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# Thames Basin Vulnerability Report Technical summary

July 2008



**HSBC  
Climate  
Partnership**



FreshWaterThinking

# Fresh Water Thinking

The Thames Basin Vulnerability Report is the first in England and Wales to assess the vulnerability of a river to climate change. The report was commissioned by WWF-UK and supported by HSBC as part of the HSBC Climate Partnership. Throughout a five year UK freshwater programme WWF will work on solutions to help our precious freshwater systems adapt to the impacts of climate change. We will work with government, stakeholders and communities to raise awareness, engage and influence. We will focus on improving national policies that govern the use of water and rivers. We will push for better river basin planning, and work to enhance the resilience of rivers so that they can better resist the impacts of climate change and increased water demand.

For more information about the WWF UK freshwater programme please contact Liane Jarman on [ljjarman@wwf.org.uk](mailto:ljjarman@wwf.org.uk)

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# Introduction



Climate change due to increasing carbon concentrations in the atmosphere is one of the greatest challenges facing humanity. Climate change will make the complex task of managing water resources and ecosystems more difficult. The Thames is one of the most historically and economically significant river basins in the world, with a long history of human impacts and management. This report summarises recent scientific analysis of the potential impacts of climate change on the Thames Basin and assesses the key points of vulnerability for the basin.

The purpose of this preliminary report is to communicate the key climate change risk to the Thames. It is intended to be used to stimulate a discussion among key decision makers and stakeholders to gain a clear understanding of the key issues facing the Thames over coming decades. It does not address adaptation plans, but it is intended to provide the starting point for understanding adaptation needs and priorities.

The report brings together the outcomes of the latest scientific research and policy documents relating to climate change in the region. It considers how changes in climate and human activity could impact the river basin in the coming century. It includes a simplified water balance for key points in the basin in the 2020s, accounting for changes in patterns of rainfall and people's consumption of water, and reviews general trends in climate, water quality, flows, ecology and flooding across the basin, focussing attention on two particular case study rivers – the River Kennet and the River Lee.

# Key vulnerabilities

Climate change is predicted to result in hotter drier summers, warmer wetter winters and more extreme rainfall events in the Thames basin. The increased rainfall in winter may not be sufficient to balance the decreased rainfall in summer, leading to an overall decrease in water availability for public supply, and lower river flows during summer months. At the same time, climate change is predicted to lead to an increase in demand for water by people in summer for watering gardens and washing and bathing more often, and for agriculture.



**The Thames Basin is most vulnerable to climate change in the following ways:**

1

Public water supply may be more vulnerable to drought. Although winters are predicted to be wetter on average, drought years with low winter rainfall will still be possible. Threats to public water supply in the Thames result from sustained periods of low precipitation, in particular low winter rainfall that results in reduced groundwater recharge. Predicted low summer rainfalls and higher demand for water will leave public water supply more vulnerable to below average winter rainfall.

2

More people and properties in the Thames Basin will be vulnerable to flooding. The chance of rivers flooding in the Thames Basin may be five times higher by the 2080s. Peak river flows are predicted to increase by 20% leading to an increase in annual average flood damage.

3

Low summer rainfall could leave ecosystems in rivers in the basin vulnerable to low flow conditions, particularly when combined with higher summer demand. At the moment, in summer months current abstractions are higher than available water resources for one and a half months; this will increase to two and a half months by the 2020s under projected climate change and water demand.



4

Flows in tributaries of the Thames, such as the Kennet and the Lee, are more vulnerable to low rainfall than the River Thames itself. These rivers are among the most ecologically important ecosystems in the basin, and the ecology of these important rivers is more vulnerable to climate change than the main stem of the Thames. Analysis undertaken for this report highlights a 17% decline in the average summer flow of the Kennet by 2020.

5

Recent improvements in water quality in the Thames Basin are vulnerable to reduced flow volumes, higher water temperatures and extreme rainfall events. Low flow volumes could increase the concentration of pollutants such as nitrogen in rivers and streams. High temperatures and higher concentrations of organic pollutants could reduce the concentration of oxygen dissolved in the water.

6

Increased intensity of heavy rainfall events in summer could increase the amount of pollutants including sewage washed into rivers, further compounding the problems of low flows and high water temperatures. A foretaste of what might be expected occurred in the River Lee after a heavy rainfall event in July 2007. Within the space of three hours there was a significant increase in the flow at Lea Bridge, during which time the biological oxygen demand increased six fold from 4.4 mg/l to 28.2 mg/l.

7

The most serious impacts on the ecology of the basin are likely to result from a combination of pressures from both development and climate change. In particular, the combination of lower summer flows, higher temperatures and declining water quality may leave ecosystems vulnerable to collapse, for example as a result of a sudden increase in pollution levels from urban and agricultural run-off and combined sewer overflows following a heavy summer storm event.

8

The ecosystems of the Thames estuary are vulnerable to sea level rise, more intense storm events, increasing water temperature, declining water quality and reduced fresh water flows from the rivers of the basin. These impacts could lead to changes in fish species found in the estuary and increase the vulnerability of birds, particularly those that depend on tidal marshes.

# 1 Basin profile

The Thames Basin and estuary is one of the most historically and economically important regions in the world. The River Thames rises in the Cotswold Hills, with its traditional source at Thames Head near Cirencester, and flows 237km downstream to Teddington to become the Thames estuary. Located in the south-east of England, the Thames region covers less than 10% of England and Wales but is one of the countries most important areas.

Nearly a quarter of the population of England and Wales (around 14 million people) lives and works in this region, producing more than a quarter of the Gross National Product. The region has some areas that are particularly heavily urbanised and densely populated including London, Oxford, Swindon, Reading, Luton, Stevenage, Guildford and Crawley.

Trends suggest that the economy in the Thames region will continue to increase in importance both within and outside its boundaries. The number of people living within the region will increase, putting even more pressure on resources, particularly land and water. It is estimated that around 56,000 new homes will be built in the Thames River Basin District every year for the next 15 years and that population may increase by around 2 million by 2026 (Environment Agency, 2007). A large percentage of the new development is planned in the lower Lee valley and in the tidal floodplain of the River Thames.

Many of the freshwater ecosystems of the Thames have been very heavily impacted by centuries of human modification, including major physical alterations to much of the river to facilitate navigation and reduce flood risk. Despite this history of modification, there remain important ecosystems in the basin. These are enjoyed by millions of people, and include internationally important ecosystems and biodiversity resources. The most significant internationally important ecosystems include the chalk-fed tributaries of the Thames, including the River Lambourn SAC (a tributary of the Kennet), and important marshland habitat that attracts migrant birds.

Significant progress in addressing some of the most serious water quality problems in the basin in the last half century has resulted in notable improvements in ecosystem health in some parts of the basin. However, significant and at times growing problems remain from over-abstraction, agricultural pollution, sewage treatment and overflows and urban run-off.



# 2 Climate predictions

The UK Climate Impacts Programme (UKCIP) provides detailed estimates of the impacts of climate change based on the best climate modelling data available. The UKCIP modelling results released in 2002<sup>1</sup> (UCKIP02) predict that the Thames region will experience:

- warmer and wetter winters;
- hotter and drier summers;
- more extreme rainfall events.

Climate predictions are made for three different time-slices: 2011-2040 (2020s), 2041-2070 (2050s) and 2071-2100 (2080s). Predictions are made using four different global carbon emissions scenarios – low, medium-low, medium-high and high. The scenarios account for different possible international responses to the global challenges of reducing carbon emissions. Each scenario assesses how global climate change might affect the UK on a regional scale during the 21st century. A detailed representation of changes in temperature and rainfall in the Thames region can be seen in Table 1.

	Summer rainfall	Winter rainfall	Summer temperature
<b>2020s</b>	10-12% decrease	4-6% increase	1.1-1.3° increase
<b>2050s</b>	18-29% decrease	8-14% increase	2.0-3.2° increase
<b>2080s</b>	25-50% decrease	11-24% increase	2.8-5.5° increase

**Table 1:** Predicted climate change impacts compared with the 1961-1990 baseline for locations in the Thames region. Ranges shown are for the UKCIP low and high emissions scenarios (Hulme et al. 2002).

## Sea-level rise

By the 2080s, and depending on the emissions scenario, sea level may be between 26 and 86 cm above the current level in southeast England (Hulme et al. 2002). Extreme sea levels, occurring through combinations of high tides, sea-level rise and changes in winds, will be experienced more frequently in many coastal locations. Increasing storm intensity is expected to result in an increase in both the height and number of storm surges that will affect the tidal part of the Thames region, with the height of the 1 in 50 year storm surge event increasing by as much as 1.4m under the UKCIP02 high emissions scenario.



<sup>1</sup> UKCIP02 results were the most up to date predictions available at the time of writing. UKCIP is expected to release new data (UKCIP08) later this year.

# 4 Flooding



Climate change is likely to exacerbate the flood risk in the Thames. The main types of flooding in the Thames region are:

- Fluvial flooding as a result of heavy rain which may cause rivers to overtop their banks with excess water flowing on to the floodplain;
- Surface water flooding is hard to predict and is usually associated with heavy rainfall events which overwhelms the drainage system. This is a significant issue in urban areas where much of the land surface is impermeable;
- Sewer flooding is generally a mixture of raw sewage and storm water and can occur after both fluvial flooding and intense rainfall events and surface water runoff which overwhelms the capacity of the sewer network;
- Groundwater flooding as a result of fluctuations in the water table, this can affect people and property both within and outside the floodplain;
- Tidal flooding due to storm surge events caused by low atmospheric pressure, high winds and high tides which can result in large amounts of water flowing upstream from the Thames estuary. This problem is further exacerbated by rising sea levels.

Of these, tidal flooding of the Thames threatens the most catastrophic adverse event, as illustrated by the flood event in January 1953 that killed over 300 people in Southern England. The risks of fluvial flooding in the basin were clearly illustrated in the summer of 2007.

## Fluvial flooding

Estimates of the future cost of fluvial flooding in the Thames region are based on two reports: The Foresight Flood and Coastal Defence Project: Future Flooding (Evans et al. 2004) and the Thames Catchment Flood Management Plan (TCFMP) (Environment Agency 2007).

By the 2080s Foresight predicts that the expected annual probability of flooding in the Thames region will increase by as much as 5 times. The number of people deemed to be at high risk from flooding (both fluvial and tidal) increases marginally under the low emissions scenarios but almost doubles under the high emissions scenario.

The TCFMP highlights climate change as potentially the most significant driver that will affect flood risk. Estimates of the potential increased flood risk are based on guidance provided by DEFRA (i.e. a 20% increase in peak flows for a given flood event by the 2050s). As well as increasing the frequency of flooding, this will lead to an increase in both its extent and its depth. Consequently the number of people exposed to flooding will rise and there will be a greater risk to life and increased economic damage.

## Surface water flooding

Comprehensive records of surface water flooding are scarce (Greater London Authority 2007) and no data exists regarding the cost of surface water flooding to the Thames region as a whole and how this might be expected to change in the future as a result of climate change and urban development (Professor Edmund Penning-Rowsell, personal communication, March 17, 2008). However, the frequency and severity of surface water flooding is expected to increase throughout the present century as a result of the anticipated higher rainfall in the Thames region during the winter months and the likelihood of heavy summer storms. This may be further exacerbated by up to a 50% reduction in soil moisture during the summer months by the 2080s across the Thames region (Hulme et al. 2002). This may have severe consequences particularly in areas such as the Lower Lee basin and London where clay soils dominate and infiltration rates are already low leading to enhanced run-off.



## Sewer flooding

There are around 10,000 homes at risk of flooding from sewer overflow in the Thames region (Greater London Authority 2007). Flooding of this nature is generally a mixture of raw sewage and stormwater and has two main causes (Environment Agency 2007):

- Overload through lack of system capacity (e.g. sewer size; pumping failure; sewer collapse, etc).
- Impact of wider fluvial flooding from rivers and watercourses, typically by backflow or constraint on flow due to fluvial flood water levels.

Heavy rainfall events can result in severe, but localised flooding which is often exacerbated by surface run-off over impermeable urban environments. Consequently sewer systems may be overloaded, properties can be flooded and large amounts of raw sewage released into the water. This often has major consequences for the environment and public health (Environment Agency 2007).

The Greater London Authority's Draft Regional Flood Risk Appraisal (Greater London Authority 2007) has stated that climate change should not make a substantial difference to the problem of sewer flooding as Thames Water is currently investing around £300 million between 2005 and 2010 to address the situation by undertaking direct works to those parts of the sewer network linked to the affected property or group of properties.

## Groundwater flooding

Arnell (2002) indicated that under the UKCIP high emissions scenario groundwater recharge of chalk aquifers by the 2020s in the Thames region may be 14% lower than the present day. Just how climate change will impact upon groundwater flooding is somewhat of an enigma. Jacobs (2006), state that they are unaware of any climate change literature which specifically addresses how climate change may impact upon groundwater flooding. They do however state that increased winter rainfall may result in an increase in groundwater flooding but that this might be balanced by reduced rainfall in the summer months.

# 5 Water resources

Despite wetter winters, climate change is anticipated to lead to an overall reduction in water resources in the Thames Basin. Water stress is likely to be further exacerbated by increased demand for water as a result of growing populations and higher per capita consumption. The water industry and its regulators are currently planning for the impacts of changing climate and demand for water until the 2020s.

We have used a simplified water balance to broadly characterise the effects of climate change and water demand change on Thames basin water resources. This assessment focuses on effects projected to the 2020s (centred on year 2025) of a single climate change scenario: medium-high emissions. The base-line "current" conditions used for comparison are the 1961-1990 period for hydrology and the year 2003 for water demands.

### Demand for water

Climate change is predicted to lead to increasing water use during the hotter, drier summers. We used the 2003 Climate Change and Demand for Water (CCDeW) project (Downing et al. 2003) to quantify the effect of climate change on water demands at the UK level (Table 2).

Water uses	% Increase
Water supply	1.6%
Agriculture	19.0%
Industrial, commercial, public services	2.3%
Environment	5.0%
Amenity	5.0%

**Table 2:** UK average % increases in major water demand types aggregated from the Climate Change and Demand for Water project (Downing et al. 2003). Environment and Amenity demand growth rates of 5% were chosen in this report to reflect societies' increasing demand for environmental quality.

In order to guarantee reliable water supply, water companies and some industries have built surface water reservoirs. Table 3 lists the total capacity of existing and under construction reservoirs; it does not include the Abingdon reservoir (Oxfordshire) proposed by Thames Water (150 million m<sup>3</sup>, a 68% increase of current storage). Because total storage capacity is relatively limited (i.e. the system does not function with large carry-over year storage), water suppliers are dependent on relatively constant abstraction from rivers and groundwater. Current and proposed storage capacity provides some drought buffering capacity for short-term drought. In an extreme drought

situation, where a decision would be taken not to abstract further from the natural system, current (existing and under construction) full reservoir storage provides approximately 44 days of supplies (74 days with 150 Mm<sup>3</sup> Abingdon reservoir).

Thames catchment reservoir storage	Million litres (ML)
Capacity in operation	188,756
Capacity under construction	31,405
<b>Total capacity</b>	<b>220,161</b>

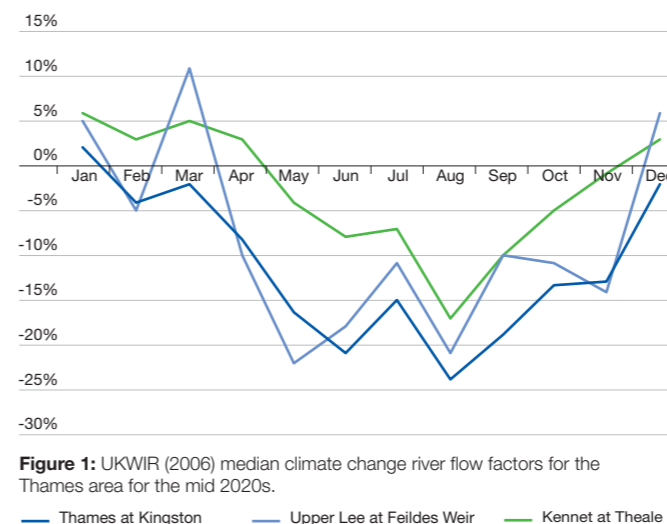
**Table 3:** Current Thames catchment reservoir storage capacity (existing and under construction). This data was purchased for this study from the Environment Agency. This table excludes the proposed new Abingdon reservoir (150,000 ML), a potential 68% increase in storage capacity.

This means that public water supply in the Thames is vulnerable to inter-annual periods of reduced precipitation, in particular in the case of one or more winter with low rainfall and consequently low recharge of groundwater resources. The impact of climate change on the frequency of such prolonged periods of below average rainfall is inherently difficult to predict.

### Climate change hydrology

Hydrological impacts of climate change have been intensely studied in the UK by academics and industry (Arnell and Delaney 2006). UKCIP helps organizations such as the water companies and their regulators assess how they might be affected by climate change. The water industry's research arm, UKWIR, together with the Environment Agency, commissioned the development of guidelines for water companies to estimate climate change effects on their water output.<sup>2</sup> River flow factors for Thames Basin are displayed in Figure 1. These flow factors give the general trend of climate change effects for the Thames. On average streamflow will be slightly higher during the winter season but significantly lower (almost 20%) during summer months.

<sup>2</sup> These guidelines (UKWIR 2006b) were used to estimate hydrological climate change effects of the UKCIP02 (Hulme et al. 2002) medium emissions scenario (A2) on the Thames catchment by the 2020s.



**Figure 1:** UKWIR (2006) median climate change river flow factors for the Thames area for the mid 2020s.

— Thames at Kingston — Upper Lee at Feildes Weir — Kennet at Theale

### Thames Basin water balance

An overall water balance of the Thames Basin shows small decreases in annual water availability for the 2020s (between a 1 and 2%). However, this smooths over the potential for the major intra-annual changes that are likely to have the most profound impact on public water supply and ecosystems. At the monthly level changes are variable (wetter winter and drier summers) and some are significant. In summer months, current abstractions are higher than available hydrological resources (excluding storage) during 1.5 months; this will increase to 2.5 months under projected climate and water demand. If negative water supply and environmental effects are to be avoided, the engineered water resource system (storage and other sources) will need to be managed more actively and water demands will need to be managed more effectively. Groundwater resources will be more actively exploited with a 4% increase in intensive aquifer use (days when abstraction exceeds recharge).

Hydrological modelling of the impacts of climate change and increased demand on stream flows undertaken for this study shows relatively stable conditions in the 2020s relative to current flows in the Thames at Kingston but shows increases in the number of days where flow is less the current ecological flow objectives in the Lee and Kennet.

# 6 Water quality

There have been very significant improvements in water quality in the Thames basin over the last half century, against a critical situation that had arisen by the post-war years. However, detailed assessments carried out for the Water Framework Directive demonstrate that water quality remains an on-going problem in the Thames, including pollution from sewage treatment works, and significant problems from agricultural pollution and urban run-off. These water quality problems result in significant on-going impacts on the ecology of the Thames, increased water treatment costs, and threats to some sources of public water supply.



The impacts of climate change are predicted to add to this problem:

- increased water temperatures and reduced flow volume during the summer months leading to reduced dissolved oxygen concentrations in the water, with potentially devastating impacts on fish communities.
- the reduced volume of flows during the summer months will also lead to a reduction in the capacity of the rivers to dilute any pollutants that enter the river; and
- an increase in the number of summer thunderstorms will result in the run-off of pollutants from rural areas and also increase the likelihood of the discharge of untreated effluent to rivers via combined sewer overflows.

Climate change is predicted to have severe consequences for organic pollution, abstraction and flow regulation of rivers in the Thames Basin (Environment Agency 2007). The reduced summer rainfall and increased potential evaporation expected over the forthcoming century are predicted to lead to reduced river flows across the region during the summer and autumn months (Diaz-Nieto and Wilby 2003; Arnell 2004; Wilby et al. 2006). By the 2020s river flow across the Thames region may decline by as much as 20% during the summer months resulting in less capacity to dilute any pollution that enters the region's rivers. Thunderstorms and flash flooding could result in a heavy pollutant load entering the region's rivers either directly from impermeable surfaces or indirectly through combined sewage overflows (CSOs).

The most significant impacts from water quality declines are likely to arise as a result of a combination of these impacts in low-flow, high temperature conditions, perhaps exacerbated by a sudden increase in pollution associated with heavy rainfall and a storm-flow event.



## Oxygen, rivers and climate change

Oxygen is essential for life, and aquatic life depends on oxygen dissolved in water. The concentration of Dissolved Oxygen (DO) in water is an important indicator of the quality of the water in a river. Oxygen dissolves in water when water mixes with air and as a result of photosynthesis by underwater plants. Oxygen is consumed by life forms such as fish, insects and bacteria. Bacteria are important for breaking down organic matter such as sewage. However, when there is too much organic matter in the water bacteria consume too much oxygen, leaving less oxygen for fish and other creatures.

Another important indicator of water quality is the Biological Oxygen Demand (BOD). This measures the amount of oxygen required by bacteria to break down the organic matter in water. When BOD is high, such as when sewage is discharged into a river, the bacteria in the water use up all the dissolved oxygen, meaning that there is no oxygen available for other life in the river. This is why sewage discharges during summer storms can lead to fish kills. The sewage does not kill the fish, but the bacteria which break down the sewage use up all the oxygen in the water and the fish suffocate.

Climate change is likely to make these problems more significant:

- When water temperatures rise, less oxygen dissolves in water;
- At higher temperatures, bacteria use up oxygen faster;
- When river levels are low, there is less water and therefore less oxygen available, meaning that the oxygen used by bacteria and other organisms has a greater impact.

As a result of all of these impacts, climate change is likely to result in increased pressure on the amount of dissolved oxygen available in rivers, most importantly at critical times of low flows and high temperature in the summer. This situation is indicative of the impact of climate change on a number of different water quality pressures on the Thames.

## 7 Ecology

The chalk streams of the Thames Basin are highly important because of the number and diversity of species they support. The plant communities in these streams are absolutely vital to ecosystem and structure and health, but are susceptible to relatively small changes in environmental factors such as flow rate, water temperature and pollution (Flynn et al. 2002). With the projected patterns of climate change leading to potential summer low flows and higher water abstraction aquatic plant communities may suffer in their diversity and abundance, although further scientific research is required in this field (Wilby et al. 2006).

Ranunculus is the dominant plant species in chalk streams and is vital to the health of aquatic ecosystems. Ranunculus is able to increase in size during times of high flow providing important protection and habitat for fish and other aquatic animals (Wright et al. 2002). In contrast, if a drought year results in the slow growth of Ranunculus and siltation of the river bed, then high nutrient levels in the water will favour the growth of algae, further reducing the area and biomass of Ranunculus. As a consequence, water levels, which normally stay high in summer due to heavy plant growth, will remain low, making it easier for wildfowl to feed, further reducing the size of the plants.

This illustrates how several different factors might act together to shift the ecological balance from one state to another. Low flow, pollution and high temperature conditions in the summer may impact on how well water plants like Ranunculus are able to respond to high flow conditions in winter, with important consequences for habitat (Flynn et al. 2002).

Changes in river flow regimes, water temperature and water quality due to climate change can affect the survival, spawning times, reproductive success and growth of invertebrates, freshwater fish and amphibians (Bragg et al. 2005). Predicted decreases in summer flows and declining water quality could result in the long-term decline of the Thames freshwater fish populations (Wilby and Perry 2006). In some regulated rivers, however, there may be opportunities to maintain physical habitats by controlled releases from reservoirs.

Wild populations of estuarine and freshwater fish are being exposed to endocrine-disrupting chemicals in concentrations sufficient to cause disruption of their reproductive physiology (Jobling et al. 2006). In severely feminized fish, fertility becomes reduced, with implications for population growth. A number of studies have examined aberrations in fish reproduction to provide information concerning the processes of endocrine disruption; however it has proven difficult to assess the ecological significance of endocrine disruptors



in the natural environment (Peters et al. 2001). The summer low flow conditions predicted for the 21st Century could have implications for the frequency and severity of endocrine disruption in the fish populations of the river Thames.

Groundwater recharge of chalk aquifers in the Thames region may be up to 14% lower than the present day by the 2020s (Arnell 2002). This will have severe impacts for the upper reaches of groundwater fed streams in the north of the Thames region including the long-term shrinkage of stream networks and the downstream spread of ephemeral stream communities dominated by macrophytes.

## 8 The Thames Estuary

Climate change could undermine recent successes improving the water quality of the Thames estuary. Drier summers would lead to a reduction in the input of freshwater to the estuary; hence there will be less dilution of effluent and other pollutants. Heavy rainfall events during the summer months could result in combined sewer overflows discharging into the estuary. Furthermore, it is likely that climate change has already brought about a 2.7°C increase in the water temperature of the estuary over the last 30 years (Attrill 2006).

### Water quality

Even without considering changes in rainfall, increasing water temperature and radiation alone could result in decreased dissolved oxygen concentrations in the estuary (Thames Water 2005b). If sea level rise is also factored in, there is a further marginal decrease in water quality. When changes in rainfall patterns are also considered (including heavier but less frequent summer storms) there is a reduction in the anticipated number of combined sewer overflow discharges to the estuary. However, with the concordant anticipated increase in temperatures, failure to meet the required dissolved oxygen standard is nevertheless likely (Thames Water 2005b).

In a study which focused exclusively on the known effects of drought on the estuary Attrill and Power (2000) measured the changes to a range of physio-chemical variables on the water quality during non-drought (1977-1988) and drought (1989-1992) conditions at West Thurrock, 67km downstream of Teddington Weir. They were able to show that drought conditions have significant effects on the water quality of the Thames. These results may provide an indication as to how these variables might react under similar conditions in the future.

Along with temperature and the input of freshwater, increased salinity may also adversely affect the dissolved oxygen content of the estuary. During the summer months, the mean 63% reduction in flow experienced during the drought (1989-1992) resulted in a mean salinity increase of 29%. This may also have a significant impact on the distribution of species within the estuary (e.g. Attrill and Power 2000a; 2000b). Salinity changes of this magnitude in the middle of the estuary mean that similar changes may be experienced further up the estuary where the ecosystem is more reliant on the input of freshwater, (Professor Martin Attrill, personal communication, 24 March 2008).

### Estuarine habitats

The lower Tidal Thames supports about 120 species of fish, 350 freshwater, estuarine and marine macroinvertebrate species, and nearly 300,000 over-wintering water birds (Environment Agency 2001). Areas of intertidal habitat are present along the entire length of the Tidal Thames, but the



most extensive reaches are below Tower Bridge where the flood defences are set further back from the main channel (London Climate Change Partnership 2002). The anticipated impacts of climate change and sea-level rise for London's intertidal habitat include increased levels of inundation and storm flooding; accelerated coastal erosion; sea water intrusion into freshwater tributaries; changes to the tidal prism, tidal range, sediment supply and rates of accretion; changes in air temperature and rainfall affecting growth of salt marsh plants (London Climate Change Partnership 2002).

The salinity gradient is the main parameter controlling the distribution of marine and freshwater organisms within an estuary, this distribution being modified by the extent of the seasonal input from the river. Decreasing freshwater flow results in the incursion of saline water into reaches of the estuary previously dominated by freshwater, exposing the communities living within these reaches to salinity stress (Attrill et al. 1996).

Reduced summer flows under future climate change scenarios have implications for the ecology of the Thames estuary, as the distribution of organisms within the estuary is dependent on the salinity gradient, which is seasonally controlled by the volume of freshwater flow into the estuary. Reduction in flow below the norm will expose organisms to increased salinity levels, resulting in the disappearance of taxa intolerant to increased salinity stress, and altering the structure of the community (Attrill et al. 1996).

# 9 The River Kennet

The Kennet rises near Avebury, Wiltshire and flows eastwards for around 40km before joining the Thames at Reading. Groundwater provides 95% of the water in the Kennet and only 9% of the Kennet floodplain is classified as being developed (Environment Agency 2007). As a major example of one of the internationally significant chalk-fed rivers of Southern England, the Kennet has some of the most important freshwater biodiversity in England.

The upper Kennet is designated as a site of special scientific interest (SSSI) because of the outstanding richness of its chalk river animal and plant communities, and a tributary of the Kennet, the River Lambourn, is a Special Area of Conservation designated under the Habitats Directive. The perceived value of the resource has led to more data gathering facilities, restoration projects (e.g. the Upper Kennet Rehabilitation Project) and several academic studies, notably focusing on climate change effects (most recently Whitehead et al. 2006; Wilby et al. 2006).

### Water balance

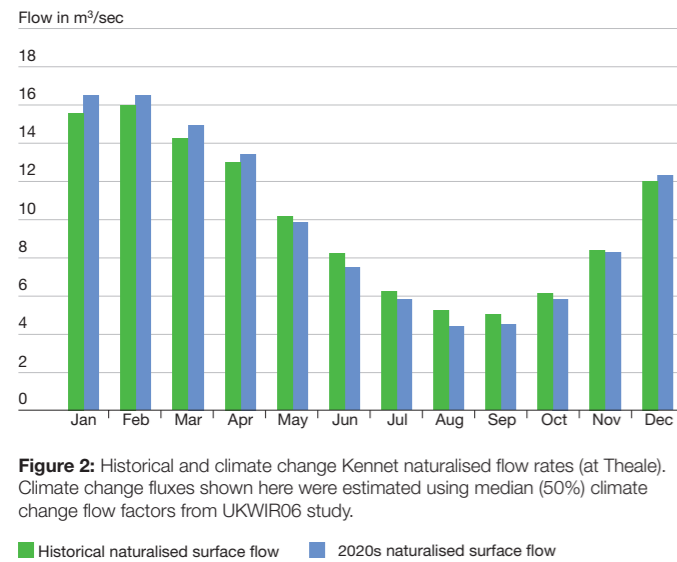
The total increase of projected water demand throughout the Kennet is approximately 18 ML/day, from 473 to 491 ML/day. Climate change effects on naturalised stream flows (not considering net abstraction/discharge rates) can be seen in Figure 2: winter flows are higher and summer flows lower. Under median climate change, observed river flows will fall below ecological objectives approximately 44% of the time; up from 26% under current conditions. Flow duration analysis reveals that on average median climate change low flow days are 28 ML/day lower than current low flows.



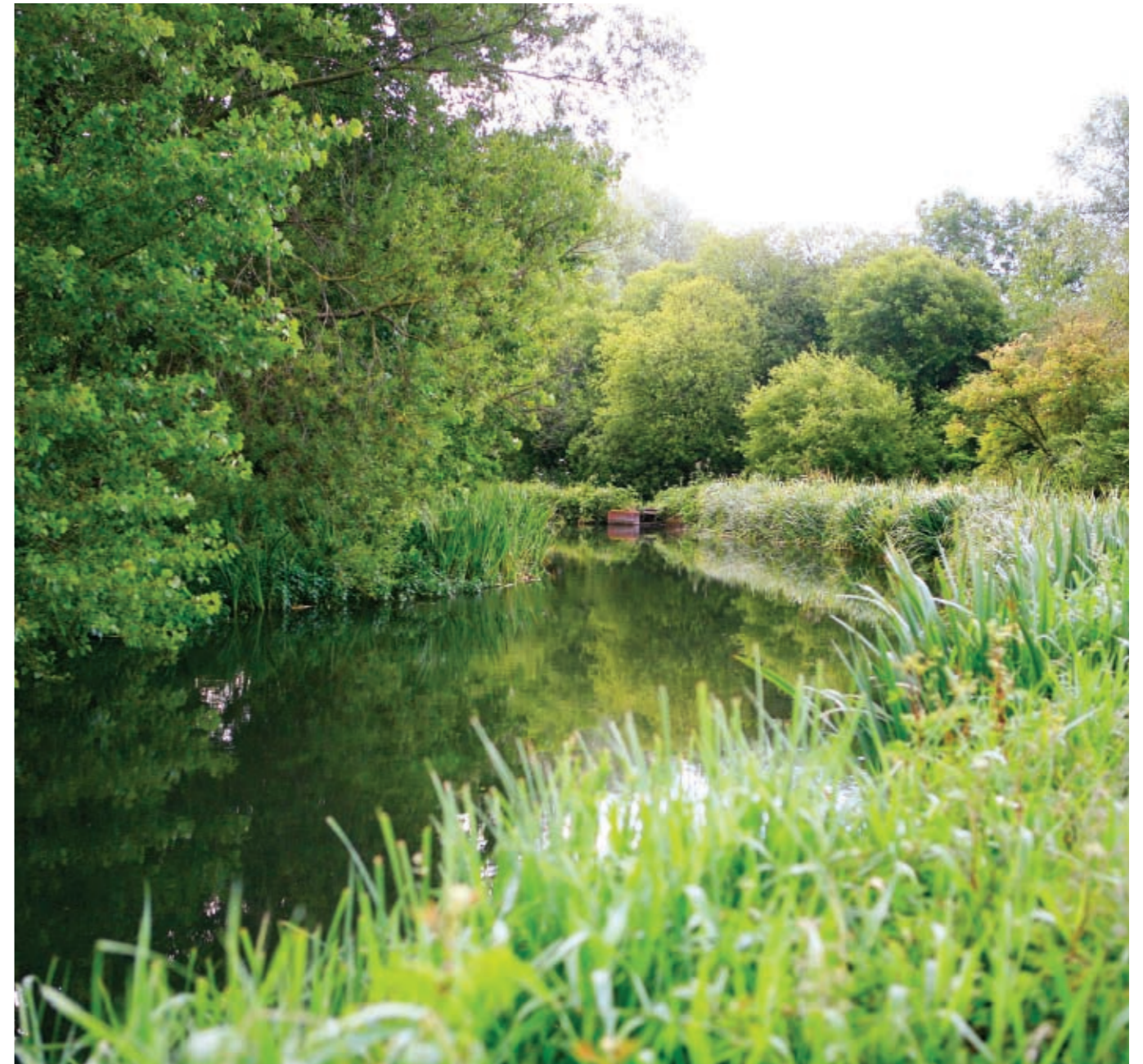
The consequence of lower summer flows and increased demand in the Kennet is likely to be a significant increase in the existing pressures on the river and its ecosystems in the absence of action to remedy the situation.

The changes in the flow regime may also have significant consequences for run-off entering the river. Reduced flows during the summer months will lead to less dilution of any pollutants entering the river while increased water temperature may lead to increased biological activity and a decline in DO. Analysis undertaken for this report highlights a 17% decline in the summer flow of the Kennet by 2020. This is a similar value to the anticipated reduction in flow by 2080 determined by Wilby et al. (2006) and as such indicates that the dilution capacity of the river during the summer months may be negatively affected in the near future.

Ranunculus is an important species in the diverse ecosystems of the Kennet. Reduced summer flows will leave the Ranunculus vulnerable to grazing by water fowl, reducing their volume overall. This in turn will increase the vulnerability of invertebrate and fish species that depend on Ranunculus for habitat in the Kennet. In particular the reduced volume of Ranunculus could lead to an overall increase in the speed of water flowing in the Kennet during the winter, further increasing the vulnerability of the freshwater ecosystem to collapse.

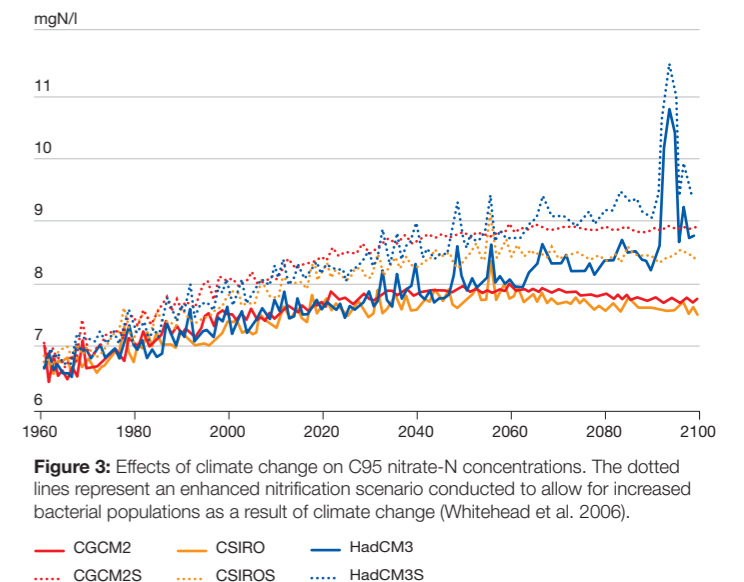


**Figure 2:** Historical and climate change Kennet naturalised flow rates (at Theale). Climate change fluxes shown here were estimated using median (50%) climate change flow factors from UKWIR06 study.



### Water quality

The effect of climate change on nitrate-N concentrations in the Kennet has been the focus of recent attention (Whitehead et al. 2006; Wilby et al. 2006). Increased concentrations of nitrate-N in the river are predicted on the basis of rising temperature and enhanced microbial activity. When determining the anticipated concentration of nitrate-N on periods of low flow, the results from the climate models used indicate rising nitrate-N concentration until around the 2050s. However by 2100 the concentration of nitrate-N in the Kennet varies depending upon the climate model used. For periods of low flow, under the medium emissions scenario HadCM3 predicts nitrate-N levels of around 11 mg/l by the end of the century (Figure 3). This is due to the GCM predicting sustained droughts during the summer and autumn which lead to the build-up of nitrogen in the soil and its subsequent run-off to the river during flash flooding. This level of nitrate-N is just below the EU legal limit of 11.3 mg/l and is similar to levels recorded during the drought in the summer of 1976. In contrast the results generated by the CSIRO and GCM2 models predict declining nitrate-N concentration in the Kennet by around the 2050s due to increased river flow after the 2050s.



**Figure 3:** Effects of climate change on C95 nitrate-N concentrations. The dotted lines represent an enhanced nitrification scenario conducted to allow for increased bacterial populations as a result of climate change (Whitehead et al. 2006).

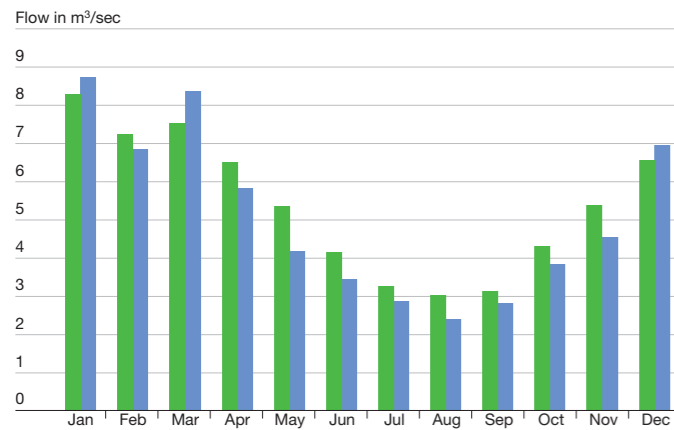
# 10 The River Lee

The River Lee is the main tributary of the Thames in Greater London and has been a significant source of London's water supply for many centuries (Flynn et al. 2002). The Lee drains a catchment of around 1400km<sup>2</sup> and from its source in Bedfordshire the Lee flows southwards for around 85km before joining the Thames at Bow Creek in east London, approximately 2.5km upstream of the Thames Barrier.

The TCFMP divides the Lee into two separate areas: the Upper Lee, from its source to Feildes weir at the confluence with the river Stort, and the Lower Lee from Feildes Weir to the Thames. The Upper Lee is predominantly rural with arable farming the most common land use although it does include built up areas such as Luton, Wheathampstead, Hertford and Ware. The Lower Lee, south of Feildes Weir is heavily urbanised and includes the London Boroughs of Enfield, Hackney, Tower Hamlets and Walthamstow. The Lee has been used as a navigable river for over 900 years and the Lower Lee is now a complicated system which consists of the Old River Lee, the Lower Lee Flood Relief Channel (LLFRC) and the Lee Navigation.

## Water balance

99% of water abstracted from the Upper Lee catchment is groundwater. The total increase of projected water demand throughout the Upper Lee is approximately 10 ML/day, from 213 to 223 ML/day. Under median climate change the natural flow (without considering abstractions/discharges) in the Lee will not be meet current ecological flow objectives 44% of the time. When taking into account net surface water abstractions, river flow increases since there is more discharge to the river from treated sewage than the volume of abstraction. However this ignores the effects of groundwater extraction on river flow which could be large considering 99% of abstracted water is groundwater in this catchment.



**Figure 4:** Historical and climate change Upper Lee average monthly naturalised flow rates (at Feildes Weir). Climate change hydrology shown here were estimated using median (50th percentile) climate change flow factors from UKWIR06 study.

■ Historical naturalised surface flow ■ 2020s naturalised surface flow



## Water quality

Projections of future climate in London and the south east during the summer months are for increased temperatures and reduced rainfall, although there may be an increase in the number of thunderstorms and consequently flash flooding. Reduced rainfall during the summer months and an already over abstracted water course will mean that any pollutants discharged into the river will be not be sufficiently diluted resulting in negative impacts for water quality and ecology. A foretaste of what might be expected occurred after a heavy rainfall event in July 2007. Within the space of three hours there was a significant increase in the flow at Lea Bridge, during which time the biological oxygen demand increased six fold from 4.4 mg/l to 28.2 mg/l.

It has already been established that low flow volumes lead to increased nitrate-N concentration within the river (Flynn et al. 2002) consequently the effects of climate change and resultant low flows can be expected to adversely affect nitrate levels within the Lower Lee. This can be exacerbated by higher temperatures and the subsequent increase in microbial activity (Whitehead et al. 2006), which in the Kennet was seen to increase nitrate levels in effluent affected reaches by around 14% to 16% (2020s), 19% to 21% (2050s) and 18% to 27% (2080s). A similar level of increase in the Lower Lee by the 2020s would result in nitrate-N levels of around 10.3 mg/l just under the EU legal limit for drinking water of 11.3 mg/l. By the 2080s an increase of 27% would result in a failure to meet these legal requirements.

The level of increased development in the Lower Lee corridor will put extra pressure on water resources potentially increasing the need for abstraction and thereby further reducing the dilution of pollutants entering the river. As discussed earlier it is likely that new developments will increase run-off to the river so flash flooding and associated pollution events may be expected to increase. The discharge of untreated effluent from Abbey Mills should however be a thing of the past due the proposed development of the Tideway Tunnel which aims to transport effluent from Abbey Mills to Beckton.

## Flood risk

The effects of climate change are considered to be the greatest risk to flooding in the future. DEFRA guidelines indicate that increased rainfall during the winter and spring is estimated to increase peak flows by 20%. Consequently TCFMP anticipates that the economic damages arising from a 1% AEP fluvial flood event incorporating the higher flow rate would increase from the baseline value of £960 million to at least around £1.5 billion.

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*Climate change is likely to result in hotter, drier summers and warmer, wetter winters – both could threaten people and nature.*

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