Centre for Ecology & Hydrology

NATURAL ENVIRONMENT RESEARCH COUNCIL

The Water Resources Sector

(Phase 1 report to the Climate Change Risk Assessment)

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THE FIRST UK CLIMATE CHANGE RISK ASSESSMENT

Sector Analyses: Water Resources

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Introduction

The Environment Agency's Water Resources Strategy (March 2009) states:

> ***"Climate change will affect the amount of rain that supports river flows and replenishes groundwater, and when it does so it will also influence the demand for water and its quality, as well as the way land is used – all of which will put pressure on water resources."***

This statement summarises the often conflicting pressures on the management of the water resources system and the additional stress that climate change could place on this. However, the UK water resources sector is undoubtedly one of the more advanced sectors in terms of addressing the potential consequences of future climate change. Indeed, it is virtually unique world-wide in explicitly incorporating climate change into the water resource management process. Both the water industry and regulators have a sound understanding of the potential risks and have provided quantitative evidence of the potential climate-change risks to their business. This understanding has fed into methodologies for incorporating climate change within water resources planning, for both water supply and demand, for the last three Periodic Reviews. These include guidelines from regulators on appropriate methods and data sources and the results of climate change modelling within water company plans.

While the majority of the quantitative work has focused on water supply, the water resources sector also needs to understand the potential risks to water demand and water quality, and some quantification of the potential risk to these from climate change have been considered within water resources planning.

1 Current risks

What are the current climate and non-climate (economic, environmental, technological, regulatory) risks in your sector?

The water resources sector, considering water availability (supply and demand) as well as water quality is intricately linked to the climate. The climate most directly drives the water supply side with river flows (and hence reservoir and groundwater levels) being determined primarily by the balance between rainfall and (temperature-driven) evaporation. The water demand side is also climate-dependent with clear links between temperature and the demand for water for domestic and agricultural use. Water quality is determined by the volume of water in the water bodies, so driven to a large extent by (climate-dependent) river flows, but also by water temperatures.

The specific climate risks are listed in Table 1 below describing the climate risk and the effect for water resources.

Table 1 Current climate and non-climate risks to water resources

Current risks (climate)	Consequence for water resources
Low rainfall	Long periods (multi-season) of lower than average rainfall leading to periods of low flows and short to medium-term risk to water supply (reservoir yield, groundwater recharge, reliability of abstractions), power generation, water quality and habitat provision. Periods of extreme low rainfall leading to both meteorological and hydrological drought affecting water supply.
High rainfall	High rainfall that leads to flooding can affect critical water resource infrastructure, as happened during the summer floods of 2007.
Extreme temperatures	Heat waves can disrupt the supply of energy, for example in France during the summer of 2003, due to lack of (cool) water for cooling and generation.
High temperatures	High temperatures drive an increase in the demand for water from households (garden watering, and higher demand for washing and bathing), agriculture (mainly irrigation) and industry. High temperatures also lead to high water temperature affecting in-stream habitats and species and increased demand for water from the energy sector for cooling.
Evaporation loss	Evaporation (driven by temperature, humidity, wind speed and radiation) leads to loss from open water sources (reservoirs), drying of wetlands affecting habitats and soil drying resulting in potential damage to water mains and increased leakage
Current risks (non-climate)	**Consequence for water resources**
Population	Concentration of population creating high water demand in some of the more water-scarce regions of the country
Pollution	Pollution incidents affect water quality and the ability to supply. Negative impacts on water ecology – environmental damage.

What have been the consequences of extreme weather conditions on your sector?

There have been operational challenges during periods of drought, most notably during the severe drought in the summer of 1976. Subsequent droughts, such as 1995 (Yorkshire), 2003 (Scottish Isles) and 2004-06 (South-East England) have presented challenges for water supply but, in most cases, good drought planning helped to maintain supplies and mitigate impacts on the environment. In general UK water supply systems are resilient to short intense droughts but a succession of dry winters (often followed by dry summers) can be more difficult to manage even for parts of the UK with large storage reservoirs. The 2004-06 drought resulted in very low river flows in the South-East of England (Figure 1) and threatened public water supplies resulting in hosepipe bans and other restrictions to reduce the demand for water.

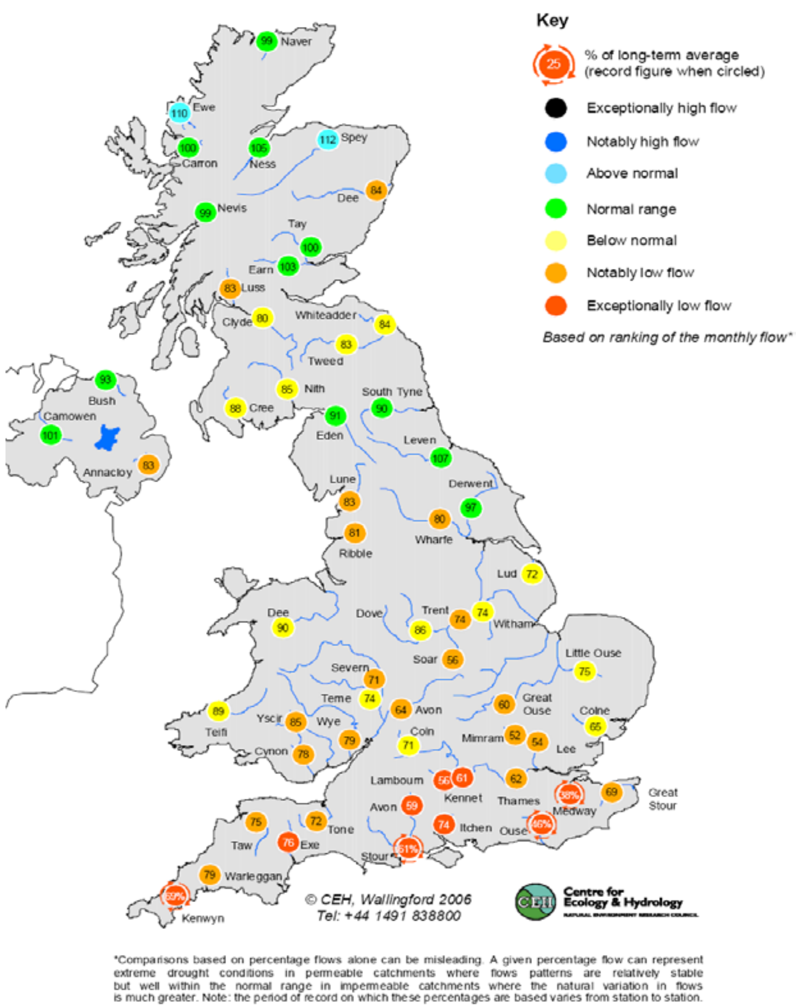

Figure 1: November 2004 – August 2006 runoff accumulations as a % of the long term average (from http://www.ceh.ac.uk/data/nrfa/water_watch.html)

Flooding incidents have also caused disruption to the supply of water, for example in Gloucestershire during the summer 2007 floods, and the floods in autumn 2000. When Mythe WTW flooded in summer 2007, drinking water was cut-off from thousands of people for 17 days

(CIRIA, 2010). Flooding also poses a risk to reservoirs, with the potential to cause severe damage which could then lead to breach. The risk of breach alone would cause surrounding areas to be evacuated, as occurred in significant areas of Rotherham in summer 2007 (CIRIA, 2010).

Extreme weather can also cause some challenges for water resources systems. Designing water supply infrastructure that can continue to provide supplies during “extreme” weather conditions, including floods, droughts and heatwaves, is an important part of the statutory water resources planning process.

What people, activities or places are particularly vulnerable?

The primary pressures on water supply appear to be in the south and east (Figure 2) where available supplies are most limited, demand is highest and there is also forecast growth in population. As the overall industry is regulated water customers are generally exposed to similar levels of risk, however the vulnerability associated with a disruption in water supply is greatest for the elderly, the ill and the disadvantaged. In England and Wales water companies maintain information on vulnerable customers as part of their contingency planning.

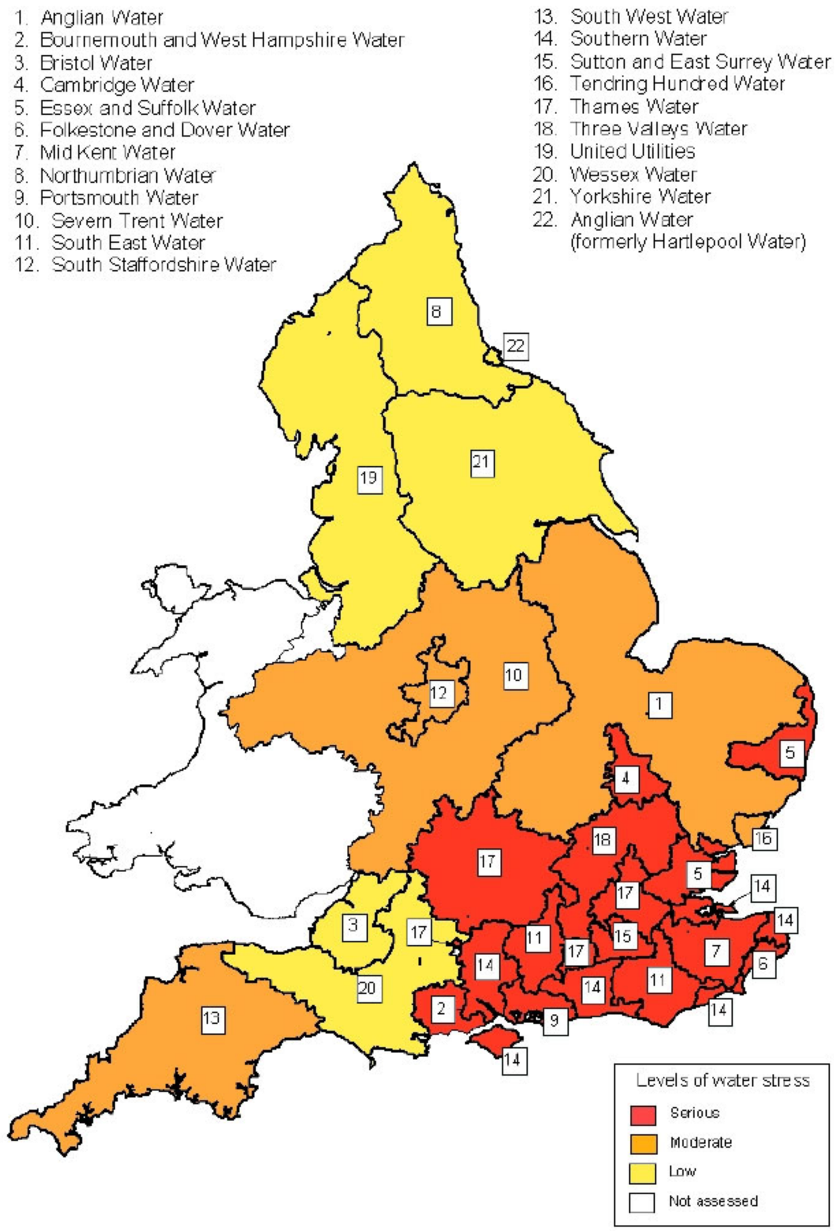

Figure 2: Map of areas of relative water stress (Source: Environment Agency, 2007)

Figure 3 shows the amount of water available for abstraction by catchment area in England and Wales, produced by the Environment Agency from a detailed review of water resources through its current cycle of Catchment Abstraction Management Strategies (CAMS). The amount of water the environment needs is one consideration in these strategies. As Figure 3 shows, some surface and groundwater is already over the limit of sustainable abstraction and so any reductions in available water resources resulting from climate change could further exacerbate this problem. This will impact on many different species. A number of different species and habitats would be affected. Low river flows and groundwater levels can impact upon the environment in a number of ways. In addition to the direct effects on fish, macroinvertebrates and macrophytes, low flows can lead to variations in water temperature and water quality which also affects the ecology of the area (Environment Agency, 2008b).

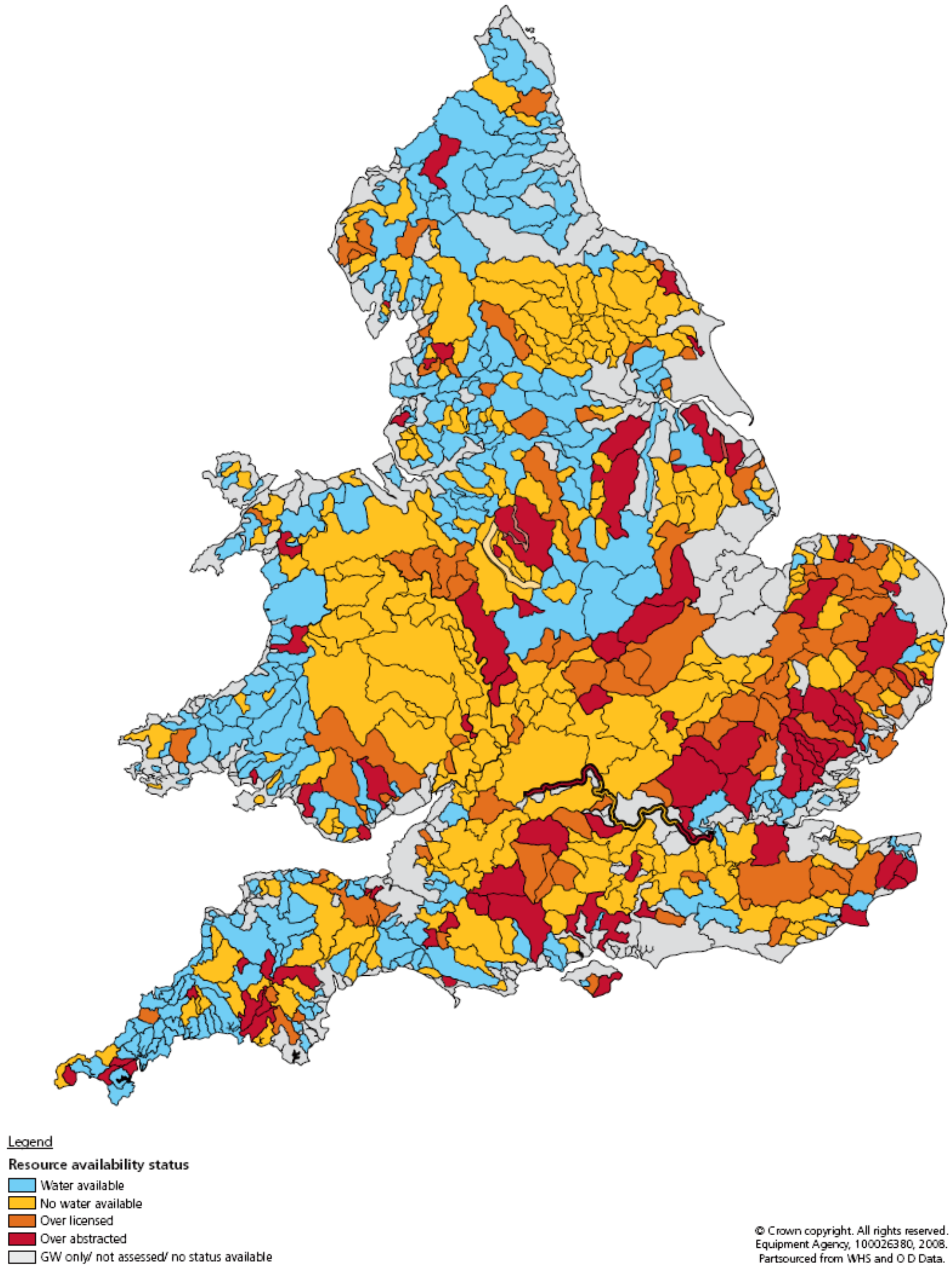

Figure 3: Map of water available now for abstraction (surface water combined with groundwater) by catchment area: (Source: Environment Agency 2009, taken from Defra (2009)

How significant are climate-related risks compared to other risks for your sector?

Operationally, the weather-related risks (e.g. a drought or a flood affecting infrastructure) are the most significant; other risks (change in demand) tend to evolve more slowly. Other short-term risks include pollution incidents/system failures. There are also concerns over pesticides and other difficult to remove pollutants that are ending up in groundwater and surface waters.

BOX 1: WATER QUALITY ISSUES

Water quality will be affected by climate change in a number of ways. These include changes in flow regime (reduced dilution), the growth of algal blooms, pollution of water bodies from increased storm events, increased water temperatures, changes in suspended solids and an increase in nutrient loads (Environment Agency, 2008b). The Environment Agency assessed the potential impacts of climate change on water quality in five river systems in the UK in a recent study (Environment Agency, 2008b). It used models to simulate flow, total and soluble phosphorus, nitrate, ammonia, sediments, and ecology (macrophytes and epiphytes) and showed that the impacts varied according to season and location. However studies into the impacts of climate change on water quality are at fairly early stages with a considerable amount of uncertainty involved.

Water temperatures are an often-overlooked facet of water quality, yet are important to consider because they affect the rate of reactions, the dissolved oxygen capacity of water, and control the suitability of water to be inhabited by a subset of species. Increased air temperatures can result in a substantial increase in river temperatures. Recent analysis by the Environment Agency of the available water temperature datasets in England and Wales revealed an increase in river water temperature over the last 20 – 30 years (Environment Agency, 2007). Figure 4 shows the annual mean water temperature trends for some of the benchmark sites, including the Thames, used in this study.

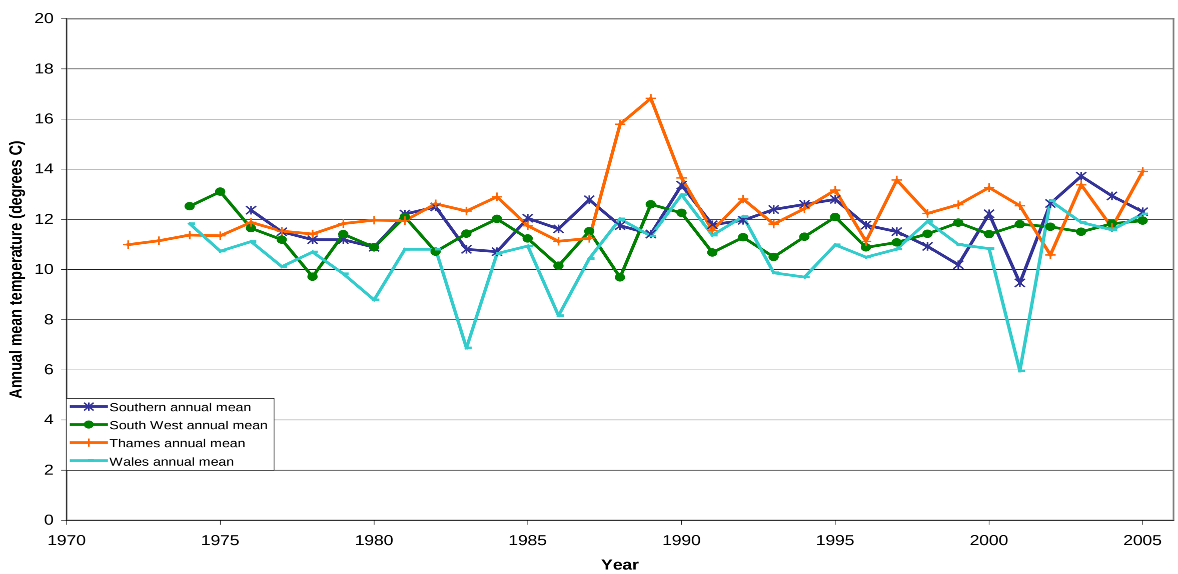

Figure 4: Annual mean water temperature trends for half the benchmark sites used in the Environment Agency study (Source: Environment Agency, 2007)

2 Future risks:

What are the future economic, environmental and physical risks in your sector in the short term (5+ years), mid term (2050s) and long term (2100)?

Table 2 below repeats the climate and non-climate risks from Table 1 but describes the potential change in the risk in the future.

Climate variability will continue to be a risk to water resources in the short-term, as outlined in section 1. In the medium and long-term *changes* to current natural variability (in addition to changes in the average climate) will also have to be factored into water resources plans.

Future Water (Defra, 2008) also highlights the current abstraction licensing system as a potential future risk to water supply. This system is the principal mechanism for achieving sustainable management and development of water resources. An abstraction licence is needed for taking water from rivers and aquifers where the quantity taken exceeds the threshold of 20 m^3 per day. For historical reasons, many licences were issued to remain in force until revoked and cannot be readily modified, although all licences issued since October 2001 have been issued with a time limit. There is a presumption of renewal such that a new licence would be granted, on the expiry of a time-limited licence, subject to a continuing need for, and efficient use of, the abstracted water and so long as the environmental impacts of the abstraction are acceptable. There is a need to ensure that water resources are allocated efficiently in order to cope with the anticipated impacts of climate change and to achieve water quality objectives.

Many of the messages on climate change and the modelling underpinning the assessments of impacts are dependent on the Environment Agency’s monitoring programme. A potential future risk is that the needs and priorities of other stakeholders for this information and data are not the same as those of the Environment Agency.

Table 2: Future risks to the water resources sector

Future change in risk (climate)	Consequence for water resources
Decreased rainfall	Decreased summer rainfall and increased variability of winter rainfall could lead to extended periods (multi-season) of low river flows and increased short to medium-term risk to water supply reservoirs, reliability of abstractions, power generation, water quality, habitats. Increased frequency of hydrological drought.
Increased rainfall	Higher rainfall (either as increased long-term averages or more frequent and intense short-duration rainfall) could lead to increased risk of flooding and damage to critical water resource infrastructure. Increased soil erosion and sediment movement with problems for water quality.
Higher temperatures	Higher temperatures will increase in the demand for water from households (garden watering, and higher demand for washing and bathing), agriculture (mainly irrigation) and industry (including power generation), particularly at peak demand times during the day. Higher temperatures will lead to higher water temperature increasing the risk to in-stream habitats and species. Higher temperatures will also drive higher evaporation leading to increased risk to open water resources, wetlands dry soils. Higher temperatures under future climate change will increase the risk of heat waves, with potential to increase the risk of disruption to energy supply.
Sea-level rise	Increased risk to water supply infrastructure near the coast. Saline intrusion of (the lower reaches of) rivers and coastal aquifers.
Future risks (non-climate)	**Consequence for water resources**
Population and demographic change	Projections of population increase will increase the demand for water. Climate change elsewhere in the world could create an influx of “climate change refugees” into countries less severely impacted. Population movement (to the more resource-poor regions in the south and east) and population growth (potential 20 million extra people living and working in the UK by the 2050s) will increase the risk to the supply-demand balance. Socio-economic change could lead to increased water demand.
Pollution	Pollution incidents could increase in response to some of the climate risks (e.g. flooding).

Climate change has already been considered in the water resources planning process in England and Wales. UK water industry and Environment Agency guidance is underpinned by research studies that have applied successive versions of the UK's national climate change scenarios from the CCIRG91 and CCIRG96 scenarios by the Climate Change Impacts Review Group (CCIRG), through UKCIP98, UKCIP02 (Arnell, 2003; Wade, 2004) and most recently a set of climate scenarios based on six Global Climate Models (GCMs) (Vidal and Wade, 2006).

These studies show that river volumes and levels of low flow are affected by climate change projections for the UK. There is a strong seasonal element to these changes with increases in winter flows and reductions in summer flows. There are also strong geographical differences across the UK, as has been picked up by detailed regional studies, such as the RegIS Project (I and II; Holman et al, 2007) and shown in the national maps of potential changes to river flows in Figure 1. These maps show potential changes to river flows across England and Wales for January, April, July and October under the UKCIP02 scenarios and are taken from the EA Water Resources Strategy for England and Wales from research at the Centre for Ecology and Hydrology and Wallingford Hydrosolutions.

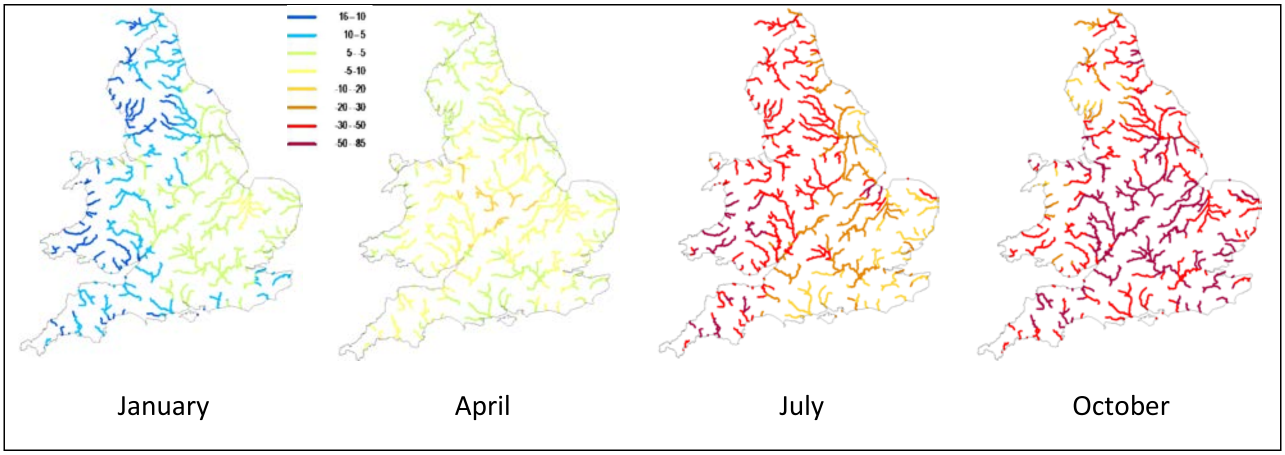

Figure 5: Percentage change in average monthly river flow (with respect to model-simulated 1961-1990 baseline) using Medium-High emissions scenario of the UKCIP02 for the 2050s

The results from the modelling exercise show significant decreases in summer and autumn flows under this particular scenario (other scenarios will give different results), driven primarily by an extended warm and dry summers. However, despite these national-level studies the analysis of water availability and the effects on water resources and quality is extremely site-specific, and most research studies look at specific catchments.

The potential impacts of change to the frequency of extreme drought are less well studied and have not been fully considered with regard to water supply, agriculture and the environment. A number of studies have suggested that there may also be changes in the frequency of drought, as assessed for the Southern region in Wade (2004) and at the UK level (Goodess et al, 2002; Vidal and Wade, 2008). Wade (2004) estimated that by the 2080s, rainfall droughts could be more frequent with the frequency of short (6 month) serious droughts, such as that experienced in 1995, increasing from 1 in 9 years (present) to 1 in 7 years (under the Low Emissions scenario) or 1 in 3 years (High emissions scenarios). A more recent study has suggested a threefold increase in short rainfall droughts by the 2080s (Vidal and Wade, 2008).

On the water demand side the challenge of addressing future risks is further increased because of the strong influence of socio-economic change on top of climate change, but also because of the cross-sectoral nature of demand. Very few studies have progressed to link availability and demand. Downing et al (2003) as part of the Climate change and the Demand for Water project (CC:DeW:) applied the UKCIP02 climate change scenarios to the EA water demand scenarios for domestic, industrial and agricultural sectors, and modelled changes in demand due to behavioural responses to climate change (e.g. from irrigation, garden watering, industrial activity etc.) in the 2020s and 2050s. The study estimated that that the additional impact of mean climate change (above the socio-economic scenarios) by the 2050s was to increase domestic demand by 2 to 4%, industrial and commercial demand by 4 to 6% and agricultural demand by 26%.

Figure 5 is an example of how per capita consumption will change with mean monthly temperature from south-east England. However, it must be considered that socio-economic impacts on water demand are larger, for example the move to more single occupier housing has a greater impact on per capita water use.

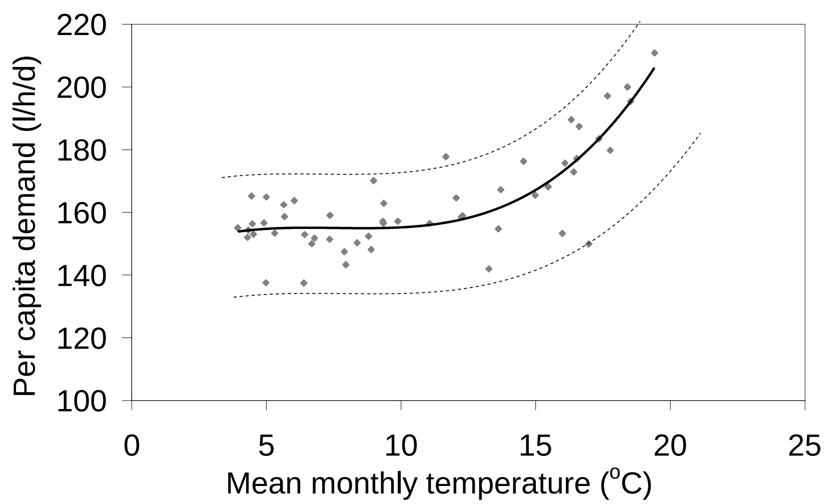

Figure 6: Change in water demand with mean monthly temperature (based on monitored properties)

What evidence is available to link climate to impacts and to monetise impacts?

The water supply companies have all estimated the effects of climate change on the available water supply (and demand). At the national level, climate change effects are of similar magnitude to the demand effects, and greater than other environmental effects (by 2035), but there is considerable variability between companies and considerable uncertainty. Companies have costed these impacts in terms of the investments required to maintain the supply-demand balance. However, the costs do not distinguish between the climatic and non-climatic drivers of change in the supply-demand balance. The costs at the resource zone level are commercial in confidence and represent company aspirations, not actual investments (which are influenced by the regulators).

There are some estimates of the economic costs of previous droughts, e.g. in the summer of 1995 the costs of supplying additional water supplies during the hot summer was around £100 million (Waughray, 1997). There are also estimates of the costs of drought at the European scale (Commission of the European Communities 2007. Communication from the Commission to the European Parliament and the Council: addressing the challenge of water scarcity and droughts in the European Union. COM (2007) 414 final).

Can critical thresholds be identified related to specific risks?

It is difficult to pinpoint critical thresholds in terms of changes in climate leading to changes in river flows, as each catchment reacts to climate change dependent on the individual set of catchment characteristics such as geology, soil type and land-use. It is likely however that certain water resource zones will have “thresholds” beyond which it becomes increasingly difficult to adapt

There are identifiable thresholds in terms of habitats for some species that require a specific thermal range, which may be exceeded under climate change. See for example, the temperature thresholds for salmon (Solomon, 2008). Other work has examined links between target flow regimes and macro-invertebrate LIFE scores (e.g., Exley, 2006).

Beyond these “natural” thresholds there are some thresholds imposed on the system through the Water Framework Directive.

What are the main international climate impacts and adaptation issues affecting the sector?

A raft of European legislation is seeking to incorporate climate adaptation principles, most notably the EU Water Framework Directive. As noted by Wilby et al. (2006) the cyclical review and risk assessment processes within the WFD are well-suited to adaptively managing the water sector under climate change.

Change in global and European (and UK) agricultural patterns and practises will lead to changes in crop production and agricultural demand for water for irrigation in the UK.

3 Adaptation - **“who” and “how”**:

Who are the key stakeholders in your sector and are they actively taking adaptation measures and how is climate change and adaptation being considered?

The main stakeholders in the water resources sector are Defra, DECC, Welsh Assembly, Scottish Government, Ofwat, the Environment Agency, SNIFFER, DoE Northern Ireland, Drinking Water Inspectorate, the water industry, Natural England, the Countryside Commission for Wales, Consumer Council for Water, Local Authorities, Development Agencies, water users (people and businesses), academia and consultants.

Adaptation measures have already been taken through the application of simple methods for incorporating climate change within the water resources Periodic Review. These methods have allowed water companies to rapidly assess the potential impact of climate change on their plans, using simple factors of changes in either climate variables (to drive rainfall-runoff models) or river flows. These methods have previously been based on just a few scenarios and have not been probabilistic in nature. The challenge now is to incorporate some of the probabilistic information from the new UKCP09 scenarios to better inform risk-based decision making.

There are a number of policies and strategies in the sector that have already considered climate change:

a. Future Water.

This report describes the Government’s (led by **Defra**) water strategy for England, laying out the long-term vision for water and the framework for water management in England by 2030. It uses information derived from the UKCIP02 scenarios and provides a vision for water policy and management to encompass continuous adaptation to climate change by 2030 at the latest.

b. Water Resources Strategy for England and Wales to the 2050s

This **Environment Agency** report used national-scale hydrological modelling to underpin messages on possible changes to river flows by the 2050s based on UKCIP02 projections of climate, and presented potential changes in water demand under four socio-economic and climate scenarios. Based on projected changes in both supply and demand the Strategy presents seven climate change-specific actions that will:

- enable habitats and species to adapt better to climate change;
- allow the way the way the water environment is protected to adjust flexibly to a changing climate;
- reduce pressure on the environment caused by water taken for human use;
- encourage options resilient to climate change to be chosen in the face of uncertainty;
- better protect vital water supply infrastructure;
- reduce greenhouse gas emissions from people using water, considering the whole life-cycle of use;
- improve understanding of the risks and uncertainties of climate change.

In terms of water management the Strategy spells out ways in which the supply of water for people and businesses can be balanced with that required to protect the environment and states that “a balance of managing demand and developing resources is both necessary and the most flexible approach to maintain future water supplies”.

c. Water resources in England and Wales - current state and future pressures

In 2008, the **Environment Agency** published this report describing the current and future pressures on water resources in England and Wales, without detailing actions that would be necessary in order to manage water resources in a sustainable way (these are covered in the EA Water Resources Strategy)

d. Adapting to climate change – water resources

The **Environment Agency** published, 2009, adaptation plans for each of its main business areas and functions, including water resources. The main future climate risks are outlined (all listed in section1) and a flexible approach to water management future water management proposed in the light of uncertainty, describing the twin-track approach is of managing both the supply of water through additional resources if appropriate, and the demand side through demand management measures such as metering and the technological development of water-using appliances in homes.

e. Preparing for a changing climate in Northern Ireland

This **SNIFFER** report in 2007 describes ways in which Northern Ireland should prepare for climate change, looking across sectors, but focusing on the impacts on and the need for adaptation by the public sector in Northern Ireland. The water resources sections within report detail the threats (and opportunities) to water resources in Northern Ireland, which have been incorporated in generic form within Table 2 above. The cross-sectoral issues are also highlighted such as the reduction in water availability for the natural environment as well as for public supply, and the effects on biodiversity, fishing, tourism and recreation.

f. Water Resource Management

The Scottish Government outline the future risks to water resources (quality and supply) from possible climate changes, and provide a list of sector actions with associated delivery responsibilities and a timetable. For example, by 2010 **Scottish Wate**r and the **Scottish Climate Change Impacts Partnership (SSCIP)** will work together to demonstrate how they may use the UKCP09 scenarios, and associated tools, to consider climate change adaptation.

g. Preparing for the future – **Ofwat**'s climate change policy statement

This policy statement outlines Ofwat's view of how climate change will affect the water and sewerage sectors in England and Wales, highlighting the main impacts and how they are responding to these challenges and how they expect the water companies to respond. Ofwat expect the water and sewerage sectors to adapt in a "phased, responsible and appropriate manner", with adaptation plans based on sound science and evidence. The periodic nature of the price review process "lends itself to a phased response to adaptation. This should lead to the adoption of an approach which avoids large commitments that are tied to one specific future climate scenario. This approach will offer both protection and value to consumers". To this end Ofwat require significant climate change-driven investments will only be included in the final baseline for AMP5 if these are based on "robust evidence using UKCP09 scenario analysis".

h. **Water Company** water resources management plans

The Environment Agency provides guidance to the water companies on best-practise for incorporating climate change within water resource management plans. Currently this advice is based on UKCIP02 climate projections, together with a relatively small number of alternative scenarios based on outputs from global climate models (GCMs) from beyond the UK. Work is due to start to consider how the probability-based information from the UKCP09 scenarios could be incorporated within these plans, as directed Defra and guided by **Ofwat** and the Environment Agency.

Can you provide examples of key decisions and information about adaptation measures being adopted?

To date there is little evidence of these impact studies feeding through to specific adaptation measures, they have tended to inform water companies and the regulators about potential risks to water supply under climate change.

Arguably, individual water users will not be taking independent adaptation decisions. They should however be encouraged to adapt through the uptake of new technology for more efficient water use, such as efficient showers and flushes or some retrofitting of homes for rainwater harvesting or grey water usage.

4 Adaptation – “issues”:

Arnell and Charlton (2009) identify nine potential barriers to effective adaptation, and assess the degree to which any of these are evident when looking at adapting to potential climate change effects on water supply reliability. Of these nine potential barriers, five are generic (G1-G5) and four are specific (S1-S4):

G1: The identification of the need for adaptation. This is well-established in the water resources sector, with climate change being recognised as a potential future risk to water resources sector by Government, the regulators, water companies, local councils and the public.

G2: The extent to which the need for adaptation can be specified in terms which inform adaptation decisions. This is a function of the climate scenarios and the ability to translate these scenarios into potential impacts on water supply and demand. In general terms this too is no barrier to adaptation in the water sector as both scenarios of climate change and potential impacts on demand and supply have been modelled with methods and guidelines describing how these scenarios should be incorporated within strategic water resource assessments. A potential barrier in this area relates to the appropriate use of the new UKCP09 probabilistic projections of climate change but research is either on-going or planned to address this.

G3: The identification of feasible adaptation options requires sectoral / institutional competences or preferences. Again, this is not generally a barrier in the water resources sector as many potential adaptation options have been identified by the Government, the regulators and the industry (see section 3 above).

G4: The ability to evaluate potential options. This remains as something of a barrier to adaptation as such evaluations would generally tend to be risk-based and use multiple scenarios (such as the UKCP09 projections). Methods are being developed to allow these scenarios to be incorporated in water resource planning that currently takes place every 5 years, looking 25 years ahead. Questions are asked as to whether climate change introduces sufficient (long-term) uncertainty that this Periodic Review should be extended beyond 25 years.

G5: The ability to select and monitor a strategy. Water companies are yet to implement adaptation options, so mechanisms for monitoring such strategies have been tested.

S1: Physical barriers to adaptation, constraining on the performance of an adaptation option. Some such barriers have been identified in the water sector in terms of constraints posed by the conflicting pressures of water supply for domestic, agricultural and industrial use with supplying enough water for the environment. Another physical barrier could be the uncertainty as to whether a new resource scheme (e.g. reservoir) is sustainable in a change future climate (could the new reservoir be filled?).

S2: Financial barriers refer not only to the absolute cost of an option, but also to the ability to raise funds to cover the costs. The costs of some of the supply-side measures are high and potentially prohibitive. The demand-side options tend to have lower unit costs. The Ofwat Change protocol for 2010-15 describes principles and outline procedures for companies to seek financial adjustments relating to changes to outcomes in the 2010-15 period. This includes “changes that may relate to emerging evidence on climate change impacts, for example or to finalising Water Resource Management Plans”.

S3: Socio-political barriers include the attitudes and reactions of stakeholders, affected parties and pressure groups to individual adaptation options. There is evidence of public resistance to development of new water supply options (from reservoirs to desalination). The planning process for major works can be very long creating barrier to adaptation. Demand-side measures tend to be easier to implement and more flexible, although there can be public resistance to change. There are no real legislative barriers to adaptation, although legislation tends to specify the outcomes of measures rather than the means of achieving it, therefore providing no guidance on the adaptation strategy itself.

S4: The characteristics of the individual organisation may affect its ability to implement a specific option, and the regulatory or market context may constrain specific choices. There is a lack of synchronisation and coordination of different policy instruments, e.g., mismatch between the Periodic Review cycle and the Water Framework Directive cycle.

5 Research gaps:

What research gaps need to be filled to enable a better assessment of climate risks and adaptation measures?

- Develop methods to incorporate climate change information into assessments of future supply and demand (including, but not exclusively UKCP09 probabilistic information);
- Investigation of the transient nature of change. Is the transition between the current and the 2080s smooth (as implied in time-slice analyses) or are there step changes involving rapid change over relatively short time periods, and if so, what is the implication for water resources planning?
- Develop future scenarios for droughts: improvement is needed in the simulation of meteorological drought in global and regional climate models, and rainfall-runoff models need to be able to model the spatial / temporal evolution of (change in) hydrological droughts;
- The role of other hydrological processes in the development of drought need to be better understood and modelled, e.g. evapotranspiration;
- Research programme that more explicitly links field experimentation and modelling to the development of tools/techniques that can "operationalize" adaptation.
- Ways of developing/supporting adaptive and flexible management approaches;
- Need to understand the environmental impact of droughts to facilitate flexible management;
- Ways of encouraging/facilitating increased water use efficiency;
- Review of appropriateness of industry and regulatory structure for encouraging adaptation to climate and other changes;
- Understanding the (knock-on) effects of implementing adaptation strategies;
- Modelling the effects of changes in demand on river flows;
- Investigate the resilience of the various water supply and demand options, for example how sustainable are options for rainwater harvesting in a changed, future rainfall regime.

Planned research

- Future Flows (Partnership funding: EA, Defra, UKWIR, NERC – CEH and BGS). The objective of this project is to develop a consistent and accessible assessment of the impact of climate change on river flows and groundwater levels that can be used in decision-making across organisations. The project will develop methods and frameworks to allow this approach to be used as a screening tool for both water resources management and other disciplines (fish, ecology, navigation, channel morphology, water quality modelling). This will enable for better management and regulatory decision making and provide a consistent approach to adapting to climate change.

- Climate change in water supply planning (EA funding). The overall objective of this project is to make sure that plans for future water supply in England and Wales adapt to and mitigate climate change effectively.

- The EA are planning to fund some new research into the potential impacts of climate change on water demand (yet to be specified).

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