ADAPTING TO CLIMATE CHANGE: PUBLIC WATER SUPPLY IN ENGLAND AND WALES

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Abstract. This paper describes an assessment of the ways in which water supply companies in England and Wales are adapting to climate change, evaluated in the context of a model of the adaptation process. The four components of the model are (i) awareness of and concern about the potential impacts of climate change, (ii) adaptation strategy, (iii) the concept of an adaptation space from which options are selected, and (iv) the notion that three groups of factors influence awareness, strategy and option selection: susceptibility to change, internal characteristics of the organisation, and regulatory and market context.

Public water supply in England and Wales is provided by private sector companies, subject to environmental and economic regulation. Hydrological simulations suggest that climate change has the potential to reduce the reliability of supply sources over the next few decades. The industry in December 2004 completed a review of investment requirements over the next five years.

Awareness of climate change is high in the water industry, but by developing assessment procedures and incorporating them into the investment review the regulators forced companies to consider explicitly the potential impacts of climate change in a consistent and rigorous manner. These analyses combined climate change with other pressures on water resources, and in practice companies did not attribute specific investment decisions or proposals to climate change or indeed any other individual drivers. The broad strategy adopted by all water supply companies – to maintain standards of service – is determined by regulatory controls and market considerations, but the degree of concern about the impacts of climate change and precise adaptation options necessary to address supply-demand imbalances varied between water supply companies, reflecting local geographic conditions. The water supply companies and regulators have different perspectives on the relative merits of supply-side and demand-side measures, reflecting different organisational priorities.

The 2004 investment review determined that no specific actions were necessary to deal with future climate change, but that measures set in place – in terms of methodologies and investment in investigations into specific resource developments – provided a sound foundation for more specific actions in the next investment review in five years time. The paper concludes by summarising the factors assisting and constraining adaptation over the next few decades.

1. Introduction

Over the last few years the literature on adaptation to climate change has expanded considerably, and broadly falls into a number of different categories. Some explore conceptual issues such as definitions and classifications (e.g. Smith, 1996; Smit et al., 2000; Yohe, 2000;Yohe and Tol, 2002), and others seek to demonstrate the benefits of different adaptation options, either generally (e.g. Reilly and Schimmelpfennig, 2000) or for specific case studies (e.g. Miller et al., 1997; de Loe

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et al., 2001; Yohe and Schlesinger, 2003; Tol et al., 2003; Beuhler, 2003; Payne et al., 2004). Some draw lessons from adaptation to climatic variability or extreme events (e.g. Schneider et al., 2000 and Tol et al., 1998), and others focus on how adaptation can reduce vulnerability to climate change (Kelly and Adger, 2000; Yohe, 2000; Adger et al., 2003). There have, however, been very few case studies either of how individuals and organisations are actually adapting to climate change, or of the constraints on their actions and decisions: a exception is the agriculture sector (e.g. Bryant et al., 2000; Finan et al., 2002), although here it is difficult to separate adaptation to climatic variability from adaptation to a long-term climate change.

This paper examines adaptation to climate change by water supply companies in England and Wales. It has three specific aims. First, it provides an empirical case study of real-world adaptation practice and processes. Second, it uses this information to test a conceptual model (based on that of Berkhout et al., 2003) which seeks to describe adaptation processes, and third, it examines the factors which influence the ability of organisations to make and implement adaptation decisions. By doing this, the paper seeks to provide valuable insights into the factors affecting adaptation to climate change of organisations in general.

The study is based on analysis of published material, business reports, websites and in-depth interviews conducted with a sample of private-sector public water supply companies in England and Wales. In principle, it is possible to examine the adaptation of these companies in two ways. The first is to explore their adaptation as private-sector entities, free to alter their product range and to move into and out of different markets: one adaptive response to water shortage, for example, could be for the company to withdraw from the water supply business. The second is to focus on their provision of a certain service. This study takes the second approach, concentrating on water supply, for two main reasons. Firstly, water supply is a public good that has to be provided in some way, and there is a clear public policy interest in ensuring that supplies are maintained. Second, the water supply companies in England and Wales have long-term licences to operate, and cannot quickly move out of the water supply business. However, it is recognised that some companies are involved with more than just water supply, and that some companies are currently owned by holding companies with diverse interests: decisions made in the company as a whole may affect the ability to adapt to climate change impacts on water supply.

The next section describes the conceptual model of the adaptation process. Adaptation processes and constraints are very dependent on context, so the subsequent sections present in some detail water supply management in England and Wales[1] (Section 3), the sensitivity of water resources to climate change (Section 4), and the water resources planning process (Section 5). Section 6 applies the model of adaptation to water supply in England and Wales in order to characterise the different constraints and influences on the adaptation process. Finally, the last section attempts to draw some generalised conclusions about adaptation processes.

2. A Model of the Adaptation Process

Very few organisations remain static, and virtually all change what they do and how they do it over time. This change may be generated internally (following a change in management, for example, or a policy of innovation and development), following technological change, or may be in reaction to changes in external conditions, such as demand, regulatory context or access to natural and other resources. Climate change is one of many drivers which may lead to changes in the external conditions for an organisation, but is distinctive in two main ways. It affects the natural resources used by the organisation – conventionally these are assumed to be constant – and second it is both uncertain and, in many senses, contested and controversial.

Berkhout et al.'s (2003) model of the adaptation process, as slightly revised here, has four basic elements: awareness of and concern about the potential impacts of climate change, the idea of an adaptation strategy, the concept of an adaptation space affecting the selection of an action, and the notion that there are three groups of factors which influence awareness of threat, adaptation strategy, and which adaptation options are implemented.

Before an organisation embarks on adaptation it must be first *aware* of the potential threat of climate change, and second *concerned* about potential impacts on its business. Without awareness there will be no concern, and without concern there will be no adaptation (except in the extreme case where organisations are forced to adapt to climate change by imposition from a higher authority).

The *adaptation strategy* defines *what* the organisation is seeking to achieve by adaptation and *how* it intends to achieve it. Possible aims include continuing to provide the same standard of service or product to customers (using different methods if necessary), providing different products and services which broadly meet the same function, ceasing to provide the product or service at all, or ignoring climate change and relying on "muddling through". The aim of adaptation need not be explicitly stated.

Adaptation space is defined as the set of options which are potentially available to an organisation to deal with possible climate and other changes. Some of the options within this adaptation space will be more feasible than others, for technical, legal, economic or cultural reasons, and some may not be perceived at all by the organisation. The adaptation space is dynamic, as new options become available through, for example, technological development, and as understanding of the characteristics of change develops.

Three groups of factors shape awareness and concern, adaptation strategy and the perception and selection of adaptation options. The first – *susceptibility to change* - defines the way in which the organisation is susceptible to and impacted by changes in external conditions. These include changing patterns of demand, technological change, regulatory change and altered access to the natural resources needed to provide goods and services. Climate change is just one of these external drivers,

potentially affecting both demand and availability of natural resources. Susceptibility to climate change depends not only on the degree of climate change affecting the organisation, but also – and probably more importantly – on how the organisation uses climate resources, how it operates, and the time scales over which decisions are made and the consequences of decisions persist (its "sensitivity" to change). The same climate change will have different impacts on different organisations providing the same goods and services, if they provide those goods and services in different ways. Also potentially important is how sensitivity to climate change compares with sensitivity to other external pressures.

The *resources and capabilities of the organisation* determine how it responds to (or anticipates) challenges and pressures. Relevant factors include access to information and knowledge, management culture, access to resources (including funding) necessary to make changes, and external relationships with suppliers, customers, regulators and other stakeholders. Finally, the *regulatory and market context* can both impose constraints on what an organisation can do and act as a source of pressure for change.

3. The Institutional Context: Water Management in England and Wales

3.1. THE PROVIDERS

Since 1989 public water supplies have been provided by private-sector water companies under long-term licence agreements. Ten of these companies were privatised from public-sector utilities, and not only supply water but remove and treat effluent (they are known as the "water and sewage companies"). These companies are broadly based on major catchments. There are also (in 2004) 15 companies which only supply water (the "water only companies"). These are the descendents of a larger number of water only companies that have served relatively small areas for many years. Patterns of ownership are complicated and dynamic. Some companies are quoted on the stock market, either as water supply companies or as part of combined utility and waste management companies. Some companies are wholly-owned subsidiaries of companies (national and multinational) that are not publicly listed in the UK, two of the smaller water-only companies are owned by water and sewage companies operating in a different geographic area, and one is a "company limited by guarantee", with no shareholders and all surplus returning to the company.

The total amount abstracted by the water companies for public water supply in England and Wales in 2002/3 was 15400 Ml/d[2]: 56% of this was supplied to households, 25% was supplied to industrial, commercial and agricultural customers, and 18% was lost as leakage through the distribution network (Ofwat, 2003a: another 6% of the total abstracted was lost by leakage from customers' pipes). Direct abstractions by industry (except cooling water) totalled 3400 Ml/d in 2002, and

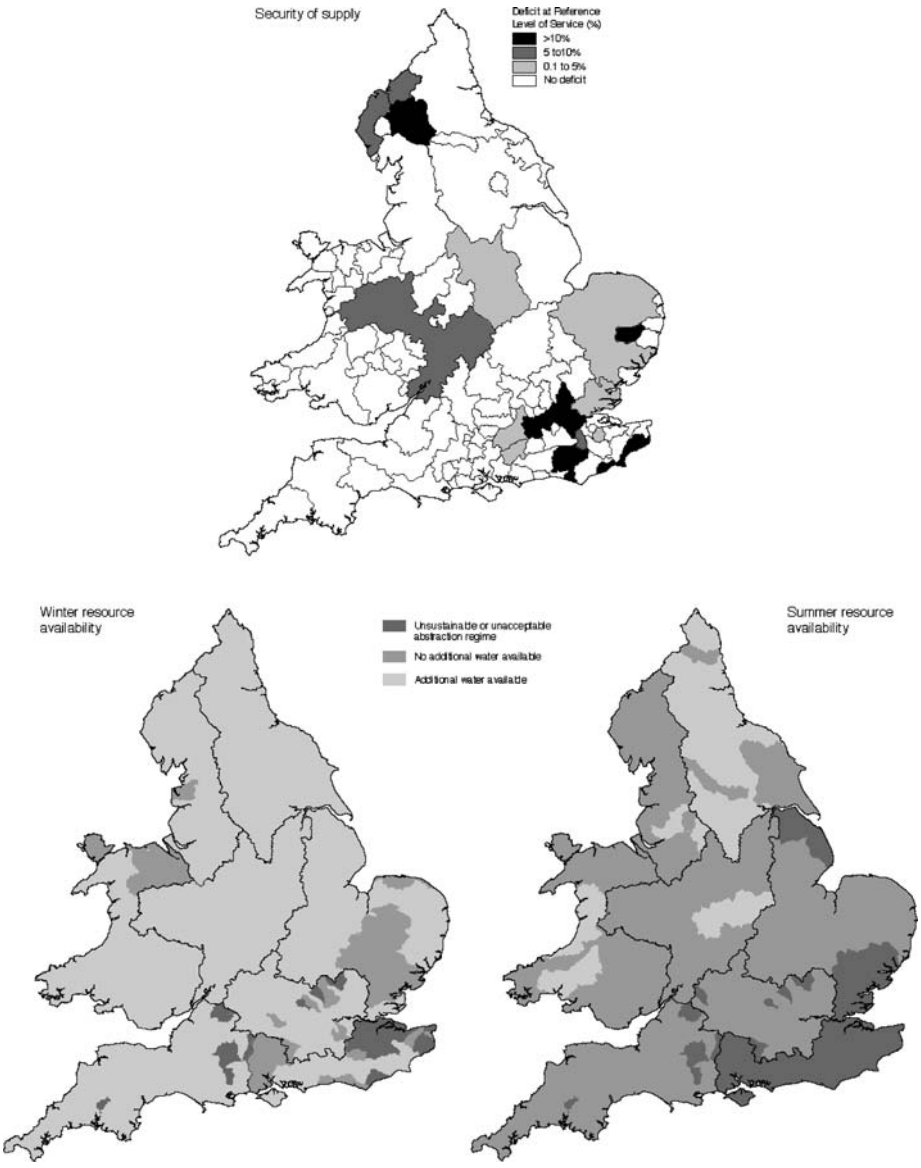

Figure 1. Water resources reliability and availability in England and Wales (after Ofwat (2003a) and Environment Agency (2001)).

actual abstractions for spray irrigation amounted to 460 Ml/d but were concentrated in the east and south of England. Figure 1 gives an indication of current patterns of water resource availability in England and Wales (Ofwat, 2003a, Environment Agency, 2001).

Industrial, commercial and agricultural customers pay by volume for their water supplies. The vast majority of domestic customers, however, pay a fixed rate fee

based on the rateable value of their property. Only 22% currently pay by meter, although the proportion varies between supply companies (Ofwat, 2003a). All new properties must install a water meter, and since 2003 customers have been able to request a meter free of charge ("optional metering"). Water supply companies can also require particular groups of customers to install meters ("selective metering"), such as those applying for licences to fill swimming pools or use hosepipes in the garden. Tariffs for domestic customers, however, currently do not vary with volume of water used.

3.2. THE REGULATORS

The water supply companies have three government regulators. The Drinking Water Inspectorate (DWI) regulates the quality of water delivered to customers. The Environment Agency has a duty to conserve, augment, redistribute and secure the proper use of water resources in England and Wales, and basically does this through issuing licences to abstractors and approving the water resources plans of water supply companies. The broad context for this regulation is set by the Department for the Environment, Food and Rural Affairs (Defra) for England and the Welsh Assembly for Wales, and by directives from the European Union. Economic regulation of the water companies is undertaken by the Office of Water Services (Ofwat), largely through determining the prices that can be charged to customers. Ofwat does this by periodically reviewing water industry investment needs and deciding how much each company can raise through its customers and how much it must raise from other sources.

3.3. CHANGING PRESSURES ON THE SUPPLY-DEMAND BALANCE

Ignoring for the moment climate change, four pressures affect the future balance between water supply and demand. Future demand for water in England and Wales is influenced significantly by assumptions about future patterns of regional population and economic growth, social change (specifically per capita water use) and control of leakage. The Environment Agency developed four scenarios for future demand, making different assumptions about growth rates and the efficiency of water use, resulting in changes in total demand in England and Wales between 1997 and 2025 of between -36 and $+61\%$ (Environment Agency, 2001). The regional pattern of change in demand is particularly relevant for individual water supply companies. In general, population growth is most rapid in the south and east of England, and there are plans for several major new housing developments in, for example, south east Kent, the Thames Gateway and north of London. Individual water supply companies in these areas project increases in demand by 2025 of up to 20% on 2003–4 levels (Environment Agency, 2004). The effects of increasing housing and economic development on demands for water in the south is identified as a major concern not only for water supply companies, but also for spatial planners in south

east England (South East England Regional Assembly, 2005). Smaller increases, due to increases in per capita use alone, are projected in areas where population growth is lower, and in some parts of England and Wales regional demand remains static or declines: this is sometimes due to reductions in industrial demands, but for some water supply companies is because reductions in leakage – a component of total demand – offset increases in domestic demand.

The second major driver of change in the supply-demand balance is increased demands for water to maintain instream ecosystems following the implementation of the European Union Habitats Directive and the Framework Water Directive. The Environment Agency estimated that this would amount to an additional 716 Ml/d of demand (just under 5% of the total amount withdrawn in 2002–3) by 2025 (Environment Agency, 2001).

The third driver of change is altered water quality, and most particularly the increasing necessity to dilute water from sources with high concentrations of nitrates: this in effect reduces the volume of water available for supply.

Finally, the use of revised methods to assess the yields of supply schemes can lead to changes in the calculated supply-demand balance. Recalculations in 2004 by water supply companies of their estimates of deployable output led to increases of up to 5% in some companies and an extreme reduction of 16% in one company (Environment Agency, 2004).

4. Sensitivity of the Water Supply System in England and Wales to Climate Change

4.1. SUPPLY AND DEMAND

Climate change has the following potential impacts on the water supply system:

- it may alter the *reliability of raw water sources* by changing the frequency of low flows and recharge, increasing the frequency of floods which may inundate bankside facilities, increasing the frequency of highly turbid flows and threatening abstraction points with saline intrusion;
- it may alter the *reliability of the supply infrastructure*, by for example altering reservoir safety;
- it may alter the *ability to treat raw water to potable standards* by changing the frequency of inundation of treatment works and by changing the quality of the abstracted water;
- it may alter the *demand for water* and the ability to distribute water to meet customers' needs, particularly at times of peak demand.

A distinction is often drawn between "supply-side" shortages, caused by a lack of raw water, and "demand-side" shortages, caused by an inability to distribute treated water quickly enough to customers at periods of peak demand. Changes in the quantity and quality of river flows and groundwater recharge may affect the

frequency of supply-side shortages; changes in peak demand for water may affect demand-side shortages.

4.2. CHANGES IN WATER RESOURCES

Several studies have explored the potential effects of climate change on river flows in England and Wales (e.g. Sefton and Boorman, 1997; Pilling and Jones, 1999; Arnell and Reynard, 1996, 2000; Limbrick et al., 2000; Arnell, 2001, 2003). Under the most recent UKCIP02 scenarios (Hulme et al., 2002) winter river flows are modestly increased by the 2020s, but summer flows are reduced by up to 30% in the south and east of England (Arnell, 2004). Other scenarios result in less extreme changes in flows, indicating the considerable uncertainty facing water supply managers. There have been fewer studies of potential changes in groundwater recharge, which is sensitive not only to changes in the volume of winter rainfall but also the duration of the recharge season (Yusoff et al., 2002). There are indications that under the UKCIP02 scenarios recharge will decrease (UKWIR, 2003).

The effect of such changes in river flows and recharge on water supply reliability, however, depends on how water resources are managed. A reduction in summer flows would be very important where water is abstracted directly from a river, but would be less significant where water is taken from a reservoir filled during the winter. The effect of changes in river flows on reservoir reliability depends on the storage provided by the reservoir and its design yield. It is therefore impossible to infer changes in water supply reliability from information on changes in river flows, although the potential magnitude of changes in streamflows under some scenarios suggests that reductions in reliable yields may be significant, at least locally. For example, similar climate change scenarios to those outlined above would reduce Severn Trent's deployable output by around 6.5% by 2025 (Crookall and Bradford, 2000), and reduce reliable supplies to London by between 11 and 13% (House of Commons, 2004; p. EV133).

There have been very few studies into the potential effects of climate change on water quality generally, so any inferences are currently speculative. However, lower flows during summer may lead to greater concentrations of pollutants which need to be removed from raw water – particularly nitrates and phosphates – which will increase supply costs. Higher peak flows would lead to increased sediment concentrations or flushes of pollutants, threatening the integrity of abstractions.

4.3. CHANGES IN THE DEMAND FOR WATER

Climate change would have relatively little effect on average domestic and industrial demand (Downing et al., 2003), but could increase average irrigation demands by

up to 20%. Peak domestic demand is, however, much more sensitive to climate change (Downing et al., 2003). This does not affect raw water supply infrastructure (abstraction schemes and reservoirs, for example), but is much more significant for the reliability of the distribution system.

5. Planning Water Resources in England and Wales

5.1. THE HISTORICAL CONTEXT

Water supply planning procedures in England and Wales have changed substantially over time (Arnell, 1998), in response to both institutional change (most recently the privatisation of water supply companies, the creation of the Environment Agency from its predecessor the National Rivers Authority, and the implementation from 2003 of the European Union Framework Water Directive) and external events, particularly a series of droughts in the early 1990s.

A major drought in 1975/76 severely challenged the water supply industry (then in the public sector) in many parts of England and Wales, and in some areas significant restrictions on use were imposed. The drought was seen as an extreme, but rare, event, and whilst there were many studies seeking to estimate return periods and search for similar past droughts (Doornkamp et al., 1980), and new methods were developed to estimate the frequency of drought flows (e.g. Institute of Hydrology, 1980), there were no suggestions that drought frequencies could change in the future. The revised design methods produced after the drought assumed climate was stable.

A series of smaller, but locally very significant, droughts in the early 1990s, however, triggered a rather different response for two main reasons. First, the water supply companies had been privatised in 1989 and were now private-sector companies generally receiving a bad press: the privatisations had been unpopular, and there was public concern over "fat cat" salaries. The public were less prepared to accept restrictions on water use from private-sector companies (see Haughton (1998) for a case study of one supply company). Second, water managers and some of the regulators had become aware of the potential threat of climate change. The first review of the potential implications of climate change for water supply was commissioned by the Department of the Environment in 1989 (Beran and Arnell, 1989), and the first papers were published in the early 1990s (e.g. Arnell, 1992). The foreword to a major government review of water supply (Department of the Environment, 1996), stimulated by the droughts, emphasised from the first paragraph that climate change had the potential to seriously threaten water supplies in England and Wales, particularly against a background of increasing demand in the dry south and east of England. The review concluded that a more strategic approach to water resources planning was therefore required: there had been no national level planning since the abolition of the Water Resources Board in the early 1970s.

Under current legislation, water supply companies are obliged to provide water to all customers within their supply area, including new customers. Whilst water companies are consulted on major planning applications, they cannot challenge developments themselves on the grounds of scarcity of water resources. However, local planning authorities, particularly in south east England, are increasingly taking environmental demands into account alongside social and economic factors, and the 2003 Water Act give local authorities duties to conserve water. Water resource availability has therefore been taken into account in the draft South East Plan, prepared by the South East England Regional Assembly (2005). Policy NRM1, for example, advises local authorities that they should

> "Ensure that the rate and location of development... is in step with current and planned provision of adequate water supply, sewerage and waste water treatment infrastructure capacity" (SEERA, 2005)

The South East Plan also notes the need for new water resources schemes are, and Policy NRM2 states

> "Local authorities should work with the water companies and Environment Agency in assisting in the timely delivery of schemes" (SEERA, 2005)

Water supply companies are therefore being increasingly consulted on development proposals, and the old presumptions of predict and provide no longer hold.

5.2. THE CURRENT PLANNING FRAMEWORK

The current (2005) water resources planning procedure contains three key elements, each set by external regulators. First, the water supply companies are required by the Environment Agency to prepare 25-year water resources plans and drought plans, which need to be approved by the Agency.

Second, the Environment Agency has developed national and regional water resources strategies (Environment Agency, 2001), and is currently implementing catchment abstraction management strategies to guide abstraction policies at the local scale. These strategies were developed as part of the procedures for implementing the European Union's Framework Water Directive, which requires members of the European Union to adopt certain consistent water planning procedures. The Environment Agency estimated reliable yields and demands for water for each region of England and Wales to 2025, using the four demand scenarios mentioned in the previous section, and used the estimated future balance between supply and demand to inform its regional water resources strategies. The effects of climate change on yields were *not* included, because the Agency believed that the evidence available suggested that these effects would be small by the 2020s (Environment Agency, 2001). Climate change was estimated, however, to add just over 1% to

domestic demands by 2025. The regional water resources strategies developed to deal with changes in the balance between supply and demand include combinations of a range of approaches (see next section), and were constructed in consultation with the water supply companies and other major regional stakeholders. The catchment abstraction management plans, which have a 5–10 year planning horizon, do not incorporate climate change.

Third, the economic regulator Ofwat determines investment levels by fixing limits on price increases at Periodic Reviews. Ofwat completed its Third Periodic Review of the water industry in 1999, at which it reviewed investment plans and set price limits for individual companies. The vast proportion (90%) of allowed capital spend was earmarked for water quality improvements, and less than 7% of the remainder (£ 113 million) was allocated to maintaining the reliability of supply (Ofwat, 1999).

The fourth Periodic Review (PR04) was completed in 2004, and covers the period 2005–2010. Each company's 5-year business plan covers expenditure for capital replacement, to meet increasing environmental standards (largely driven by European Union directives) and to ensure continuing reliability of supply. The Environment Agency reviews the business plans for their feasibility and consistency with water resources strategies, whilst Ofwat concentrates on the financial and economic aspects of business plan. Both the regulators define guidelines for companies in the preparation of their business and water resources plans.

5.3. DEVELOPING WATER RESOURCES AND BUSINESS PLANS

The Ofwat guidelines on business plans and Environment Agency guidelines on water resources plans are informed by ministerial guidance from Defra (the ministry ultimately responsible for water resources in England) and the Welsh Assembly. The initial ministerial guidance for the fourth Periodic Review (Defra, 2003) refers specifically to climate change, and required companies and regulators to deal with climate change in a "sensible" way, being neither over-precautionary nor ignoring real risks (para. 3.6.8). More specifically (para. 3.6.11) it states that companies should review their supply systems against climate change scenarios, and put in place plans that will allow them to deal with a changing climate. The guidance states that companies should make maximum use of "low-regrets" options which would be valuable even if climate change predictions did prove incorrect, and "does not expect companies to rely only on new resource development as a response to climate change" (para. 3.6.11).

In both the third and the fourth Periodic Reviews the guidance from the Environment Agency required companies to use a single planning scenario to estimate future resource development needs, but also to consider the implications of other scenarios representing different assumptions about demand and supply. The

guidelines for the fourth Periodic Review (Environment Agency, 2003a) required companies to explore different scenarios for future demand and supply, to conduct sensitivity analyses of proposed strategies, to demonstrate that steps have been taken to quantify risks, and finally to include appropriate allowances for climate change: this can be just through the headroom allowance, or – with justification – by directly including climate change into the planning scenario. The Environment Agency guidelines (Environment Agency, 2003b) also state:

- "If it is clear that the impact of climate change makes little or no difference to activities before 2030, the company may state this and does not need to change its water resources plan;
- If the impact of climate change makes little difference before 2020 but could to 2030 consideration must be given to the timing of the necessary investigations;
- If the impact of climate change is great enough to require changes to the water resources plan before 2020, the company should consider the further investigations and analysis that will be needed.

  . . . where it is identified that the impact of climate change may be a significant driver for investment in the next 10 years, it should provide sufficient information to allow the scoping of such action to begin. Options in these zones are:
- To decide to carry out further investigations between 2005 and 2010;
- To decide to carry out further investigations after 2010."

The Ofwat guidelines (Ofwat, 2003b) focus more on financial aspects of investment and what Ofwat is prepared to consider when assessing future prices, but also refer explicitly to climate change. They state that "where companies can demonstrate that climate change is likely to lead to a material change in their water resources plans, they may wish to build an appropriate allowance into their planning forecasts" (para. 5.11). They also state that "where climate change gives rise to material investment requirements in the period 2005-10, we will expect these to be separately identified and justified with reference to the UKCIP02 scenarios" (para. 5.12), and that they will scrutinise closely assumptions made. The OFWAT guidelines for the previous periodic review made it clear that whilst climate change was a potential threat to the security of supply, Ofwat was only prepared to consist allowing funding for feasibility studies (Ofwat, 1998).

5.4. ESTIMATING THE SUPPLY-DEMAND BALANCE: TECHNICAL PROCEDURES

Water supply companies use industry-agreed procedures for estimating future deployable output of their supply systems (UKWIR, 1998a). In the most general terms, these basically involve estimating deployable output from past data – often the output during the largest drought on record - and then adding a "headroom"

TABLE I
Sources of uncertainty for headroom calculations (UKWIR, 1998b)

Supply-side	Demand-side
Vulnerable surface water licences	Accuracy of demand data
Vulnerable groundwater licences	Accuracy of demand forecasts
Time limited licences	Climate change effect on demand
Reliability of inter-basin imports	
Gradual pollution of source	
Accuracy of supply-side data	
Reliance on single source	
Climate change effect on yield	

allowance (typically 5–10%) to account for uncertainties. A standardised approach to estimating headroom was developed for the third Periodic Review (Carnell et al., 1999; UKWIR, 1999b), which identifies eight sources of supply-side uncertainty and three sources of demand-side uncertainty (Table I). Each is given a score in a range of between 1 and 5 or 15 (depending on the source of uncertainty), the total headroom score is summed, and then converted into a percentage headroom with the maximum 80 points translating into a headroom of 20%.

Climate change contributes to headroom through both the supply side and the demand side. In the third Periodic Review four climate change scenarios were provided to the water companies (Arnell et al., 1997), and the "supply-side" climate change headroom score effectively represented the range in effect between these scenarios (Table II). The maximum score occurs where three of the four scenarios give yields lower than the average of the four scenarios, and the range between scenarios is more than 35% of the resource zone deployable output. The "demand-side" climate change score depends on the estimated effect of climate change on average demand, with an estimated increase of more than 10% earning the maximum 5 points. The maximum total climate change score is therefore 15 points, and this would translate to an additional 1 to 4% of headroom, with the greatest effect where the headroom score is lowest.

Whilst the approach leads to consistent assessments of headroom between companies, it is not particularly sophisticated and does not claim to based on a rigorous risk-based approach. In practice, climate change had relatively little effect on estimated deployable output, and hence estimated supply-demand balances, in the third Periodic Review.

A broadly similar technical approach to the incorporation of climate change into estimates of supply and demand was used in the fourth Periodic Review PR04 (Environment Agency, 2003a, b), but using streamflow and groundwater scenarios (UKWIR, 2003) and demand scenarios (Downing et al., 2003) based on the UKCIP02 climate scenarios. The Environment Agency noted in their review of

TABLE II
Headroom "score" characterising the effect of climate change on resource zone yield (UKWIR, 1998b)

Range in resource zone yield between the four scenarios, as percentage of the yield under the mean scenario	Case 1: two scenarios above, and two below the mean	Case 2: three scenarios below the mean and one above	Case 3: three scenarios above the mean and one below
<15%	2	3	1
15–25%	4	6	2
25–35%	6	9	3
>35%	8	10	4

company plans, however, that not all companies actually applied best practice in their plans (Environment Agency, 2004).

6. Adaptation in Practice in the Water Industry

6.1. INTRODUCTION

The previous section has reviewed the context for company-level water resources planning. This section examines how individual companies make adaptation decisions, in the context of the model of the adaptation process described earlier. It is based on information gathered from in-depth structured interviews with four water supply companies, representing a variety of environmental settings and ownership structures, supplemented by material gathered from published documents, business plans submitted by each water supply company in 2004 for PR04, the Environment Agency's commentaries on these plans (Environment Agency, 2003c, 2004), and discussions with other managers in other water companies.

6.2. PERCEPTIONS OF CLIMATE CHANGE

6.2.1. *Awareness of Climate Change*

The water supply industry in England and Wales has a long history of awareness of climate change, dating back in many instances to the droughts of the early 1990s (Subak, 2000). Although water supply engineers have traditionally assumed that past experience was the best guide to future events, a number of "champions" within water companies began in the 1990s to talk and write in professional journals about changing climates, based both on their own interpretation of trends in data and their reading of the broader scientific literature on climate

change. There have always been strong links between water resources managers and the research community, fostered by organisations including the Chartered Institution for Water and Environmental Management and the British Hydrological Society: both hold meetings on topical matters involving both academics and practitioners.

The water resources managers in all of the surveyed companies were also very well aware of statements on climate change by the Intergovernmental Panel on Climate Change, the Environment Agency and Defra. They were also aware of the UK Climate Impacts Programme (UKCIP), and one company had participated in a UKCIP-funded study into the impacts of climate change.

Awareness of climate change is not related to the sensitivity of the company to change, nor to the market and regulatory context. In the early 1990s awareness differed between companies depending on whether individual water managers were aware of emerging information on climate change, but coverage in the general and professional media has been so extensive over the last few years that there are now no water managers unaware in broad terms of the issue of climate change.

6.2.2. *Concern About Climate Change*

Whilst awareness of climate change is high in the water supply industry, concern over the impact of climate change varies between companies. This variation in concern is manifest in references to climate change in company websites and annual reports, and varies not with the potential impact of climate change on river flows, recharge or company deployable output, but with the current and future balance between supply and demand. 36% of the 11 companies with none of their population in resource zones with demand greater than supply (Ofwat security of service category A) made reference to the potential impacts of climate change on their websites, compared with 64% of the 11 companies which did have zones where demand was greater than supply (categories B, C and D)[3]. Significantly, three water only companies (all in security of service class A) declined initially to participate in the project as case studies because they believed that they would not be impacted by climate change because they had a large gap between available supplies and demand.

Sixteen of the 24 company business plans submitted to PR04 in April 2004 explicitly mention the need to invest to maintain security of supplies over the next five years, but only two of the publicly-available summaries explicitly refer to climate change. The future balance between supply and demand is affected not only by climate change, but also in most company supply areas by increases in demand and increased environmental obligations, and over the short term these are more significant than climate change. Water managers in all the companies surveyed were more concerned about the implications of increases in demand for water, due to demographic change and population movements, than about the implications of climate change.

Climate change is therefore generally seen as having relatively little effect *over the next five years*, compared to other drivers of change, although it is one of the components affecting projections of the supply-demand balance over the next one or two decades. An exception is provided by Severn Trent, which projects a reduction in deployable output of 6.5% by the 2030s and uses this as partial justification for preparing now for the development of new resources.

The general apparent lack of concern over the implications of climate change implied by the business plans appears to be inconsistent with strong concerns expressed by the regulators and individual water managers, and indeed with the messages portrayed in advertising leaflets distributed by many companies in southern England with utility bills in the summer of 2005. This can largely be interpreted in terms of time scales. The business plans submitted to the regulators focus on investment decisions over the next five years. Over this time scale, climate change is small compared to the other drivers of change, particularly change in demand. Climate change becomes much more significant over longer time scales, beyond the regulator-imposed investment cycle.

One of the surveyed companies was more concerned with the effect of climate change on the *quality* of water – in terms of sediment load and concentrations of nutrients and pesticides – than the potential impacts on the balance between supply and demand.

6.3. ADAPTATION STRATEGIES

Under the terms of their licences, water companies are assessed against performance in a number of areas, and companies are effectively ranked each year to produce "league tables". Performance in terms of reliability of supply is more difficult to index than performance in most other areas, largely because of difficulties in defining terms (was a one week hosepipe ban equivalent to a six month ban?) and partly because it would be unfair to "punish" a company that introduced restrictions on use during drought conditions when other companies were not exposed to drought. The "security of supplies index" was therefore introduced in 2002/3, indexing the proportion of a company's consumers living in resource zones where demand would exceed supply during a dry year. For the sake of consistency, companies are required to calculate this index using not only their own standards of service, but also reference levels of service. The reference levels of service broadly specify that demand may be restricted by up to 5% for between 3 and 12 months once in 10 years, and by an additional 5% with drought orders once in 40 years. Whilst some companies were in the 1990s working to less strict targets, by 2003 all had set standards equal to or exceeding the reference levels of service. This is largely for reputational reasons, both amongst customers and shareholders.

In its guidance for the PR04, Ofwat (2003b) "expects companies to maintain current levels of service" (para. 4.1). All the surveyed companies stated that their

aim in adapting to change was to continue to provide current standards of service, and to enhance these standards where necessary. They seek to do this by a combination of risk avoiding (increasing ability to cope with risk) and risk sharing (entering into cooperative agreements with other companies), as discussed in the next section.

Company adaptation strategy is therefore largely determined by need to meet regulatory requirements and desire to maintain reputation. Implicitly, then, a successful adaptation strategy (Adger et al., 2005) is one that ensures that the water supply company continues to meet, or exceed, standards set by the regulators under changing conditions. It is unlikely that these standards will reduce over the next few decades, and indeed they are likely to become even more stringent.

6.4. ADAPTATION SPACE

There are two broad types of adaptation to climate change. The first can be seen as the enhancement of the capacity to adapt to changing circumstances, through development of methodologies and skills training, for example. The second comprises actual measures to alter infrastructure or operational practices in order to meet altered circumstances.

The water industry collectively has sought to develop capacity to assess the implications of climate change (through, for example, the development of methods to assess systematically climate change impacts (Arnell et al., 1997; UKWIR, 2003), and has funded methodological research.

Water supply companies have a long history of actually adapting to altered circumstances – typically increases in demand – and a very large number of adaptation options can be identified (see for example Smith, 1996; de Loe et al., 2001 and Ramaker et al., 2005). A distinction is commonly drawn between supply-side and demand-side options. The former basically seek to increase the amount of water able to be provided to customers, either through new sources or more efficient use of existing sources, and the latter seek to manage demand in order to achieve a balance between supply and demand (see Leggett and Schaffer (2002) for methods using rainwater and grey water). Table III summarises supply-side and demand-side options, all of which have been considered – with varying degrees of seriousness – for England and Wales (in, for example, National Rivers Authority (1994) and Environment Agency (2001)).

The broad limits of the adaptation space are set by technical feasibility, and change over time with technological innovation. At present, for example, re-use of water within the house is very expensive: as costs reduce, the adaptation space will expand to encompass these options. Desalination has also historically been seen to be very expensive, primarily due to large energy costs.

Until the early 1990s supply-side options dominated water resources planning, which followed what has been termed a "predict-and-provide" approach. The 1995

TABLE III
Supply-side and demand-side adaptation options

Supply-side options	
New sources	New or enhanced reservoirs
	New direct river abstractions
	Groundwater development
	Bulk water transfers
	Artificial aquifer recharge
	Aquifer Storage Recovery (treated water)
	Desalinsation
	Import of icebergs
Improvements in resource utilisation	Conjunctive use of sources
	Improvements to supply network linkages
	Resource sharing
	Seasonal forecasting
Improvements in distribution and treatment	Improvements to raw water treatment capacity and capacity of distribution network
Demand-side options	
	Leakage reduction
	Water efficient equipment and fittings
	Promotion of more efficient use through education
	Promotion of more efficient use through tariff structures
	Control over location of new development
	Water reuse and recycling
	Managing garden use
	Use of rainwater

government review of future water resources, however, urged a twin-track approach, considering both demand-side and supply-side measures (Department of the Environment, 1996), for several reasons. First, it was recognised that in some areas water was being used very inefficiently, and in particular that large proportions of the water being put into supply were being lost through leakage. Second, it was increasingly difficult to obtain approval for major works, such as reservoirs, both for environmental and local political reasons. Third, attitudes to resource management in general had changed away from the conventional predict and provide approach towards the management of demands. In practice, a mix of supply-side and demand-side options is usually necessary to continue to maintain a balance between supply and demand. The Environment Agency's regional water resources strategies all consist of both demand-side and supply-side options, but in general state that supply-side options should only implemented once all the opportunities for demand-side measures have been exploited.

6.5. SELECTION OF ADAPTATION OPTIONS

6.5.1. *Introduction*

Once a company has estimated the effect of climate change on its supply-demand balance (using the methods outlined above) and determined that it needs to consider adapting to climate change (following the water resources planning guidelines described above), the options considered and selected will be influenced by the three groups of factors described in Section 2: susceptibility to change, the characteristics of the company, and the external market and regulatory context.

6.5.2. *Susceptibility to Change*

The magnitude of the potential effect of climate change has a clear influence on adaptation options considered, as it determines the technical feasibility of different measures. Is the change, for example, within the limits of feasible reductions in demand, can it be met by minor alterations to existing supply sources, or will it require the development of new sources? The technical feasibility and costs of different options determines which options are selected for inclusion in a company business plan.

6.5.3. *Company Characteristics*

Four aspects of the company influence adaptation options. The first is the *infrastructure* used by the company to supply water. Are supply sources already interconnected, for example, and what is the state of its distribution network? The second is the *customer base*, and more particularly the ability to influence customer behaviour. This is partly influenced by the penetration of metering and the ability to use tariff structures which can influence water use, but is also influenced to a certain extent by the relationship between company and customers.

The third influence is the *attitude* within the company towards different adaptation options, and more specifically the degree of risk aversion: demand management measures may be cheaper but less effective; large infrastructure investments may be more expensive but more likely to meet requirements. Many companies are sceptical of the ability of demand-side measures to meet imbalances between supply and demand, partly because the effectiveness of many measures is unknown (e.g. cistern devices to reduce water used in toilet flushing), partly because their effect depends on decisions by customers[4], and partly because their cost effectiveness is unclear (meters may cost several hundred pounds to install). The difference in attitude between water supply companies and the Environment Agency is apparent in written and verbal evidence presented to the House of Commons Select Committee on Environment, Food and Rural Affairs, which conducted an investigation into climate change and water security in spring 2004 (House of Commons, 2004). The Committee reported, for example, that "The Environment Agency suggested that more widespread water metering could help to alert domestic consumers to the value of water and help to manage water use, saying that metering 'has a proven

track record in reducing demand"' (para. 17), but "Water companies did not take the view that metering was necessarily a cost-effective way of reducing demand" (para. 18). The Committee concluded that more could be done by government to promote products and services that increase water efficiency, and that methods for linking consumption to price should be examined in detail, but noted that some new reservoir capacity was likely to be necessary.

Finally, the *resources* available to the company and its capacity to use them effectively will influence which options are selected. To a large extent the ability to raise funds for investment in adaptation is determined by Ofwat – as mentioned below – but a company may decide to invest in adaptation without being able to pass the costs on directly to customers through prices. It will only be able to do this if it can release funds from elsewhere in the business by efficiency savings, or can borrow from capital markets. The owners of the company will, however, only sanction this if there are clear benefits either in terms of financial performance (i.e. the adaptation makes the company more efficient) or reputation. Other parts of the company may also be competing for any surplus capital, perhaps to adapt to other aspects of climate change.

Available resources include not only the finance to develop adaptation options, but also the technical capabilities within the company. All the water companies surveyed felt that they either had access to appropriate technical capacity in-house or could access these capacities through sub-contractors. It is significant that the water supply industry and the Environment Agency have developed industry-standard procedures for resource assessment in general and assessing the implications of climate change in particular. This "automates" many of the assessment procedures, and facilitates the use of specialist sub-contractors. However, several of the sample companies (supported by anecdotal evidence from other companies) noted that the reductions in the workforce in the water industry since the 1990s had reduced the engineering and operational experience within water companies, potentially leading to problems during drought conditions.

6.5.4. *Regulatory and Market Context*

The actions of water supply companies are significantly affected by key external drivers, including the regulatory environment, the planning context, prices for raw materials (specifically energy), and relationships with competitors.

The regulatory context affects company actions in four main ways, via the approval of plans, the assumptions made by regulators, through the nature of the regulatory process itself, and through the implementation of regulation.

A company's water resources plan must be consistent with the Defra planning guidelines and, in a much more specific sense, be approved by the Environment Agency. The water resources plan produced for the third Periodic Review by one of the case study companies was rejected by the Environment Agency, and a revised plan had to be agreed after considerable negotiation. The Environment Agency required "significant further work" on more 13 of the 24 draft business plans submitted

for PR04 (Environment Agency, 2003c), and "some further work" on another 9. All the final business plans were approved (Environment Agency, 2004), although the Environment Agency highlighted some specific concerns with 9 of the plans.

Ofwat's price determinations have a major impact on what a company can afford to do, and the price determinations are heavily influenced by Ofwat's perceptions of what customers are prepared to pay for. A major opinion survey conducted in preparation for PR04 revealed that customers are generally happy with the level of reliability of supply, and few (16%) were prepared to pay more specifically to improve supply reliability (MORI, 2002). Substantially larger proportions of customers were prepared to pay more to improve the quality of rivers and bathing waters. Ofwat saw this as support for investment to improve water quality, but not for enhancements to water supplies. However, the Ofwat customer survey did not ask respondents to state the priority they would give to maintaining supplies in the face of a changing climate.

The time scales imposed by the periodic review process influence company adaptation actions. The periodic review process defines investments and sets prices over a five year horizon, although plans must be placed in the context of a longer-term strategy. The focus on the short-term discourages investment with a longer-term payoff, such as investment now to adapt to (or at least investigate) the effects of climate change: this is likely to discourage investments in actions with long lead times.

Practical control over water supply management is exercised by the Environment Agency through the issue of licences to abstract and charges for abstraction. Licences have historically been without time limit, but from 2004 new licences have been for limited periods and from 2006 it is intended that time limits be added to older licences. Whilst this gives flexibility to the Environment Agency and helps it adapt to changing hydrological conditions, it can discourage long-term investment by water supply companies.

As noted in Section 5.1, regional spatial and local development planning authorities are increasingly taking the availability of water resources into account when locating and approving developments. This is particularly significant for water supply companies not only because it ensures that company views on the feasibility of supplying new developments are considered, but also because it can embed new proposals for supply-side options into regional and local plans. The South East Plan, for example, states that "There is a demonstrable need for new water resources schemes and increased demand management over the period of the Plan..". Policy NRM2 reminds local authorities of the need to give careful consideration to water resource proposals (which need permission from the local planning authority as well as a licence to abstract from the Environment Agency), but the reference to a number of specific new water resource options gives explicit support for some schemes. Through the planning process, however, local planning authorities have the powers to constrain water supply companies and limit adaptation options. An application for a desalination plant in London, for example, has been rejected by

the planning authority on the grounds that the scheme uses too much energy and demand management would be cheaper[5].

The water industry is a significant user of energy, primarily for pumping raw and treated water and for treating raw water and sewage effluent. The price and availability of energy is therefore a key cost and determinant of how supplies are provided to the public, and future price and availability will influence changes in the way water is supplied. Many adaptation options are energy-intensive, and will be less attractive as energy becomes more expensive or as caps on energy use are imposed. The UK government introduced a Climate Change Levy on the business use of coal, gas and electricity in 2001. Some energy intensive businesses have negotiated a discount on the levy in return for agreeing emissions reduction targets, but despite intense lobbying the water industry has not been awarded a discount. There is therefore a strong financial incentive for the water industry to curb its use of energy or to exploit renewable sources and this will constrain adaptation choices.

Although the geographical extents of the ten water and sewage companies are defined by catchment boundaries, the supply areas of the water only companies are not based on catchments and are nested within the supply areas of the water and sewage companies. There is therefore potential for the sharing of sources – some supply sources are jointly owned – and the transfer of raw or treated water from one supplier to another. The availability of surplus supplies from nearby companies, and the relationships between companies, will therefore influence adaptation options. The water resource plan of one of the surveyed companies, for example, relies on sharing resources with neighbouring supply companies and negotiating acceptable contracts.

Finally, the current regulatory context assumes that all investments in maintaining and enhancing water supplies are effectively generated by the water supply companies themselves, through allowable increases in prices to customers, efficiency savings or raising capital from private capital markets. The House of Commons Select Committee on Environment, Food and Rural Affairs concluded that there was a case for central government funding for meeting the cost of maintaining environmental standards in the face of climate change, rather than expecting water customers to bear the cost (House of Commons, 2004).

6.5.5. *Adaptation in Practice: Climate Change and Company Business Plans*

The business plans presented by the water supply companies in April 2004 for PR04 contain proposed actions to ensure security of supply. Significantly, climate change is seen as just one of the threats to security of supply, and most water supply companies do not separately identify climate change as a specific driver for adaptation.

The proposed measures to ensure security of supply, with the exception of measures to reduce leakage, are dominated by supply-side approaches. Three major new reservoirs are proposed, together with a large number of schemes to increase the efficiency of exploitation of existing resources. Three supply companies proposed

constructing desalination plants: these were regarded as being too expensive five years ago.

In its review of the business plans, the Environment Agency noted:

> "Many companies still have plans dominated by resource development such as construction of new or enlarged reservoirs. We will expect these companies to carry out more work to demonstrate whether demand management measures could deliver the same benefit as new resources" (Environment Agency, 2004, p.1)

The Environment Agency also observed that companies were making rather conservative assumptions about future reductions in leakage. Since the mid 1990s there has been an extensive debate between the companies and the regulators on the "economic level of leakage" (below which it is cheaper to use other sources than make further reductions) and whilst the methodology is now accepted (Ofwat, 2004), individual leakage targets for companies are controversial. The difference in attitude between the regulators and the water companies was highlighted by the House of Commons Select Committee on Environment, Food and Rural Affairs (House of Commons, 2004).

Ofwat's final determination on future water prices, and hence its assumptions about investment by water supply companies, was published in December 2004 (Ofwat, 2004b). Ofwat "approved" a total capital investment between 2005 and 2010 of around £8 billion on water supply and £8.8 billion on sewerage. £2.2 billion (27.5%) of the water supply investment is for maintaining the supply/demand balance (with £477 million recouped from various charges and the rest would be recovered through increased charges to customers). Of this £2.2 billion, £1.36 billion is to cope with new development and the growth in demand, £206 million is to cover the costs of installing meters to those customers who request them, and the remaining £613 million is for enhancing security of supply. Most of this is to address current shortfalls, and includes a number of small schemes to improve interconnections between parts of the supply network. The Ofwat determination, however, does include funding for investigations into five potential new reservoirs and augmentations to two existing reservoirs and, significantly, funding for two of the three desalination plants proposed by companies[vi]. The total of £2.2 billion is approximately two thirds of the amount requested by the water supply companies. A further £892 million of the sewerage investment (10%) is associated with improving supply reliability.

None of this investment is specifically directed towards adapting to climate change. Ofwat noted that "it is neither possible nor sensible to set out detailed requirements to cater for these eventualities now" (Ofwat, 2004b; p43). This is partly due to the uncertainty in the magnitude of future climate change but largely because climate change effects over the short-term planning horizon (to 2010) are small relative to other pressures. However, Ofwat also note "..the action proposed

for the period 2005–2010 will prepare the industry to deal with changes within the range of possibilities forecast without undertaking inappropriate and unncessary investment. We will take account of the latest and best evidence as it develops" (Ofwat, 2004b; p43). Specifically, the approved investigations into new resource developments will explicitly take into account the effects of climate change on design and timing. The Environment Agency (2004) requested several companies to continue and enhance their investigations into the implications of climate change for supply reliability, implicitly in readiness for more specific measures in the next periodic review.

7. Conclusions

7.1. ADAPTING TO CLIMATE CHANGE IN PUBLIC WATER SUPPLY MANAGEMENT IN ENGLAND AND WALES: CAN THE WATER COMPANIES ADAPT TO CLIMATE CHANGE?

This paper describes an investigation into the way in which private-sector public water supply companies in England and Wales are adapting to climate change. These companies are heavily regulated, there is a great deal of variety in structure and ownership patterns of the 25 water supply companies, and each is differently exposed to changes in demand and climate change. Each company updated its water resources and investment plans in 2003–4 for Ofwat's fourth Periodic Review, and as part of this process considered explicitly climate change.

Successful adaptation to climate change will be measured in terms of whether or not the water supply companies continue to meet the standards of service specified by the industry regulators (which may be different from the standards pertaining at present). Several features of water management in England and Wales will facilitate this adaptation, and a number of features will make hinder it. The key positive features are:

- A strong awareness of, and concern over, the potential effects of climate change for water resources, particularly in the south east of England
- A conceptual shift within the water industry and its regulators that the past can no longer be assumed to be a good guide for assessing future resources
- The development of climate change impact assessment methodologies, at the industry level, with widespread consensus and agreement across water supply companies and regulators
- The availability of an evolving set of "official" climate change scenarios (currently UKCIP02: Hulme et al., 2002)
- The development of medium-term (25 year) water resource plans and strategies by the companies, Environment Agency and, in south east England and least, the spatial planning authority

- The recognition by some planning authorities of the need to ensure adequate supplies of water for existing and new developments

The factors that will *hinder* adaptation include:

- The limited number of locations for uncontroversial development of new resources: all the proposed sites for new water resources options are contested, and any application would be challenged
- The related problem of the long lead times (typically around 20 years) necessary for implementation of new resource schemes, due largely to the planning process. . .
- ..and the connected problem of the short time horizon imposed by the five-year periodic review of investment requirements. Although the Ofwat guidelines encourage companies to take a longer perspective, there must be considerable pressure to delay investments to the next planning round in order to reduce pressures on customer prices.
- Difficulties in exerting control over the demand for water. Few domestic customers are metered, and tariff structures do not currently discourage high use; there is also limited understanding within the water industry of how to influence customer behaviour to reduce usage.
- The pressures of competing demands on water resources, including environmental obligations.
- Fragmentation of the water supply industry, particularly in south east England, with diverse and changing patterns of ownership
- The current requirement that all investment in adapting to climate change by the water supply companies should be funded by efficiency savings, borrowing or through increased charges to customers, with no direct government contribution
- Time-limited abstraction licences, which give flexibility to the Environment Agency but can potentially deter water company investment.

7.2. GENERAL IMPLICATIONS

This study has examined in detail adaptations in public water supply in England and Wales, and many of conclusions are very specific to this sector and country: indeed, the first general conclusion is that adaptation processes, and the constraints on adaptation, are very context specific (a conclusion also drawn by Ivey et al. (2005) in their study of adaptation by local communities to climate change). The model of the adaptation process used in this paper is informative, but its details will vary considerably between sectors and locations. It is, however, possible to draw some general conclusions.

First, where awareness of, and concern for, climate change is high, there is an incentive for investment in building capacity to begin to deal with climate change,

through the development of methodologies and changes in conceptual approaches. This "capacity building" is an essential component of adaptation, and provides a knowledge base to inform policy.

Second, climate change is generally seen as one amongst several pressures, and not necessarily the most important in the short term (Ivey et al. (2005) found low – or zero – priority attached to climate change amongst community water managers in a Canadian watershed: in England and Wales it has a high priority, but as one amongst many important drivers).

Third, the regulatory approach under which organisations operate can encourage organisations to consider explicitly adaptation to climate change (through provision of guidelines and instructions, for example), but may impose constraints on the ability of organisations to take specific actions. It may encourage short-termism, for example, or encourage inflexible capital-intensive actions rather than flexible, revenue-funded actions (Stakhiv, 1998; Ramaker et al., 2005).

Fourth, the variability in adaptive actions of organisations providing the same function in different geographic areas will be determined more by the variability in potential impact of climate change than by variability in organisational characteristics. Also, very different organisations may react in similar ways where heavily regulated.

Finally, awareness of climate change and concern about its potential impact can be very significantly influenced by the occurrence of extreme and challenging events: the droughts of the mid 1990s in England and Wales, for example, triggered fundamental reviews of how water should be managed whilst scientific interest in climate change was expanding dramatically.

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Notes

[1] Institutional structures and procedures are different in the other parts of the United Kingdom, and Scotland and Northern Ireland are therefore not considered in this paper.

[2] Megalitres per day.

[3] Two of the smallest companies do not have websites, and one of the water only companies owned by a water and sewerage company does not have its own website.

[4] During the 1995 drought, customers of Yorkshire Water responded to a request to curb demands by *increasing* demands, and this was attributed to the unpopularity of the recently-privatised supplier (Haughton, 1998).

[5] As of November 2005, this decision is the subject of an appeal by the water supply company.

[6] Although as noted earlier, planning permission for one of these has been refused.

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