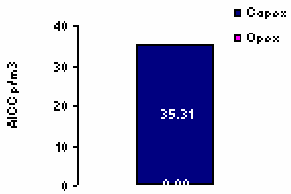




Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					327.9	0.328	0.07	0.00
Capex: Manufacture		see below					262.3	0.262	0.07	0.00
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.07	0.00
Capex: Install	travel	km	transit van	10	0.21		2.1	0.002	0.07	0.00
Opex: Operate		see below					0.0	0.000	1.00	0.00
Capex: Materials	Totals->			-	-		590.3	0.590	0.07	0.00
Washing machine		kg	steel- general	42.8	1.82	80%	140.1	0.140	0.07	0.00
		kg	aluminium - ger	1.8	8.53	80%	27.6	0.028	0.07	0.00
		kg	plastic	11.1	2.53	80%	50.5	0.050	0.07	0.00
		kg	stainless steel	20.0	6.15	80%	221.4	0.221	0.07	0.00
Dishwasher		kg	steel- general	12.6	1.82	80%	41.2	0.041	0.07	0.00
		kg	plastic	24.0	2.53	80%	109.4	0.109	0.07	0.00
Annual Opex: Operate	Totals->			-	-		0.0	0.000	1.00	0.00
Annual water savings		ML	water	0.000	6682	n/a	0.0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e



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Water supply/demand management options
Carbon foot-print calculator
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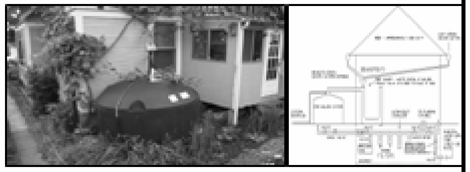
Environment Agency



Demand Management: **Rainwater harvesting** - individual household system

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	145.6		l/capita/c default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per hom	30%		default 30%
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Include water saved? n

Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	5795	tCO_2e	Capex	1335	tCO_2e	A. Source/conveyanc	0.09	p/m^3	-0.04	
	2.57	tCO_2e/M	Opex	0	tCO_2e	B. Treatment	0.47	p/m^3	-0.08	
Carbon Cost (CC)	280303	£				C. Distribution	0.30	p/m^3	-0.13	
Water Savings	37.6	Ml/yr	Capex	2.66	p/m^3	D. Household	36.28	p/m^3	10.76	
Average Incremental CC	10.76	p/m^3	Opex	8.10	p/m^3	E. Waste	1.95	p/m^3	0.00	
						Total	39.09	p/m^3	10.51	27%

*per Ml water saved

*In water industry 05/06 data

Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					298.8	0.299	0.04	0.32
Capex: Manufacture		see below					155.1	0.155	0.04	0.17
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.04	0.01
Capex: Install	travel	km	transit van	10	0.21		2	0	0.04	0.00
Opex: Operate		See below					74.3	0.074	1.00	1.98
Capex: Materials	Totals->			-	-		453.9	0.454	0.04	0.48
tank - 1950lt		kg	MDPE	75	1.65	50%	185.6	0.186	0.04	0.20
tank base - mass concrete plinth		kg	concrete	739	0.13	20%	118.8	0.119	0.02	0.06
pipework - 12.5cm dia, 10m long		kg	PVC	2	2.41	50%	7.8	0.008	0.05	0.01
pump - 0.5hp, 17l/min - PP parts		kg	polypropylene	7	3.90	100%	51.7	0.052	0.07	0.09
pump - metal parts		kg	steel- general	1	1.82	100%	2.7	0.003	0.07	0.00
parts (PVC) - filters, first flush valve et		kg	PVC	4	2.41	100%	21.7	0.022	0.05	0.03
parts (metal) - valves, gauges, collector		kg	steel- general	18	1.82	100%	65.5	0.066	0.05	0.09
Annual Opex: Operate	Totals->			-	-		74.3	0.074	1.00	1.98
pump		kWh	electricity	113	0.43		48.5	0.049	1.00	1.29
treat - 40w power consumption		kWh	electricity	60	0.43		25.8	0.026	1.00	0.69
Water savings		Ml	water	0.000	271	n/a	0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e

http://ecocon.sustainabilitylane.com/rainwatr.htm
http://www.water-tanks.net/acatalog/rainwaterharvesting.html
http://www.pipestock.com/PVC-Pipe-Dimensions.php
http://fp.centralpumps.plus.com/flux/flux_air_operated_double_diaphr
PURA model UV20-1 - capable of sterilizing water at 10 gallons per minute
Rainwater and greywater in buildings: project report and case studies, Buil
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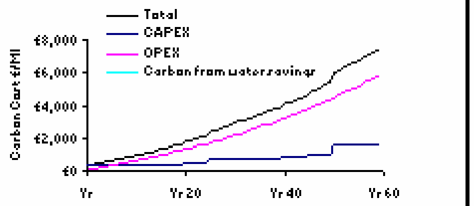

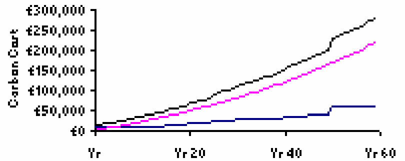

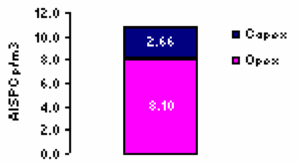

Halcrow

Water supply/demand management options
Carbon foot-print calculator
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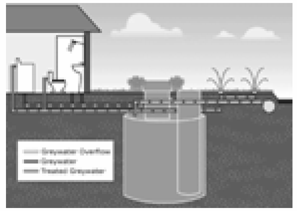
Demand Management: **Greywater reuse** - individual household system



[Environment Agency - Water Infrastructure Options science report](#)
http://www.environment-agency.gov.uk/subjects/waterres/286587/2865
http://www.environment-agency.gov.uk/commondata/105385/greywate
http://www.ozzikleen.com/greywater/operation.php
Rainwater and greywater in buildings: project report and case studies, Buil-
Rainwater and greywater use in buildings - best practice guidance, CIRIA C
Rainwater and greywater use in buildings: decision-making for water conse

Input (default values or user defined)

Households	1000		number
PCC - per capita consumption	147.0		l/capita/d default set to WaterUK 2006/07 data
People per home	2.36		number default set to Office of National Statistics
Average water saving per home	20%		
Discount rate for PV analysis	3.5%	3.0%	default set to Treasury Green Book (2007)
Planning period	1-30 yr	31-60yr	planning period fixed at 60 years

Include water saved? n

Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

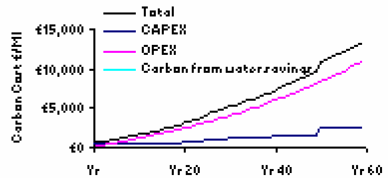
Output (over planning period)

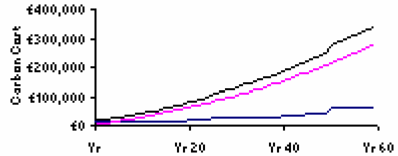
			Breakdown		
Carbon 'footprint'	7035	tCO_2e	Capex	1385	tCO_2e
	4.60	tCO_2e/Ml*	Opex	0	tCO_2e
Carbon Cost (CC)	341265	£			
Water Savings	25.5	Ml/yr	Capex	4.08	p/m³
Average Incremental CC	19.25	p/m³	Opex	15.17	p/m³

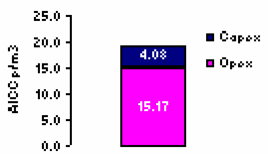
*per Ml water saved

AICC: water-use-disposal system			Variance*	
A. Source/conveyance	0.10	p/m³	-0.02	
B. Treatment	0.50	p/m³	-0.06	
C. Distribution	0.35	p/m³	-0.09	
D. Household	44.76	p/m³	19.25	
E. Waste	1.80	p/m³	-0.16	
Total	47.50	p/m³	18.92	40%

*to water industry 05/06 data







Basis for carbon 'footprint' calculation - for single household

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					307.8	0.308	0.04	0.49
Capex: Manufacture		see below					159.6	0.160	0.04	0.26
Capex: Distribute	travel	km	transit van	50	0.21		10.5	0.010	0.04	0.02
Capex: Install	travel	km	transit van	10	0.21		2.1	0.002	0.04	0.00
Opex: Operate	energy	kWh	electricity	219	0.43		94.2	0.094	1.00	3.70
Capex: Materials	Totals->			-	-		467.3	0.467	0.04	0.75
tank - 1950lt		kg	MDPE	75	1.65	50%	185.6	0.186	0.04	0.29
tank base - mass concrete plinth		kg	concrete	739	0.13	20%	118.8	0.119	0.02	0.09
pipework - 12.5cm dia, 10m long		kg	PVC	3	2.41	50%	11.6	0.012	0.05	0.02
pump - 0.5hp, 17l/min - PP parts		kg	polypropylene	7	3.90	100%	51.7	0.052	0.07	0.14
pump - metal parts		kg	steel- general	1	1.82	100%	2.7	0.003	0.07	0.01
cistern replacement		kg	ceramic	12	0.55	50%	9.7	0.010	0.07	0.03
parts (PVC) - filters, first flush valve et		kg	PVC	5	2.41	100%	21.7	0.022	0.05	0.04
parts (metal) - valves, gauges, collecto		kg	steel- general	18	1.82	100%	65.5	0.066	0.05	0.13
Annual Opex: Operate	Totals->			-	-		94.2	0.094	1.00	3.70
pump/treat		kWh	electricity	219	0.43		94.2	0.094	1.00	3.70
Water savings		Ml	water	0.000	271	n/a	0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO_2e from manufacturing as percentage of embedded CO_2e

Halcrow

Water supply/demand management options
Carbon foot-print calculator
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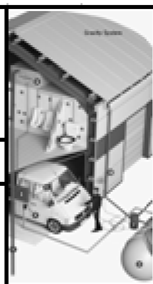

Demand Management: **Rainwater harvesting** - community level system (non-potable)

Input (default values or user defined)

Total households	1000	number	
PCC - per capita consumption	145.6	l/capita/d	default set to WaterUK 2006/07 data
People per home	2.36	number	default set to Office of National Statistics
Average water saving per home	30%		
Volume of storage tank	25000	litre	
Tank material	concrete	concrete/MDPE	
Discount rate for PV analysis	3.5% / 3.0%		default set to Treasury Green Book (2007)
Planning period	1-30 yr / 31-60yr		planning period fixed at 60 years

No of schemes: 40 — Homes per scheme: 25

Include water saved? n

Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

http://ecosan.sustainabilitylane.com/rainwatr.htm
http://www.water-tanks.net/acatalog/rainwaterh-
http://www.pipestock.com/PVC-Pipe-Dimensions.
http://fp.centralpumps.plus.com/flux/flux_air_operated_double_diaphr-
PURA model UV20-1 - capable of sterilizing water at 10 gallons per minute
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Harvesting rainwater for domestic uses: an information guide, EA, July 200
Rainwater and greywater use in buildings - best practice guidance, CIRIA C
Rainwater and greywater use in buildings: decision-making for water conse

Output (over planning period)

			Breakdown			AICC: water-use-disposal system			Variance*	
Carbon 'footprint'	3403	tCO_2e	Capex	1235	tCO_2e	A. Source/conveyance	0.09	p/m³	-0.04	
	1.51	tCO_2e/M	Opex	0	tCO_2e	B. Treatment	0.47	p/m³	-0.08	
Carbon Cost (CC)	163692	£				C. Distribution	0.30	p/m³	-0.13	
Water Savings	37.6	Ml/yr	Capex	5.10	p/m³	D. Household	32.21	p/m³	6.69	
Average Incremental CC	6.69	p/m³	Opex	1.59	p/m³	E. Waste	1.95	p/m³	0.00	
						Total	35.02	p/m³	6.44	18%

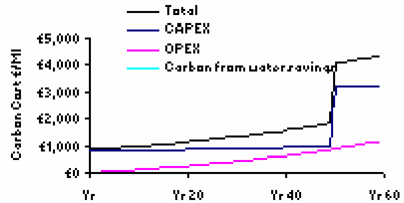
*per Ml water saved

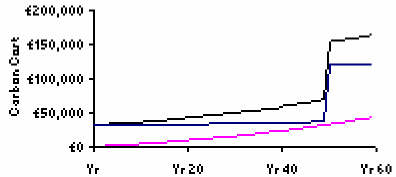
*In water industry 05/06 data

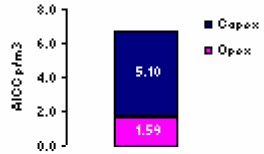
Basis for carbon 'footprint' calculation - for 25 households

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					20180.5	20.180	0.02	11.38
Capex: Manufacture		see below					10427.3	10.427	0.02	5.88
Capex: Distribute	travel	km	transit van	1000	0.21		209.0	0.209	0.02	0.12
Capex: Install	travel	km	transit van	250	0.21		52	0	0.02	0.03
Opex: Operate	energy	kWh	electricity	849	0.43		365.2	0.365	1.00	9.70
Capex: Materials	Totals->			-	-		30607.7	30.608	0.02	0.43
underground storage tank		t	concrete	30	134.00	50%	6124.6	6.125	0.02	0.08
Pipework - 25cm, 250m long		t	steel- general	8	1820.00	50%	22863.8	22.864	0.02	0.30
Pipework - 12.5cm, 250m long		kg	PVC	75	2.41	50%	271.1	0.271	0.05	0.01
Diesel for construction		lt	diesel	38	2.63	100%	197.3	0.197	0.02	0.00
pump - metal parts		kg	steel- general	150	1.82	100%	546.0	0.546	0.04	0.01
parts (PVC) - filters, first flush valve et		kg	PVC	50	2.41	100%	241.0	0.241	0.05	0.01
parts (metal) - valves, gauges, collector		kg	steel- general	100	1.82	100%	364.0	0.364	0.05	0.01
Annual Opex: Operate	Totals->			-	-		365.2	0.365	1.00	0.24
pump and treatment		kWh	electricity	849	0.43		365.2	0.365	1.00	0.24
Water savings		Ml	water	0.000	271	n/a	0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e







Halcrow

Water supply/demand management options
Carbon foot-print calculator
v1 © Environment Agency

Demand Management: **Greywater reuse** - community level system

Input (default values or user defined)

Total households	1000	number	
PCC - per capita consumption	147.8	l/capita/c	default set to WaterUK 2006/07 data
People per home	2.36	number	default set to Office of National Statistics
Average water saving per home	20%		
Volume of storage tank	25000	litre	
Tank material	concrete	concrete/MDPE	
Discount rate for PV analysis	3.5% / 3.0%		default set to Treasury Green Book (2007)
Planning period	1-30 yr / 31-60yr		planning period fixed at 60 years

No of schemes: 40 — Homes per scheme: 25

Include water saved? n
Select "no" to calculate only emissions to install/ operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

			Breakdown		
Carbon 'footprint'	3849	tCO_2e	Capex	2588	tCO_2e
	2.52	tCO_2e/Ml	Opex	1261	tCO_2e
Carbon Cost (CC)	185114	£			
Water Savings	25.5	Ml/yr	Capex	7.72	p/m³
Average Incremental CC	11.10	p/m³ *	Opex	3.39	p/m³

*per Ml water saved

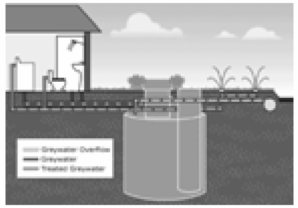
AICC: water-use-disposal system			Variance*	
A. Source/conveyance	0.10	p/m³	-0.02	
B. Treatment	0.44	p/m³	-0.11	
C. Distribution	0.35	p/m³	-0.09	
D. Household	36.62	p/m³	11.10	
E. Waste	1.80	p/m³	-0.16	
Total	39.31	p/m³	10.72	27%

*to water industry 05/06 data

Basis for carbon 'footprint' calculation - for 25 households

Stage in life cycle	Item	Unit	Type	Quantity kg	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Capex: Materials		see below					20345.5	20.345	0.02	17.62
Capex: Manufacture		see below					10509.8	10.510	0.02	9.10
Capex: Distribute	travel	km	transit van	1000	0.21		209.0	0.209	0.02	0.18
Capex: Install	travel	km	transit van	250	0.21		52.3	0.052	0.02	0.05
Opex: Operate	energy	kWh	electricity	1222	0.43		525.6	0.526	1.00	20.64
Capex: Materials	Totals->			-	-		30855.2	30.855	0.02	0.67
underground storage tank		t	concrete	30	134.00	50%	6124.6	6.125	0.02	0.12
pipework - 25cm, 250m long		t	steel- general	8	1820.00	50%	22863.8	22.864	0.02	0.45
pipework - 12.5cm, 250m long		kg	PVC	75	2.41	50%	271.1	0.271	0.05	0.01
Diesel for construction		lt	diesel	38	2.63	100%	197.3	0.197	0.02	0.00
pump - metal parts		kg	steel- general	150	1.82	100%	546.0	0.546	0.07	0.04
cistern replacement		kg	ceramic	300	0.55	50%	247.5	0.248	0.07	0.02
parts (PVC) - filters, first flush valve et		kg	PVC	50	2.41	100%	241.0	0.241	0.05	0.01
parts (metal) - valves, gauges, collector		kg	steel- general	100	1.82	100%	364.0	0.364	0.05	0.02
Annual Opex: Operate	Totals->				-		525.6	0.526	1.00	0.52
pump and treatment		kWh	electricity	1222	0.43		525.6	0.526	1.00	0.52
Water savings		Ml	water	0.000	271	n/a	0	0.000	1.00	0.00

Notes: [1]materials embedded CO_2e; [2]CO2e from manufacturing as percentage of embedded CO_2e



Environment Agency - Water Infrastructure Options science report
http://www.environment-agency.gov.uk/subjects/waterres/286587/286
http://www.environment-agency.gov.uk/commondata/105385/greywate
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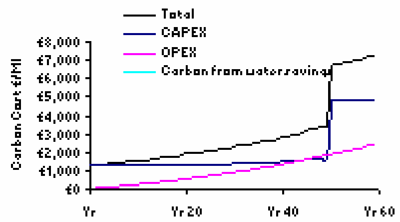
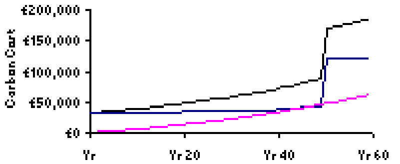
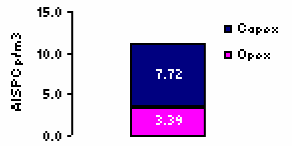






Halcrow

Water supply/demand management options
Carbon foot-print calculator

Demand Management: Leakage control

Input (default values or user defined)

Leakage option	Leaks detected		- "user" to select from table below
Water saving	16	ML/d	- "user" to select from table below
Carbon emissions	1203	tCO2	- "user" to select from table below
Frequency (tCO2)	1	/year	- "user" to select from table below
Planning period	60	years	
Discount rate	3.5%	default set to Treasury Green Book (2007)	

Include water saved? y y/n

Select "no" to calculate only emissions to install/operate metering; and "yes" to add additional benefit of reduced water use that results in carbon savings.

Output (over planning period)

Carbon 'footprint'	72180	tCO2e
	0	tCO2e/Ml
Carbon Cost (CC)	3,555	£k
Water Savings	5731	ML/yr
Average Incremental CC	0.002	p/m3
Water saved	0.00	p/m3

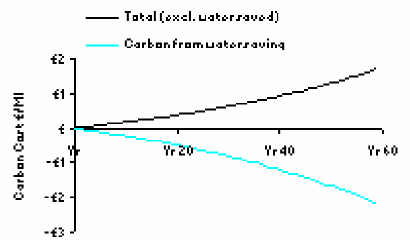
Basis for carbon 'footprint' calculation

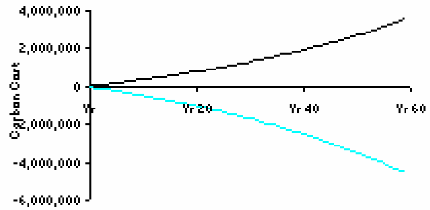
No calculation - data drawn from studies by others

Leakage option	saving ML/d	emissions tCO2	frequency per year	Source
Leaks detected	4.1	406	1	Ofwat ELL
Leaks reported	15.7	1203	1	Ofwat ELL
Mains renewal	1	11082	20	Ofwat ELL
Pressure control	17			Ofwat ELL
Leaks detected	1	86	1	Wessex Water
Service pipe renewal	1	1621	20	Wessex Water
Mains renewal	1	4775	20	Wessex Water

Stage in life cycle	Item	Unit	Type	Quantity	kg CO2-e per unit Em[1]	kg CO2-e per unit Man[2]	kg CO2	t CO2	Annual frequency	tCO2/Ml
Water savings		Ml	water	-5731	271	n/a	-1,552,966	-1553	1.00	0.27

Notes: [1]materials embedded CO_2e; [2]CO_2e from manufacturing as percentage of embedded CO_2e





We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

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