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MACROWater: a Top-down, Policy-driven Model for Forecasting Domestic Water Demand

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This version 2.0 contains a revision to Table 14, correcting an error and adding some information.

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ABSTRACT

MACROWater is a top-down domestic water demand model developed for the WaND project (Water Cycle Management for New Developments). Forecasts have been produced for all local authorities in England and Wales. They can be aggregated for different reporting areas (such as Government Office Regions, Sustainable Communities and water companies). *Sustainable Community* is the official term for key strategic areas, earmarked for rapid expansion of housing supply (such as the M11 corridor, Ashford, Milton Keynes). This model description uses the UK's biggest Sustainable Community, Thames Gateway, as the example case study.

Utilising Domestic Consumption Monitors from the water companies supplying this area, combined with housing, household and population projections, the authors have modelled domestic demand in detail. Alternative futures are considered using a set of urban water management scenarios, which represent different levels of adoption of water-saving technologies and different consumption patterns. For example, under the greener scenarios, new homes are fitted out with water-efficient equipment, allied with incentives to replace/refurbish as much old housing stock as possible. The modelling work demonstrates that increased demand from new developments can be accommodated but only through strict demand management and some new water supply measures.

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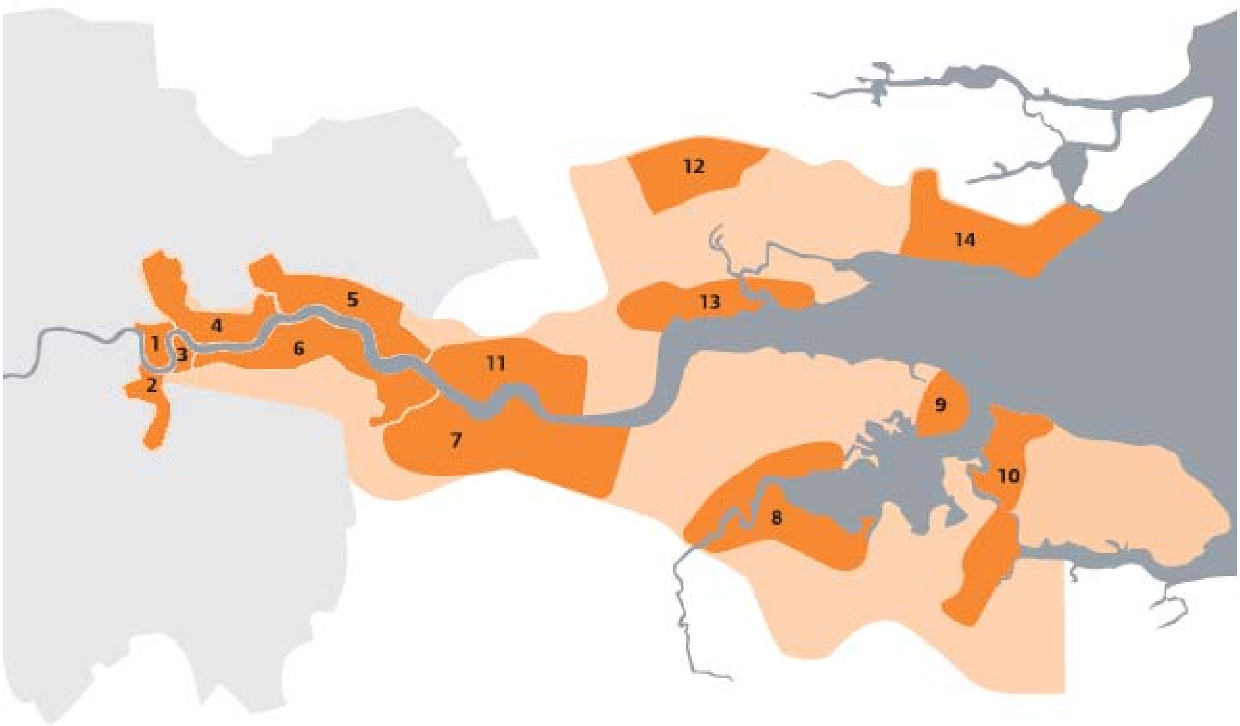
1. INTRODUCTION

1.1 Context

The UK government has earmarked Thames Gateway, the M11 Corridor and Ashford in Kent for large scale development. These “sustainable communities” were the brainchild of the Office of the Deputy Prime Minister (ODPM, 2003) but are now overseen by the Department of Communities and Local Government (DCLG, 2006a). Thames Gateway is the UK's biggest growth area, with about 200,000 new homes planned by 2020 (DoE, 1996). Within Thames Gateway sustainable community (Figure 1), 14 zones of change, have been set higher than average house building targets (Table 1). These zones were selected because they had post-industrial brownfield sites, formed part of a planned transport hub or were included in other strategic plans.



1	Isle of Dogs	6	Woolwich, Thamesmead, Erith	11	Thurrock Riverside
2	Deptford and Lewisham	7	Kent Thameside	12	Basildon
3	Greenwich Peninsula	8	Medway	13	Canvey, Shellhaven
4	Stratford, Lower Lea, Royal Docks	9	Grain	14	Southend
5	London Riverside and Barking	10	Sittingbourne, Sheerness		

Figure 1: Thames Gateway zones of change
Source: GLA, 2004

Table 1: New homes 2001-2016 for the Thames Gateway zones of change

Zone of change	*Govt. target*	*Regional Plan target*
Isle of Dogs	4000	7,790
Deptford and Lewisham	5000	9,800
Greenwich Peninsula	10000	10,000
Stratford	4000	7,300
Lower Lea	8400	15,400
Royal Docks	5600	10,300
Barking Town Centre	2000	3,710
London Riverside	13000	17,890
Woolwich, Thamesmead, Erith	7000	8,810
LONDON TOTAL (LDA)	59,000	91,000
Thurrock	13,500	13,500
Basildon	6,000	6,000
Castle Point	2,500	2,500
Southend, Rochford	4,500	4,500
SOUTH ESSEX TOTAL (EERA)	26,500	26,500
Kent Thameside	20,000	20,000
Medway/Grain	15,000	15,000
Sittingbourne, Sheerness	8,000	8,000
NORTH KENT TOTAL (SEERA)	43,000	43,000
THAMES GATEWAY TOTAL	128,500	160,500

Source: Interregional Planning Statement (ODPM, 2004) plus authors' calculations

For example, the Stratford City development has outline planning consent for about 4,500 homes. Regeneration of the Lower Lea Valley was a key element of the successful Olympic bid. This area has the potential to deliver around 20,000 homes. The Thames Gateway Development Corporation is working with the Olympic Delivery Authority to revitalise this part of East London (ODPM 2005a). At the moment this area is one of the most deprived regions in Britain. The land is contaminated and underused, and the community suffers from high unemployment and poor housing. The London Development Agency (LDA) estimated that 9,000 new homes will be built in the Olympic Park alone. Many of these houses will be affordable to local people. To support these new homes, there will be new hospitals, new schools, family health services and other community facilities (Mayor of London and LDA, 2005).

The early priorities (2003-08) are for development activity to be concentrated in those areas where the market is already active. These include major developments in the Isle of Dogs, the Royal Docks, and Greenwich Peninsula, and some development at existing hubs like Barking and Woolwich. Ensuring adequate public water supplies are provided to existing and new houses and businesses, while also ensuring that the environment is protected and enhanced, is a key challenge. The challenge is exacerbated by additional demand created by new households, changing lifestyles and the impact of climate change on demand and supply.

1.2 Aim of the paper

The aim is to create forecasts of people, households and their water consumption, to 2031, under alternative futures (scenarios). Scenario forecasts help planners and developers form an opinion as to whether possible developments are sustainable, that is, whether a balance can be achieved between economic, environmental and social equity criteria. For example, what is the relative impact on water demand of low, medium and high housing growth? How high must the water efficiency targets for new and existing homes be set to alleviate the impact?

We model household water consumption (also referred to as domestic water demand). We *do not* model future water resource (supply), leakage, industrial or agricultural consumption, so we do not calculate future water balance (the difference between supply and total demand) but we can relate future household water consumption to current resource to highlight those areas (local authorities) where the situation may be most critical. Note that we use the terms "domestic demand" and "household consumption"' interchangeably. The term "projection" suggests the future will follow past trends, as in the "Business as Usual" scenario. Most scenarios require imagining how the future might be different from the past and are labelled "forecasts".

1.3 Outline of the paper

The second section of the paper describes alternative approaches to water demand forecasting and introduces the forecasting techniques employed in this paper. Section 3 goes into detail about the water demand model: which forecast variables were chosen and why, how the baseline population was constructed and a step-by-step worked example. In Section 4, we describe how we developed alternative trajectories of model input variables based on general scenario storylines. Section 5 presents the results and Section 6 draws some conclusions and makes recommendations.

2. APPROACHES TO WATER DEMAND FORECASTING

2.1 Alternative forecasting approaches

In general, forecasting methods can be split into four categories:

(i) Time series methods (e.g. moving average, linear prediction, trend estimation). Time series methods use historical data as the basis for estimating future outcomes.

(ii) Causal methods (e.g. regression analysis, autoregressive moving average, econometric methods). Causal methods use the assumption that it is possible to identify the underlying factors that might influence the variable that is being forecasted. If the causes are understood, projections of the influencing variables need to be made and used in the forecast.

(iii) Judgemental methods (e.g. surveys, scenario building, technology forecasting). Judgemental forecasting methods incorporate intuitive judgements, opinions and probability estimates.

(iv) Experimental methods (e.g. simulation, probabilistic forecasting). The aim may be the model the behaviour of each household or person in a study area. This behaviour is not entirely predictable, hence the need for random sampling, and hence require many runs for a reliable average to be obtained.

All of these approaches have been applied to water demand forecasting over the years:
(i) In the 1960s, a time series approach was common in the water industry – and can be a surprisingly good predictor. At an industry conference, South West Water revealed that they can draw a straight, upward line through their annual household consumption records covering the last 40 years. Household water consumption appears to have increased in line with living standards (greater ownership of water-using appliances and increased frequency of their use). In contrast, industrial water consumption has declined over the same period, as the UK economy has shifted from manufacturing to service sectors (for a good model of industrial demand, see Mitchell *et al.*, 2000). Nearly every household has a washing machine now and appliances are becoming more water-efficient, so a linear projection is no longer satisfactory.

(ii) Many studies have used causal methods to explore links between economic status and water use (Consumers' Association, 1996; Cuninghame *et al.*, 1996; Alhumoud, 2002). The Best Practice Manual (UKWIR/EA, 1997) gives an example of a regression equation based on average occupancy and presence or absence of various household technologies. Many water companies follow this approach. One water company uses a neural network but such 'black box' methods lack transparency and so are not often employed. Similarly, models based on ARMA (autoregressive moving average) or M5 model trees (Bhattacharya and Solomatine, 2005) are more suited to short-term forecasting, where the input data is noisy and explanatory variables are in short supply.

The idea of using the *microcomponents* of water demand was proposed by an econometrist, (Herrington, 1972, cited in EA 2001), who devised a method for calculating household water consumption as the sum of its constituent uses (e.g. WC, bath, shower, power shower, hand basin, washing machine). Since the mid-1990s, the Environment Agency has promoted the microcomponents approach as an industry standard, due to the high-level of explanation the method provides. For example, it allows current demand estimates (water company annual returns) to be checked for plausibility. Future scenarios can be easily catered for, e.g. what would happen if twice as many homes had outside taps. At Leeds University, this approach has been applied in MicroWater, a microcomponents-based forecasting model for medium to large areas (Sim, 2006). It uses the same scenarios and DCM as the model behind this paper (results are compared to this model, MACROWater, in Table 17).

(iii) Pioneering work on scenario building was done by the Global Scenarios Group (Gallopin *et al.*, 1997). In 1999, the Foresight Energy and Natural Resources Panel published *Environmental Futures* (DTI, 1999), commonly known as the "Foresight Scenarios". These constitute a logical framework for building long-term scenarios, which has been taken up by many industries. The Foresight Scenarios are defined using two orthogonal axes, Globalisation/Regionalisation and Consumerism/Community. The space is divided into four quadrants: where Globalisation and Consumerism are strong we have the "World Markets" scenario; where Globalisation and Community are strong we have the "Global Sustainability" scenario; where Regionalisation and Consumerism are strong we have the "Provincial Enterprise" scenario; where Regionalisation and Community are strong we have the "Local Stewardship" scenario. The Environment Agency adapted the four Foresight Scenarios to water demand forecasting in their 'black book' (EA, 2001), which proposed microcomponent analysis as the most appropriate way of linking the drivers of household demand to scenarios. This allowed the effect of changes in drivers (regulations, policy, technology, social trends) to be expressed in a fine grained way as changes in microcomponent use.

Since the early 1990s, several water companies have conducted ongoing surveys of household use, known as Domestic Consumption Monitors (DCM). These contain records of household water consumption linked to information about the household structure and facilities, so there is a strong evidence base to draw upon to connect scenario drivers and water consumption. DCM surveys are not too judgemental as they increasingly use automated logging methods instead of diaries (they collect data through logging devices providing demand data down to 15 minute intervals). Typical fields in a DCM are number of adults, number of children, socio-economic class, accommodation type, tenure, rateable value; sometimes they go down to microcomponent level (e.g. water butt, jacuzzi, shower rating, WC cistern size). Sadly, there is no common standard for DCM fields and tables, so there is a lot of data preparation required for studies that cut across water company boundaries.

(iv) When it comes to experimental methods, Leeds University has a good track record in simulating collections of households to do fine-grained policy impact analysis. Williamson *et al.* (1996) showed how static microsimulation could be used to estimate small area demand. Monte Carlo sampling is used to combine data from DCM with other household surveys to create a detailed synthetic population. A microsimulation model of water demand in the Thames Gateway Study Area was also constructed for the WaND project (Jin, 2006). In dynamic microsimulation, household occupants age over time, get married, start families, invest in a water butt (based on probabilities). Another method emerging from research labs is agent-based modelling of water demand (Barthelemy, 2003; Downing *et al.*, 2003). Households (or individuals) are represented as agents with attributes and behaviours. The main difference between agent-based modelling and microsimulation is that agent-based models use rules rather than probabilities, which can simulate more complex and dynamic forms of behaviour.

2.2 Top-down vs. bottom-up

Another way of categorising water demand forecasting models is top-down and bottom-up. The ‘bottom up’ approach (Herrington, 1996) assigns typical consumption figures to every household appliance then sums together each microcomponent (ownership × frequency × volume) to arrive at Total Household Consumption. Its transparency and ability to link consumption to specific water use (e.g. toilet flushing) has enabled microcomponents to become industry ‘best practice’ (EA, 2001).

However, Sim *et al.* (2006) point out some limitations: There is usually no detail as to the demographic profile that the ‘typical’ quantities of microcomponents are based on. Thus microcomponents may deviate significantly when applied to areas which differ demographically. With regard to new developments in the South East this is problematic as these are expected to have smaller than average household sizes. In particular the lack of socio-economic context prevents comparison between two areas. This effect also increases when applied to smaller scales, where deviation from demographic norms becomes statistically more likely.

This paper employs a ‘top down’ approach that puts the emphasis on people, households and broad demographic trends, as Thames Gateway is clearly going through significant, planned demographic change, and we believe that this will be the main driver behind increased demand. Other drivers can be modelled in terms of the net impact they have on baseline consumption (number of households multiplied by typical consumption for a household of that type). When it comes to modelling scenarios, the top-down approach is simple to calculate and a good fit with government policy, such as The Sustainable Buildings Code (ODPM, 2005b), which proposes targets for new-build water efficiency but does not dictate to developers which specific technologies to use.

2.3 Approaches used for this paper

To begin, a causal method (analysis of variance) was used to select the variables which best categorised household demand (this is described in section 3.2). Much use was made of judgemental methods, in order to support scenarios representing futures that represented a break with the past. For example, we forecast household numbers with respect to alternative housebuilding targets. Population is estimated from the forecast of households combined with a projected household size distribution. Only for the *Business as Usual* scenario was a time series method (trend estimation) applicable.

3. THE WATER DEMAND MODEL

3.1 Summary of the model structure

In order to build a model of household water consumption, we need to specify the model elements and model structure, which are described below.

3.1.1 System of interest (case study area)

The underlying model, MACROWater, is capable of forecasting water demand for all local authorities and water company areas in England and Wales. In this paper we report on forecasts for local authorities and water company areas that are encompassed by the outer boundary definition of Thames Gateway, known as the Thames Gateway Study Area (DCLG, 2006a). Thames Gateway Study Area was chosen because it consists of whole local authorities, making visual comparison easier and more meaningful. Table 2 shows the 19 local authorities and 4 water companies covered.

Table 2: Basic information required at local authority level

Quadrant/LA name	*GOR*	*2001 total households*	*Govt. target p.a.*	*Water supplier(s) (% of LA population)*
NORTH LONDON				
Waltham Forest	London	92,410	460	Thames
Hackney	London	88,467	720	Thames
Tower Hamlets	London	80,781	2,070	Thames
Newham	London	93,781	890	Thames
Redbridge	London	94,175	540	Thames (71%), Essex & Suffolk (29%)
Barking	London	68,381	510	Thames (22%), Essex & Suffolk (78%)
Havering	London	93,980	350	Essex & Suffolk
SOUTH LONDON				
Lewisham	London	109,449	870	Thames
Greenwich	London	95,837	800	Thames
Bexley	London	91,729	280	Thames
SOUTH ESSEX				
Thurrock	East	59,416	925	Thames (11%), Essex & Suffolk (89%)
Basildon	East	70,844	535	Essex & Suffolk
Castle Point	East	35,808	200	Essex & Suffolk (78%), Southern (22%)
Rochford	East	32,770	230	Essex & Suffolk
Southend-on-Sea	East	74,310	300	Essex & Suffolk
NORTH KENT				
Dartford	South East	36,031	785	Thames (97%), Mid-Kent (3%)
Gravesham	South East	39,133	465	Thames (22%), Southern (73%), Mid-Kent (5%)
Medway	South East	102,894	815	Southern (82%), Mid-Kent (18%)
Swale	South East	51,315	415	Southern (45%), Mid-Kent (55%)
Total		1,411,511	3,020	

Sources: Census, Regional Development Plans and authors' GIS calculations
Note: "Barking" is used throughout as an abbreviation for "Barking and Dagenham"

3.1.2 Spatial units

Local government authority areas are the main units of analysis, linking to other information stored at water company and GOR level, as required. For example, we convert local authority (LA) forecasts into water company forecasts using lookup tables containing fractions of the LA household population covered by water companies. Mapping results at LA level shows those areas where housing growth, and hence household water demand, is highest.

A water company resource zone is historically the largest area that can be supplied by a single water source (occasionally they are amalgamated following mergers and acquisitions). Water companies report to government agencies (Environment Agency, or EA, and Office of Water Services, or Ofwat) at resource zone level. Unfortunately, these agencies are not permitted to pass this information on to third parties, due to copyright and competition laws, so our results are not as spatially precise as we would have liked, sometimes just using data at company level for calibration purposes. As a compromise, we used an intermediate geography for processing, which we call ‘consumption zones’ – they are aggregations of resource zones (between one to five per company), usually based on merging contiguous boundaries. Figure 2 shows water company consumption zones for South East England. Those water companies which have provided us with DCM and GIS boundaries, are covered in more detail. For example, Essex and Suffolk Water has 2 resource zones, one for Essex and one for Suffolk and in this instance, our consumption zones map directly to the resource zones. Thames Water has 9 resource zones but, for convenience, we aggregate into just 3 consumption zones, called London, Guildford and Provinces. We do not have any detailed data for Mid-Kent Water, so we treat that as one big consumption zone.

3.1.3 Household classifications used

The households in an LA are classified by household size (occupancy) and accommodation type, as these were found to be the most discriminatory variables in an analysis of Domestic Consumption Monitors (DCM) for Essex and Suffolk and Thames water companies. Section 3.3 describes the statistical analysis.

3.1.4 The baseline data

All development and water efficiency initiatives were assumed to take effect from the baseline year of 2001. This is a good baseline as DCM, Ofwat and Census data are all

Figure 2: Example water company consumption zones
Source: Authors' map created from Ofwat (2006)

available for this year. The baseline water consumption data are Per Household Consumption (PHC) averages for households in each household size and accommodation type, derived from the DCM and from Ofwat per capita consumption (PCC) reports on metered and unmetered customers. Data on households were assembled for 2001 from the Census of Population administered by the Office of National Statistics (ONS). We use a commissioned table for numbers of households by household size and accommodation type for all local authorities in England.

3.1.5 Forecasts for housing (from 2006 to 2031 in five year intervals)

Forecasts for housing development are extracted from regional development plans for the Thames Gateway Local Authorities, published on the websites of each Regional Assembly. There is a separate plan for the Thames Gateway zones of change, the figures from which are linked and reconciled with the Local Authority regional plan figures.

3.1.6 The structure of the model

The model develops a time series of housing stocks: 2001 housing, housing that is replaced (demolished and rebuilt), housing that is refurbished and newly built housing. In section 3.8, we specify in detail the stocks of and changes in housing units, the water consumption variables and the model equations and the sequence of output variables that are generated. With the model structure in place, we can vary the assumptions used in forecasting to implement scenarios describing the results of new policies about water technology or different water-using behaviours.

3.2 Model variables and data sources

The goal of WaND work package 12 was to produce a reusable model to forecast the number and location of households under different planning scenarios (WaND, 2003) – which we did and called MACROPop (see Figure 3). The goal of WaND work package 1 was to produce a suite of water demand forecasting tools - of which, MACROWater, is the model described in this paper. To feed the water demand models, demographic and water data were prepared for all parts of England and Wales.

The number of households and people in these local authorities in the Census year of 2001 was used as the base population. From Standard Table S048, the fields ‘All Household Spaces’ and ‘All Household Spaces – occupied’ were stored plus ‘All People – Household

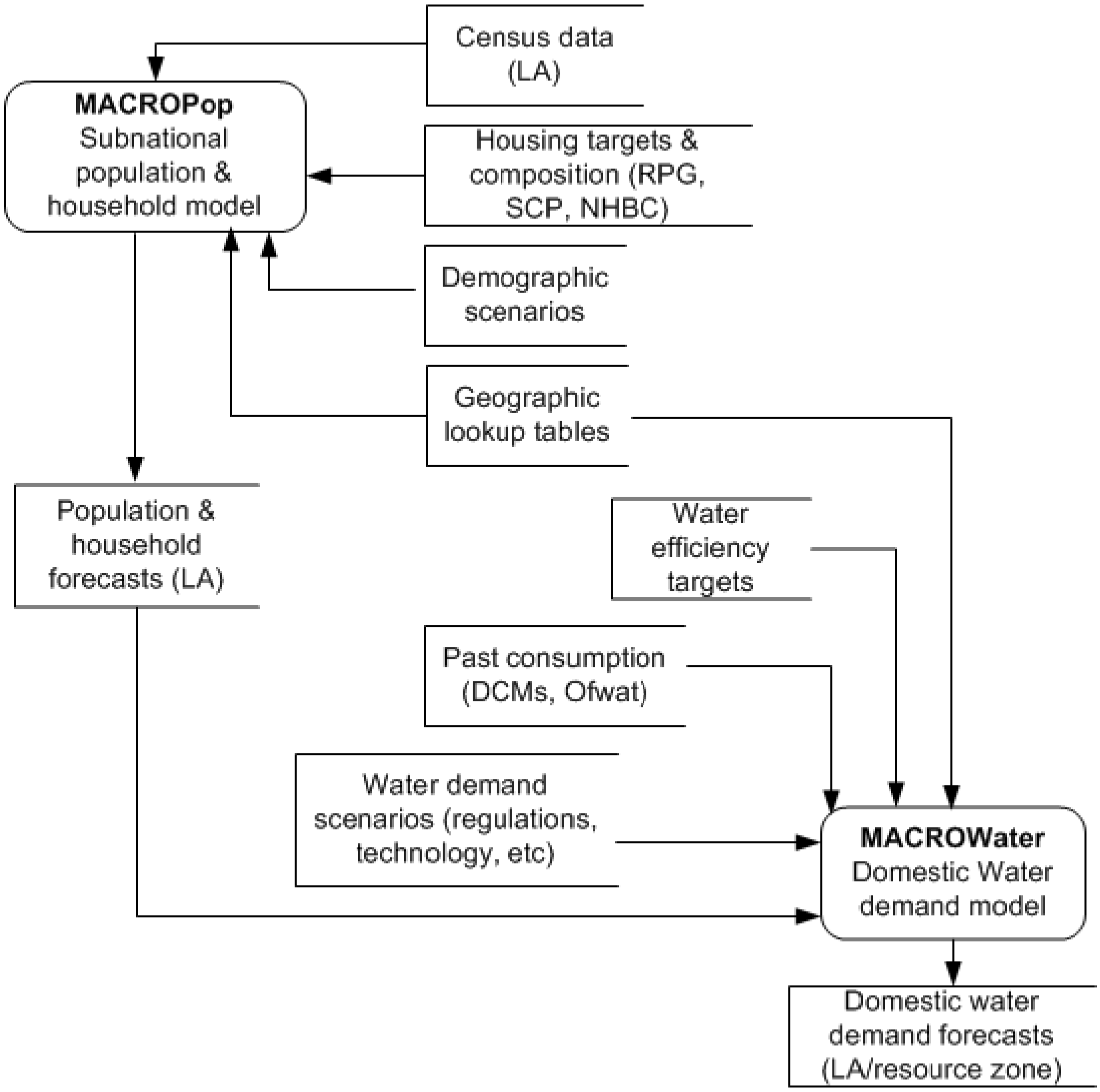


Figure 3: Model inputs and outputs

residents' from Standard Table S001. A crude estimate of occupied household spaces in future years was based on total future household spaces multiplied by the proportion occupied in 2001.

The statutory regional and LA housebuilding targets were determined by the draft Regional Spatial Strategies encompassing Thames Gateway (ie The London Plan, South East Plan and East of England Plan). They provide a per annum housebuilding target (as shown in Table 2). Below that, Local Development Frameworks will be produced by Local Authorities but, so far, these do not break down the targets into smaller areas (such as mid-layer super output area), so we have simply used 2001 MSOA-LA population proportions to achieve this, when required.

The decision to distinguish between existing housing units, refurbished units and new-build was taken as different policies (regulations, incentives, taxation, etc) apply to these different types. To improve the water efficiency of existing units, householders must be influenced to invest to change their dwelling water delivery and consumption infrastructure. With new housing (including replacement of demolished housing) building regulations apply which impose higher standards of water savings. Refurbishment of existing units falls in between these two situations (or is the expression of changes by the householder). The National House-Building Council (NHBC) is a trade body representing 85% of developers. It collates data from its members and sells it in booklet form. An annual breakdown (2001-2005) of new-builds by accommodation type and region was extracted from NHBC (2006), Table 17 and converted into proportions.

For this study area, we are able to draw upon DCM from Thames Water and Essex & Suffolk Water. These panel surveys contain monthly consumption records for a sample of up to 1,000 households. After removing inconsistent or extreme records from the 2001 data, matrices of average Per Household Consumption (PHC) and Per Capita Consumption (PCC) were extracted for different cross-sections of customers - measured in litres per property per day (l/p/d) and litres per head per day (l/h/d), respectively. For smaller DCM, such as Essex & Suffolk, 2000-2002 records were combined to increase the sample size, and hence, cross-sectional coverage.

Every 5 years (such as April 2004), each water company must submit a Water Resource Plan to the regulator, Ofwat, which includes detailed information and plans down to resource zone level, including Unmeasured household PCC, Measured household PCC and Meter ownership and target ownership. A subset of this information, at company level, is made publicly available on the Ofwat website (Ofwat 2006b, 2006c) and this has been used to calibrate our base year DCM-based demand estimates (section 3.6 gives more detail).

The models draw on a large variety of data sources, at different spatial scales, so a variety of lookup and lookdown tables had to be constructed. Simple GIS and statistical operations were used to infer which water companies/consumption zones supply each local authority. It involved creating a fractional lookup table, based on the number of people in their common output areas relative to the local authority population.

The scenario-driven inputs, set out in Table 3, to the model were chosen, as they encompass the main drivers behind large area water demand: the number of households/people, the overall water efficiency of their dwellings, the impact of climate change and householder behaviour. Table 4 sets out the values assumed in each scenario for the inputs while Table 5 shows how these different values are combined to produce the different scenarios.

We call these inputs ‘macrocomponents’ for short, as they are similar to microcomponents but on a macro scale:

- **New Housebuilding –** number of new-builds since 2001, based on alternative government targets. The original Sustainable Communities targets (ODPM, 2003) were based on Regional Planning Guidance (RPG9). The Government response to the Barker Review (Barker, 2006) recommended higher targets, mainly to help first-time buyers.
- **Replacement Housing –** number of properties demolished or refurbished since 2001. We must take account of this since government policy, under the Pathfinder programme, is that every property demolished must be replaced by an equivalent one. This doesn’t affect the total number of houses but we need to know how many contain new appliances in order to multiply by the appropriate household consumption level.
- **Housing Occupancy Rate –** a ratio reflecting average household size in a given LA (e.g. 2.1 persons per household). Modelling changes in household size will help us assign the correct proportion of 1, 2, 3, 4, 5 and 6-person households. Smaller households use proportionally more water and they are on the increase (particularly in new developments).
- **Water Efficiency New Developments –** a percentage change in demand, mainly due to regulatory targets. The Sustainable Building’s Code advises developers to look for a saving of at least 8% (125 l/h/d). More recent consultation (DCLG, 2006b) suggests a target in the range 120-135 l/h/d.
- **Public Buy-In –** a scaling factor representing the difference between efficiency targets and reality, for different social norms, as only a minority will have the knowledge and enthusiasm to use the equipment in new homes to its optimum capacity.

Table 3: Macrocomponents and their possible values

Macrocomponent		Setting	Description
NH	**New Housebuilding**	Low growth Medium growth High growth	Local targets (based on past trends) Incorporates Sustainable Communities target Incorporates Government response to Barker Review
RH	**Replacement Housing**	No change Low growth Medium growth High growth	Current demolitions and refurbishments Incorporates Pathfinder target for demolitions Rate equivalent to 225-year house lifespan Rate equivalent to 150-year house lifespan
OR	**Housing Occupancy Rate**	Decline No change Increase	Based on downward trend in recent Censuses Average Household Size stays the same Reverts to 1981 rate over 40 years (then stays constant)
WEN	**Water Efficiency New Developments**	Slight decrease No change Slight increase Moderate increase Large increase Very large increase	8.3% efficiency decrease, e.g., due to growth of power showers Current PCC (typically 140-160l) is maintained 8.3% increase, e.g., due to improved white goods and taps 16.6% increase, e.g., by adding butts and dual flush WCs 33.3% increase if all mid-priced technologies used 50% increase if high-priced technologies, such as recycling, used
PB	**Public Buy-In**	Moderate decrease Slight decrease No change Slight increase Moderate increase	% difference between median PCC and the bottom 40% % difference between median PCC and the bottom 45% No change in public attitudes and, hence, PCC % difference between median PCC and the top 45% % difference between median PCC and the top 40%
WEE	**Water Efficiency Existing Developments**	Moderate decrease Slight decrease No change Slight increase Moderate increase	0.6% p.a. efficiency decrease 0.4% p.a. efficiency decrease Current PCC (typically 140-160l) is maintained 0.4% p.a. efficiency increase 0.6% p.a. efficiency increase
MT	**Metering**	Base growth Medium growth High growth	Current company rate At least 50% metered by 2025 100% metered by 2025
CC	**Climate Change**	No change Low emissions Medium-Low Medium-High High emissions	(Not considered) Investment in clean and technologies; 1°C hotter in 2100 (Not considered) Similar fuels and economic growth to present; 4°C hotter in 2100 (Not considered)

Table 4: Macrocomponent settings for scenarios

		New House-building	Replace-ment Housing	Housing Occupancy Rate	Water Efficiency New Devs	Public Buy-In	Water Efficiency Exist. Devs	Metering	Climate Change
S1	**Business As Usual**	Medium growth	No change	Decline	Slight increase	No change	Slight decrease	Base growth	Medium High emissions
S2	**High Growth, Small Savings**	High growth	No change	Decline	Slight increase	No change	Slight decrease	Base growth	Medium High emissions
S3	**Current Policy**	High growth	Low growth	Decline	Moderate increase	No change	No change	Medium growth	Medium High emissions
S4	**Technocratic**	High growth	Medium growth	Decline	Slight increase	Slight decrease	No change	Medium growth	Medium High emissions
S5	**Free Market**	High growth	No change	Decline	Slight decrease	Slight decrease	Slight decrease	Base growth	Medium High emissions
S6	**Green Policy**	Medium growth	High growth	No change	Large increase	Slight increase	Moderate increase	High growth	Low emissions
S7	**Eco-communalism**	Low growth	Medium growth	Increase	Large increase	Moderate increase	Slight increase	Medium growth	Low emissions
S8	**Sustainable World**	Low growth	High growth	No change	Very large increase	Moderate increase	Moderate increase	High growth	Low emissions
S9	**Fortress World**	Medium growth	No change	Decline	Slight decrease	Moderate increase	Slight decrease	Base growth	Medium High emissions

Table 5: Example microcomponent drivers for the 'Water Efficiency New Developments' macrocomponents

Use	**No change**		**Slight increase**		**Moderate increase**		**Large increase**		**Very large increase**	
	Volume (l)	**PCC (l/h/d)**	**Volume (l)**	**PCC (l/h/d)**	**Volume (l)**	**PCC (l/h/d)**	**Volume (l)**	**PCC (l/h/d)**	**Volume (l)**	**PCC (l/h/d)**
Toilet	6	28	6	28	4	17	3	14	3	0
					Low volume WC		2/4l dual flush WC		WC uses recycled water	
Shower	45	25	45	25	45	25	30	17	30	17
							Low flow shower			
Bath	85	30	85	30	85	30	80	28	80	28
							Lower volume bath			
Taps	-	12	-	10	-	10	-	8	-	8
			Low flow taps				Aerated taps			
Washing Machine	60	13	40	9	40	9	34	7	34	4
			Water-efficient model				Most efficient model		First cycle uses recycled water	
Dishwasher	20	8	15	6	15	6	15	6	15	6
			Water-efficient model							
Garden	-	6	-	6	-	5	-	1	-	0
					Watering can (not outside tap & hose)		Watering can and water butt		Special outside tap for recycled water	
Miscellaneous	-	23	-	20	-	20	-	15	-	10
			Small technical advances		Small technical advances		Efficient heating, waste disposal, etc		Car washing uses recycled water, etc	
TOTAL (l/h/d)		145		134		122		96		73
SAVING (%)				7.6%		15.9%		33.8%		49.7%

Sources: Extended from Harker (2005) and EA (2001)

Notes: Average household occupancy of 2.5 assumed. Interventions shaded grey

Water Efficiency Existing Developments – a small percentage change in demand driven by consumer behaviour. It may be for the better (such as more water butts) or it may be for the worse (such as buying a sprinkler or upgrading to a power shower).

- Metering – a percentage change in demand due to yearly increases in the percentage of metered customers. Metered customers typically use circa 10-11% less water than un-metered (Southern Water 1997, House of Lords 2006), so if metering went from 50% to 100%, a 5-5.5% discount should be applied.
- Climate Change – a percentage change in demand caused by hotter summers and wetter winters. Previous studies (Downing *et al.*, 2003) suggest a small increase in demand (due to more garden watering, showering, car washing and kitchen usage).

3.3 Classifying households for water demand estimation

The way we classify households is constrained by what variables are present in both the DCM and Census tables. First of all, we performed some statistical tests on the socio-economic attributes within the Thames Water and Essex & Suffolk Water DCM in order to rank them in order of significance. The DCM attributes were: Household Size (aka occupancy), Number of Adults, Number of Children, Number of Daytime Residents, Accommodation Type (aka property type), Rateable Value, ACORN category, ACORN type, Tenure and Ethnicity.

A two-dimensional PHC matrix works best, given the limited sample size (1000 customers or less), otherwise the matrix becomes very sparse. One-way Analysis of Variance (ANOVA) tests were used to determine which two socio-economic variables to use. They confirmed that Household Size was by far the biggest influence on PHC, with average F-statistic of 138 for Thames Water (London consumption zone) and 93 for Essex & Suffolk (Essex resource zone). This strong correlation can also be seen in Figure 4’s barcharts for PHC by household size, accommodation type and rateable value. The bars represent median PHC and the lines show plus/minus one standard deviation.

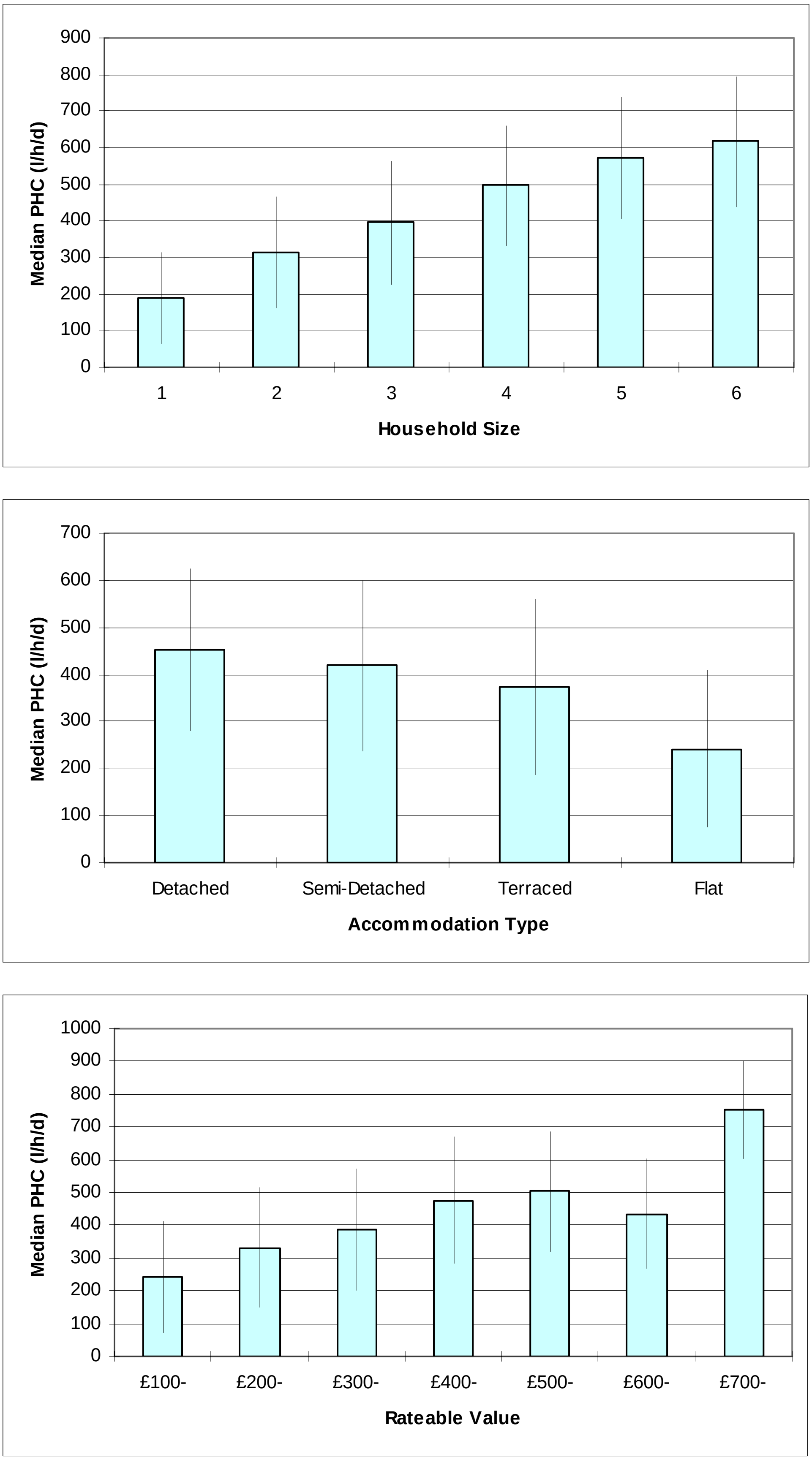


Figure 4: PHC by household size, accommodation type and rateable value
Source: Thames Water

A second set of ANOVA tests was run (Table 6), comparing the remaining variables against PCC (because dividing PHC by Household Size gives PCC, and we want to remove Household Size from this test). As before, all of the variables are highly significant (p-value less than 0.05 - generally 0.00 in fact), so the F-statistic had to be used to rank the list (the higher the F-statistic, the greater the influence of the independent variable). Tenure and ACORN rated surprisingly poorly. Adults and Children can be discounted because they are already covered by the Household Size (the total of Adults and Children). Ethnicity scored quite well but can be discounted as only Thames Water is the only company to use it – and also it is isn't representative as only 4 of out of a possible 10 ethnic groups are in the sample.

Table 6: Correlation to PCC (sorted by declining average F-statistic)

Dependent variable	*Independent variable*	*Distinct values*	*Thames Water Zone 2 F-statistic*	*Essex & Suffolk Essex RZ F-statistic*
PCC	Accommodation Type	Up to 5	8.828	5.215
PCC	Rateable Value	8 bands	2.512	9.875
PCC	Ethnicity	Up to 10	5.197	N/A
PCC	Day Residents	Up to 7	6.582	1.546
PCC	ACORN category	6	3.101	N/A
PCC	ACORN type	17	2.254	5.178
PCC	Tenure	4	N/A	1.106

Sources: DCM from Thames Water and Essex & Suffolk Water

That just leaves Accommodation Type and Rateable Value as the only contenders for the second matrix variable. We selected Accommodation Type as it has the bigger average F-statistic across both zones. Rateable Value scored more highly for Essex & Suffolk, but we have more confidence in the Thames DCM as it is a bigger sample with 'cleaner' data.

3.4 Baseline data for 2001: households by size and accommodation type

There is no Census table that cross-tabulates household size by accommodation type, so we commissioned one from the Office for National Statistics. It is now available online (ONS, 2005) for other researchers to use, free of charge. Data for all LAs in England was read from this spreadsheet into a database, for ease of combination with other sources (such as alternative targets for housebuilding by LA).

For estimation of water consumption for LAs, the other main baseline dataset is unmeasured Per Household Consumption (UPHC) matrices by household size and accommodation type. These crosstabulations can be created fairly easily (using Access or SPSS) for those water companies which providing a DCM, but what about the others, such as Mid-Kent Water and Southern Water? The problem of missing data was resolved via a socio-economic matching algorithm: For all companies, a classification was derived by aggregating the constituent output area classifications (OAC), across 7 supergroups, and converting them to proportions (as shown in Figure 5). The best match, was the DCM provider that had the smallest summed absolute difference across supergroups. As an example, for Mid-Kent Water the best match was the whole of Essex & Suffolk Water (it is like a mixture of the countryside of Suffolk and the prospering suburbs of Essex), so that company's raw UPHC matrix was substituted (solely for its proportional distribution, not the actual figures).

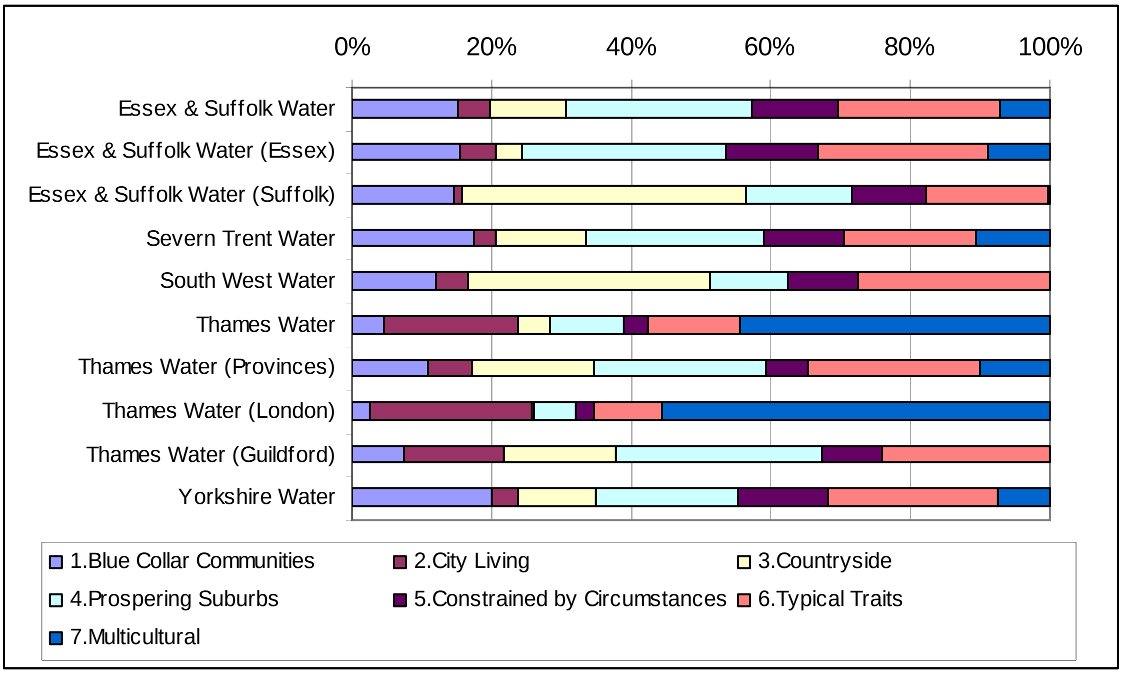


Figure 5: Socio-economic OAC profile for known DCM
Source: ONS, 2006 aggregated to GIS boundaries

In either case, before the raw UPHC data could be used, it had to be calibrated to achieve agreement with Office for Water Regulation (Ofwat) statistics for water companies (ie the unmeasured and measured PCC figures for 2001). This required taking the UPHC matrix for the entire company area and multiplying it by the matching household matrix. Both are 2d matrices with Household Size and Accommodation Type as the categories. Adding the cell products together gives total household consumption. To derive PCC, this figure must be divided by the number of people, which is estimated by multiplying household size by household count for each category, then summing the products. Dividing consumption by people gives a default unmeasured PCC, which can be divided into the published one to create a scaling factor. The raw unmeasured PCC can be up to 10% below the published figure, as water companies add on extra amounts to account for the Hawthorne effect and an MLE adjustment to reconcile all demand components with the known amount of water put into supply (UKWIR/EA, 1997). Each company has a different, undocumented way of calculating these inflations, so we best we can do is to infer the net effect, in this way.

3.5 The demand equations

To calculate Consumption (total water demand in an area), Per Household Consumption and Per Capita Consumption requires forecasting people counts and household counts/types, taking into account possible changes in water consumption through adoption of new technology or through changes in use of water consuming appliances. Here are the equations in algebraic form.

The superscript indicates the type of housing stock (st): N = new-build, E = existing.
The subscripts are: s = scenario, y = year.

The main variables are shown in capitals:
H = households, P = people, C = consumption,
Δy = years elapsed since base year,
PCC = Per Capita Consumption, PHC = Per Household Consumption,
UPHC = unmeasured Per Household Consumption (based on DCM sample),
UPCC = unmeasured Per Capita Consumption, MPCC = measured Per Capita Consumption (both from Ofwat reports),
WE = net effect on demand of water efficiency levels in the specified housing stock,
PB = net effect on demand of public buy-in,
MT = change in demand due to metering, MO = meter ownership as a proportion, MV = metering effect on PCC volume,
CC = change in demand due to climate change,
NH = target new households per annum,
RH = target replacement households per annum,
RR = residency rate (proportion of households with 1+ people), OR = household occupancy rate (average number of people in resident households).

Total Household Consumption is the sum of existing and new household consumption. Likewise, total households is the sum of existing and new households:

$$C_{sy} = C_{sy}^{E} + C_{sy}^{N} \qquad (1)$$

$$H_{sy} = H_{sy}^{E} + H_{sy}^{N} \qquad (2)$$

For Existing stock, consumption is calculated as gross consumption (number of households times unmeasured household consumption) scaled up or down, based on the combined impact of water efficiency measures, metering and climate change:

$$C_{sy}^{E} = H_{sy}^{E} \times UPHC_{sy}^{E} \times \left(1 + WE_{sy}^{E} + PB_{sy} + MT_{sy}^{E} + CC_{sy}\right) \qquad (3)$$

where existing stock declines over time as a result of replacement (through demolition or refurbishment). It is also scaled down by the 2001 residency rate (to take account of unoccupied households in the given area):

$$\Delta y = y - 2001 \qquad (4)$$

$$H_{sy}^{E} = (H_{2001} - \Delta y \times RH_{s}) \times RR_{2001} \qquad (5)$$

and metering impact is based on (increased) meter ownership and the typical effect on PCC volume reported by the water company that supplies this area:

$$MT_{sy}^{E} = MO_{sy} \times MV \qquad (6)$$

For New stock, the equation is very similar, but we assume 100% meter ownership (in line with building regulations):

$$C_{sy}^{N} = H_{sy}^{N} \times UPHC_{sy}^{E} \times \left(1 + WE_{sy}^{N} + PB_{sy} + MT_{sy}^{N} + CC_{sy}\right) \qquad (7)$$

where

$$H_{sy}^{N} = (NH_{sy} + \Delta y \times RH_{s}) \qquad (8)$$

$$MT_{sy}^{N} = MV \qquad (9)$$

The effect of metering on PCC volume is estimated using figures derived from the annual water company return for 2001 (Ofwat, 2002a), by dividing the official measured PCC figure by the unmeasured one and substracting one in order to adjust the compound multiplier downwards:

$$MV = \left(MPCC^{E}_{sy} \div UPCC^{E}_{sy}\right) - 1 \qquad (10)$$

The number of people can be calculated by multiplying households by occupancy rate for each stock type (as shown in equation 11). In practice, H is stored as a matrix of household counts (household size by accommodation type), so rather than calculating the overall occupancy rate, the people count can be calculated as the sum of each household size times household count subtotal. An analysis of the 2001 Census: Special Licence Household SAR (CCSR, 2006), which features household sizes from 1 to 8+, suggested that 6.5 was a good multiplier to use for the 6+ category.

$$P^{st}_{sy} = H^{st}_{sy} \times OR^{st}_{sy} \qquad (11)$$

Then sum up total people:

$$P_{sy} = P^{E}_{sy} + P^{N}_{sy} \qquad (12)$$

PHC and PCC are simple calculations now that we now total consumption, total households and total people:

$$PHC_{sy} = C_{sy} \div H_{sy} \qquad (13)$$

$$PCC_{sy} = C_{sy} \div P_{sy} \qquad (14)$$

These calculations are performed for each unique combination of local authority and water supply company. A weighted average is calculated for each LA and then constituent LAs get summed together. The H and UPHC arrays are broken down by Household Size and Accommodation Type, so it is, in practice a matrix multiplication, with the resultant products summed together.

3.6 Worked example

To illustrate the computations that the model carries out, here is an example for a single Local Authority in Thames Gateway (Waltham Forest), a single scenario (*Current Policy*) and 2021 as the target year. Waltham Forest is supplied solely by Thames Water (from its London consumption zone). In terms of administrative geography, it is located in the London GOR.

First, lookup the effect of metering on PCC volume for Thames Water, which equates to a discount of about 8% (expressed as a proportion and a negative number to satisfy this adjustments to gross consumption in equation 7):

$$MV = (154 \div 167) - 1 = -0.078$$

For new stock, we assume 100% meter ownership, so the discount is applied in full. For existing stock, the discount is scaled relative to ownership – a figure read/interpolated from water company forecasts, published for various years between 2003 and 2030 (EA, 2004a; Ofwat 2002b). 2021 need interpolating and results in a meter ownership for Thames Water of about 49%. This gives a scaled-down discount of just under 4%:

$$MT(Existing, s, y) = 0.49 \times -0.078 = -0.038$$

Next, lookup the net effect on demand of water efficiency levels for the *Current Policy* scenario (assumed to have immediate effect on all stock). For new developments, a moderate increase in efficiency means a 16% discount; for existing developments, no change is assumed.

$$WE(New, s) = -0.16$$

$$WE(Existing, s, y) = dy \times WE(Existing, s) = 20 \times 0 = 0$$

Under *Current Policy*, Public Buy-In is unchanged:

$$PB(s, y) = 1$$

Climate change increases demand by just over 1%. That is 20/24ths of the 2025 impact published by Stockholm Environment Institute (shown in Table 7). The London GOR maps to EA region “Thames” and the *Current Policy* scenario maps to the EA scenario “Beta” under the UKCIP scenario “Medium-High Emissions”:

$$CC(s, y) = dy/24 \times CC(s, 2025) = 20/24 \times 1.37/100 = 0.011$$

Table 7: Estimates of climate change impacts on domestic demand (% change), by EA region and UKCIP scenario

	Alpha and Beta Reference Scenarios		
Region	Low 2020s	Mid-High 2020s	Mid-High 2050s
Anglian	1.45	1.83	3.04
Midlands	1.71	1.83	3.68
North East	1.36	1.48	3.04
North West	1.31	1.43	2.97
Southern	1.33	1.45	2.92
South West	1.26	1.39	2.81
Thames	1.26	1.37	2.67
EA Wales	1.34	1.45	2.79
	Gamma and Delta Reference Scenarios		
Region	Low 2020s	Mid-High 2020s	Mid-High 2050s
Anglian	1.00	1.28	2.18
Midlands	1.19	1.10	2.30
North East	1.00	1.13	2.10
North West	1.04	1.08	2.11
Southern	0.99	1.07	1.81
South West	0.97	0.95	1.92
Thames	0.87	1.02	2.05
EA Wales	0.93	1.06	2.05

Source: SEI, 2003

Lookup Unmeasured Per Household Consumption, UPHC(Existing, s, y). The raw PHC matrix is derived by cross-tabulating the Thames Water DCM for 2001 (household size by accommodation type), after filtering the records to cover just the London consumption zone (Table 8).

Table 8: Unmeasured Per Household Consumption in London consumption zone of Thames Water

Household size	**Detached**	**Semi-detached**	**Terraced**	**Flat**	**Other**
1	213.9	260.8	213.8	203.1	0
2	382.6	390.5	376.5	295.1	0
3	568.4	490.9	434.9	419.3	0
4	504.8	547.1	526.9	476.7	0
5	560.2	640.9	678.4	361.3	0
6+	1,057.1	831.8	698.3	604.8	0

Source: Thames Water DCM, 2001

Before it can be used, the data must be calibrated to match official Ofwat unmeasured and measured PCC figures for 2001. This requires taking the Unmeasured Per Household Consumption in the whole of Thames Water and multiplying it by the matching number of households. Adding these products together gives total household consumption (1,068,886,648 l). To derive PCC, this figure must be divided by the number of people. This is estimated by multiplying household size by household count for each category, then summing (7,342,263 people). 1,068,886,648 ÷ 7,342,263 gives a raw PCC of 145.58 l/h/d. The target PCC is derived from 2001 Ofwat figures for Thames Water (UPCC = 167, MPCC = 154). A weighted average based on the 2001 metering level (17.4%) gives a target PCC of 164.73). Hence, the DCM scaling factor is about 13% (164.73 ÷ 145.58 = 1.1315).

Calculate new stock as the sum of new-build housing units and replacement housing units. Under '*Current Policy*', the new-build policy is 'High Growth', which means accounting for the combined effect of Regional Development Plan, Barker Review and Sustainable Community targets. The Regional Development Plan for London specified a baseline target of 460 properties p.a. for Waltham Forest. This is increased by about 11% to get a higher Barker p.a. rate, which is then multiplied by the time elapsed (20 years). In Waltham Forest, there is no additional Sustainable Community increment, as it doesn't intersect a zone of change (as shown in Table 1). Finally, the figure is downscaled to reflect occupied households only (97%, based on Census data showing that 89,788 of the LA's 92,410 housing units were occupied in 2001).

$$NH(s, y) = ((20 \times (460 \times 1.111)) + 0) \times 0.972 = 9{,}930$$

Replacement households are based on estimates for demolished and refurbished properties. Waltham Forest is in the south of England, so demolition will be lower but refurbishment higher than for Pathfinder areas in the north. Both estimates are based on the Census figure for unfit households (8,421), multiplied by scaling factors calculated for areas where actual demolition and refurbishment data is available (giving approximately 114 demolitions and 336 refurbishments p.a. in this case). These scaling factors have been adjusted to reflect *Current Policy* of low growth in the replacement housing rate. Again, the total is downscaled to reflect occupied households only.

$$RH(s, y) = (20 \times ((8{,}421 \times 0.013549) + (8{,}421 \times 0.039894)) \times 0.972 = 8{,}749$$

Calculate new stock as the sum of new-build and replacement housing:

H(New, s, y) = NH(s, y) + RH(s, y) = 9,930 + 8,749 = 18,679

Calculate existing stock as 2001 occupied housing units minus replacement housing:

H(Existing, s, y) = 89,788 – 8,749 = 81,039

H(s, y) = 81,039 + 18,679 = 99,718

Put it all together to calculate existing consumption.

C(Existing, s, y) = H(Existing, s, y) x UPHC(Existing, s, y) x (1 + WE(Existing, s) + PB(s, y) + MT(Existing, s, y) + CC(s, y))

Gross consumption (represented by the first 2 terms) is calculated by taking the existing stock total and applying it to a probability matrix for household occupancy in 2021 under continued decline in occupancy rate (Table 9), before multiplying it by the corresponding cells in UPHC matrix for London (Table 8). Summing these products and then multiplying by the raw-to-reported scaling factor (1.1315) gives an existing baseline consumption of 32,864,679 l. Now calculate the other scaling factors, to do with water efficiency, public buy-in, metering and climate change:

Scaling factors = 1 + (0 + 0 - 0.078 + 0.011) = 0.933

Therefore,

C(Existing, s, y) = 32,864,679 x 0.933 = 30,662,746 l

Table 9: Probability matrix for occupancy of existing households, in 2021, under continued decline in occupancy rate

	Detached	**Semi-detached**	**Terraced**	**Flat**	**Other**
1	0.012332	0.049239	0.106182	0.206925	0.000592
2	0.011913	0.059132	0.109045	0.097813	0.000242
3	0.008099	0.038330	0.072277	0.038517	0.000133
4	0.007145	0.031522	0.052623	0.017815	0.000072
5	0.004298	0.016520	0.025870	0.008645	0.000072
6+	0.002959	0.006987	0.011739	0.002900	0.000063
Total			1		

Table 9 was precalculated using iterative proportional fitting to a projection of household size with a projection of accommodation type. For both, Holt's linear exponential smoothing

(Holt, 1957) was used to project forward Census data for 1981, 1991 and 2001 (in 5 year steps) to create category totals. These category totals were turned into proportions so that they could act as consistent IPF marginal totals (ie they both added up to the same number: 1). Holt's algorithm was used, as it is a quick and simple method, that lends itself to the automated production of many projection results. It is an extension of exponential smoothing to take into account a possible linear trend.

Estimate people living in existing stock. Table 10 shows the calculations behind the total: P(Existing, s, y) = 161,776

Table 10: Estimating people in existing households, 2021, in Waltham Forest

	Detached	Semi-detached	Terraced	Flat	Other
1	1 x 877 = 877	1 x 3501 = 3501	1 x 7550 = 7550	1 x 14714 = 14714	1 x 877 = 877
2	2 x 847 = 1694	2 x 4205 = 8410	2 x 7754 = 15508	2 x 6955 = 13911	2 x 847 = 1694
3	3 x 576 = 1728	3 x 2726 = 8177	3 x 5140 = 15419	3 x 2739 = 8217	3 x 576 = 1728
4	4 x 508 = 2032	4 x 2242 = 8966	4 x 3742 = 14968	4 x 1267 = 5067	4 x 508 = 2032
5	5 x 306 = 1528	5 x 1175 = 5873	5 x 1840 = 9198	5 x 615 = 3074	5 x 306 = 1528
6+	6.5 x 210 = 1368	6.5 x 497 = 3230	6.5 x 835 = 5426	6.5 x 206 = 1340	6.5 x 210 = 1368
Total			161,776		

Put it all together to calculate new consumption.

C(New, s, y) = H(New, s, y) x UPHC(Existing, s, y) x (1 + WE(New, s) + PB(s, y) + MT(New, s, y) + CC(s, y))

Gross consumption (represented by the first 2 terms) is calculated by taking the new stock total and applying it to a probability matrix for household occupancy in 2021 under continued decline in occupancy rate (Table 9), before multiplying it by the corresponding cells in UPHC matrix for London (Table 8). Summing these products and then multiplying by the raw-to-reported scaling factor (1.000656) gives an existing baseline consumption of 6,823,513 l. Now calculate the other scaling factors, to do with water efficiency, public buy-in, metering and climate change:

Scaling factors = 1 + (-0.16 + 0 - 0.038 + 0.011) = 0.813

Therefore,

C(New, s, y) = 6,823,513 x 0.813 = 5,547,516 l

Table 11 was precalculated using the same iterative proportional fitting technique as described for Table 9, but with accommodation type proportions derived from the 2005 NHBC statistics for new-builds by region (see section 4.4 for a more detailed explanation).

Table 11: Probability matrix for occupancy of new households, in 2021, under continued decline in occupancy rate

	Detached	**Semi-detached**	**Terraced**	**Flat**	**Other**
1	0.004363	0.002751	0.011472	0.356683	0.000000
2	0.006239	0.004890	0.017439	0.249576	0.000000
3	0.005693	0.004254	0.015513	0.131896	0.000000
4	0.006784	0.004726	0.015257	0.082410	0.000000
5	0.004184	0.002539	0.007689	0.040994	0.000000
6+	0.003350	0.001249	0.004058	0.015993	0.000000
Total			1		

Estimate people living in new stock. Table 12 shows the calculations behind the total:

P(New, s, y) = 42,543

Table 12: Estimating people in new households, 2021, in Waltham Forest

	Detached	**Semi-detached**	**Terraced**	**Flat**	**Other**
1	1 x 82 = 82	1 x 51 = 51	1 x 214 = 214	1 x 6662 = 6662	0
2	2 x 117 = 233	2 x 91 = 183	2 x 326 = 651	2 x 4662 = 9324	0
3	3 x 106 = 319	3 x 79 = 238	3 x 290 = 869	3 x 2464 = 7391	0
4	4 x 127 = 507	4 x 88 = 353	4 x 285 = 1140	4 x 1539 = 6157	0
5	5 x 78 = 391	5 x 47 = 237	5 x 144 = 718	5 x 766 = 3829	0
6+	6.5 x 63 = 407	6.5 x 23 = 152	6.5 x 76 = 493	6.5 x 299 = 1942	0
Total			42,543		

Given the above totals for consumption, people and households, it just requires division to calculate PHC and PCC (summarised in Table 13). As expected, PHC and PCC are much lower in new-builds, due to higher water efficiency requirements. For example, under *Current Policy*, new-build PCC will be about 131 l/h/d and existing PCC about 166 l/h/d, creating an overall PCC of 160 l/h/d.

Table 13: Output variables for Waltham Forest, 2021

	C (l/d)	*H*	*P*	*PHC (l/p/d)*	*PCC (l/h/d)*
Existing	30,662,746	80,944	184,168	378.82	166.49
New	5,547,516	18,679	42,497	296.99	130.54
Combined	36,210,261	99,623	226,665	363.47	159.75

4. SCENARIOS FOR WATER DEMAND

4.1 Overview of scenarios selected

There are differing opinions about the impact of climate change, the appropriate number of houses to build and the level of water efficiency to enforce, so alternative forecasts must be produced. Scenarios represent a plausible and possible future, useful for strategic planning and management, as they are not limited to following past trends. By organising scenarios along axes representing social values (consumerism vs. community) and system of governance (regionalisation vs. globalisation), it is possible to cover all possible extremes. This approach was pioneered in the UK by the Foresight programme (DTI, 2001), and adapted for the water demand forecasts by the Environment Agency (EA, 2001), who came up with these four scenarios:

- Alpha scenario: consumerism and regionalisation
- Beta scenario: consumerism and globalisation
- Gamma scenario: community and globalisation
- Delta scenario: community and regionalisation

Our nine scenarios are influenced by the Environment Agency scenarios, but primarily based on the urban water management scenarios created for the WaND programme (Makropoulos *et al.*, 2006). They can be thought of as an extension of the Environment Agency scenarios, only with several scenarios in each quadrant of the Foresight grid, not just one. This allows a wider range of futures to be explored.

First of all, there are the ‘realistic’ scenarios. The WaND programme defined *Business as Usual*, and we added two similar scenarios (*Current Policy* and *High Growth, Low Savings*) to allow comparison with government forecasts, which focus on only the more plausible futures. However, government water demand forecasts assume that the population is static and that household growth is caused primarily by a redistribution of existing households (House of Lords, 2006). We can’t find any evidence to support that view, so there is population growth under all scenarios, consistent with past trends. We have assumed that new developments will attract people into an area, as well as meeting existing housing demand.

Then, there are three consumerist scenarios: *Technocratic* and *Free Market* and *Fortress World*. *Technocratic* puts all its faith in technical solutions without addressing public attitudes and behaviour. *Free Market* is characterised by a decline in attitudes to water efficiency, just seeking to maximise the number of new houses.

Finally, there are three ‘green’ scenarios: *Green Policy*, *Eco-communalism* and *Sustainable World*, differentiated by technology spend, systems of governance and public buy-in for water efficiency. *Green Policy* has central funds to invest in water-efficient technologies, allied with a slight increase in public buy-in. *Eco-communalism* has high buy-in due to community involvement (e.g. estate-wide greywater recycling schemes), though it takes more of a ‘make do and mend’ approach than *Green Policy*, so technologies are introduced at a slower rate. *Sustainable World* is an ideal society; with the highest macrocomponent settings for both buy-in and water efficiency.

For any given year and scenario, we estimate numbers of existing households and new/replacement households and multiply them by the corresponding typical PHC to derive Total Household Consumption (Domestic Demand). We assume that new households will have a different water use profile to existing ones, generally lower due to new and more efficient taps, sanitaryware and white goods installed in them. However, rather than take account of each microcomponent, we just consider their net effect – different ways they could add up to satisfy alternative water savings targets. Table 3 summarises the scenario-related settings supported by each macrocomponent (how they were categorised and calculated is described in the subsections below). Finally, we subjectively assigned macrocomponent settings to scenarios (Table 4), so as to get a good spread of values across all categories.

4.2 Forecasting new housebuilding under different scenarios

Three forecasts of new housebuilding are required. The *Low growth* forecast was created by adding the Regional Development Plan target for each LA to the 2001 Census baseline (these targets are only marginally above or below past trends). *Medium growth* adds on the difference due to the Sustainable Communities Plan (for those LAs that intersect zones of change). *High growth* adds on the difference in Regional Development Plan target, if the figures quoted in the Government Response to the Barker Review where put into practice. The Government Response moderates the Barker recommendations but would still be a sizeable increase, especially in social housing.

4.3 Forecasting replacement housebuilding under different scenarios

'No change' in replacement housing means use the 2001 level of demolitions and refurbishments for each LA. Where published data is not available, these figures are estimated from other Census variables (e.g. demolitions are 1% of unfit stock) and then constrained to match higher area totals (e.g. 18,000 demolitions and 53,000 refurbishments in England and Wales). DCLG policy is to assume a one-for-one replacement of demolished properties, therefore net additional dwellings is zero (this is obviously a simplification and won't be achieved in all areas in practice).

The 'low growth' forecast accounts for higher levels of demolition and refurbishment under the Government's Pathfinder scheme, designed to regenerate low housing demand parts of the Northern England (a total of an additional 19,920 replacements in England and Wales between 2001 and 2020). For LAs within Pathfinder zones, an initial estimate of 6% of unfit stock is used for demolitions. This approximate relationship between unfit stock and demolitions is based on the Pathfinder plan for Newcastle-Gateshead. As Thames Gateway isn't affected by Pathfinder, the lower 1% estimate is used for 'low growth'.

Green Policy and *Eco-communalism* would put more emphasis on replacing existing stock (in situ) than building new stock on brownfield sites. In a *Free Market*, developers tend to build rather than refurbish, as the former is exempt from VAT. The current demolition rate of 18,000 is actually very low compared to total stock: it suggests a 1,200 year house lifespan! In 2001, there were 22,538,641 households in England and Wales - if 100,000 were replaced every year, that would (just using division) take 225 years.

4.4 Forecasting housing occupancy rate under different scenarios

Housing occupancy rate (household size) is important factor as PCC has been estimated to be 40% higher in a 1-person household than in a 2-person household (Butler and Memon, 2006). Official projections are for single-person households to constitute 72% of the annual growth over the next 20 years (DCLG, 2006c). There is a danger, though, of this becoming a self-fulfilling prophecy if developers take these trend-based projections too literally and build an excess of 1-bedroom properties. Imtiaz Farookhi, NHBC's Chief Executive, warns: "In 2000, high rise building made up less than a quarter (22 per cent) of new housing stock in the UK, however in 2005, this number almost doubled to 44 per cent. Figures for August show that flats and maisonettes are continuing to dominate the market, with fewer detached properties being built than ever before. There are a number of factors driving this increase, from house builders meeting Government planning regulations, to an increase in demand for smaller properties to cater for first-time buyers. With the trend for multi-storey building looking set to continue, especially as house builders endeavour to meet the demand for new homes, the industry must be cautious not to swamp the market with one type of home that might not necessarily fit with the aspirations of future homebuyers."

LA household counts by household size (1 to 6+) were extracted from 1981, 1991 and 2001 Censuses and then projected using Holt’s linear exponential smoothing. This algorithm can be implemented using spreadsheet equations (Swansea University, 2006), making it suitable for quickly generating a large number of projections. The projected counts are turned into proportions and then combined with accommodation type proportions (for new and existing households) using an iterative proportional fitting routine (implemented using SQL). These probability matrices get rescaled into household counts by multiplying each cell by the new and existing household totals (calculated additively).

For existing stock, the accommodation type proportions are again extracted from past Censuses and projected using Holt’s linear exponential smoothing. For new stock, accommodation type proportions derived from the 2005 NHBC statistics for new-builds by region. A projection based on a 2001-2005 time series of NHBC data was abandoned as it made certain accommodation types drop to zero over the forecast period and this seemed unrealistic. By holding the 2005 proportions constant over time we are making the assumption that the big switch away from terraced and large detached houses and towards flats has already occurred by 2005 and is unlikely to get much more extreme. The NHBC data on housebuilding trends in south east England (Figure 6) seems to bear this out.

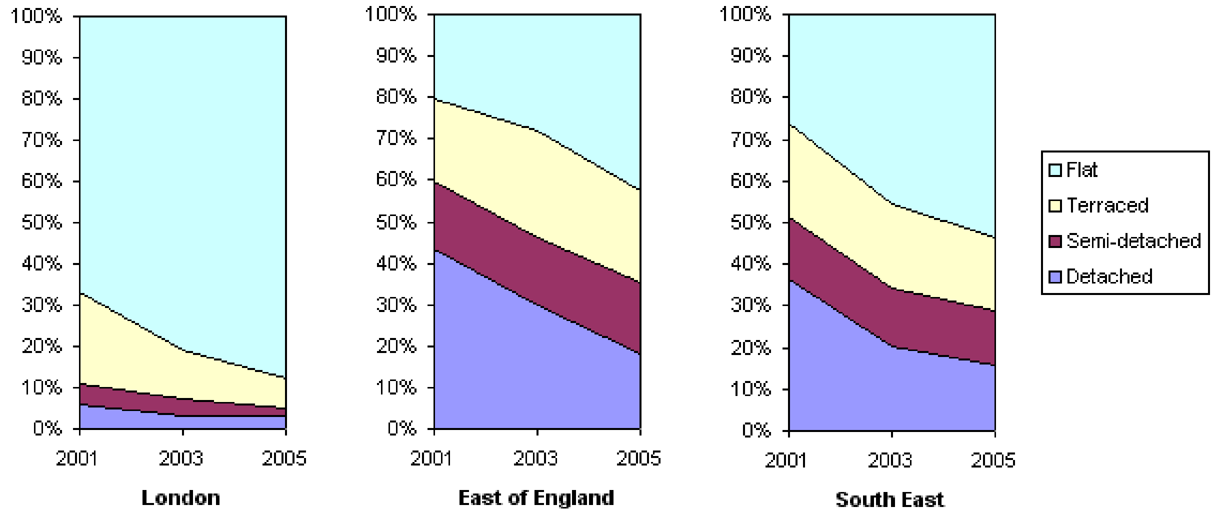


Figure 6: Housebuilding trends in South East England
Source: NHBC, 2006

Nearly all scenarios assume that housing occupancy rate will decline at current (local authority) rates. However, *Sustainable World* keeps occupancy static and under *Eco-communalism* it is made to linearly decline back to the 1981 level (over 2001-2041) to represent a return to more communal living and a lower divorce rate (however unlikely). For all scenarios, population estimates were derived by multiplying the household total by the prevailing occupancy rate.

4.5 Forecasting water efficiency of new households under different scenarios

The Government is proposing to make minimum standards of water efficiency performance mandatory in all new homes and new commercial developments (DCLG, 2006b). These standards will underpin those set out in the Code for Sustainable Homes. We have used the best-known target (PCC of 125 l/h/d) from the Sustainable Buildings Code (ODPM, 2005b) to calibrate this setting. Table 5 shows how this 'moderate increase' in efficiency could be achieved with current technology. It gives developers flexibility on how they could meet a building performance standard, e.g. specifying an ultra low flush toilet to compensate for a higher consumption shower.

125 l/h/d represents a readily achievable 16-18% increase over current PCC, so it is easy to envisage the actual saving being half as much, twice as much or even three times as much, depending on scenario (as outlined in Table 3). The latter would constitute a very large efficiency increase and would require all new developments to be built to the same standard as Beddington Zero Energy Development (BedZED), with all mid-priced technologies (improved white goods, aerated taps, dualflush WCs, etc) implemented as well as rainwater/greywater recycling (which is costly but has the most dramatic effect). An advanced plumbing system enables different grades of water to be used for different purposes, e.g. harvested rainwater for automated garden watering.

We also need to consider a theoretical future in which the Code for Sustainable Homes doesn't become policy. If new developments were fitted out with high-consumption devices such as power showers or jacuzzis, then efficiency could easily decline by 8.3% or more.

4.6 Forecasting public buy-in under different scenarios

Annual demand (averaged over the year) was down 10% in the 1976 drought year due to public cooperation (e.g. bricks in cisterns, bath sharing). Thirty years later, and the hosepipe ban was regularly flouted in London, despite the threat of fines. The public is much better informed now about the environment but it is well-off, high consumers who are often most reluctant to change their behaviour. Anecdotal evidence suggests that many continued to water their lawns under cover of darkness - and got away with it. The Government is tackling the next generation of consumers, with water efficiency and climate change added to the curriculum. Getting adults to moderate their behaviour is a longer, harder process.

We can't be sure if society will be more or less selfish compared to now, that is why we need scenarios. Including public buy-in as a variable particularly helps distinguish between the greener scenarios. For example, *Green Policy* and *Eco-communalism* would both see a large increase in new development water efficiency but *Eco-communalism*, being community-based, would have higher public buy-in. The ideal case, *Sustainable World*, should have the highest settings in both categories.

We weren't sure how to quantify public buy-in until we thought of using BedZED water meter records that had been provided to us for a WaND report on the development (Shirley-Smith *et al*, 2007), since it is the closest thing we have to a controlled environment. As every property comes pre-installed with the exactly same white goods, taps, toilets and usage instructions, calculating the PCC for each household should reveal the difference that is done to behaviour alone.

Analysis of the 2004-5 metered records (Figure 7) show a very low median PCC of 59.9 l/h/d. We can treat this as the ‘no change’ in buy-in setting and calculate change in efficiency by seeing what the PCC is 5 and 10 percentiles above and below the median to give a range of 5 macrocomponent settings (as shown in Table 3). For example, let us represent a ‘slight increase’ in buy-in as the difference between the median PCC and the PCC achieved by the top 45% of the sample population: 58.4 l/h/d. So, (59.9 – 58.4) ÷ 58.4 = 0.0251, or a 2.51% increase. A ‘moderate decrease’ is calculated from the PCC of the bottom 40% (the 60th percentile): 64.4 l/h/d. So, (59.9 – 64.4) ÷ 58.4 = -0.0762, or a 7.62% decrease.

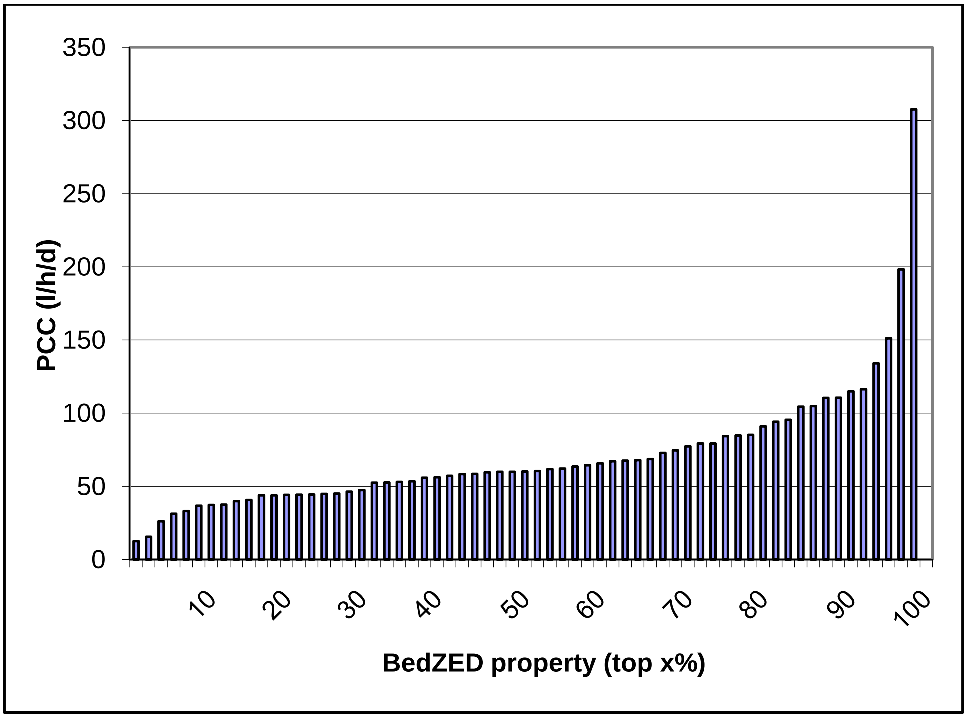


Figure 7: BedZED metered PCC, 2004-2005, ordered by size
Source: South West Water metered records

Out of interest, we also took a quick look at the extreme low and high consumers. The top 5% have a PCC in the range 12-26, and are generally families with 2 children (living in slightly cramped conditions). The bottom 5% have a PCC in the range 151-308 and are generally single people paying a subsidised rent to the council or housing association.

The mean PCC at BedZED was 71 - still very low, even including the few extreme users. It shows that the vast majority had bought into the green lifestyle, many of them moving to the borough just to live in BedZED. On the whole, social/council rent tenants exhibited a lower level of buy-in, with a mean PCC of 84.6. Not surprising, if they had been on a housing waiting list and assigned to live there, rather than making an active choice. These socio-economic differences justify having Public Buy-In as a variable in the model. If society, as a whole, becomes wealthier and better-educated, then buy-in will increase accordingly.

4.7 Forecasting water efficiency of existing households under different scenarios

There was a dramatic increase in household demand of 2.1% p.a. over the last 25 years (DCLG, 2006b) mainly due to increased ownership and use of washing machines (now in 95% of homes). In future, water companies foresee demand either staying static or increasing by a comparatively modest 0.4% p.a. (Ofwat, 2006b), possibly 0.48% p.a. (DCLG, 2006b). Washing machines have reached saturation point but there is still scope for increased ownership of power showers and dishwashers (to a lesser extent, swimming pools and jacuzzis).

The range of values in Table 3 were derived by treating 0.4% as a ‘slight decrease’ and having 0.6% to act as an upper band (‘moderate decrease’). Mirror values were created to represent possible efficiency increases, due to general regulations/innovations making only more water-efficient white goods and sanityware available to the public. Public attitudes may not have changed, but the choice may have been made for them as a side-effect of large demand from Government and housebuilders for water-efficient devices to go into new homes.

4.8 Forecasting metering under different scenarios

Three metering levels were designed: (i) Base growth: Current company rate, taken from forecasts provided by each company to the Environment Agency (EA, 2004a), (ii) Medium growth: Each company must be at least 50% metered by 2025, (iii) High growth: Each company must be 100% metered by 2025. Our calculations show that two-thirds of water companies are on target for 50% or higher metering by 2025 (ie medium growth). The remaining companies have their rate of uptake boosted by the minimum necessary to achieve 50%. A similar process is applied to create a variant forecast corresponding to high growth.

To achieve 100% metering would require a 20-300% increase in the current rate of uptake (depending on company). Northern parts of the UK have a water surplus and so are not under any pressure to promote or accelerate metering. Realistically, it would take an act of parliament to bring in compulsory metering everywhere for 100% metering to happen in this timescale. Present UK legislation allows a water company to apply for water scarcity area status. The Secretary of State decides on the basis of that application, after consulting the Environment Agency and Ofwat, including the people who would be affected. Once status has been achieved, compulsory metering can be brought in. This may happen for Sutton & East Surrey Water and Folkestone & Dover Water.

4.9 Forecasting climate change under different scenarios

Meteorological records suggest we are in for wetter winters and drier summers, with longer periods of dry weather as the norm. Summer rainfall is the more critical factor as that is when demand peaks, and not all winter rainfall can be preserved to maintain the balance. CCDeW (2003) have assumed in their forecast model that this will lead to greater garden watering and personal washing. Table 7 shows the EA regions and scenarios they used to classify demand-side climate impact. We treat the 2020s column as representing 2025 and rescale the figure linearly based on the year being forecast for. Only the three ‘green’ scenarios have been given the settings for Low Emissions; the rest assume Medium-High Emissions. The effect of climate change is driving water reduction initiatives. The South East Climate Change Partnership advocates the increased use of the EcoHomes (now Zero Carbon homes) standard, water appliance efficiency, rainwater collection and grey water recycling (GLA, 2005).

Impact studies conducted by Yorkshire Water suggest that climate change will have only a minor effect on water demand but more of an impact on supply, in terms of droughts and flooding (Stevens, 2006); already, deterioration in water quality has been detected in some rivers. Yorkshire Water’s reports to Ofwat are based on a ‘Medium’ climate change scenario, as they believe the impact will be half-way between the standard Medium-Low and Medium-High settings. The loss of resource is estimated to be 130 Ml/d by 2030 for the Yorkshire Region under the current Medium climate change. That’s a significant 9% drop on current resource (1,454 Ml/d), as it could have a significant effect on the water balance. By comparison, the impact of climate change on domestic demand is fairly modest with only a 1-1.5% growth (for the North-East EA region covering Yorkshire Water) in water demand over the period to 2020s (CCDeW, 2003). This adds only a marginal increase in domestic demand of 3-6Ml/d to 2030. Results for industrial and commercial water demand, based on the similar scenario as domestic, also shows a very small impact of climate change on water demand: 1.4 - 2.8% to 2020s. This is equivalent to industrial and commercial water demand being higher by about 2-3 Ml/d than without climate change (CCDeW, 2003).

In Thames Gateway, an alarming 89% of the proposed properties are in the flood plain (Brown, 2005). The London Assembly have warned that a major flood in London could cause £30bn damage. According to the Department for Environment, Food and Rural Affairs, if the government provided only the legal minimum over the next 20 years, flood plains could become "ghettos" of unsellable homes, where there would be "more potential for loss of life". At the other extreme, London and the South East are vulnerable to droughts, as we saw in summer 2006. Two successive dry winters had left reservoir levels very low and hosepipe bans had to be brought in.

5. MODEL RESULTS

5.1 Analysis of spatial variation

The maps (Figure 8) show that, as expected, water consumption will continue to be highest in East London (plus Medway, in Kent, which is supplied by Southern Water). Table XX shows the impact on each water company supplying Thames Gateway. Essex and London zones will both need to find over 30 Ml/d additional resource by 2031 - and they are already both have a negative water balance (demand exceeds supply). Mid-Kent will only need to find an additional 6 Ml/d due to Thames Gateway; the Ashford sustainable community will be its main cause for concern.

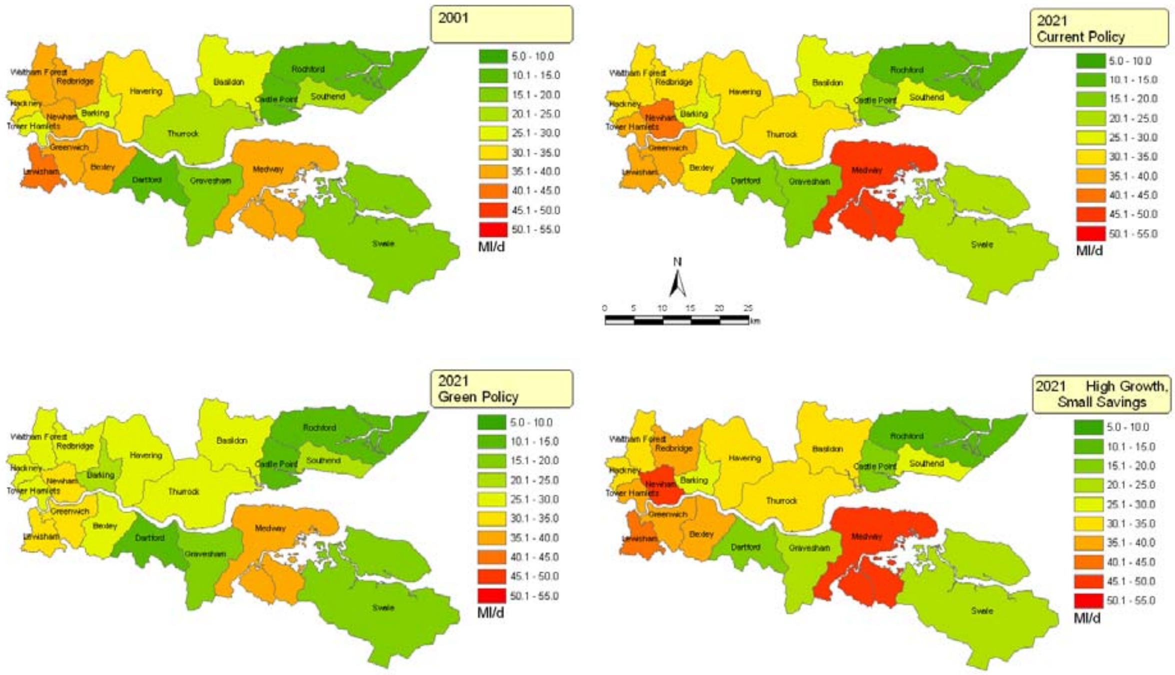


Figure 8: Domestic demand by district, year and scenario

Table 14: Domestic demand within Thames Gateway Study Area by water company (*Current Policy* scenario)

Water company	TGSA coverage	Domestic demand (Ml/d)			Current situation		
		2001	2016	2031	Water balance	Largest source	Leakage
Thames	56%	302.12	329.93	338.75	London in deficit	Surface: 72%	33%
Essex & Suffolk	30%	160.72	180.99	191.71	Essex in deficit	Surface: 82%	14%
Southern	10%	52.31	62.97	70.93	Occasional deficits in dry years	Ground: 48%	27%
Mid-Kent	4%	17.61	21.02	23.50	Occasional deficits in dry years	Ground: 86%	17%
Total	100%	532.76	594.91	624.89			

Sources: Authors' calculations; EA, 2004a; DWI, 2005

Compared to the rest of the UK, London is more vulnerable to changes in the surface water regime as this supplies 80% of its water resources (Thames Water, 2004), compared to a UK average of 30%. Moreover, London uses 60% of all directly available water resources. Reduced precipitation will lower the available volume of surface water further stressing London's water supply. Dawson et al. (2006) point out that population growth will place further strain on water resources, and a warmer climate may have a positive feedback increasing household demand. Higher summer temperatures and lower rainfall may reduce soil moisture and groundwater replenishment which may not be fully compensated by increases in winter rainfall.

5.2 Analysis of scenario differences

Figure 9 shows there is a significant difference in consumption between the best scenario, Green Policy (S6) and the worst, Free Market (S5) – nearly 100 Megalitres per day in 2016. Green Policy assumes that all new homes meet existing best practice (greywater recycling, water-saving taps and showers, etc) and that developers are encouraged to replace/refurbish old stock, where possible. Figure 10 shows that PCC follows a similar pattern, with…

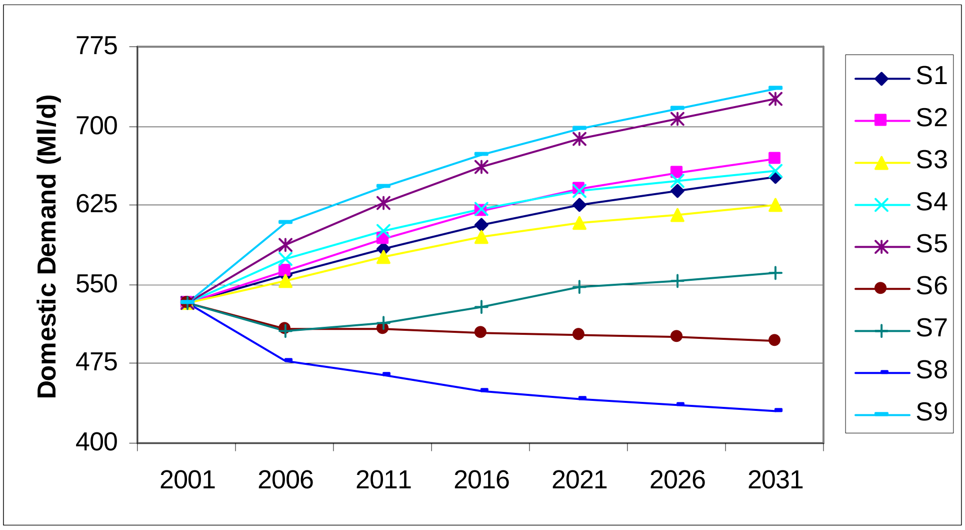


Figure 9: Domestic demand by year and scenario

Tables 15 and 16 list the resultant figures for each scenario, for years 2016 and 2031, respectively. Let’s compare 2016 to the 2001, when there were 1.38m households, consuming a total of 485Ml/d:

- With *Green Policy* (S6), the number of households would increase 17.7% but household consumption by only 2.7%
- Under *Business as Usual* (S1), households would increase 17.7% and consumption by 16.9% - an unsustainable trend
- Under *Current Policy* (S3), households would increase 21.0% and consumption by 14.7% - better but still of concern
- With *High Growth, Small Savings* (S2), households would increase 21.0% and consumption by a resource-critical 19.4%

Our forecasts are much higher than the official Government forecasts of a 6.1% increase in demand by 2016 due to new housebuilding and 0.1% above that if the higher Barker Review target was used (Cooper, 2006). Unlike us, they have assumed that no population growth, with new households created by separation, bereavement or children leaving home. We believe in-migration to the South East will continue – partly attracted by Thames Gateway's new homes and jobs.

Table 15: Domestic demand forecasts, 2016 (ordered most to least demand)

Rank	*Scenario*	*Dom. demand (Ml/d)*	*Households*	*People*	*PHC (l/p/d)*	*PCC (l/h/d)*
1	S9. Fortress World	672.22 (+26%)	1,619,411 (+18%)	3,753,945	415.1	179.07
2	S5. Free Market	661.26 (+24%)	1,663,915 (+21%)	3,860,126	397.41	171.31
3	S4. Technocratic	621.99 (+17%)	1,663,913 (+21%)	3,860,197	373.81	161.13
4	S2. High Growth, Low Savings	620.04 (+16%)	1,663,915 (+21%)	3,860,126	372.64	160.63
5	S1. Business as Usual	606.33 (+14%)	1,619,411 (+18%)	3,753,945	374.41	161.52
6	S3. Current Policy	594.91 (+12%)	1,663,915 (+21%)	3,860,126	357.53	154.12
7	S7. Eco-communalism	528.01 (-1%)	1,553,176 (+13%)	4,026,977	339.96	131.12
8	S6. Green Policy	504.58 (-5%)	1,619,411 (+18%)	3,910,021	311.58	129.05
9	S8. Sustainable World	449.78 (-16%)	1,553,174 (+13%)	3,747,884	289.59	120.01

Note: Change relative to 2001 shown in brackets

Table 16: Domestic demand forecasts, 2031 (ordered most to least demand)

Rank	*Scenario*	*Dom. demand (Ml/d)*	*Households*	*People*	*PHC (l/p/d)*	*PCC (l/h/d)*
1	S9. Fortress World	734.44 (+38%)	1,760,762 (+28%)	3,893,061	417.12	188.65
2	S5. Free Market	725.85 (+36%)	1,818,484 (+32%)	4,025,260	399.15	180.32
3	S2. High Growth, Low Savings	669.23 (+26%)	1,818,484 (+32%)	4,025,260	368.02	166.26
4	S4. Technocratic	657.64 (+23%)	1,818,483 (+32%)	4,025,273	361.64	163.38
5	S1. Business as Usual	651.49 (+22%)	1,760,762 (+28%)	3,893,061	370	167.35
6	S3. Current Policy	624.89 (+17%)	1,818,484 (+32%)	4,025,260	343.63	155.24
7	S7. Eco-communalism	560.83 (+5%)	1,731,002 (+26%)	4,682,607	323.99	119.77
8	S6. Green Policy	496.96 (-7%)	1,760,757 (+28%)	4,251,244	282.24	116.9
9	S8. Sustainable World	430.46 (-19%)	1,731,003 (+26%)	4,176,590	248.67	103.06

Note: Change relative to 2001 shown in brackets

5.3 Sensitivity analysis of model variables

The model variable that has the biggest single impact on consumption is New Housebuilding. More houses means more people means more water consumed. If we assume that rapid housing growth is unavoidable, a boxplot of the other inputs (Figure 10) may provide guidance on the relative priority of other demand drivers. The boxplot shows that Water Efficiency New Developments (WE_N) is the most sensitive variable, having a wide range of possible impacts, from an 8.33% increase to a 50% decrease. However, the median value across all LAs, scenarios and years is an 8.33% decrease.

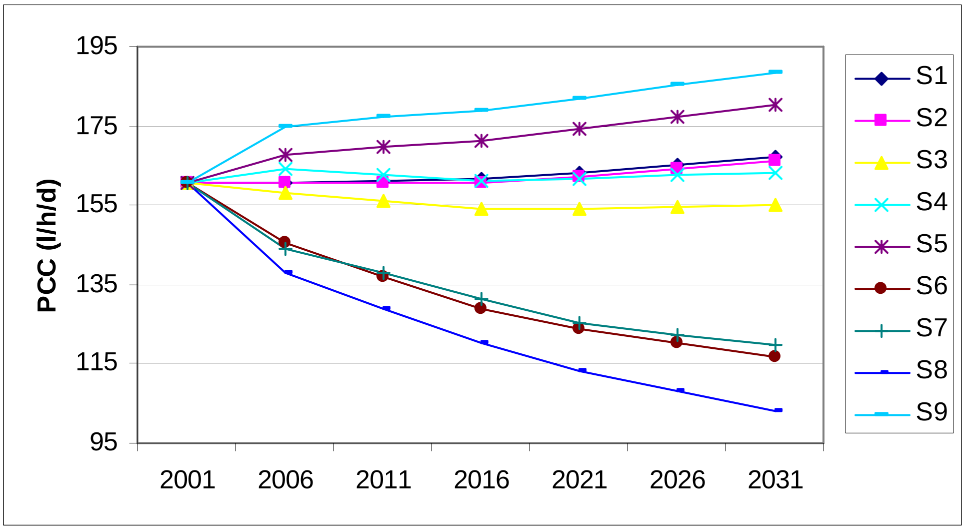


Figure 10: Projections of per capita consumption (PCC) by year and scenario

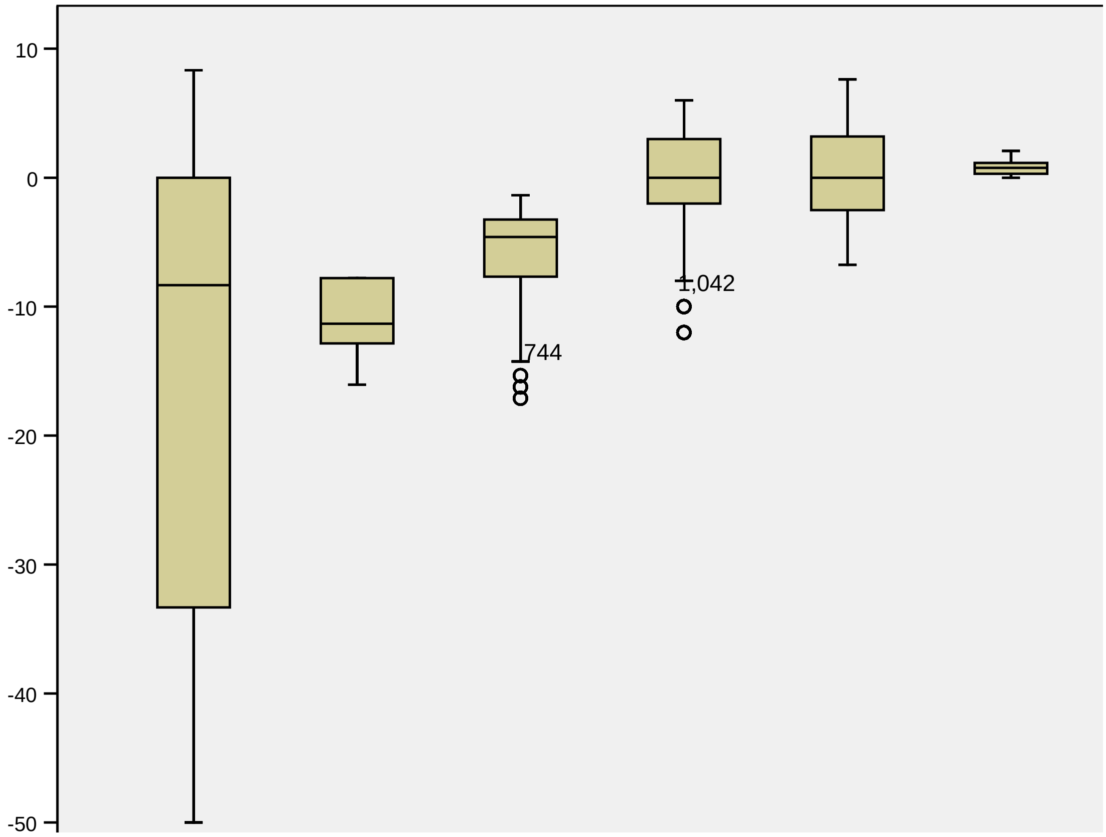


Figure 11: Sensitivity analysis of model variables

The forecast growth in metering is the most consistent factor in achieving savings: a median decrease in consumption of 11.32% for new developments (MT_N) and 4.59% for existing stock. Water Efficiency Existing Developments (WE_E) and Public Buy-In (PB) are both forecast to have only minor positive/negative impact, with their median around 0%. Climate Change (CC) is the least sensitive and least significant variable, causing only a median increase of 0.76%.

6. CONCLUSIONS

6.1 Discussion of model

The MACROWater model gave a good spread of results across scenarios and an intuitively correct ranking (with *Fortress World* as the worst case and *Sustainable World* the best). The PCC forecasts consistent with other UK domestic demand models (Table 17). With scenarios the relative performance is more important than the precise accuracy of the numbers generated. It should be borne in mind that scenario forecasts are heavily dependent on the interpretation of the underlying storylines (which can be ambiguously worded). This explains the difference in ranking of the 'green' scenarios between the MACROWater and MicroWater models, despite them being based on the same demographic inputs. Both agree that *Sustainable World* is the most water-efficient scenario, but MACROWater places *Green Policy* second (due to its heavy investment in water-saving technology), whereas MicroWater places *Eco-communalism* second (due to its very high public buy-in leading to reduced frequency of use). There is no absolute right or wrong answer; these differences can actually aid the debate. That there is otherwise broad agreement between the results shows that the 'macrocomponent' forecasting approach is a valid alternative to the industry-standard microcomponent one, in certain circumstances. They are complementary approaches which allow slightly different enquiries to be asked. In summary, MACROWater can be considered a successful experiment. It is a slightly different approach to long-term, policy-driven demand forecasting - that is new to the water industry, and could be easily reapplied to other sectors, such as waste and energy (satisfying the project brief).

Table 17: Comparison of MACROWater PCC forecasts with other models

EA Black Book (England & Wales, 2025)	***MicroWater (Thames Gateway, 2031)***	***MACROWater (Thames Gateway, 2031)***
1998 = 142 – 153	2001 = 161	2001 = 161
Alpha = 180 – 195	Technocratic = 155	Technocratic = 163 Fortress World = 189
Beta = 170 – 192	Business as Usual = 169 Free Market = 174	Business as Usual = 167 Free Market = 180
Gamma = 102 – 125	Green Policy = 140 Sustainable World = 95	Green Policy = 117 Sustainable World = 103
Delta = 115 – 118	Eco-communalism = 97	Eco-communalism = 120

Sources: EA (2001), authors' calculations

6.2 Recommendations

The combined and committed efforts of regulators, planners, developers and householders will be required to meet the pressing need for new homes in a sustainable way. Both demand and supply-side actions are likely to be required:

- Research from the energy sector (Schipper and Meyers, 1992) shows that it is over-optimistic to rely on improvements in public buy-in to deliver the necessary savings. Public education is important, but when it comes to the crunch, constraining consumer choice and punishing profligacy are likely to have more impact, however politically unpopular these actions might be.
- Legislation enforcing a greater level of water efficiency in all new development than occurs as standard at present. The government’s temporary suspension of stamp duty on ‘zero carbon’ homes is a step in the right direction. Incentives may need to be found to persuade developers to meet the higher water efficiency targets. DCLG’s proposed Code for Sustainable Homes needs to be compulsory and incorporated into building regulations.
- Support must be given to manufacturers to ensure that water-efficient devices are of sufficient quantity and quality that they can be rolled out on a large scale. Smaller, more innovative manufacturers (such as those making vacuum-driven, waterless toilets) must be included in the tendering process, even if they can’t yet compete of quantity with industry leaders.
- Public goodwill is critical both in times of crisis (hosepipe bans, drought orders) and ordinarily. Not all water companies have met their leakage targets and this must be addressed urgently in order for householders to take water efficiency seriously. In 2006, Thames Water’s leakage was equivalent to the entire water consumption of Leeds (ref). Half of London’s pipe network is over 100 years old and some of London’s reservoirs are almost 200 years old (Thames Water, 2004).
- The EU Water Framework Directive (WFD, 2000) states that cost recovery is to be incorporated into the provision of water services. It does not propose leakage reduction or metering *per se*, but makes clear that water abstraction policy needs to be developed upon a river basin, rather than national or regional basis. Good practice for an urban network is for less than 20% distribution losses in areas where water is scarce and expensive.

- 50% metered customers by 2025 should be a minimum target for all water companies. There is no substantive evidence of a ‘bounce back’ to pre-metering levels (Jeffrey, 2007). Consideration should also be given to the potential of smart metering with associated tariff options.
- A review of the high levels of planned development to alleviate damage to the environment and existing communities is required. There are energy and infrastructure costs involved in supplying water, which in turn, contribute to carbon emissions.
- Unfortunately development of new water resources seems inevitable, new or expanded reservoirs, desalination plants and recharge of aquifers. Since planning and construction can take up to 20 years, decisions must be made soon. Currently being considered are a reservoir at Abingdon and a desalination plant at Woolwich. Desalination plants are more usually found in the Middle East, but with per capita rainfall of only 0.02mm per annum, London is on a par with Istanbul (Dawson *et al.*, 2006).
- Contingency for a 9% reduction in resource by 2030, due to climate change, must be considered. It is only the decline of the UK manufacturing sector that has prevented the situation being more acute than it is. Water companies must do more forecasting and planning for untypical weather patterns (such as successive dry winters), so that they are not caught out again.
- Although, there is a surplus of water in the north (e.g. Kilder reservoir), the energy required to pump it long distances is one argument that has held back the development of a national grid. Better sharing of resource between neighbouring water companies should be encouraged though. Following the 1986 drought, when water had to be transported in tankers, Yorkshire Water added piping to connect all its resource zones, ensuring that it is now regionally self-sufficient and much better equipped to cope with future extremes. In its planning and management, it can serve as an example to other utility companies.

Failure to act could result in serious impacts on UK economy, infrastructure and public health (House of Lords, 2006). Fortunately, the Government is taking this issue very seriously and its twin-track approach of managing demand and developing sustainable resources where needed (DCLG, 2006b) is the only sensible way forward. The sensitivity analysis suggests that policymakers and housebuilders have the key role to play in determining whether planned levels of housebuilding are sustainable or not. Managing demand by building all new homes to the highest possible efficiency standard is the key to success.

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