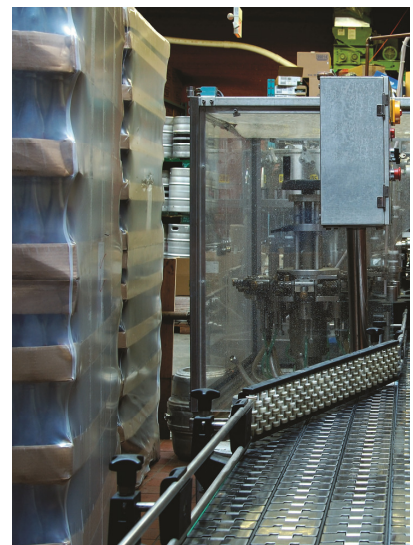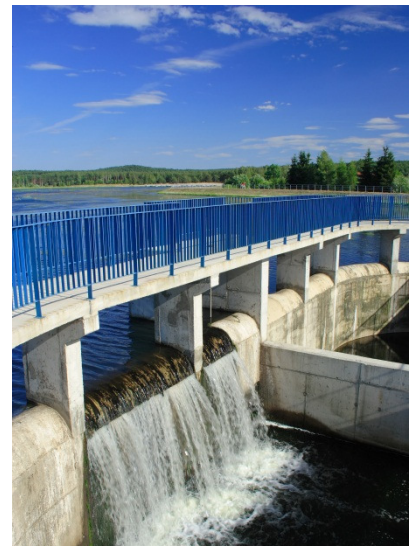# URS

Optimal water allocation under climate change

Interim report

Prepared for: Adaptation Sub-Committee of the Committee on Climate Change

UNITED KINGDOM & IRELAND

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1. INTRODUCTION AND APPROACH

1.1 Background to the project

Population growth, economic uncertainty, rising consumer expectations, and climate change are likely to place increasing pressure on water supplies. Overcoming this challenge will require water to be managed and used in a more sustainable and efficient way. This, in turn, necessitates an understanding of the value of the resource itself.

At present, the price that UK water customers pay for water from the public water supply reflects only the costs of extraction, treatment, distribution, and billing, rather than the costs of using a scarce resource that won't be available for other uses once abstracted. Further, those who abstract water directly from the environment typically pay little or nothing for each additional unit of water they use.

Under the present system, the amount of water that can be abstracted directly from the environment is tightly controlled through an abstraction licensing system, and across England and Wales as a whole, only about 10% of the available freshwater resources are used for abstraction; although this varies considerably at the regional level, reaching up to 22% of freshwater resources in the South East and Eastern England.[1]

The Environment Agency is responsible for deciding the maximum amount of water that may be taken directly from the environment, and abstractions are managed through a licensing system that regulates all abstractors taking more than 20 m^3/day of water (excluding activities currently exempt from licensing). Licences are granted depending on the amount of water available after the needs of existing abstractors and the environment are met and whether the justification for the abstraction is reasonable.

However, since water users do not face the full costs for the water they use, the current abstraction system can lead to water being undervalued. In order for the abstraction system to represent the full value of water, the cost of water would need reflect its scarcity value *in situ*; something which may be different across different sectors depending upon their dependence on the resource and the speed at which they are able to adjust to changes in supply.

The aim of this research is to establish the extent to which an alternative abstraction regime, which is based on the full value of water, would result in a more efficient allocation of water under a changing climate.

The project is to be conducted around two key activities:

1. A literature review to establish:

    • The demand curves for different abstractors;

    • A demand curve for the natural environment; and

    • Supply curves for different abstractors and/or catchments in England.

2. Estimation of an optimal allocation of water, and corresponding societal net benefit, under a number of different future climate change and socio-economic scenarios.

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[1] Wrap (2011), 'Freshwater availability and use in the United Kingdom', Project code: RSC014-001.

1.2 Purpose of this report

The purpose of this report is to present the findings from the first task (literature review) and to determine, based on the review findings, whether there is sufficient data to produce a reasonably robust picture of what an optimal allocation of water might look like and to quantify the benefits such an allocation may confer (Task 2).

1.3 Approach to the literature review

A research protocol was developed at the start of the study to provide a structured and consistent approach to the way in which relevant studies were identified and selected (see Appendix A). Ultimately, the aim of the protocol was to help ensure that the review was as focused as possible by retrieving the most relevant evidence to support a robust estimation of the demand (or willingness to pay) for water under conditions of increasing scarcity.

It is important to note that the review is in no way considered exhaustive. Rather, efforts have been focused around trying to identify the most recent and relevant information to provide answers to the following questions within a short timeframe:

- What are the demand curves for different abstractors (industry[2], agriculture, and residential)?

- What is the demand curve for the natural environment (environmental flows)?

- What are the factors that influence demand (e.g. seasonality, price, efficiency measures, etc?)

- Can both short run and long run curves be described[3]?

- What are the supply curves for different abstractors and/or catchments in England?

- Does supply and demand for water vary geographically and temporally?

- What is the most appropriate spatial scale at which to derive supply and demand curves?

1.4 Structure of this report

Sections 2 – 5 examine the nature of water demand in the residential, industry, agriculture, and environment sectors respectively. Section 6 covers water supply issues. Section 7 brings together the findings of the literature review and sets out a methodology for estimating an optimal allocation of water under conditions of increasing water scarcity using East Anglia as a regional case study. Finally, Section 8 concludes with recommendations for further work.

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[2] Including energy
[3] A short run demand curve is characterised by both variable and fixed factors of production, whereas in the long run, all factors of production are characterised as being flexible. In this way, short run demand curves are often less responsive to changes in the price of factors of production than long run demand curves.

2. RESIDENTIAL SECTOR FINDINGS

2.1 Demand for residential water

Residential water use typically refers to the water that is used by households for indoor activities such as drinking, food preparation, washing, and outdoor uses such as watering private lawns or gardens. In England and Wales residential water is supplied by ten private regional water and sewerage companies and 13 private 'water only' companies, unlike in Scotland and Northern Ireland, where water is provided by a single public company. Water companies in England and Wales are subject to economic regulation through Ofwat, environmental regulation through the Environment Agency, and quality regulation through the Drinking Water Inspectorate.

In 2011, the average residential water use in England was around 145 litres of water per person per day (l/p/d); this is somewhat higher than the average volume of water used in similar European countries such as Germany, which, in 2008, used about 117 l/p/d.[4] Household water consumption accounts for around a third of total water abstractions in the UK, representing a much higher proportion than the global average; where residential water use makes up around 11% of total global water abstractions and agricultural demand dominates (see Figures 1 and 2)[5].
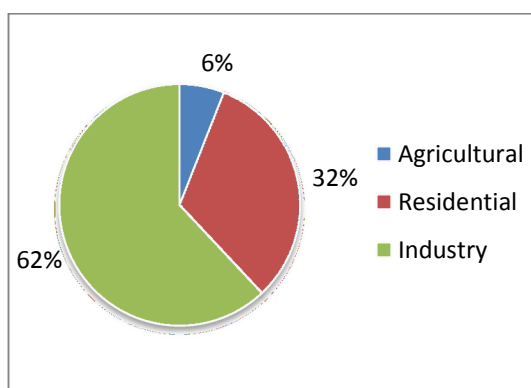
Figure 1 UK water abstractions[6]

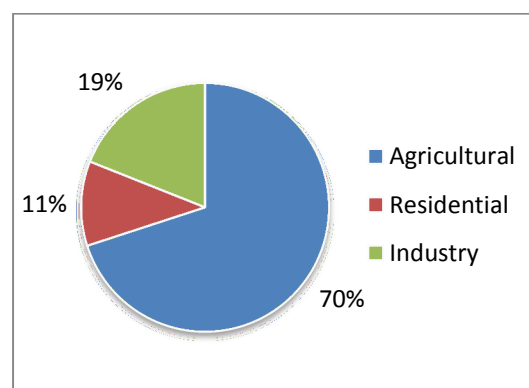**Figure 2 Global water abstractions[7]**

Figure 3 shows non-tidal surface water abstraction by region for the residential sector in England over the past 11 years. Most of the residential sector obtains its water from this source. In 2011, residential sector abstractions from non-tidal surface waters were 3,431 Mm^3, or approximately 65% of total water abstractions for this sector. Overall, the volume obtained from this source has shown a slight downward trend with a 7% reduction between 2000 and 2011, most likely as a result of improvements in the efficiency of household water usage[8].

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[4] Adaptation Sub-Committee (2012), Progress Report, http://archive.theccc.org.uk/aws/ASC/CCC_ASC_2012_bookmarked_2.pdf (accessed 29/05/13)
[5] Note that Aquastat refers to municipal water withdrawal, a term which is used interchangeably with domestic water withdrawal, see http://www.fao.org/nr/water/aquastat/data/glossary/search.htML?_p=100&submitBtn=-1&keywords=Municipal+water+withdrawal&subjectId=-1&termId=-1&submit=Search (accessed 9/4/13)
[6] Environment Agency (2011) Actual abstraction data 2000 – 2011. Downloaded from http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[7] Aquastat (2008), http://www.fao.org/nr/water/aquastat/water_use/index.stm (accessed 9/4/13)
[8] Defra (2012) Water Abstraction from Non-Tidal Surface Water and Groundwater in England and Wales, 2000 to 2011 [online] available at http://webarchive.nationalarchives.gov.uk/20130123162956/http://www.defra.gov.uk/statistics/files/water-abstraction-statistics-release.pdf

Figure 3 Residential sector non-tidal surface water abstraction by region[9]
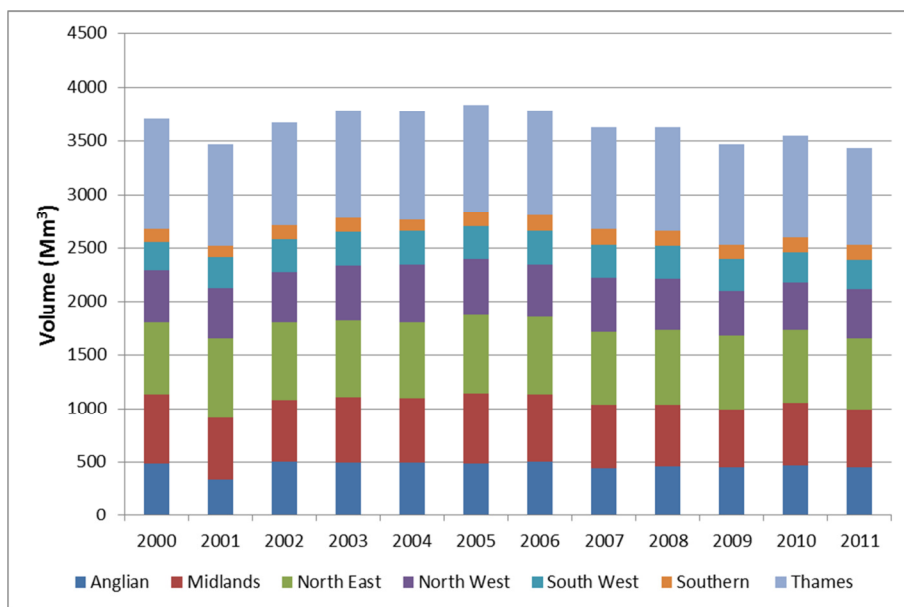

Figure 4 shows groundwater abstractions for the residential sector by region. The volume of water obtained from this source has been relatively stable over the past 11 years and, in 2011, represented approximately 33% of total residential abstractions (or 1,729 Mm^3). Groundwater sourced from the chalk aquifers is a particularly important source of water for the Southern region.

**Figure 4 Residential sector groundwater abstraction by region[10]**

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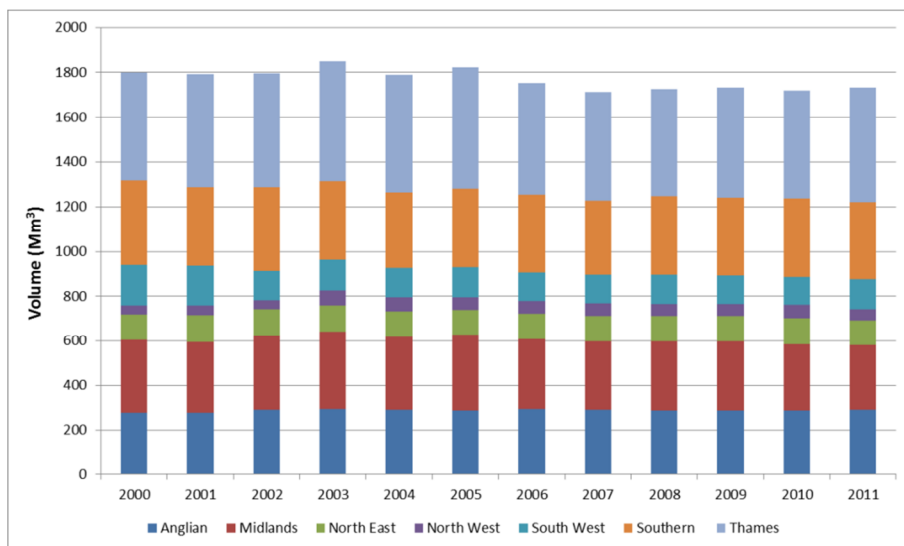
[9] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[10] Ibid.

Figure 5 shows the tidal surface water abstractions by region for the residential sector. In the past, no public water was obtained from this source but in recent years the Thames region[11] has supplemented non-tidal surface water and groundwater abstractions with abstractions from tidal surface water via the Thames Water desalination plant. In 2011, the estimated volume of water abstracted from tidal surface water was 13 Mm^3.

Figure 5 Residential sector tidal surface water abstraction by region[12]
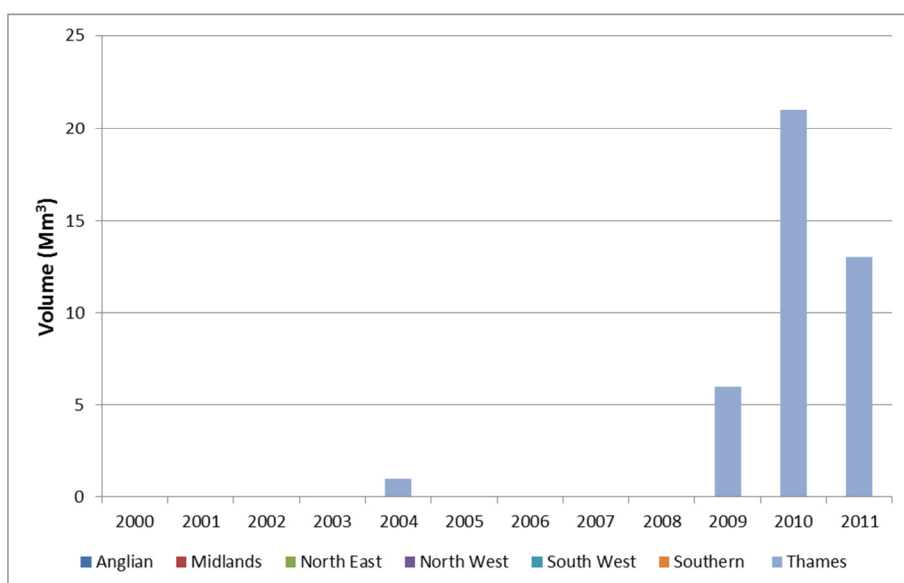
The price of residential water use in the UK is typically high relative to other countries, with a 2008 survey of residential water prices across the OECD finding that water prices were second highest in Scotland at £3.72/m^3 and sixth highest in England and Wales at £2.49/m^3. The survey also found that the level of water metering is much lower than the OECD average, with 37% of households metered in the UK in 2008 compared to close to 100% in countries such as Denmark, Australia, United States, Belgium, Czech Republic, France, and Portugal.[13] It should be noted that in 2012, the proportion of household metering in England is estimated to have increased to 43%.[14]

Within the UK, patterns of water consumption vary on a regional basis as well as according to whether or not households have water meters installed (see Figure 6 and Figure 7). For example, between 2000/1 and 2008/9, average household water consumption in unmetered households in England increased by 1 litre from 149 to 150 litres per person per day (l/p/d), while metered household water consumption decreased by 5 litres from 132 to 127 l/p/d over the same period. On a regional basis, unmetered households supplied by Thames Water and Northumbrian South consumed the most water (163 l/p/d), while metered household consumption was highest in Northumbrian South (147 l/p/d)[15], although usage data may not be comparable between regions since different companies use slightly different sampling methods for measuring water consumption.

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[11] Note that from 1 April 2011 EA Thames and EA Southern merged to form EA South East. The two regions are still shown separately as this is the basis of the Water Resources charges scheme.
[12] *Ibid.*
[13] OECD (2010), 'Pricing Water Resources and Water and Sanitation Services', OECD, Paris.
[14] Adaptation Sub-Committee (2012), Climate change – is the UK preparing for flooding and water scarcity? Progress report 2012. http://archive.theccc.org.uk/aws/ASC/CCC_ASC_2012_bookmarked_2.pdf (accessed 28/05/13).
[15] Defra (2010), http://archive.defra.gov.uk/sustainable/government/progress/regional/summaries/16.htm (accessed 9/4/13)
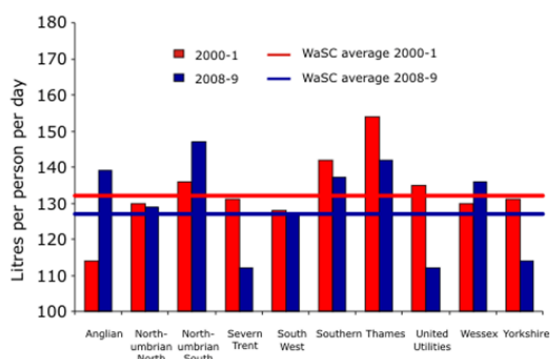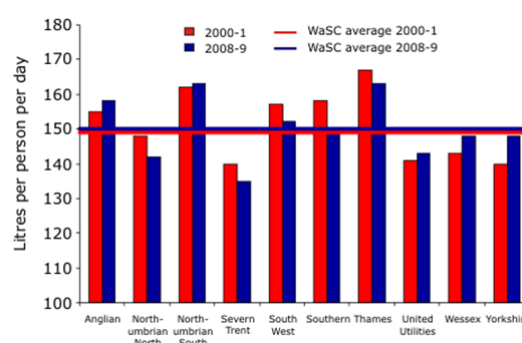
Figure 6 Metered water consumption[16]   **Figure 7 Unmetered water consumption[17]**

Residential water consumption also varies in relation to changes in the weather, climate, population, economic development, cultural norms etc. In 1996, the Department of the Environment looked at the possible effects of climate change on domestic demand for water and forecast that unmetered water use in the South East would rise from 147 l/p/d in 1991 to 155 l/p/d in 2001,166 l/p/d in 2011, and 178 l/p/d in 2021.[18] To date, however, there has been no underlying increase in per person consumption rates and annual changes in consumption have been largely driven by weather patterns – for example, in Figure 8, 2003-4 was particularly warm and dry[19].

Figure 8 Domestic water consumption in litres per person per day, 1995-6 to 2008-9[20]
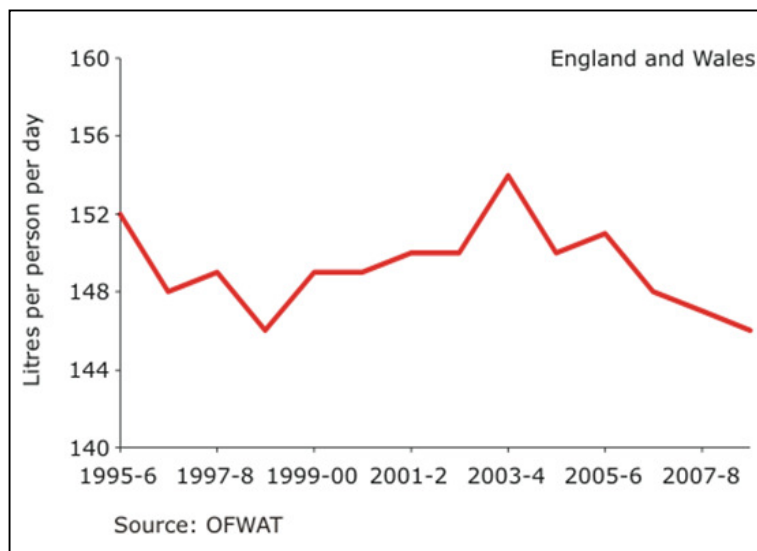
While the level of residential water use per person has not risen as much as predicted over the last decade, total household demand is predicted to increase in future, primarily due to a

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[16] *Ibid*
[17] *Ibid*
[18] Herrington, P. (1996), 'Climate Change and the Demand for Water', Department for the Environment, UK.
[19] Defra (2010), http://archive.defra.gov.uk/sustainable/government/progress/national/16.htm (accessed 11/4/13)
[20] *Ibid*

growing population. The Environment Agency[21] for example, looked at predicted trends in residential water demand from 2008 to 2050 under four different scenarios:

- **Innovation scenario** – high rates of retrofitting and refurbishment together with high efficiency standards for new homes reduces per capita residential water demand from 155 to 125 l/p/d, however total household water demand increases from 8,500 Ml/day to 9,250 due to significant population growth.

- **Uncontrolled demand scenario** – significant population growth combined with profligate attitudes increases use of water-intensive goods and outdoor use is high for garden watering and water based recreation, per capita demand rises to 165 l/p/d and overall demand increases to 13,000 ML/day.

- **Sustainable behaviour** – the only scenario which sees a decrease in both per capita use (down to 110 l/p/d) and total use (7,250 ML/day) despite a growth in population, primarily due to the adoption of a positive attitude to efficiency with more composting toilets and rainwater harvesting.

- **Local resilience** – a combination of population growth and a shift in attitudes to saving water but less innovation and greater use of old, inefficient goods, together with leisure time and outdoor water needs becoming less important means that per capita use falls to 140 l/p/d but total use rises to 9,000 ML/day.

Further studies by the Water Resources in the South East (WRSE) group also suggested that total demand for the public water supply in the South East could rise between 300 and 400 ML/day (13% to 16%) over the 20 years following 2005-06; with household demand expected to constitute between 63% and 70% of this increase.[22] Likewise, an analysis of water demand and supply in Birmingham forecast that future water demand could rise to 338 ML/day by 2035, potentially exceeding the available supply from present sources of 315 ML/day.[23]

2.2 Estimates of the value of water for residential use

The value of different products or services is typically derived from demand curves based on transactions in the market place. However, for residential water uses, most consumers do not choose between a range of water services at different prices, rather they pay the rate determined by the local water company which is set on the basis of costs.

These cost-based prices underestimate the often considerable consumer surplus that water users enjoy for consumption over and above that which is necessary to satisfy basic human needs. Research by Ofwat indicates that households are willing to pay the equivalent of £10 per day not to have their water supply and sanitation disrupted which is equivalent to around £33/m^3 for water supply at average consumption levels.[24]

As such, the value of residential water use should be estimated on the basis of households' willingness to pay for water, rather than the prices they actually pay. There are, however, very few studies which estimate the value of residential water use in the UK. The most recent

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[21] Environment Agency (2011) 'Current and future water availability', UK Environment Agency. National Water Demand Management Centre, Worthing.
[22] *Ibid*
[23] Khatri & Vairavamoorthy (2009), 'Water Demand Forecasting for the City of the Future against the Uncertainties and the Global Change Pressures: Case of Birmingham', Conference report, available at: http://www.delftcluster.nl/website/files/Water_Demand_Forecasting_Uncertainties_Birmingham.pdf (accessed 9/4/13)
[24] OFWAT, 2008. Guaranteed Standards Scheme. http://www.ofwat.gov.uk/consumerissues/rightsresponsibilities/standards/gud_pro_gss08.pdf, (accessed 1/5/13)

study, carried out by Moran and Dann in 2008, estimates a marginal value for treated household water in Scotland between £0.000548 – 0.00164/m^3 and between £0.00067 – 0.00244/m^3 in England and Wales (not adjusting for inflation).[25]

2.3 Determinants of demand

Water demand can vary according to a range of factors including household size and garden area and the level of environmental awareness across the population. In order to better understand the willingness to pay for water and improve the accuracy of residential demand forecasting, the key factors which determine water demand need to be understood. A large number of studies have been carried out looking at the determinants of residential water demand, both in the UK and internationally, and have identified a number of factors which influence demand. This section sets out a summary of the key factors identified across these studies, alongside a brief explanation of the related issues and research:

- **Price** – once basic household water requirements are met, residential water demand is typically thought of as a normal good i.e. as the price rises individual's demand falls as people change their behaviour such as by reducing the time spent in the shower or switching to more efficient water saving devices. While there is a considerable degree of uncertainty over the responsiveness of UK households to changes in water prices (see Box 1), the literature suggests that households do respond to price changes and price is a key factor in determining residential water demand.[26,27,28]

- **Climate** – a number of climate variables can affect residential water use including the level of rainfall, humidity, evapotranspiration rates, temperature, hours of sunshine etc. and these factors can, in part, explain some of the regional variation in residential water use.[29] Households in hotter, drier, more humid regions, for example, typically have higher water demand than those in cooler, wetter, less humid areas.

- **Household characteristics** – owner occupied households, for example, typically consume greater amounts of water relative to rented properties while households in urban areas with gardens, swimming pools, and several bathrooms are also likely to consume more water.[30]

- **Socio-economic characteristics** – factors such as age, income, level of education, household size, and number of children can also impact water use. A survey of 10,000 households across ten OECD countries found that increases in each of these variables can increase the level of residential water use.[31]

- **Water metering** – a number of UK studies have found that introducing water meters leads to a reduction of residential water demand of around 10-15%.[32,33] This may be due to the fact that metered households are made more aware of their level of consumption and the cost that they are incurring thereby encouraging water-saving behaviour (see Box 1).

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[25] Moran, D. and Dann, S. (2008),' Economic Value of Water Use Implications for Implementing the Water Framework Directive in Scotland', *Journal of Environmental Management*, Vol. 87, pp.484-496.
[26] Arbues et al. (2003), 'Estimation of residential water demand: a state-of-the-art review', *Journal of Socio-Economics*, Vol. 32, pp. 81-102.
[27] Waddams & Clayton (2010), 'Consumer Choice in the Water Sector', Ofwat, UK.
[28] Olmstead & Stavins (2009), 'Comparing price and nonprice approaches to urban water conservation', *Water Resources Research*.
[29] Arbues et al. (2003), 'Estimation of residential water demand: a state-of-the-art review', *Journal of Socio-Economics*, Vol. 32, pp. 81-102.
[30] *Ibid*
[31] OECD (2011), 'Greening Household Behaviour', OECD, Paris.
[32] Herrington, P. (2007), 'Waste Not Want Not? Water Tariffs for Sustainability', WWF, UK.
[33] Waddams & Clayton (2010), 'Consumer Choice in the Water Sector', Ofwat, UK.

- **Water efficiency** – the use of water efficient devices such as rainwater tanks, low flow shower heads, and dual flush toilets should in theory lead to lower residential water use, however, several studies have found that the impact of such devices on water consumption is mixed.[34,35] This is because an increase in the water efficiency of a device effectively reduces the unit cost of using it and so can cause an increase in its use thereby offsetting (or even potentially increasing) net water use. [36] Another factor that can influence the extent to which water use efficiency is achieved includes user-behaviour (e.g. flushing low-flow toilets more than once because the first flush is not powerful enough).[37]

- **Environmental awareness** – a further key factor which can determine residential water use is the level of awareness amongst water users of their impact on water resources and their perception over the importance of water scarcity issues. Evidence from the literature is mixed regarding the impact of such factors, with a recent OECD survey finding that pro-environmental attitudes have no significant impact on demand although they are correlated with the use of water saving devices such as low flow shower heads and dual flush toilets (see above point).[38] A number of studies have found that public information and awareness campaigns can reduce water demand on average by around 2-5%, although such reductions can be temporary.[39] However, a study in Swindon in the UK by Thames Water and the Environment Agency of 8000 residences found that a campaign involving direct mailing, newspaper and radio advertisements, and posters had no impact on demand and only 5% of the population questioned indicated that they had noticed the campaign.[40]

Box 1 Residential water pricing and elasticities

Intuitively, higher water prices should lead to lower water demand. This is because an increase in water prices may mean that:

— Some water-using activities with relatively low values to the household are no longer worthwhile (such as leaving the tap running while brushing teeth);
— The benefits of reducing water losses in the home (such as by fixing any leaks) now outweigh the costs; and
— There is an incentive to invest in water saving devices (such as dual flush toilets) or alternative supplies of water (such as through rainwater harvesting).[41]

While it seems clear that higher prices and lower demand are linked, quantifying the impact of a change in prices on water use, or the 'price elasticity', is difficult and there is a significant degree of uncertainty over the price elasticity of residential water in the UK.

Numerous studies have been carried out to estimate price elasticities for residential water

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[34] OECD (2011), 'Greening Household Behaviour', OECD, Paris.
[35] Olmstead & Stavins (2009), 'Comparing price and nonprice approaches to urban water conservation', *Water Resources Research*.
[36] Grafton, R.Q. et al. (2011), 'Determinants of Residential Water Consumption: Evidence and Analysis from a 10-country Household Survey', Water Resources Research, Vol. 47.
[37] Environment Agency (2003) 'The economics of water efficient products in the household'.http://www.environment-agency.gov.uk/static/documents/Leisure/eweph_1597545.pdf (accessed 28/05/13)
[38] OECD (2011), 'Greening Household Behaviour', OECD, Paris.
[39] Bellfield (2001), 'Short term domestic water demand: estimation, forecasting and management', PhD Thesis, available at: http://etheses.whiterose.ac.uk/2576/ (accessed 9/4/13)
[40] Howarth, D., and S. Butler (2004). Communicating water conservation: How can the public be engaged?, vol. 4, 3 Edition, IWA Publishing, pp. 33-44.
[41] Herrington, P. (2007), 'Waste Not Want Not? Water Tariffs for Sustainability', WWF, UK.

use and summaries of such studies suggest the average figure is around -0.4 to -0.5 i.e. a 10% increase in water prices leads to a 4-5% decrease in water demand. However, there are significant variations and uncertainties surrounding such estimates and although a large number of countries are covered in the residential water demand modelling literature, only two studies relate to the UK and neither contains a reliable estimate.[42]

The lack of information about residential water price elasticity in the UK may be due to the fact that consumer understanding of consumption and price is low in the UK. In a recent survey of the UK only 2% of respondents knew the price of water within a 10% band of accuracy, and only 13% knew it within a 25% band of accuracy; while 85% knew the price of petrol within 10%. Consumers were more aware of their total bill than the price of water, with 52% estimating their water bill within a 20% band of accuracy. With respect to consumption, only 9% of respondents knew their daily litre consumption within 10%, despite this being clearly displayed on their bill. Quarterly cubic meter consumption was more accurately perceived with 23% of respondents knowing their consumption within a 10% band of accuracy.[43]

A number of studies have demonstrated that the installation of water metres in households leads to lower water demand and higher price elasticity due to the fact that meters increase the awareness of the level and costs of water use. For example, a recent survey of 10,000 households across the OECD found that metered households which faced a volumetric charge for their water consumed around 20% less water than unmetered households and a 10% rise in water prices led, on average, to a 5.6% decrease in water use.[44]

A further constraining factor on elasticity of demand estimates is that elasticity is likely to vary with the quantity used. Water is an essential good, and as such, each household requires a certain amount of water to meet their basic needs. The elasticity of water below this threshold is likely to be very inelastic and any change in price is unlikely to reduce usage beyond a certain level. However, once basic needs have been met, water use is likely to be more responsive to price, as people can adapt their behaviour and consume less water without have a significant impact on their well-being.

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[42] Waddams & Clayton (2010), 'Consumer Choice in the Water Sector', Ofwat, UK.
[43] *Ibid*
[44] OECD (2011), 'Greening Household Behaviour', OECD, Paris.

3. INDUSTRY SECTOR FINDINGS

3.1 Demand for industrial water

The industry sector encompasses a broad range of water-using industries, including energy production, the manufacture of food and beverages, plastics, chemicals, pulp and paper, vehicles, and service-related activities such as sports facilities (golf courses, turf, etc), hospitals, and laundries. Each of these industries has different water resource requirements.

In 2011, the total volume of water abstraction attributed to the industrial sector (including energy) was estimated to be 9,924 Mm^3.[45] This volume comprised tidal and non-tidal surface water and groundwater abstractions. The majority of water abstracted by this sector is used in the electricity supply industry which accounted for approximately 85% of total abstractions by the industrial sector in 2011.[46] While net abstraction is insignificant in the energy sector, there is a significant change to quality of the water through the increased temperature of discharge when water is used for cooling. In hydropower schemes, water is diverted, used to generate electricity, and then returned back to the watercourse. This can also create problems, for example, if there is a significant distance between abstraction and discharge points, water diversion may lead to low flows in a portion of the river, particularly during periods of when the river is naturally in low flows.[47] The extent to which this is problematic may be influenced by the water quality and temperature characteristics of the receiving environments and the organisms that inhabit them.

The industrial sector obtains most of its water from tidal abstractions. In 2011, this volume was 7,872 Mm^3, or approximately 80% of the total volume abstracted by industry. Figure 9 shows tidal surface water abstraction by the industrial sector by region over the past eleven years. It shows a mixed trend with total volume increasing over the period 2000 – 2007, but decreasing to 7,872 Mm^3 in 2011.

Figure 9 Industrial sector tidal surface water abstraction by region[48]

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[45] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[46] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[47] *Ibid.*
[48] *Ibid.*

Figure 10 shows the industrial sector's non-tidal surface water abstractions. In 2011, abstractions from this source accounted for 1,858 Mm^3, or almost 20% of the total volume abstracted by industry. Over the past 11 years, abstractions from this source have declined by approximately 45% which may be, at least in part, attributed to changes in the level of activity in industry sectors and improvements in the efficiency with which water is used.

Figure 10 Industrial sector non-tidal surface water abstraction by region[49]
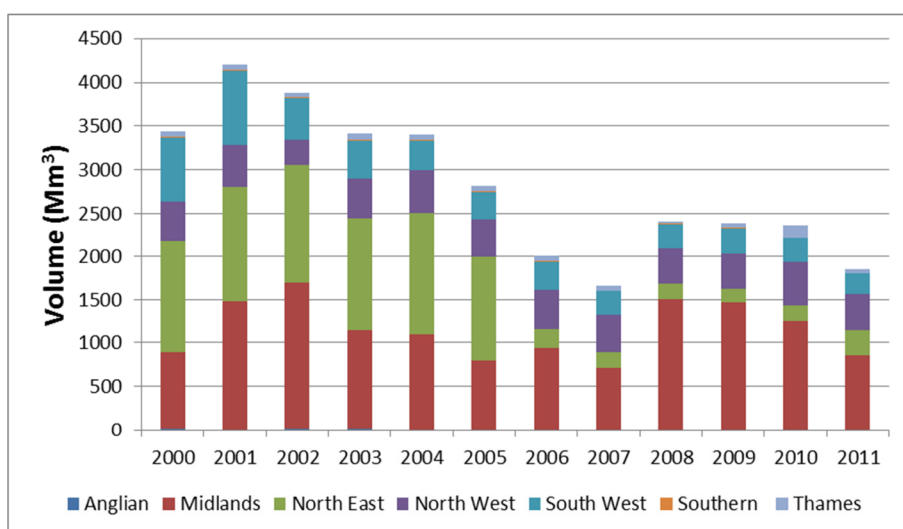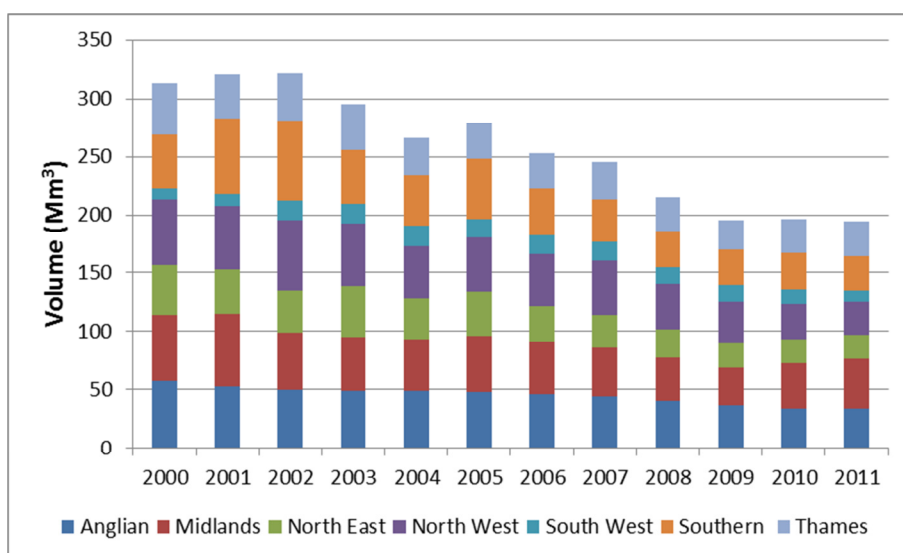

Figure 11 shows the industrial sector's groundwater abstraction by region over the past eleven years. It shows a declining trend in overall volume abstracted, from a peak in 2000 at 313 Mm^3 to 194 Mm^3 in 2011. The sector obtained less than 2% of its water from this source in 2011.

Figure 11 Industrial sector groundwater abstraction by region[50]

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[49] *Ibid.*
[50] *Ibid.*

In 2011, Kowalski et al.[51] estimated water abstractions across England and Wales using five Standard Industrial Classifications (SIC) related to the manufacturing sector based on 2006 data. Across England and Wales, the following SIC divisions were the greatest users:

- Manufacture of chemicals and chemical products;

- Manufacture of basic metals;

- Manufacture of paper and paper products;

- Manufacture of beverages; and

- Manufacture of food products.

In England, the 'manufacture of chemicals and chemical products' was found to be the largest in terms of volume directly abstracted, representing over half of the total volume directly abstracted by the manufacturing sector.[52] Another significant user was the 'manufacture of paper and paper products'. In total, these two industries accounted for approximately 400,000 Ml, or 70% of the total volume directly abstracted for use by the manufacturing sector in England.

The authors also note that these results vary regionally and found that, while there are some existing sources of information for water use in specific sectors, the majority of these data have been collected for studies that are now outdated. Furthermore, these data have generally been collected via surveys of individual manufacturers rather than representative samples of the industry as a whole.

3.2   Estimates of the value of water for industrial use

As noted by Moran and Dann (2008)[53], the complexity of many industrial processes means that placing a value on their usage of water is not straightforward. The most realistic method for valuing industrial water use is the marginal productivity approach. While it is the most data intensive and most difficult, it allows the most comprehensive inclusion of information on the costs of other inputs to production. However, estimating the marginal value of water to industry can be problematic as the value of water tends to be low relative to the total costs of industrial production and actual water intake is often less than gross water use amongst firms that are able to recycle water. The maximum willingness to pay (WTP) for water therefore tends to approximate the marginal costs of treatment and re-use of water, or of alternative technologies that conserve water.

There is insufficient data on industries' water and other input costs in England to be able to estimate the change in output associated with a one unit change in water use (i.e. the marginal product of water). However, work undertaken by Renzetti and Dupont (2003) in Canada,[54] which was subsequently updated by the Scottish Environment Protection Agency in 2005[55] uses a cost minimisation function to establish the relationship between industrial output

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[51] Kowalski, M., Lynn, S., Waylen, C. and Bujnowicz, A. (2011) Freshwater use in the UK: manufacturing sector. WRAP research report. http://www.wrap.org.uk/sites/files/wrap/PAD101-201%20-%20Manufacturing%20sector%20water%20report%20-%20FINAL%20APPROVED%20for%20publication%20-%2012%2C03%2C12.pdf

[52] Ibid.

[53] Moran, D. and Dann, S. (2008) The economic value of water use: Implications for implementing the Water Framework Directive in Scotland. Journal of Environmental Management, 87, pp484-496.

[54] Renzetti, S., and Dupont, D.P. (2003) The Value of Water in Manufacturing, CSERGE Working Paper ECM 03-03.

[55] Scottish Environment Protection Authority (SEPA) (2005) An Economic Analysis of Water Use in the Scotland River Basin District. Summary Report Rep., SEPA.

and water input, holding other inputs constant. They report a marginal value across a range of industries (excluding energy) of between £0.04–0.375/m^3 (in 2004 prices). While these provide a reasonable indication of the relative value of water use *between* industrial sectors, Dann and Moran (2008) caution that applying the 1991 estimates generated by Renzetti and Dupont to the present-day UK industry sector implicitly assumes that there have been no efficiency improvements in industrial processes since 1991 and that this is unlikely to hold in practice.

The Scottish Environment Protection Agency[56] also estimated the marginal value of water used in hydroelectricity to be between £0 – 0.0082/m^3 in Scotland (in 2004 prices). However, they note that personal correspondence with Scottish and Southern Energy suggests that this value may be a significant underestimate, with their internal calculations giving values up to £0.052/m^3. The results of the study suggest that the energy sector shows relatively low marginal values for water for cooling but for large throughputs. The value of water for hydropower is particularly sensitive to assumptions about the price of energy and the cost of alternative sources.

The value of water for energy production is likely to vary depending on the technology employed and the timeframe over which changes in value are being estimated. A short-run marginal value is likely to be more appropriate where there are temporary restrictions on water management and short-term displacement to other types of generation, while a long run average value may be more appropriate in considering the potential for new energy-generating facilities. Furthermore, changes in the price of carbon on the EU Emissions Trading Scheme (EU ETS) may influence the value of water to different types of energy producer. It can reasonably be expected that the value of water to producers of renewable energy (and hydropower in particular) would increase in response to an increase in the price of carbon.

3.3 Determinants of demand

While it is possible to obtain an estimate of industry water use, understanding the drivers of demand is more challenging.

In 2003 the Environment Agency[57] commissioned a research project investigating the optimum water requirements of different agricultural and industrial practices from the perspective of water-use efficiency. In developing the water requirements, the researchers identified factors that contribute to variability within the industries. Although not an exhaustive list, the following provides an indication of the drivers of water use, as identified by the participants in the research:

- Cost of water;

- Seasonality arising from rainfall, customer demand or other criteria;

- Location;

- Scale of production;

- Availability of water (particularly where subject to drought restrictions);

- Production inefficiencies (e.g. bottlenecks);

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[56] *Ibid*.
[57] Environment Agency (2003) Optimum use of water for industry and agriculture: Phase 3. http://evidence.environment-agency.gov.uk/WaterResources/docs/optimumuse.pdf

- Process technology;

- The commitment of high level management to water use efficiency; and

- Changes in the carbon price.

The literature review for the current project has not yielded data sources that would allow these drivers to be modelled with confidence. Under the set of criteria set out in the protocol, the literature search did not yield any information on the price elasticity of demand for water by the industrial sector in England. However, a wider scope, encompassing countries outside England and longer timeframes, is likely to yield this information. Reynaud (2003), for example, estimates elasticity of demand values for industrial water users across France of between -0.3 for the food and beverage industry to -0.73 for non-metallic mineral products.

Intuitively, we would expect industry to be largely unresponsive to price changes, at least in the short term. Over the longer term, industrial infrastructure, technologies and processes may evolve to be more water-efficient (or make use of appropriate substitutes) in response to increasing prices.

4. AGRICULTURE SECTOR FINDINGS

4.1 Demand for agricultural water

Within the agricultural sector, water is used for a range of activities such as irrigating nursery and field crops, watering livestock, and washing down machinery within dairy farming enterprises. Approximately 40% of total agricultural water use is by livestock enterprises, with drinking water for livestock accounting for 75 Mm^3 per year.[58] A further 40% (approximately 70 Mm^3) is used for irrigating field crops such as potatoes and vegetable crops. The remaining 20% of water is utilised in the nursery crop sector.[59]

In England, the majority of the agricultural sector's water needs are met through precipitation. Additional water is used to irrigate arable and horticultural crops.[60] However, because of the relatively high costs associated with this type of irrigation, farmers tend to restrict the volume of water they use to the dry summer months or for irrigating high value crops such as potatoes, field vegetables, and soft fruits. [61]

In 2011, the total volume of water abstracted by the agricultural sector (including spray irrigation, but excluding fish farming, cress growing, and amenity ponds) was estimated to be 143 Mm^3. This volume was primarily sourced from non-tidal surface water and groundwater water abstractions, with no water obtained from tidal surface water sources.

The sector obtains most of its water from groundwater abstractions. In 2011, this volume was 79 Mm^3, or approximately 55% of the total volume abstracted by the sector. Figure 12 shows the agricultural sector's groundwater abstractions over the past 11 years. During this time abstractions from this source have fluctuated, but over the past three years have shown an increasing trend. The changes in abstraction levels from 2000 to 2011 could be due to a variety of factors, including weather conditions (for example wetter years could result in a decrease in abstraction for agriculture and spray irrigation), change in the production of livestock and crops, and improvements in the efficiency of water usage.

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[58] Charlton, M.B., Bailey, A. and Arnell, N. (2010), 'Water for Agriculture – Implications for Future Policy and Practice', Royal Agricultural Society of England.
[59] *Ibid.*
[60] Moran, D. and Dann, S. (2008),' Economic Value of Water Use Implications for Implementing the Water Framework Directive in Scotland', *Journal of Environmental Management*, Vol. 87, pp.484-496.
[61] *Ibid.*

Figure 12 Agricultural sector groundwater abstraction by region[62]
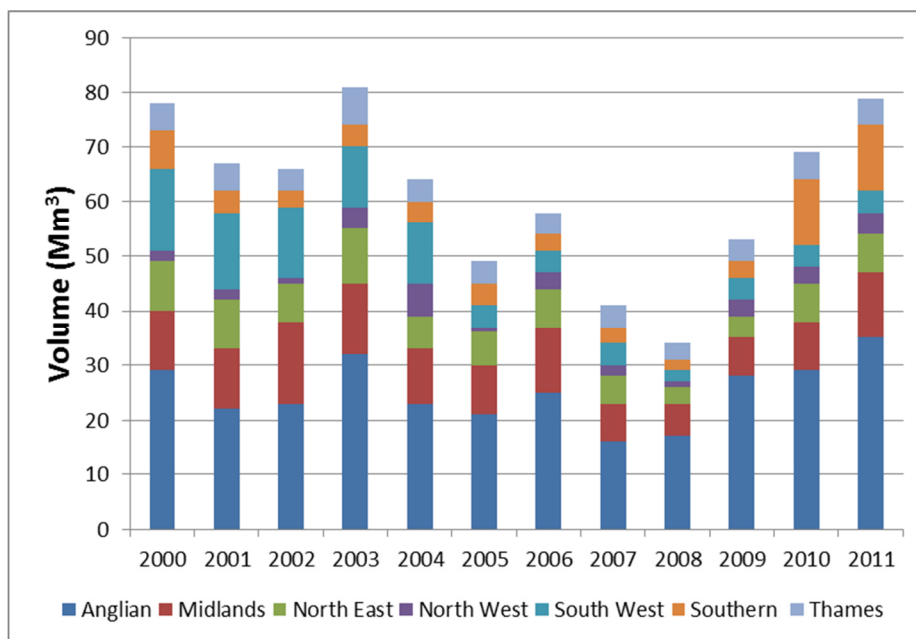
Figure 13 shows the agricultural sector's non-tidal surface water abstraction by region over the past eleven years. It shows a downward trend between 2000–08, but since this time abstraction volumes from this source have increased.

Figure 13 Agricultural sector non-tidal surface water abstraction by region[63]

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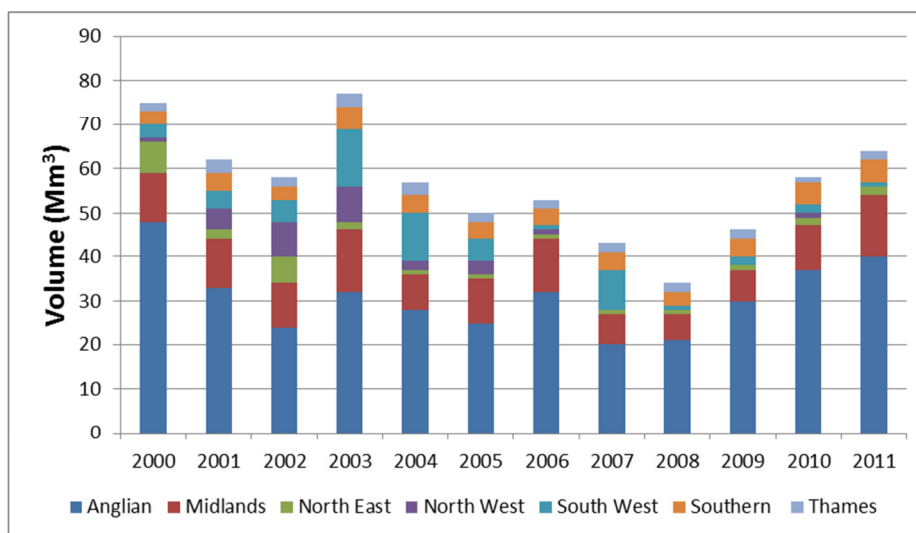
[62] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[63] *Ibid.*

4.2 Estimates of the value of water for agricultural uses

Morris *et al.* (2003)[64] found that, across a range of irrigated crops, the marginal value of water was £1.58/m^3. However, they also found that the marginal value increased as the volume of water available decreased; such that when water was unconstrained, the marginal value was estimated to be £0.026/m^3 while, when no water was available, the marginal value was estimated to be £1.96/m^3.[65]

It is important to note that any estimates of the marginal value of water are likely to vary considerably in relation to the type of crop grown and the point in the season when water is abstracted. A study by Moran and Dann in 2008 used an extended net-back analysis method that compares yields with and without irrigation to estimate an average value of farmers' willingness to pay for irrigation water. To apply this method to agricultural irrigation, it is necessary to have data on the costs associated with irrigation, yield, and revenues. As noted by Moran and Dann, the only crop for which this information is presently available is for potatoes. Using a small data set from a farm trial in Cambridgeshire, they estimated a value of water for irrigation at between £0.23 and £1.38/m^3. These estimates do not, however, consider the costs of abstraction licences, the effects of potato subsidies, or the potential relatively higher demand for irrigation water in Cambridgeshire (compared to other regions) because of lower rainfall.

Knox *et al.* (2000) used mathematical programming to build partial equilibrium models (i.e. economic models of agricultural production) in order to estimate the value of sprinkler irrigation across a variety of crops in East Anglia. They found estimates of the marginal value of irrigation water to range from £0.03 – 2.89/m^3 with an average of £1.40/m^3; for potatoes the estimate was £1.76 /m^3. Such a method requires specialised knowledge of the production processes using water as an intermediate good and the relevant data on costs and water uses. As such, any estimate may be location specific and difficult to replicate in regions where such extensive data is not available.

4.3 Determinants of demand

There is a broad consensus within the water industry that the components of demand include information on water abstraction licences, uses, frequency, and volume.[66] Past levels of demand offer useful information for forecasting future demand when taking into consideration the fact that demand varies over space and time due to a variety of factors such as localised weather patterns, changes in water use habits, changes in price or charging method, seasonality factors, and climate change.

1. Regional variation

The weather and climate factors, particularly precipitation and temperature, vary across regions and this variance influences the volume of water used by the agricultural sector. For example, the area of irrigated land in 2010 was found to be almost 30% less than the area in 2005. This is attributed to wetter weather conditions across England in 2010, relative to the drought conditions experienced in 2005.

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[64] Morris, J., Vasileiou, K., Weatherhead, E., Know, J., Leiva-Baron, F. (2003), 'The Sustainability of Irrigation in England and the Impact of Water pricing and regulation policy options, in Advances in Water Supply Management', edited. Taylor & Francis, UK.
[65] *Ibid.*
[66] Environment Agency (2002), 'The economics of balancing supply and demand (EBSD) Guidelines', Report Ref. No. 02/WR/27/4 UKWIR, UK.

Figure 14 reflects the variation in the volume of water abstracted across regions and shows that the Anglian region had the greatest estimated level of abstractions (75 Mm^3) in 2011, while the North West region had the lowest (4 Mm^3).[67]

In addition to the spatial variation based on weather and climate, there is also variation based on the type of agriculture undertaken. Godwin et al. in Charlton et al. (2010)[68] found that western England has a relatively high water demand for livestock. In contrast, agricultural abstractions in the east and south of England are used to irrigate crops and demand is highest during the drier summer months.

Figure 14 Agricultural sector total abstraction by region, 2011[69]
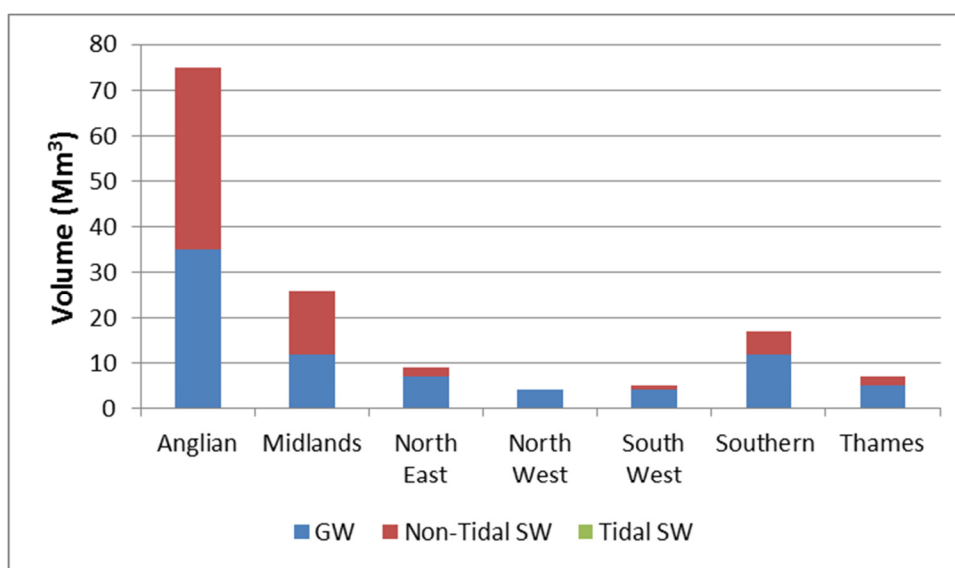
2. Irrigation technology

Trickle irrigation is a type of irrigation technology that results in increased water use efficiency and a reduction in evapotranspiration loses.[70] In 2003, Knox and Weatherhead[71] found the area of trickle irrigation in England was 10% of all irrigated holdings in 1987. However, by 2001, this area had increased to represent 16% of holdings. Southern regions accounted for the greatest uptake of this technology although it is also used in the Anglian and Midland regions. A continuation in the trend for increased uptake of this technology may result in reduced demand for water within the agricultural sector, assuming other factors remain constant.

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[67] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)

[68] Charlton, M.B., Bailey, A. and Arnell, N. (2010), 'Water for Agriculture – Implications for Future Policy and Practice', Royal Agricultural Society of England.

[69] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)

[70] Kay, M. (1992), 'A Review of Trickle Irrigation Use in England and Wales.' Report for the National Rivers Authority, UK.

[71] Knox, J.W. and Weatherhead, E.K. (2003), 'Trickle Irrigation in England and Wales', R&D Technical Report W6-070/TR, England.

4. Climate change

In 1996, the Department for the Environment[72] looked at the possible effects of climate change on irrigated agriculture and horticulture and found that the current drier climatic conditions experienced in eastern England have the potential to spread to central England by 2020, resulting in a 20% increase in irrigation use. By 2050, the continuation of this trend is forecast to result in eastern, southern, and central England having potentially 30% higher irrigation needs than is currently the case.[73] The Environment Agency[74] suggests that, given these projections, direct abstractions will be less reliable because existing aquifers and infrastructure for water storage are considered to be ill-equipped to deal with periods of drought and higher intense rainfall. The impact of these changes on demand for water is uncertain.

The Environment Agency[75] modelled a number of demand scenarios for 2050 and predicted that irrigated agriculture demand could increase by between approximately 30% to 170%, depending on the industry's assumed response to climate change.

4.3.1   ***Price elasticity of demand***

There are limited substitutes for agricultural water and because of this, demand for water is generally considered to be price-inelastic. Morris *et al.*[76] for example, estimate the price elasticity for agricultural water use to be -0.008 for prices less than £0.6/m^3 and -0.015 for prices above, i.e. if water costs more than £0.6/m^3, a 10% increase in price leads to a 0.15% decrease in use. However, there is a considerable amount of uncertainty over agricultural water estimates, and values are likely to vary considerably by crop and by region. In a meta-analysis of US agricultural water use since 1963, Scheierling *et al.* (2006)[77] estimate a median price elasticity of -0.16 (for a 10% increase in price, the volume an irrigator uses decreases by 1.6%) and a mean of -0.48.

This reflects the fact that, for the majority of agricultural uses, there are no alternatives to water in the short term, especially if the price rise occurs after a crop has been planted; however, if the price rise is anticipated prior to planting, alternative, drought resistant crops may be cultivated. Over the long term, water-efficient technologies (such as trickle irrigation) may be employed and therefore price elasticity of demand is typically expected to be higher in the long term.

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[72] Herrington, P. (1996), 'Climate Change and the Demand for Water', Department for the Environment, UK.
[73] *Ibid.*
[74] Environment Agency (2005),' The Climate is Changing, Time to Get Ready', http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0205birs-e-e.pdf (accessed 9/4/13)
[75] Environment Agency (undated) The Case for Change – Current and Future Water Availability, http://www.environment-agency.gov.uk/research/planning/135501.aspx (accessed 28/05/13)
[76] Morris, J., Vasileiou, K., Weatherhead, E., Know, J., Leiva-Baron, F. (2003), 'The Sustainability of Irrigation in England and the Impact of Water pricing and regulation policy options, in Advances in Water Supply Management', edited. Taylor & Francis, UK.
[77] Scheierling, S.M., Loomis., J.B. and Young, R.A. (2006) Irrigation water demand: A meta-analysis of price elasticities. *Water Resources Research*, 42(9).

5. ENVIRONMENT

5.1 Demand for environmental water

Environmental water demand can be defined as the amount of water needed in a watercourse to sustain a healthy ecosystem. It covers the requirements of riparian and aquatic ecosystems that depend upon a 'natural flow regime' as well as a number of in-stream uses (e.g. angling and recreation). The 'health' of the ecosystem is in turn defined by the community allocating water to the environment.

The primary mechanism for allocating water resources and protecting the environment is through the abstraction licensing system administered by the Environment Agency. Generally, anyone wanting to abstract more than 20 m^3 of water per day requires a licence.

When the Environment Agency assesses applications for abstraction licences, it is obliged to ensure that the needs of the environment and existing abstractors are fully recognised. Licences are granted with conditions to ensure that there are no unacceptable effects on the environment or other legitimate users.

To do this, the Agency uses information contained in Catchment Abstraction Management Strategies (CAMS). CAMS consider the rainfall reliably received, the water requirements of the environment and the amount of water already licensed for abstraction. Resource availability is expressed as a surplus or deficit of water resources in relation to an Environmental Flow Indicator (EFI). The EFI is a percentage deviation from the natural river flow represented using a flow duration curve. This percentage deviation is different at different flows and also depends on the ecological sensitivity of the river to changes in flow. The EFI is based on flow standards for the Water Framework Directive (WFD) that have been adapted for use within the existing abstraction regulatory regime and set at a level to support good ecological status.

The EU Water Framework Directive (WFD) is a framework for establishing the water quantity and quality requirements of rivers to achieve particular ratings. It is designed to:

- Enhance the status and prevent further deterioration of aquatic ecosystems and associated wetlands which depend on the aquatic ecosystems;

- Promote the sustainable use of water;

- Reduce pollution of water, especially by 'priority' and 'priority hazardous' substances; and

- Ensure progressive reduction of groundwater pollution.

Under this framework, the UK must aim to reach 'good' chemical and ecological status in inland and coastal waters by 2015. In some ways, this could be considered the overarching basis of demand for environmental water.

However, within this overarching framework, the water requirements of a given catchment to achieve the desired WDF status will vary depending on the current status, the implications of climate change for water flows, and the extent to which the environment competes with other users of water throughout the year. Because of this, estimating the demand curve for water is problematic at the national scale.

In this way, environmental water use could be derived by calculating the difference between the total supply of water and the total volume of water abstraction licences, should this data be available at the appropriate spatial and temporal scale.

In most studies into the value of water for environmental uses, an assumption is made regarding the volume of water flowing in a given river and the quality of water and, hence, the ecological health of the river.

5.2 Estimates of the value of water for environmental uses

The framework used for the other sectors included in the literature review is less well-suited to the environment because the environment is not typically recognised as a 'paying consumer' and the value cannot be estimated using productivity approaches. However, environmental values can be established using methods to value non-market benefits through, for example, examining beneficiaries' willingness to pay (WTP) for a change in the ecological health of a river, assuming that ecological health is at least partly related to river flow levels.

Johnstone and Markandya (2005),[78] for example, in their study on anglers' WTP for a marginal change in flow, consider river flows as a proxy or constituent component of quality. Other studies have examined WTP to reduce the frequency with which rivers run dry, e.g. Jacobs Gibb (2002)[79] or to avoid a decrease in water levels, e.g. Eftec and CSERGE (1998).[80]

Table 1 contains data relating to the estimated marginal value derived from water resource and enhancement services associated with inland and coastal wetlands. The estimates of marginal value are based on an increase in wetland area of 10%. However, Morris and Camino (2011)[81] caution that because of the assumptions underpinning the estimates, the estimates should be considered indicative of direction and magnitude at a broad scale only.

These estimates could be used to estimate the demand curve for the environment; however to do this would require that changes in flow volumes can be converted into an increase in the area of wetland that is sustained by the increase in flow. Such a calculation is unlikely to be robust.

Table 1 Estimated marginal values for specified ecosystem services provided by inland and coastal wetlands in the UK, 2010*[82]

	UK Inland Wetlands	UK Coastal Wetlands
Resource & environmental enhancement services	Marginal value of extra provision	Marginal value of extra provision (£/ha/year)
Flood control and storm buffering	407 (442)	2,498 (2,712.2)
Surface and groundwater supply	1 (1)	12 (13)
Water quality improvement	292 (317)	1,793 (1,947)
Non-consumptive recreation	82 (89)	504 (547)
Amenity and recreation	227 (247)	1,394 (1,514)

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[78] Johnstone, C. and Markandya, A. (2005) Valuing river characteristics using combined site choice and participation travel cost models. Journal of Environmental Management, 80, 237 – 247.
[79] Jacobs Gibb (2002) River Mimram Low Flow Public Preferences Study. Final Report – Phase 1. Report to Environment Agency Thames Region.
[80] Eftec and CSERGE (1998) Valuing Preferences for Changes in Water Abstraction form the River Ouse. Report to Yorkshire Waters. London, UK.
[81] Morris, J. and Camino, M. (2011) UK National Ecosystem Assessment Working Paper. Economic Assessment of Freshwater, Wetland and Floodplain Ecosystems Services.
[82] Ibid.

	UK Inland Wetlands	UK Coastal Wetlands
Biodiversity	304 (330)	1,866 (2,026)
Direct consumption and resource extractive services		
Recreational fishing	-51 (-55)	-310 (-337)
Commercial fishing and hunting	-8 (-9)	-48 (-52)
Recreational hunting	-147 (-160)	-900 (-977)
Harvesting of natural materials	-87 (-95)	-528 (-573)
Material for fuel	-153 (-166)	-938 (-1018)

*Area weighted estimates for all UK inland wetland sites using the Brander et al. benefit function and CORINE data sets. Values in parentheses reflect £2012 values

Although it falls outside of the scope of this review, an earlier study by Eftec and CSERGE[83] was identified which estimates use and non-use values in the River Ouse, Yorkshire in 1998. The study reports marginal willingness to pay to avoid 5 cm reductions in water levels of -£3.77 (2010 prices). To avoid a 45 cm reduction, marginal willingness to pay was found to be -£8.82 (2010 prices).

However, these values are highly location and beneficiary specific and the ability to reliably transfer the estimates to other locations is limited.

5.3 Determinants of demand

Using the EFI framework, the environment's demand is influenced by the ecological sensitivity of a given river. UK TAG (2008)[84] identified the percentage deviation from natural flow that supports good ecological status for differing river 'types, and at different flows.

The environment's demand for water is also influenced by seasonal rainfall. For example, in drier summer months, a given river's demand for water is greater than in periods of higher rainfall.

5.4 Price elasticity of demand

No studies were retrieved that provide estimates of the elasticity of demand for the environment. As such, it is not considered possible to derive a demand function for changes in environmental flows.

Figure 15 contains a representation of the water that is available for abstraction across England in 2009. This can be used as an approximation of the water available for environmental uses. Table 2 indicates the status of the available resource using the following categories and descriptions.

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[83] Eftec and CSERGE (1998) Valuing Preferences for Changes in Water Abstraction form the River Ouse. Report to Yorkshire Waters. London, UK.
[84] UK Technical Advisory Group (UKTAG) (2008) UK Environmental Standards and Conditions Report (Phase 1). Final report SR1-2006.
http://www.wfduk.org/sites/default/files/Media/Environmental%20standards/Environmental%20standards%20phase%201_Finalv2_010408.pdf (accessed10/04/13)

Table 2 Abstraction licence availability in England

Status	Licence availability
Water available	Water is likely to be available at all flows, including low flows. Restrictions may apply.
No water available	No water is available for further licensing at low flows. Water may be available at height flows with appropriate restrictions, or through licence trading.
Over licence	Current actual abstraction is such that no water is available at low flows. If existing licences were used to their full allocation they could cause unacceptable environmental damage at low flows. Water may be available at high flows, with appropriate restrictions, or through licence trading.
Over abstracted	Existing abstraction is causing unacceptable damage to the environment at low flows. Water may still be available at high flows, with appropriate restrictions, or though licence trading.

Figure 15 also highlights the variability across England, which suggests that a national scale estimation of environmental water needs is not likely to be robust. However, it may be possible to estimate the range of volume of water that is required for the environment by determining the volume that is required to return 'over-abstracted' areas to 'water available' areas. This calculation could be used to determine the upper bound estimate of the proportion of total water supply that could be redirected to the environment.

Figure 15 Water available for abstraction (surface water combined with groundwater), 2009
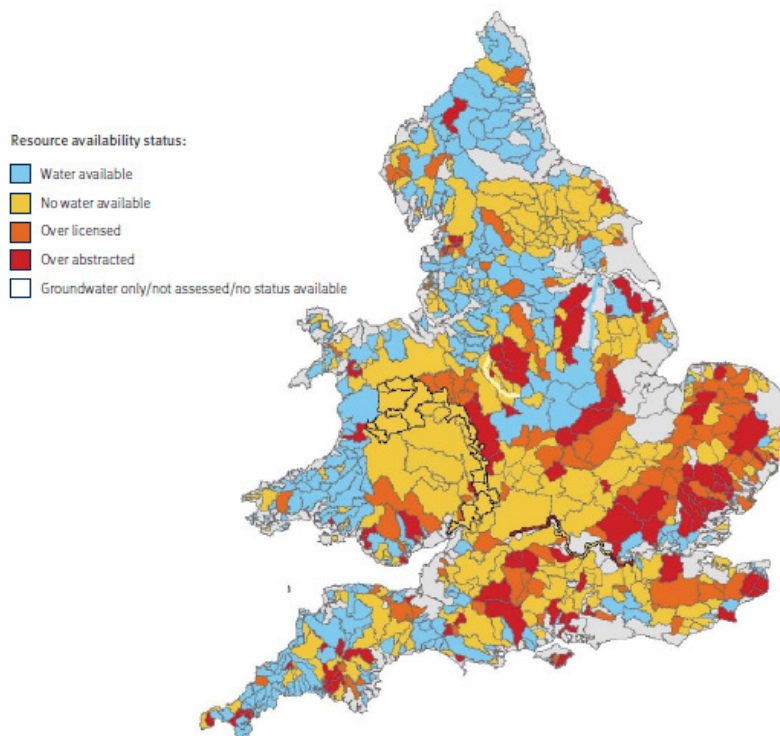
Source: Environment Agency, 2009[85].

5.5 Summary

Table 3 provides an overall summary of the marginal values and demand elasticities identified for each of the key abstractors through the literature review.

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[85] Environment Agency (2009) Water for People and the Environment. Water Resources Strategy for England and Wales. Available from: http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0309bpkx-e-e.pdf

Table 3 Summary of marginal values of water and elasticities of demand across sectors

| Sector	Valuation basis and year	Key assumptions	Marginal values (£/m^3)	Elasticity of demand
Residential	Gibbons' WTP formula (2008)	Assumes all customers pay volumetric charges levied on metered customers Includes value of clean and dirty water	0.00164 (Scotland) 0.00102-0.00244 (E&W)	-0.2
	Benefits transfer from Stated Preference study (2008)	Only considers value of supply of clean water	0.000548-0.000864 (Scotland) 0.00067 (E&W)	*n/a*
	Willingness to pay study (2008)	Value can be estimated from WTP to avoid water supply and sanitation disruptions	33	*n/a*
Industry	Benefits transfer from a cross-industry study in Canada that used a marginal productivity approach (2004)	Industrial water use in England assumed to be the same as that for Canada No improvements in water efficiency since 1991	0.04-0.375	*n/a*
	Marginal productivity	Hydroelectricity in Scotland	0-0.0082	*n/a*
	n/a	Various industrial water uses across France are a useful proxy	*n/a*	-0.3 - -0.73
Agriculture	Extended net-back analysis using a limited data set from Cambridgeshire	Assumes that the catchment in Cambridgeshire is representative of other areas where potatoes are irrigated	0.23-1.38	*n/a*
	Irrigated crops	When water is constrained marginal value is higher	1.58	-0.008 - -0.015
	Partial equilibrium models	Sprinkler irrigation values vary across crops and season	0.03-2.89	*n/a*
	Meta analysis	US agricultural water uses since 1963 are a useful proxy	*n/a*	-0.16

6. WATER SUPPLY

6.1 Supply of water

The UK has an estimated annual supply of 147 km[3] of renewable freshwater resources, providing a potential 2,350 m[3] of water for each person each year.[86] The amount of water that can be abstracted from the environment is tightly controlled through an abstraction licensing system, and across England and Wales as a whole, only about 10% of the available freshwater resources are used for abstraction; although this varies considerably at the regional level, reaching up to 22% of freshwater resources in the South East and Eastern England.[87]

The Environment Agency is responsible for deciding the maximum amount of water that may be taken from the environment, and abstractions are managed through a licensing system that regulates all abstractors taking more than 20 m[3]/day of water (excluding activities currently exempt from licensing). Licences are granted depending on the amount of water available after the needs of existing abstractors and the environment are met and whether the justification for the abstraction is reasonable. There are approximately 21,500 abstraction licences in England and Wales and total quantities in England have remained relatively stable across the last fifteen years[88] although more recently they have begun to fall (see Figure 16).

Figure 16 Total abstractions in England 2000-2011[89]
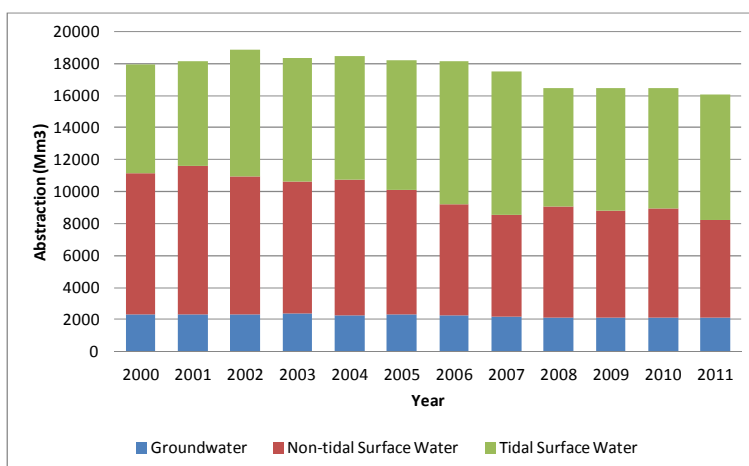
Under the abstraction regime in 2011, a total of around 16 billion m[3] of water were abstracted in England, 38% from non-tidal surface waters, 13% from groundwater, and around 49% from tidal waters (mainly used for cooling within the electricity supply industry, which is not considered to be a consumptive use).[90,91] The proportion of water licensed between surface water and

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[86] Aquastat (2013) http://www.fao.org/nr/water/aquastat/data/factsheets/aquastat_fact_sheet_gbr_en.pdf (accessed 11/4/13)
[87] Wrap (2011), 'Freshwater availability and use in the United Kingdom', Project code: RSC014-001.
[88] Environment Agency (2011) 'Current and future water availability', UK Environment Agency. National Water Demand Management Centre, Worthing.
[89] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[90] Ibid.
[91] Wrap (2011), 'Freshwater availability and use in the United Kingdom', Project code: RSC014-001.

groundwater varies considerably at a regional level; reaching 25% and 31% in the East and South East respectively compared to just 2% in the North West.[92]

Of the 8 billion m^3 extracted from non-tidal sources in England, around 63% was used for the public water supply (see Table 4). A further 17% was used for electricity power generation. Industry took around 8% while aquaculture and amenity around 10% (also considered a non-consumptive use).[93] Spray irrigation accounted for around 1% of total abstractions and was concentrated in the relatively dry Anglian region in summer.

Table 4 Non tidal water abstractions in England 2011[94]

Region	Sector water abstractions (Mm3)							
	Public water supply	Spray irrigation	Other agriculture	Electricity supply industry	Other industry	Fish farming & amenity	Private water supply	Other
North West	513	2	2	273	183	14	0	1
North East	764	7	2	262	36	107	2	3
Midlands	833	25	1	677	213	15	1	8
Anglian	742	72	3	2	43	14	2	1
Thames	1413	4	3	33	48	63	2	2
Southern	489	7	10	1	31	416	1	6
South West	406	1	4	185	65	178	1	1
Total	*5,160*	*118*	*25*	*1,433*	*619*	*807*	*9*	*22*

The main consumptive uses of water in England are therefore the public water supply, industry, and agriculture. Of the water abstracted for distribution within the public water supply, around 70% goes to the residential sector and the remaining 30% covers non-household uses. This figure includes losses from customers' supply pipes but excludes losses from water company-owned assets (distribution losses).[95] The major non-household uses of water in England are:

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[92] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
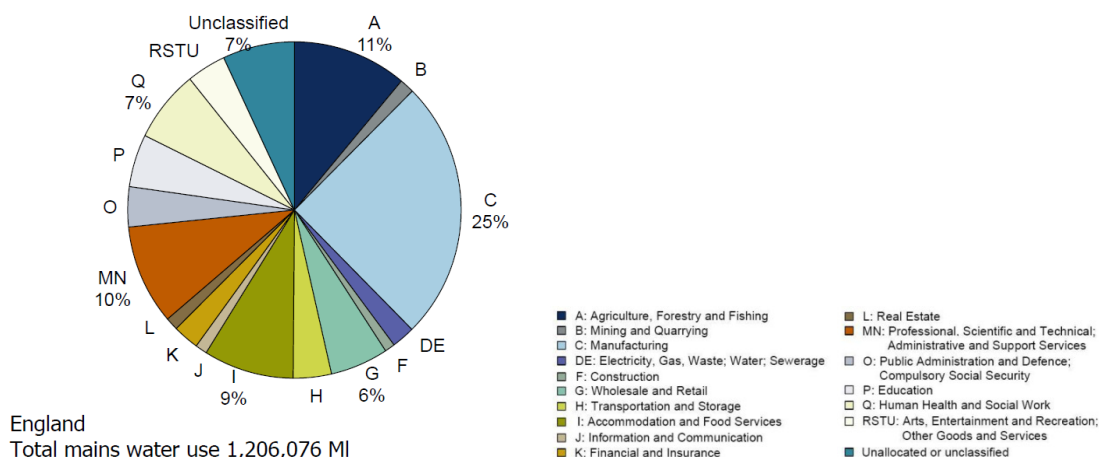[93] Wrap (2011), 'Freshwater availability and use in the United Kingdom', Project code: RSC014-001.
[94] Environment Agency (2011) Actual abstraction data 2000 – 2011. http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)
[95] Wrap (2011), 'Freshwater availability and use in the United Kingdom', Project code: RSC014-001.

manufacturing; agriculture, forestry, and fishing; and professional, scientific, and technical administrative and support services (see Figure 17).

Figure 17 Non-household water use within the public water supply[96]

England
Total mains water use 1,206,076 Ml

A: Agriculture, Forestry and Fishing
B: Mining and Quarrying
C: Manufacturing
DE: Electricity, Gas, Waste; Water; Sewerage
F: Construction
G: Wholesale and Retail
H: Transportation and Storage
I: Accommodation and Food Services
J: Information and Communication
K: Financial and Insurance
L: Real Estate
MN: Professional, Scientific and Technical; Administrative and Support Services
O: Public Administration and Defence; Compulsory Social Security
P: Education
Q: Human Health and Social Work
RSTU: Arts, Entertainment and Recreation; Other Goods and Services
Unallocated or unclassified

Regardless of the abstraction regime in place, the availability of water resources for abstraction depends on the climate, particularly for surface water flows. As such, changes in the UK's climate resulting from greenhouse gas emissions are predicted to impact the physical availability of water resources.[97]

The 2012 Climate Change Risk Assessment looked at the potential impacts of climate change on water supplies in the UK and found that winter river flows are likely to increase while summer flows are likely to decrease, although there is a significant degree of variability in the results of the various models assessed. The CCRA analysis also indicated that by the 2050s, summer river flows could reduce by 35% in the driest parts of England (Anglian river basin region).[98]

As a result of the potential changes in UK water supplies, the CCRA concluded that the majority of the UK population could be living in areas with increased pressure on water resources by the 2020s (2010-2039) and water users may be affected by more frequent restrictions and changing levels of service by the 2050s. Further, summer abstraction may become unsustainable in a large proportion of UK rivers due to low summer flows. In the near term (2020s), a large proportion of rivers could be at risk in meet existing environmental flow requirements.[99] One study found that even a moderate climate change scenario could reduce the level of water available for immediate abstraction by 10% by 2060, equivalent to about 1.4 billion m^3/y for the UK at current levels of abstraction.[100]

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[96] *Ibid*
[97] Environment Agency (2011) 'Current and future water availability', UK Environment Agency. National Water Demand Management Centre, Worthing.
[98] Climate Change Risk Assessment (2012), 'Water Sector', http://ccra.hrwallingford.com/CCRAReports/reportviewer.htML?sector=water&link=LinkTarget_1 (accessed 11/4/13)
[99] *Ibid*
[100] Morris & Camino (2011), 'Economic Assessment of Freshwater, Wetland and Floodplain (FWF) Ecosystem Services', UK NEA Working Paper.

6.1.1   *Deriving supply curves*

As described in the previous sections, permission to abstract water in England is controlled by the award of licences and abstraction charges for licensed quantities are set to cover the cost of administering the licensing system rather than to reflect the value of water. Additional levies were introduced in 2008 to reflect the cost of 'environmental compensation', ranging from zero in Northumbria to an additional 20% charge in the Anglian region.[101]

As such, once an abstraction licence has been acquired the marginal costs of supplying an additional unit water are often relatively low; with estimates of costs varying from £0.003 - £0.06/m^3 of abstracted raw water.[102] For individual abstractors, therefore, the supply curve is likely to be close to zero, with a limit where the abstraction licence is reached beyond which any further abstraction is prohibited.

Over the long term, abstractors may be able to acquire further abstraction licences, however, increasing supply beyond a particular quantity often requires substantial upfront costs to cover investment in abstraction infrastructure such as a reservoir or dam. For example, when increasing the amount of water abstracted from a particular groundwater resource, the marginal cost of supply is likely to be low and relatively flat (they key costs would typically be the costs of energy required for pumping water). However, once the resource is fully exploited, increasing supply any further will require investment in extraction from an alternative source of water which can trigger a step change in the costs of the water supply.

The costs of investing in options to enhance freshwater supply therefore depend on the type of abstraction, with investments in surface and ground water development typically costing between £1-5/m^3, reservoirs £3-10/m^3, and desalinisation £4-8/m^3.[103] As such, water companies typically use Average Incremental Costs (AIC) to decide on supply decisions. AIC are obtained by dividing the net present value (NPV) of an investment option by its volumetric water yield, discounted over time. Regional AIC are contained in Table 5.

Table 5 Regional AIC (£/m^3)[104]

Regional Factors	Min	Max	Average
Anglian	32.15	81.98	53.49
Midlands	20.44	113.38	61.84
North East	21.96	98.92	51.80
North West	23.48	84.45	41.76
Southern	85.80	101.07	93.43
South West	39.26	75.62	57.48
Thames	11.50	44.20	27.85
Wales	33.51	85.66	55.38

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[101] *Ibid*
[102] *Ibid*
[103] *Ibid*
[104] EA draft calculations based on WRMP data.

7. DEVELOPING AN OPTIMISATION MODEL

7.1 Conceptual approach to optimisation

Economics provides a framework to assist in the allocation of water resources between competing uses. This framework is based on the concept of maximising the net benefits to society (total benefits minus total costs) that can be obtained from using water resources by allocating them to their most highly valued uses, including consumptive uses such as irrigated agriculture and other uses such as water used for the environment. The underlying framework that underpins water economics is to allocate water so that the net marginal values are equal across all uses (including consumptive and non-consumptive uses) in order to maximise the net overall benefit to society.

Different uses of water can have very different marginal values and marginal costs. For instance, additional units of water supplied to urban centres which are facing water shortages may, for example, be more valuable than additional water supplied to irrigated farms. In order to allocate water across competing uses which have different marginal values and costs, the optimal allocation of resources is reached where the net marginal value (NMV) i.e. the marginal benefit of using an additional unit of water relative to the marginal cost of extracting and using that water, is equal across all uses (see Figure 18).

Figure 18 Allocating water efficiently
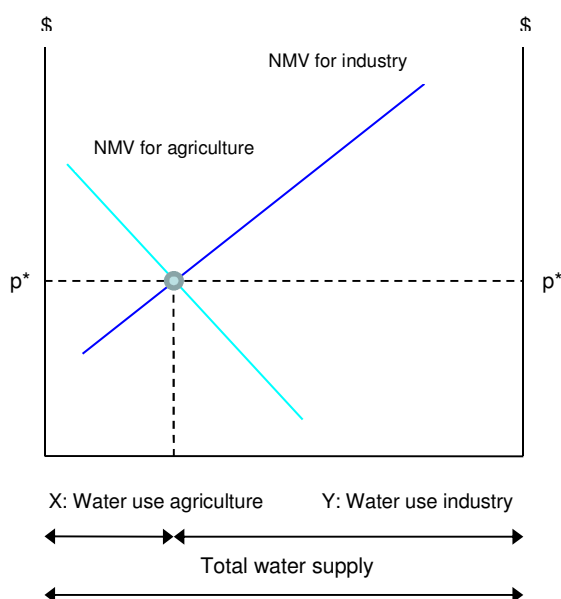
In the simplified example shown in Figure 19, it is assumed that there are only two uses of water: industry and agriculture, both of which have different net marginal values of water. The optimal allocation is reached where X units of water are allocated to agriculture and Y units to industry, at the point where the net marginal values of water in each sector are equal (at price p*).

This economic framework could be used to create an Excel-based optimisation model to calculate the optimal allocation of water across three sectors within each region: industry,

agriculture, and residential, as well as ensuring that there is enough water left *in situ* in order to meet environmental needs.

Solving this optimisation model would calculate the optimal allocation of water across the sectors within each region (as well as the optimal price for water) and the net total benefit to society from allocating water efficiently. The model would also allow the parameters to be changed in order to estimate:

- The impacts of climate change on total water supply and how this changes the allocation decision;

- Changes in requirements for environmental water, for example, turning this on and off will allow estimates of the total cost of securing environmental flows in the region and thereby indicate an approximate value placed by the selection of this environmental limit, the environmental flow requirement can then be altered to investigate alternative valuation options;

- Changes in socio-economic conditions including population growth and various development scenarios i.e. changes in the relative size of the agriculture, industry, and residential sectors driven by expansion or contraction or changes in efficiency improvements.

Once set up the model could be used to allocate water across competing sectors for all regions as well as to estimate the relative prices of water within each region. This could then be used to assess the potential for inter-regional water trading and provide an indication of the possible economic benefits of trade.

The first task in developing an optimisation model is to derive demand curves for each of the sectors (which estimate the marginal value of each additional unit of water) and the total value curves (which estimate the total value of each additional unit of water). Once these curves are derived they can be entered into simple optimisation model and the optimal allocations can be found.

7.2 Deriving Demand Curves

Using the Anglian region[105] as a case study, this section sets out methods for estimating demand curves for each of the four sectors, the data and assumptions made, and the limitations of such assumptions. It is important to note that this section focuses on gross water demand rather than net water demand i.e. the total amount of water abstracted from the environment, not taking into account any water which is returned. **It is also important to note that this section is an illustrative exercise demonstrating what could be done within the study timeframe and budget using the available data.**

It would be possible, with more time and resources, to apply a more sophisticated, comparatively data intensive approach. Such an approach would build up a picture of the composition of demand at the selected area of analysis (probably somewhere between catchment and regional level) for the present and consider how this may change in future in response to, for example, population growth, advances in technology, efficiency gains, consumer choice, fuel prices, etc.

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[105] East Anglia was chosen as a case study as it is a water stressed region and has readily available data.

7.2.1   *Residential*

Moran & Dunn (2008)[106] use a point expansion method to estimate gross WTP for residential water as set out in Gibbons (1986):[107]

$$GWTP = \left(\frac{PQ_2^x}{1-x} \right) \left(\frac{Q_2}{Q_2^x} - \frac{Q_1}{Q_1^x} \right)$$

Where:

- Q_1 is residential consumption

- P is the volumetric charge

- x is the inverse of price elasticity (i.e. $1/e$, where e is the price elasticity of demand)

Using this method, together with price and quantity data from the Anglia water companies' annual report to Ofwat, the following values were estimated:

- Quantity of metered water consumption in 2008-09 in Anglia = 216,416.0124 Ml/y[108] (assuming all households are metered)

- Average volumetric price of metered water consumption in 2008-09 in Anglia = £1,015.50/Ml (mean value across all tariffs)[109] or £1.02/m^3 (rounded to 2 decimal places)

- Price elasticity = -0.2 (as used in Moran & Dann (2008))

- Marginal value = £1,015.488269/ML (using the point expansion estimation technique set out in Moran & Dann (2008)) or £1.02/m^3.[110]

Assuming a linear demand curve, the following curve was estimated:

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[106] Moran, D. and Dann, S. (2008),' Economic Value of Water Use Implications for Implementing the Water Framework Directive in Scotland', *Journal of Environmental Management*, Vol. 87, pp.484-496.
[107] Gibbons, D. (1986), 'The Economic Value of Water', Resources for the Future, Washington D.C.
[108] Ofwat (2009), 'Annual returns data', Available at: www.ofwat.gov.uk/regulating/junereturn/jrlatestdata/sub_jr09_anh_datatables2.xls (Accessed 30/4/13)
[109] Ofwat (2010), 'Volumetric water charges for metered households 2001-02 to 2010-11', Available at: www.ofwat.gov.uk/content?id=ec55fad0-585b-11df-8460-ef021dc9a7ef (Accessed 30/4/13)
[110] The lack of difference between the two rounded estimates is due to the inherent limitations of the point estimation technique combined with the small impact of one additional ML of water relative to current regional use of ~216,000 ML each year. At an individual level, 2008-09 consumption was 50.78 m^3/y with a price of £1.02/m^3. Using the same technique, the estimated marginal value of an additional unit of water is £0.97/m^3.

**Figure 19 Residential water demand in East Anglia**
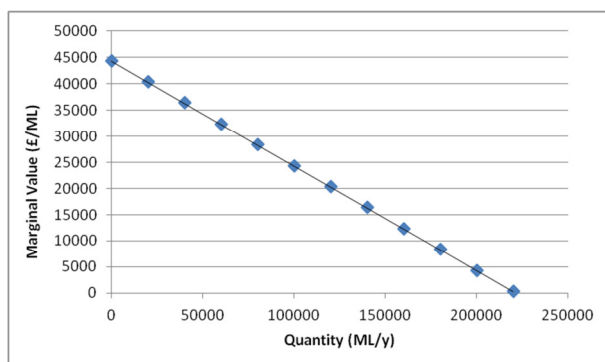
As described above, the point expansion estimation technique used in Moran & Dunn can be used to estimate the gross willingness of a household to pay for one additional unit of water. However, trying to estimate a demand curve from this point requires several simplifying assumptions.

Firstly, it must be assumed that the demand curve is linear, with constant slope. However, this is unlikely to be the case as willingness to pay for units of water above the level of basic needs is likely to be much lower than that below the level of basic needs

In reality the demand curve is more likely to be non-linear. In Figure 20, for example, a non-linear demand curve is estimated using the method set out in Hoekstra et al. (2001)[111] using the same input data described above and assuming the demand curve takes the form $MV = \alpha Q^{\frac{1}{e}}$.

As is clear from the example, the assumption over the shape of the demand curve makes a significant difference over estimates of the marginal value of water; in this case the marginal value of water is relatively flat then increases rapidly below a certain quantity.

Figure 20 Residential water demand in East Anglia
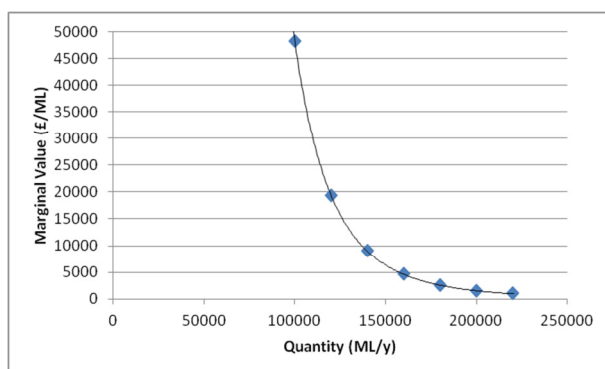
Second, using a single point to extrapolate an entire demand curve also assumes that all households within the Anglian region behave in a similar manner, despite the fact that not all households are metered, households are subject to different price tariffs, households are of

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[111] Hoekstra et al. (2001), 'An integrated approach towards assessing the value of water: A case study on the Zambezi basin', *Integrated Assessment,* 2: 199–208,

different size, some households have gardens while others do not. The estimate is also heavily dependent on the behaviour in one particular year (in this case 2008-09). Such a demand curve does not, therefore, account for inter-annual variations or long term changes in demographic and climate trends. The particular measure of elasticity is also subject to a significant degree of uncertainty considering the lack of robust UK estimates.

To estimate a more robust demand curve a much more comprehensive data set is needed than a single point. The most suitable method for estimating residential demand curves is likely to be regression analysis. Regression analysis requires a data set which contains either: data on household water consumption for a particular area over time as well as data on water prices and the other determinants of demand (as identified in Section 2.3); or water consumption data across a number of areas in a particular year as well as data on water prices and the other determinants of demand (as identified in Section 2.3). The demand curve can then be estimated by regressing the dependent variable (in this case the quantity of water used) against a series of factors which influence demand.

For example, by comparing residential water use within a region during a particular period to the average unit price of water, the average temperature and rainfall, total population, meter percentage, and the rate of GDP growth, a basic demand curve could be estimated using standard regression techniques:

$$Quantity = \alpha + \beta_{price}Price + \beta_{temp}Temp + \beta_{rain}Rain + \beta_{pop}Pop + \beta_{meter}Meter + \beta_{GDP}GDP$$

Then, by holding each of the characteristics constant and varying the price, the equation could be used to estimate how household demand varies in response to changes in price. Plotting these points graphically could then be used to derive a simple residential water demand curve for the UK as a whole or for a particular region. Other factors can then also be varied to test the impact of different scenarios on residential water demand; such as modelling climate change scenarios through increasing the average temperature or modelling demographic changes through increasing the level of population or GDP growth.
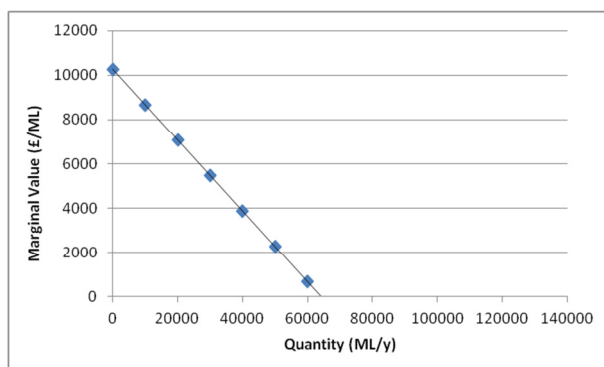
7.2.2   *Agricultural*

A similar approach can be adopted for estimating demand curves for irrigated agriculture. The following variables were used to estimate the demand curve:

- Quantity of water abstracted for agriculture in 2009 in Anglia = 58,400 ML/y[112] (including spray irrigation and other agriculture but excluding fish farming, cress growing, amenity ponds)

- Price elasticity = -0.16 (as used in Scheierling *et al.* (2006))

- Marginal value = £920/ML (based on average value in Moran & Dann (2008)) or £0.92/m^{3}.

Assuming a linear demand curve, the following curve was estimated:

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[112] Environment Agency (2011) Actual abstraction data 2000 – 2011. Downloaded from http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)

Figure 21 Agricultural water demand in East Anglia

Again, however, there are a number of limitations with this demand curve. The first is, as described above, the slope is assumed to be constant (in this case it is assumed to be -0.16). In the agricultural sector, however, price elasticity is likely to differ in the short and long run. While a farmer may not be able to reduce water use in a particular year without reducing the quality and quantity of that year's crop (making the short run relatively inelastic), over the longer term, farmers can choose to plant less water intensive species or adopt more efficient water saving practices, thereby making water demand more elastic.

Further, as described in section 4.3, water demand is heavily dependent on the type of crop planted and the point in the growing season. Knox et al. (2000), for example, find the benefits from irrigation are highest in April and May then decrease steadily to zero in September, while a study looking at agriculture in East Anglia[113] estimates that the marginal value of irrigated water for various crops ranges from 0.003-2.89 £/m^3.

A more robust estimate of demand would require individual demand curve estimates for each of the key crops grown in each region, as well as for non-irrigation water use such as in dairy farming, which could then be aggregated into a regional water demand curve.

7.2.3 *Industrial*

The demand curves for industrial water use can be derived in a similar manner to those for residential and agricultural use. The power generation sector is excluded from this illustrative analysis due to its unique nature relative to other industrial uses, in particular, the high rate of return flows. With this caveat in mind, the following variables were used to estimate the demand curve:

- Quantity of water abstracted for industry in 2009 in Anglia = 44,895 Ml/y[114]

- Price elasticity = -0.4275 (average across food, beverage, non-metallic mineral products, and chemical and chemical products industries using data from SEPA (2005) and Reynaud (2003))

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[113] Knox, J. W., J. Morris, E. K. Weatherhead, and A. P. Turner (2000), Mapping the financial benefits of sprinkler irrigation and potential financial impact of restrictions on abstraction: A case-study in Anglian Region., Journal of Environmental Management, 58, 45–59.
[114] Environment Agency (2011) Actual abstraction data 2000 – 2011. Downloaded from
http://www.defra.gov.uk/statistics/environment/inland-water/ (accessed 24/01/13)

- Marginal value = £208.75/Ml (average across food, beverage, non-metallic mineral products, and chemical and chemical products industries using data from SEPA (2005) and Reynaud (2003)) or £0.21m^3.

Assuming a linear demand curve, the following curve was estimated:

Figure 22 Industrial water demand in East Anglia
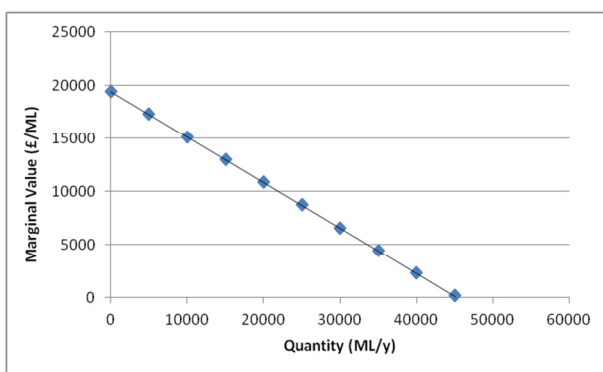
Again however there are considerable limitations with such a simplistic estimation of demand. As in the agriculture sector, the marginal value of water and the elasticity of water is likely to vary significantly across different industries; particularly the power sector.

Further, this abstraction data focuses solely on industrial water directly abstracted from the environment. As discussed in section 6.1, a significant proportion of the public water supply is used across a range of industries. This factor complicates matters further because the price of water faced for using water from the public supply is very different to that faced when abstracting directly from the environment.

A more robust estimate of demand would require individual demand curve estimates for each of the key industries in each region (including those using water from the public water supply and those directly abstracting from the environment) which could then be aggregated into a regional water demand curve following a stepwise function (i.e. separate demand curves for each type of industrial use laid on top of each other), with an entirely separate demand curve estimated for the power sector.

7.2.4 *Environment*

Due to the lack of willingness to pay and elasticity studies for environmental water use, it is not considered possible to derive a meaningful demand curve for environmental water uses in England; however, a study from Australia provides an illustration.

In a landmark study on the Murray-Darling Basin in Australia, the Wentworth Group of Concerned Scientists used the best available science to arrive at the conclusion that there is a substantial risk that a working river will not be in a healthy state when key system level attributes of the flow regime are reduced below two-thirds of their natural level.[115] As such, environmental water demand could be considered as a perfectly inelastic point whereby, after a certain quantity of water is abstracted, the ecosystem reaches a critical threshold and begins to decline sharply.

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[115] Grafton et al. (2010), 'Sustainable Diversions in the Murray-Darling Basin', Available at: www.wentworthgroup.org/uploads/Sustainable Diversions in the Murray-Darling Basin.pdf (accessed 30/4/13)

Using such an approach, the demand for environmental water could be estimated to be 66% of total water supply in each region. However, it is important to note that the method for environmental demand estimation is based on a case study from Australia and so care should be taken when applying it in a UK context. While the underlying approach for estimating the amount of water required in a particular river system to meet environmental needs is directly transferable to the UK, transferring the figure estimated for a particular river system in Australia, without taking into account UK specific factors is likely to produce significant error margins. This is because the level at which the critical threshold level is reached is likely to vary considerably between countries and on a river-by-river basis within countries, as well as on a seasonal basis within particular rivers.

7.3 The supply curve for East Anglia

As set out in section 6, it is likely to be possible to derive supply curves for private water companies (including the fixed costs of investing in different supply options as well as the costs of clearing, purifying, and pumping water through the distribution system) through the data contained in their annual submissions to Ofwat. However, it is unlikely to be possible to estimate the costs of securing supplies for the agriculture and industrial sector given the data available. Further, the marginal abstraction costs of abstracting water for both private water companies as well as industrial and agricultural extractors is likely to be close to zero in the absence of volumetric abstraction charges. As such, the marginal cost of supply curve is estimated to be zero for the purposes of this example. A potentially useful feature of the optimisation model would be to introduce a supply curve into the model based on the introduction of a volumetric abstraction charge in each region. This would allow the model to predict the impacts of introducing a charge on water abstractions on the allocation of water, as well as the costs and benefits to society of such a charge.

## 7.4 Optimising the allocation of water in Anglia

With these extensive caveats in mind, the illustrative demand curves for the three key sectors in the Anglian region are shown together in Figure 23.

Figure 23 Marginal value of water use in Anglia for residential, agriculture, and industrial uses (Illustrative purposes only)
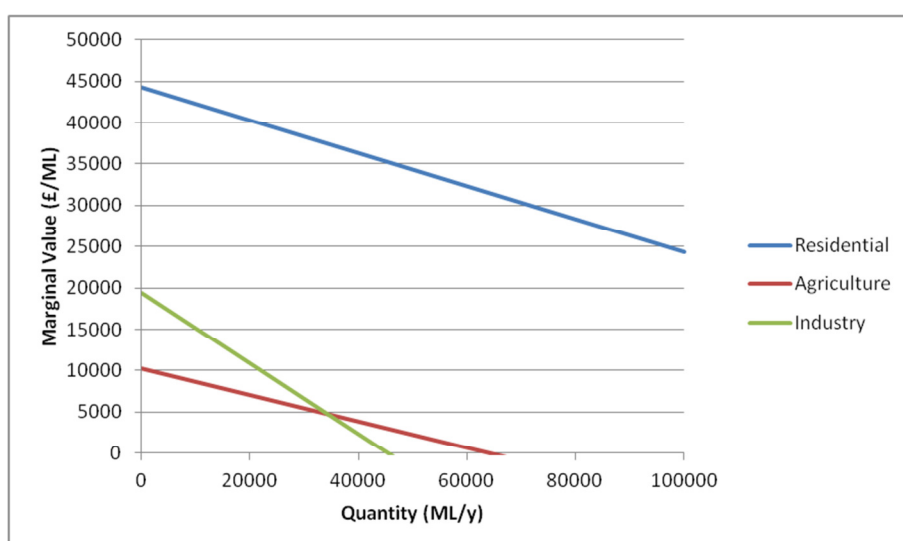
In order to run the optimisation model, the total benefits of water use in each of the different
sectors would need to be estimated. The area under the marginal value curve is equal to the
total benefits of the water used in that sector. The total benefits can be estimated through
integration; a standard mathematical technique used to estimate the area beneath a curve.
The curves are shown in Figure 24:

**Figure 24 Total value of water use in Anglia for residential, agriculture, and industrial
uses (Illustrative purposes only)**
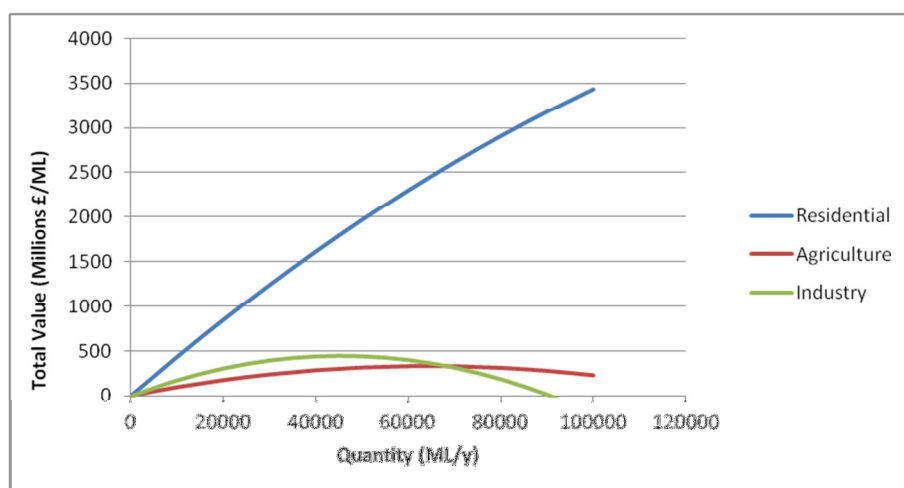
With the marginal and total values of water in each sector estimated, the allocation problem is
to maximise the net total value (NTV) to society by allocating optimal quantities of water to
each of the competing sectors (Q_a is the quantity of water allocated to agriculture, Q_i for
industry, Q_r for residential, and Q_e for the environment). This allocation will be subject to
constraints in terms of the total annual water supply (S), the level of environmental flows
required to avoid environmental damage (E), and the amount of water required to meet basic
human needs in the residential sector (R).

$$Max_{Qr,Qa,Qi}NTV = [TV_r(Q_r) - TC_r(Q_r)] + [TV_a(Q_a) - TC_a(Q_a)] + [TV_i(Q_i) - TC_i(Q_i)] + Q_e$$

Subject to:

$$Q_e \geq E$$

$$Q_r \geq R$$

$$Q_r + Q_a + Q_i + Q_e \leq S$$

As set out in section 7.3, in this example the marginal cost of supply is assumed to be equal to
zero for each of the sectors. The total available water supply for the Anglian study region in
2009 (S) is estimated to be 3,905,500 Ml (total abstractions were 859,210 Ml and an estimated
22% of total available resources were abstracted – this estimate could be improved by looking
at the CAMS data for each catchment in the region). The amount required for environmental
flows (Q_e) is estimated to be 2,577,630 Ml as set out in section 7.2.4. The minimum amount
required to meet basic human needs (R) in the residential water sector (to cover drinking,
sanitation, and hygiene) is estimated to be 50 l/p/d or 77,774.7475 Ml.[116] Adding these

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[116] Gleick, P. (1996), 'Basic Water Requirements for Human Activities: Meeting Basic Needs', *Water International,* Vol. 21. pp. 83-92.

constraints to the optimisation model will ensure that: (a) environmental requirements are met before any water is allocated; (b) basic human residential water requirements are met before any water is allocated (calculated by multiplying the population by a fixed level of basic personal water requirements); and (c) the total supply of water is allocated between the four sectors.

Solving this optimisation problem would calculate the optimal allocation of water across the four sectors within the case study region (as well as the optimal price for water) and the net total benefit to society from allocating water efficiently.

In order to illustrate this impact a simple optimisation has been carried out for the Anglian region using the data described in the previous sections. However, it is important to note that, due to the lack of data and myriad of assumptions made, the outcome is illustrative of the *method only*, and should not be taken as an indicative value. The results of the illustrative optimisation model are shown in Figure 25.

Figure 25 Current vs. optimal allocation of water in Anglia (Illustrative purposes only)
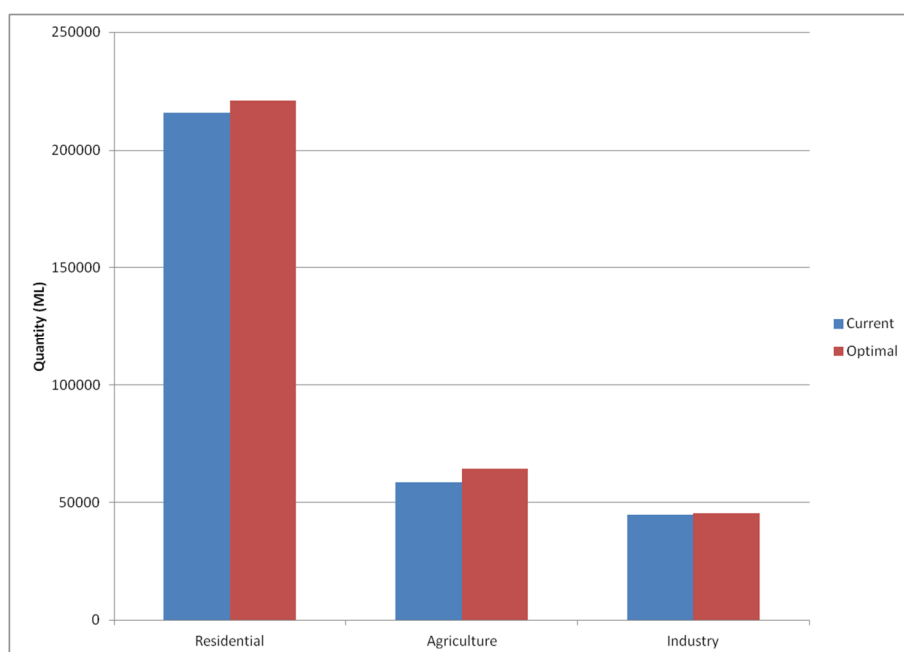
Moving to an optimal allocation within the constraints of this model, residential water use would increase by 2.3%, agricultural water use by 9.8%, and industrial use by 1.1%. This would generate a total net benefit of around £5.3 million each year. Due to the simplifying assumptions made (constant elasticity and zero marginal cost) the optimal allocation is only marginally different to the current allocation. This is because, if marginal costs are zero (or close to zero), abstractors are likely to currently be abstracting water up to the point where the marginal benefit of withdrawing another unit of water is equal or close to zero, so additional use in any of the sectors is unlikely to significantly change the total benefits (in practical terms this is demonstrated by the fact that the actual level of abstractions is significantly lower than the number of licences which are granted). Further, since it is assumed that elasticity is constant, it is assumed that abstractors cannot invest in any technology/processes which may increase their demand for water and so increase the benefits of using additional units (e.g. it is assumed that within the scenario year, farmers cannot plant an extra field of potatoes which would increase their demand for water).

In the context of the model, the supply constraint is not binding on the decisions of any abstractors i.e. there is more than enough water to meet the demands of the residential, agriculture, and industry section, as well as meeting environmental needs. In such a situation, the optimal allocation in the model is only likely to change significantly during periods of water shortage, when sudden constraints on the water supply mean that abstractors are no longer able to extract their desired level of water and the supply constraint becomes binding. In such cases, the optimal allocation of water is likely to change depending on which sectors have the highest marginal value of water. For example, if the total available water supply dropped by 30% to 2,800,000 Ml (either through a reduction in abstraction licences or during a period of drought) then the supply constraint would become binding and water would have to be reallocated between sectors. Assuming that the environmental flow requirements stays constant, the optimal allocation of water in the model would lead to a reduction in residential use by 16.1%, agricultural use by 75.7%, and industrial use by 40.6%. The net cost to the Anglian region would be around £430 million. Again, it is important to stress that such an example is illustrative of the potential uses of an optimisation model, rather than being taken as actual estimates of any likely scenarios.

Figure 26: Changes in water allocation during periods of water shortage (Illustrative purposes only)
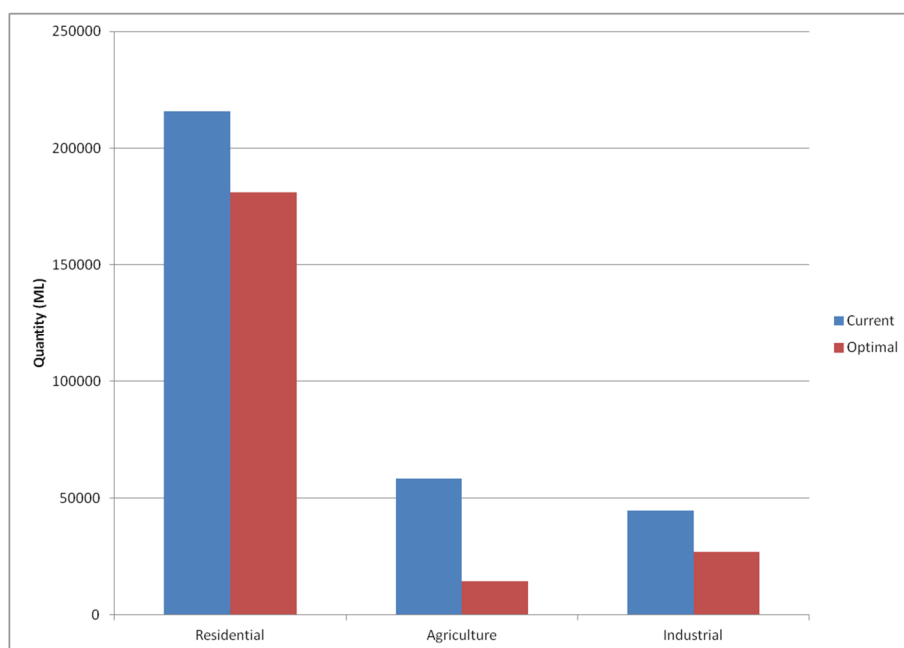
This exercise serves to illustrate the methodology of setting up a simple optimisation model to look at the impacts of water allocation decisions. The model could be used to predict the impact of various scenarios such as climate change, population growth, demographic change etc. The simple model illustrated in this section could also be extended to account for catchment level variations, temporal variation, demand in other sectors (such as the power sector), the impact of introducing a volumetric abstraction charge etc.

8. CONCLUSIONS AND RECOMMENDATIONS

By applying a set of simplifying assumptions, and using the available data, it is possible to estimate illustrative demand and supply curves for each of the key abstractors and the environment and to paint a picture of how water allocation might change under conditions of increasing water scarcity. However, these are not considered sufficiently robust to inform discussions around an optimal allocation of water for the purposes of policy- and decision-making.

Further work would be required to:

- Collect data on the area of agriculture (and crop types) under spray irrigation (e.g. using Farm Business Data);

- Collect data on the number of power stations and generating capacity within each region / catchment (available from DECC) and the volume of water required to produce one MWh for each different type of power station;

- Estimate willingness to pay for water amongst non-metered households (for clean water only);

- Consider variation of willingness to pay between and within regions;

- Examine the implications and effects of storage and inter-regional transfers;

- Test the sensitivity of the outcomes to changes in assumptions around marginal values and, more importantly, to changes in the scale of analysis (i.e. to capture features such as relative water scarcity, movement of water between water resource zones or across catchments); and

- Consider differences in short- and long-run demand curves.

The optimisation approach described in the previous chapter could be adopted if more time was available to collect data on a regional/catchment level. However, given the intensive data and resource requirements for completing the optimisation model, a more feasible approach may be to adopt a discrete approach to deriving demand curves for water use across the different sectors.

This approach would involve estimating a single demand curve made up of the quantities used and willingness to pay for each of the different uses. An example of such an approach is shown in Figure 27 using the data described in previous sections of this report. The demand curve plots the total quantity of water used for each use and the willingness to pay for an additional unit of water for that use. The area under the demand curve provides a rough estimate of the total value of water across different uses. Such a curve could be derived at a regional or national level by using data on water uses within each region.

Figure 27 Example discontinuous demand curve for water use in Anglian region
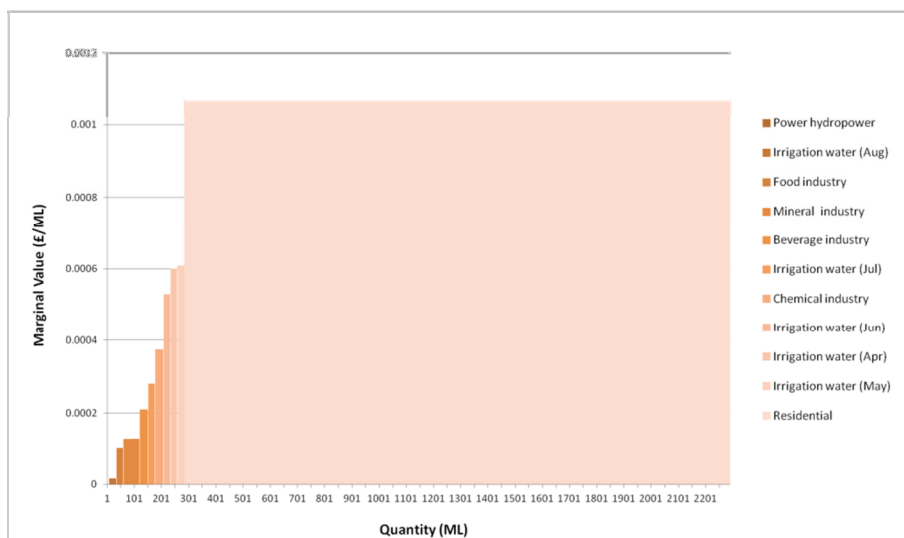
The benefits of reallocating water across uses could then be estimated in order to assess how the allocation of water could be improved (although an optimal allocation would be difficult to determine). Demographic, climate, and economic changes could be introduced into the model by, for example, expanding the demand for energy use. While this would not be as detailed nor as comprehensive as the optimisation approach, given the data available it may be a more useful and feasible option.

APPENDIX A   RESEARCH PROTOCOL

URS

ASC Water Abstraction Optimisation: Research Protocol

Prepared for:
Adaptation Sub-Committee

UNITED KINGDOM & IRELAND

Committee on Climate Change Adaptation

REVISION SCHEDULE

Rev	Date	Details	Prepared by	Reviewed by	Approved by
1	26th March 2013	Research protocol	Chris White Environmental Economist	Lili Pechey Principal	Petrina Rowcroft Associate

URS
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1 INTRODUCTION

1.1 Background

The Adaptation Sub-Committee (ASC) of the Committee on Climate Change has a statutory duty to report to Parliament with an independent assessment of the UK Government's progress in implementing its National Adaptation Programme. This programme, due for publication in 2013, will set out the Government's objectives and policies for adaptation, addressing the risks and opportunities identified by the UK Climate Change Risk Assessment (CCRA), published in January 2012.

In making an independent assessment of progress in its statutory report due in 2015, the Committee will have to assess whether the NAP is enabling the UK's preparedness for the key climate change risks it faces. In preparation for this, the ASC is undertaking analysis to look at the preparedness for the main risks and opportunities facing the UK from climate change, and is halfway through a series of annual progress reports:

Completed:

- 2010- identifying priorities for adaptation and the ASC's approach to assessing progress

- 2011- preparedness in land use planning, managing water, building design/renovation

- 2012- preparedness for flooding and water scarcity

Planned:

- 2013- preparedness in natural environment, agriculture, forestry

- 2014- preparedness in health, energy, business supply chains

- 2015- statutory report to Parliament

How water is used and distributed amongst different users in England is a key aspect of considering preparedness for climate change, and has particular links to the Committee's analysis in 2013 on agriculture and the natural environment (as well as analysis already completed on public water supply in 2012).

Climate change and population growth are likely to increase the risk of future water scarcity. It is estimated that there will be an extra ~9 million people in England by the 2030s, and climate change is likely to change the seasonal patterns of rainfall and increase the risks of drought. As such, the allocation of scarce supplies to users in accordance with how much they value water and incentives to use water more efficiently are important adaptation actions.

Water allocation between various human uses and the natural environment is currently operated through the Abstraction Regime in England. The historic abstraction regime, in place since the 1960s, was not designed to optimise the sharing of available water between users; instead its aim was to prevent interference between different abstractors.

There are two major issues with the current abstraction system from a climate change adaptation perspective:

- The volume of water permitted for abstraction is not dynamically linked to the actual volume of water available. Charges for abstraction licenses are fixed, which means

that the amounts of water permitted for abstraction bear little relation to the amount of water available through time.

- Charges for licences are not linked to the volumes abstracted, so they do not reflect the availability of water or the competing demands and value that users place on it. Once water is allocated, there is no financial incentive to use it efficiently, or to consider its scarcity and other environmental impacts.

It is apparent that the current system is not optimising the allocation of water. In some cases users are taking more water from rivers and aquifers that is naturally being replaced, not leaving enough to maintain a healthy ecosystem (demand is greater than supply). For example, 11% of rivers are being investigated for not reaching good ecological standards due to over-abstraction.

With this in mind, Defra's Water White Paper (2011) stated that the current abstraction regime will be reformed to make it more responsive to future risks of water scarcity. Options for how this should be done are currently being scoped by Defra, including research on how water trading could operate to ensure a more efficient allocation of water. A new abstraction regime is due to come into force by 2027.

1.2 This paper

Population growth, economic growth, climate change and rising water supply costs are likely to drive up the general value of water. The aim of this research is to establish the extent to which an alternative abstraction regime would result in a more efficient allocation of water under a changing climate. In doing so the analysis will seek to answer the following questions:

1. How do different abstractors value water?

2. How water supply and the costs of supply vary over time and space?

3. How would a system that optimises allocation affect the distribution of water under different future climate and socio-economic scenarios, compared to the way water is currently distributed?

4. What is the net benefit of such a system over the current regime?

The first task of this project is to carry out a review of the literature in order to answer questions 1 and 2 from the list, above. The purpose of the protocol is to describe all the decisions regarding how the review will be undertaken – from information retrieval to the synthesis of review findings. A systematic review methodology will help ensure that all the available research evidence (necessary for developing robust analysis) is retrieved. In addition, information contained in the protocol will form part of the progress report, which will help with the management of the review.

2 KEY RESEARCH QUESTIONS TO BE ADDRESSED

To inform the development of a model which optimises the allocation of water across different abstractors and quantifies the net benefit of such a system over the current regime, the first task will be to develop a more detailed understanding of the values that different abstractors place on water and the costs of supplying water to different abstractors.

This task involves a detailed literature review to establish:

- Demand curves for different abstractors;

- The demand curve for the natural environment; and

- Supply curves for different abstractors and/or catchments in England.

Drawing on the available literature, the aim of this task to set out:

- The most appropriate spatial level at which to derive such curve; and

- Short run and long run curves for both demand and supply.

3   THE REVIEW PROTOCOL

3.1   Search strategy

The search strategy covers the resources to be searched and the search terms to be employed. The aim of the search strategy is to identify as many sources of information as possible in order to ensure that the research questions can be fully addressed. However, there is likely to be a compromise between the sensitivity of the search strategy (in order to identify as much material as possible), and the need to focus the search in order both to exclude irrelevant material and to contain the amount of information retrieved.

3.1.1   *Resources to be searched*

We will rely extensively on use of the internet to both identify and obtain relevant studies. Search engines and journal databases to be interrogated will include (but will not be limited to):

Google Scholar	ParesFirst
ScienceDirect	SSRN
JSTOR	Citation databases e.g. Web of Science
Ingentia	IDEAS
Interscience	IBSS (BIDS)
REPEC	IDOX
Proceedings First	ESRC Database

Some of the key sources which we expect to draw on include:

- Water Data Hub

- Global Water Forum

- WRAP

- Ofwat

- EA National Abstraction Licensing Database (NALD)

- EA Water situation reports and frequency analysis bands

- Defra

- Water company Water Resource Management Plans

- CAMS documents

- UKWIR

- Water UK

3.1.2 Search terms

Each search engine and database will be searched using a range of keywords. Search terms can be used either singularly or in combination and would use as a starting point to identify relevant literature. These include:

- Value / water / residential / demand / elasticity

- Value / water / industry / demand / elasticity

- Value / water / agriculture / demand / elasticity

- Value / water / environment / demand / elasticity

- Cost / water / residential / supply

- Cost / water / industry / supply

- Cost / water / agriculture / supply

- Cost / water / environment / supply

3.1.3 Study selection criteria

The inclusion and exclusion criteria have been developed to assist with providing a review that has coherence and is manageable. The aim of study selection is to identify those articles that help to answer the review questions. Therefore, selection criteria (both inclusion and exclusion criteria) should follow logically from the questions and they should be defined in terms of the population, the interventions, the outcomes, and the study designs of interest. In order to be selected, a study should fulfill all of the inclusion criteria and none of the exclusion criteria.

The study selection procedure consists of several stages. Initially, the criteria are applied to the citations generated from searching to make a decision about whether to obtain full copies of potentially relevant references. Once copies are obtained the inclusion/exclusion criteria are applied and decisions made about inclusion of each study. Details must be given about the way in which decisions concerning the selection of individual reports are made.

The selection criteria are described below.

Geographical coverage

The scope of the study is restricted to England but, where appropriate, studies from Scotland and Wales may be reviewed in case they contain relevant data. We will also review the Australian abstraction reform model as a working example of where the allocation of water has been optimized through a process of abstraction reform.

Language

The search will be conducted in English.

Timeframe

The review will focus on evidence sources that have been produced in the last ten years (i.e. since 2003).

Quality

This is, to an extent, subjective, but can be tested by reference to the number of citations and the quality of the journal the article is found in. Similarly, articles or reports for major organisations such as Defra will have high credibility. Working papers may be considered acceptable if they are written by authors with a track record in the field (i.e. who have been cited elsewhere in peer-reviewed publications).

The quality of grey-literature and business reports will be judged on a case-by-case basis and appropriate parameters for judging the quality and relevance of the literature/data will be developed.

Theoretical or empirical

Whether or not the article is theoretical or empirical may play a part in determining its inclusion or otherwise. This is particularly important when collecting data to estimate supply and demand curves as the reliability of any estimated curves will be heavily dependent on whether the data is theoretical or empirical.

If the study identified meets the selection criteria, it will be accessed and a further sift will be undertaken based on more detailed exclusion/inclusion criteria. These will be developed to assist with providing a review that has coherence and is manageable. The aim of study selection is to identify those articles that help to answer the review questions. Therefore, inclusion and exclusion criteria should follow logically from the questions and they should be defined in terms of the population, the interventions, the outcomes, and the study designs of interest. In order to be selected, a study should fulfill all of the inclusion criteria and none of the exclusion criteria.

3.2   Information extraction strategy

Data extraction is the process by which the information needed for data synthesis is obtained. In order that we can keep track of all sources of information identified during the review, it is important that each researcher records details of the primary information source. For this purpose, we will develop an inventory or reference database of studies that will serve to:

- Keep a record of the sources of all information gathered

- Help prevent duplication of research

- Help ourselves and others identify any obvious gaps in our sources before (and if) any further sifting processes are applied

The inventory will be in the form of a simple Excel database. The information to be recorded for each for each piece of literature will include, at least:

- Author name

- Date of publication

- Publication name

- Volume number and issue number where relevant

- HTML link to source (where available)

- Study abstract (where possible)

- Key words and JEL reference (where given)

More specific information will also be captured. This may include:

- Methodology/approach used
- Study location
- Values of water use
- Costs of water supply

3.3 Synthesis of extracted evidence

The aim of the synthesis is to collate and summarise the findings of the review (i.e. the information stored in the database) into a format that is both useful and relevant to the ASC's requirements.

4 RESOURCING

Within the scope of the revised budget, a total of six days have been allocated to the literature review. We propose to allow one day of research per sector for the demand side and two days for the supply side review.