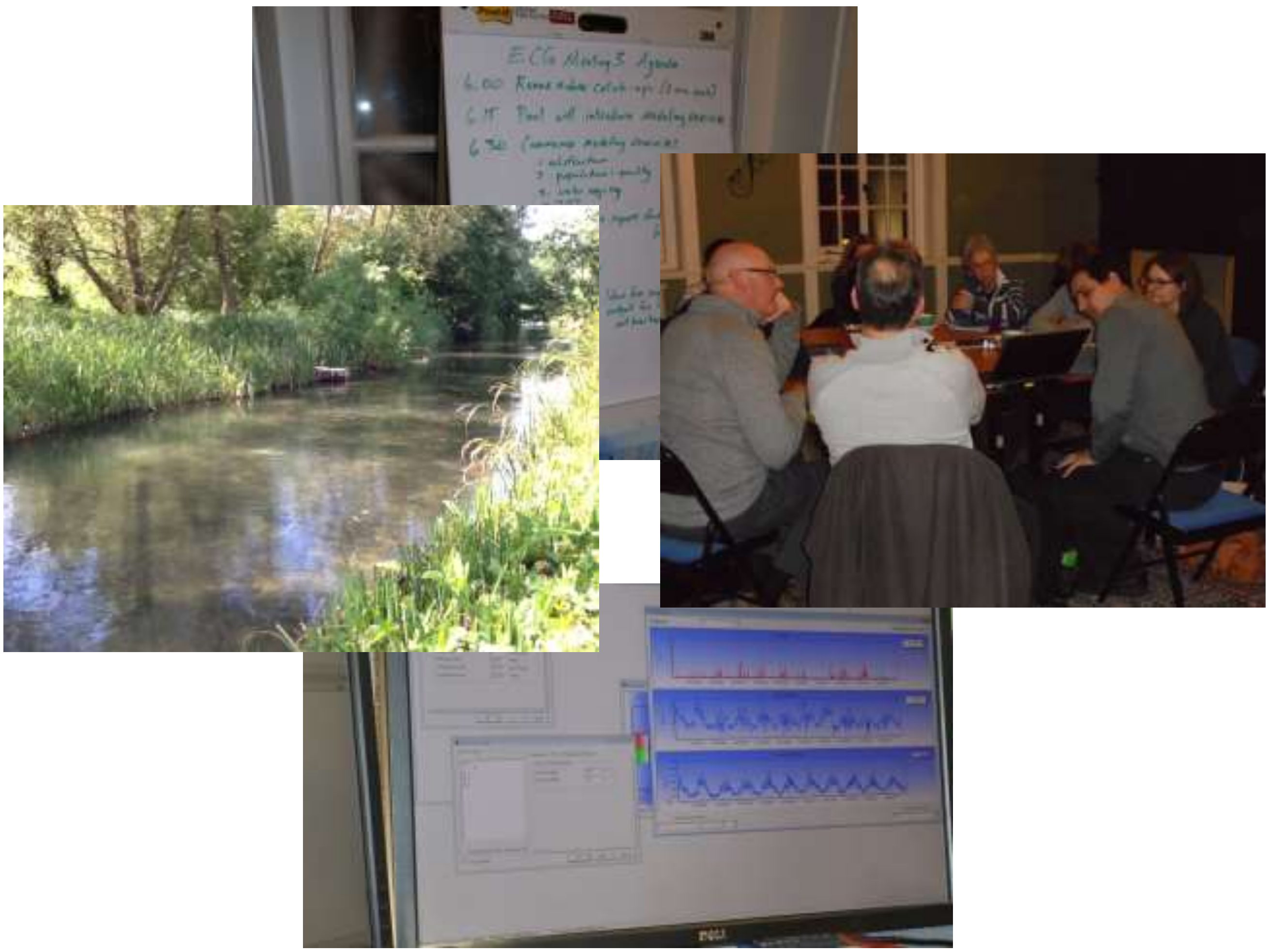
ACTIVE WATER RESILIENCE

Incorporating local knowledge in water management of the River Kennet catchment

Report of the 2015-16 River Kennet Environmental Competency Group



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EXECUTIVE SUMMARY

This report presents the findings of a collaboration of social and natural scientists from the universities of Oxford and Bristol and local residents in the Marlborough area. Working for a year this group, called the River Kennet Environmental Competency Group (Kennet ECG), examined water management in the Upper Kennet. Over the course of six meetings we drew on different types of knowledge and experience to explore water quality and quantity, using computer simulation modelling tools to gain better understanding of the risks posed by drought and low river-flows.

The River Kennet is an ephemeral river, with the uppermost reaches drying up in summer months. Droughts and low flows reduce water levels affecting fish, invertebrates and the growth of macrophytes, such as Water Crowfoot. Low flows can be caused by natural climate variability but can be exacerbated by water abstraction from the chalk aquifer underlying the Kennet.

In recent decades water quality has become an important issue because of the impacts of deteriorating water quality on ecology and water supplies. The reductions in flows coupled with the intensification of agriculture, urban pollution and population growth is causing problems in most catchments in the south east, especially vulnerable chalk streams such as the Kennet. Increased populations exacerbate water issues because of the extra water required for supply, thereby increasing the demand for abstractions. In addition, sewage effluent is generated by the increased population and is generally discharged back into the rivers. The Town of Marlborough has doubled in population since the 1950s and further expansion is planned. In order to evaluate impacts of drought and abstraction on water quality the INCA model was set up for the Upper Kennet. A set of flow and water quality scenarios have been evaluated to assess impacts on nitrogen and phosphorus, and hence ecology.

Thames Water and Affinity are the two main water companies supplying water to the Thames region. The River Kennet is in the domain of Thames Water and the Kennet ECG mainly focused on the Thames Water's supply system. A simulation model helped us to understand how changes in one source, or one part of the system, e.g. introducing a new pipeline, can impact on

the whole system. The results demonstrate the sensitivity of the water resource system to different future demand scenarios and indicate that future water demand and population growth need to be carefully monitored in order to ensure a resilient water supply.

There are different regulatory and policy frameworks that impact on the management of the Upper Kennet. Water quality, which has been examined in this report, is predominantly addressed through the Water Framework Directive (WFD). The WFD incorporates notions of local community involvement with catchment management and in the Upper Kennet there is an active Catchment Partnership, hosted by Action for the River Kennet. In contrast drought management does not involve local communities. The lack of connection between different policy frameworks governing local river and water management is a matter of concern.

By considering water quality in the Upper Kennet under different flow conditions the Kennet ECG placed scientific drought knowledge in local context. This generated knowledge about what might happen locally during droughts and low river flows, and about how local river management practices could improve resilience. This link between a local catchment and drought management would not have been made without the combination of scientific and local knowledge created in the Kennet ECG.

Local measures to improve water quality identified in this report include two changes in agricultural practice: reducing fertiliser use and using cover crops that can absorb nutrients from the soil, thereby preventing leakage into the river. A third measure is to allow for land use in the catchment that facilitates construction of water meadows and small wetlands that contribute to reducing the amount of nutrients in the water.

Local measures can also promote water quantity, i.e. keeping river flows at a level that sustains the ecology. One important forward looking measure, often overlooked, is to require water efficiency measures in new developments. A second measure, already pursued to some degree, is the retrofitting of existing buildings to reduce water use. The work currently being undertaken to address the historical structures in the river that impact negatively on flows, should be supported. A new measure is local monitoring of the impact of changes to abstraction regimes and the new pipeline.

1 Introduction

This report presents findings from a one-year collaboration between university scientists and local residents examining water management in the Upper Kennet. The collaboration, called the River Kennet Environmental Competency Group (hereafter Kennet ECG), comprised local residents in the Marlborough area and natural and social scientists from Oxford and Bristol Universities[1]. Over the course of six meetings the Kennet ECG drew on different types of knowledge and experience from local and university members to explore aspects of water quality and quantity using computer simulation modelling tools to gain a better understanding of the risks posed by drought and low river flows. The ambition to produce an outcome that could inform the Area Neighbourhood Plan emerged in the course of the meetings.

1.1 History of the Kennet ECG

The Kennet ECG was initiated by social scientists from Oxford University in order to develop the Environmental Competency Groups (ECG) methodology that was first trialled in the project 'Understanding Environmental Knowledge Controversies: The case of flood risk management' 2007-2010, funded by the Rural Economy and Land Use (RELU) programme (Landström et al 2011). The group organised by that project in Pickering, North Yorkshire was particularly successful in producing a low-cost flood defence approach, derived directly from local knowledge input into hydrological computer simulation models and adopted into local flood risk management (Whatmore and Landström 2011).

A Kennet ECG meeting

ECG is a distinct research method that makes scientists and local residents work together to create knowledge about local environmental issues. Initially developed for situations when public controversy regarding the nature of a

[1] Participants attending the majority of meetings in alphabetical order: Timothy Clarke, Val Compton, Christina Cook, Gemma Coxon, Jack Ginger, Charlotte Hitchmough, Catharina Landström, John Martin, Mohammad Mortazavi-Naeini, Eric Sarmiento, Sarah Whatmore, Paul Whitehead. All are considered co-authors of this report.

problem and/or the best way to address it has erupted, ECGs are designed to create a space in which those most directly affected by the problem can interrogate expert knowledge and bring their experiences to bear on how the problem is framed and different courses of action.

ECGs are underpinned by critical social science analysis of the relationships between science, policy and publics. Five notions are especially important in ECG design:

- The right of citizens to disagree with government / policy and their capacity to band together and to give public expression to their concerns, i.e. a politics of minority views.

- The reliability of science depends on rigorous disputation and careful provisos within scientific communities, i.e. science produces conditional knowledge.

- First-hand experience of the problem in question that has moved people to investigate it further qualifies participants, regardless of social background or involvement in an interest group, i.e. participation is personal.

- The nature of the problem is kept open by specifying it in several different ways, thereby enabling different aspects and tools to become relevant, and knowledge claims to remain conditional propositions , i.e. problem framing is multiple.

- Various ways of 'working with things' are equally as important as verbal discourse. Material objects and bodily skills are fundamental in human thinking and reasoning and constitutive of how knowledge is produced. 'Making things together' is a vital component that helps communicating knowledge claims to others, i.e. practical activities are key.

The priority for ECGs is to recruit members with personal experience and an interest in finding out more about the issues. It is advantageous for the group if these experiences and/or concerns differ, so getting a balance of men and women from different backgrounds is desirable, but the primary objective is not to achieve some preconceived 'representativeness'. Recruitment involves a two-way process of selection – with the group's convenors selecting amongst volunteers responding to recruitment adverts, but volunteers also electing whether or not to join the group on hearing more about its purposes, ethos and conduct. This process cannot guarantee that everybody who signs up attend all meetings, but it has proved successful in recruiting enough committed participants to enable the groups run so far to achieve meaningful outcomes.

The ECG methodology aims to involve local residents affected by environmental problems in the creation of knowledge used to manage risks. In the upper Kennet the impact of groundwater abstraction on the river flow has been a long-time concern for local residents. Although the problem is currently being partially addressed through the construction of a pipeline from Farmoor Reservoir that will reduce the need to abstract from the Upper Kennet area, the issue of sustainable flows, water quality and potential demand still requires consideration.

Drought raised concerns in 2012

ECGs work best when the primary objective is to develop new ways of thinking about a problem, rather than to solve it (Lane et al 2011). It is through the development of new collective competences, techniques for collaborative thinking and knowledge production, that an existing problem can be understood and addressed in new ways. This matters because involvement in the process of producing knowledge enables both closer scrutiny of expert reasoning and experiments in reasoning differently which strengthen any intervention the Group may make. So, although the knowledge produced by an ECG may go on to help to solve a problem, setting out to find the solution may not be the most constructive approach. For ECGs it is of more importance to develop collective competencies that can make a difference to the way a problem is framed and addressed.

1.2 Rationale of the ECG in Marlborough

The opportunity to try the ECGs methodology on issues other than flooding arose with the MaRIUS (Managing the Risks, Impacts and Uncertainties of Drought and Water Scarcity) project funded by the Natural Environment Research Council (NERC) programme on drought and water scarcity in the UK. The broad ambit of the multi-disciplinary MaRIUS project is to produce a risk-based, future oriented approach to drought management, a task that involves natural scientists, engineers, legal and policy experts, and social scientists. The Kennet ECG brought several of the project researchers together with local residents in the Kennet catchment, with the express purpose of generating new ways of thinking about and addressing water resource issues. Given that drought and water scarcity affect both water quantity and quality the group took a holistic approach and considered a range of water-related issues.

Local participants in the Kennet ECG were recruited through a mixture of newspaper advertisements, leaflets and word-of-mouth. Meeting six times over 12 months from September 2015 to July 2016 the members of the Kennet ECG explored relationships between water quantity and water quality against the backdrop of potential demand increases and climate change. At the group's disposal was scientific expertise in water quality, water resources and hydrology, thus allowing for the exploration of a range of computer modelling techniques that helped understand the issues. The six bi-monthly meetings were audio and video recorded and photographs were taken. The audio recordings were professionally transcribed and uploaded to the group's dropbox, to which all group members had access. The dropbox served as a repository for materials that group members wanted to share with each other. There were also a google group with an email list through which all group members could email each other and an archive of all messages sent was available.

2 Processes affecting the Kennet

The Kennet ECG drew on local knowledge and scientific data to examine the natural processes and human interventions affecting the water quantity and quality in the Upper Kennet. This section presents the knowledge generated by the group using data and scientific models.

2.1 Current water quantity and water quality issues

Water flows in the upper River Kennet (Figure 1) are subject to considerable variability because of the underlying chalk geology of the catchment and the highly variable rainfall in the Kennet catchment (Wilby et al, 2006).

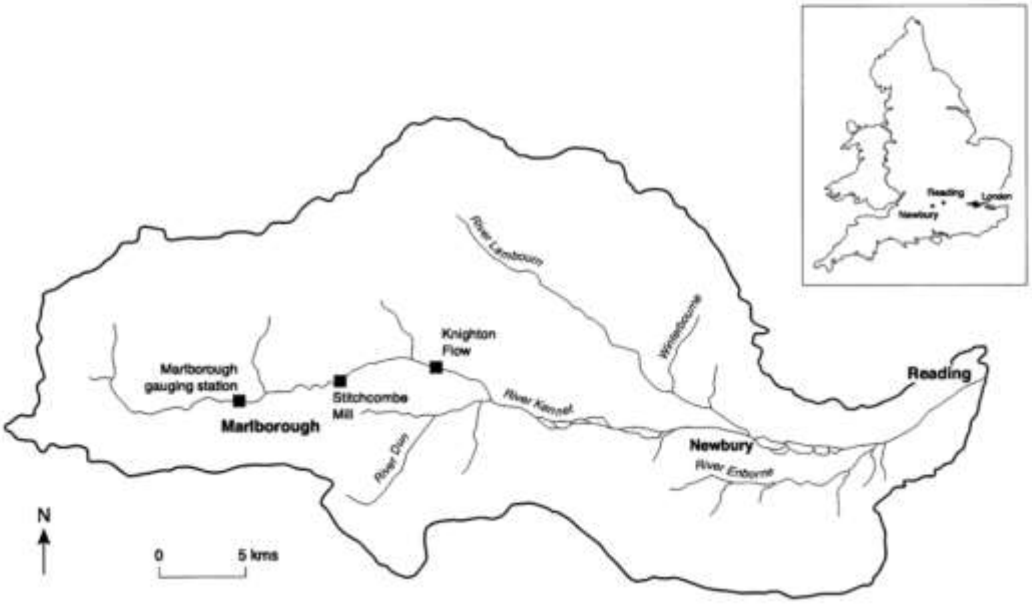

Figure 1 Map of the River Kennet

Figure 2 shows the observed daily river flow at Marlborough for the period 1972-2015, indicating highly variable flows with storm events and high flows at certain times plus significant drought periods in the past (e.g. 1976, 1992 and 2006).

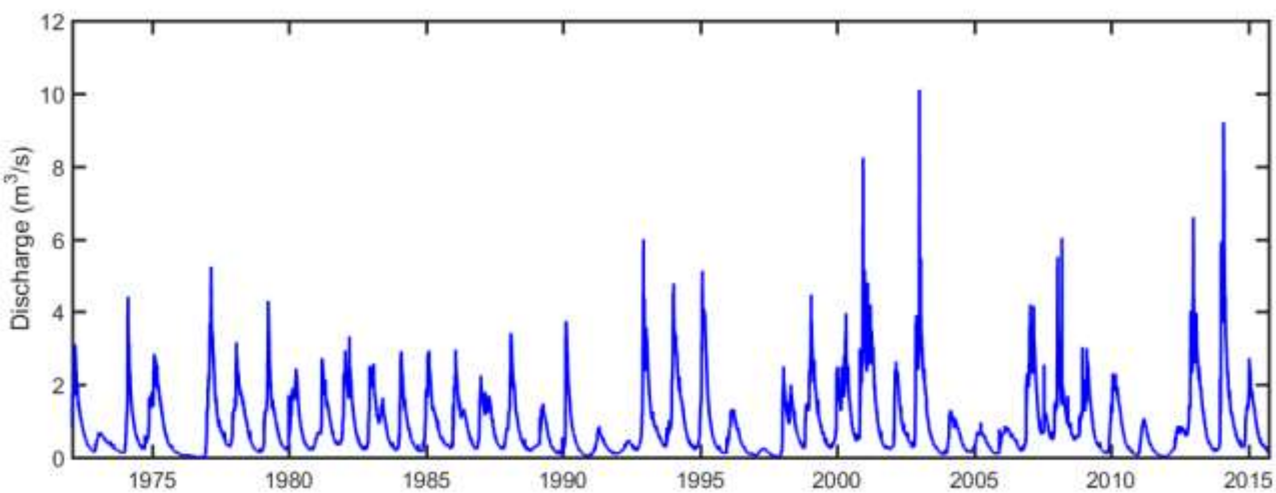

Figure 2 Observed daily flow at Marlborough gauging station

The River Kennet is an ephemeral river, with the uppermost reaches drying up in summer months and droughts and low flows reducing water levels which affect fish, invertebrates and the growth of macrophytes, such as Water Crowfoot. Low flows can be caused by natural climate variability but can also be exacerbated by water abstraction from the chalk aquifer underlying the Kennet (see Figure 3).

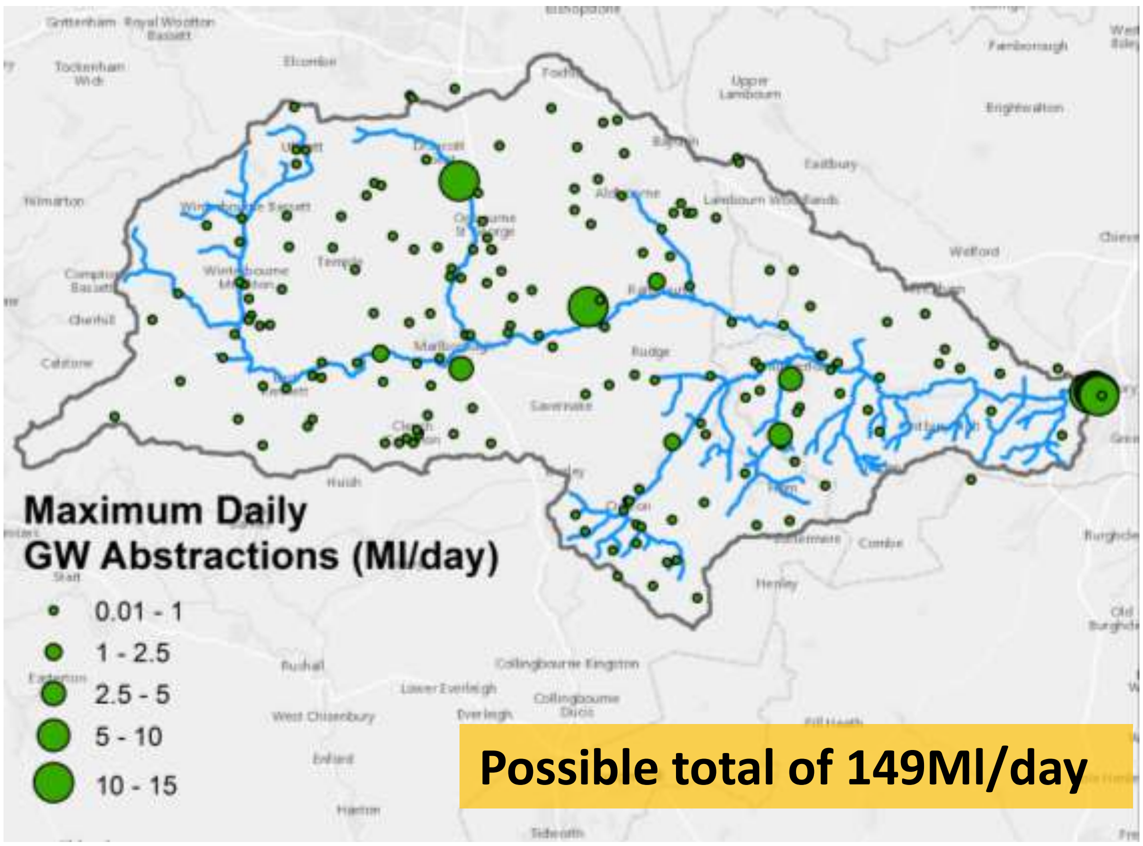

Figure 3 Maximum daily licensed groundwater abstractions (Ml/day) across the Kennet catchment for 2015.

Water is abstracted from the chalk aquifer to supply homes and businesses with water and to irrigate crops. This can have significant impacts on the flow in the River Kennet as shown in Figure 4 where observed flows and naturalised (no abstractions or modification by human activity) flows produced by the Environment Agency are plotted against one another for a drought period in 1997. Significantly, abstractions affect the entire flow range but have the most impact at low flows. As piped water supplies became more readily available from the early 1900s and populations have increased since the 1950s, abstractions have increased and climate change is becoming a major threat to streams in the South East of the UK (Whitehead et al, 2009).

To study the impacts of abstractions and climate change on current and future drought risk, water resource managers and scientists often use hydrological models to simulate and predict river flows. This is a particularly challenging task in the Kennet catchment as we are limited by our knowledge of the chalk aquifer underlying the Kennet and also the availability of tools for the integrated modelling of surface-groundwater interactions. Consequently, demonstrating the impact of abstractions (particularly groundwater abstractions) on river flows and the benefits of particular catchment management decisions can be a contentious issue.

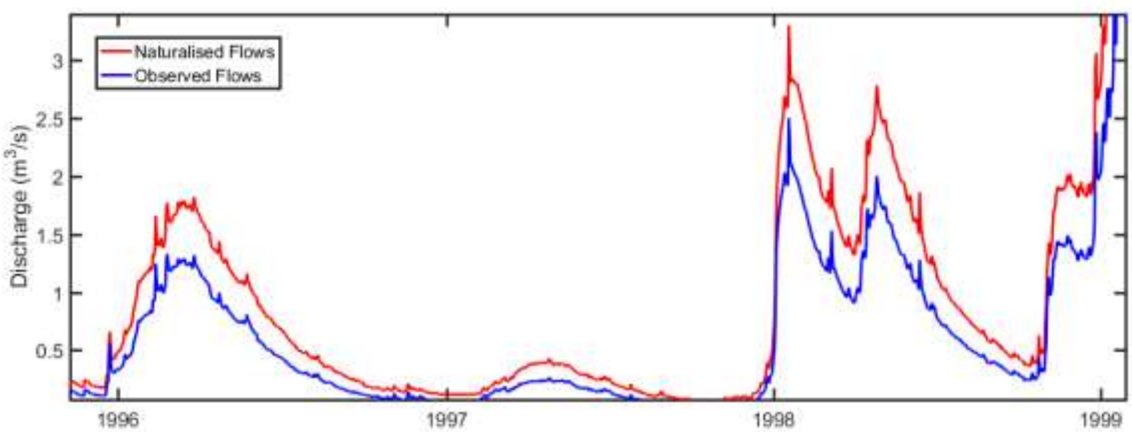

Figure 4 Observed and naturalised flows for the River Kennet at Marlborough from 1996-1999.

In recent decades, water quality has become an important issue because of the impacts of deteriorating water quality on ecology and water supplies. The reductions in flows coupled with the intensification of agriculture, urban pollution and population growth has caused, and is causing, problems in most South-East catchments, especially vulnerable chalk streams such as the Kennet. Increased populations exacerbate water issues because of the extra water required for supply, thereby increasing the demand for abstractions. In addition, sewage effluent is generated by the increased population which is generally discharged back into the rivers. In the case of the upper Kennet, the Town of Marlborough has doubled in population since the 1950s and further expansion is planned. Treated Marlborough Sewage Effluent is discharged into the river just upstream of Mildenhall and river observations have shown that the impacts of the effluent have been significant, increasing nitrogen (N), phosphorus (P) and sediment concentrations (Jarvie et al, 2002, Whitehead et al, 2006). This in turn has stimulated the growth of epiphytic algae and these algae have impacted the water crowfoot macrophytes, prematurely killing the macrophytes by smothering the plants with epiphytic algal growth.

The second major impact on the upper Kennet over many years has been the urban and agricultural runoff during storm events when waters rich in nutrients (N and P) and sediments are flushed into the river system. These nutrients are derived either from road/pavement runoff in urban areas, from agricultural fertilizer applications or from animals or animal manure spreading in the agricultural areas. All the extra nutrients increase N and P concentrations in the river system, thereby creating the ideal conditions for nuisance algae to grow which damage the macrophyte growth. Algal blooms also lower Dissolved Oxygen (DO) levels at night (due to respiration) which can result in very low DO levels such that fish and macroinvertebrate populations can be damaged.

During drought, wildlife and ecology is also impacted. Some of the impacts are clear, for example fish which become stranded either die through lack of oxygen or become easy targets for heron. Some impacts are more subtle, for example the plant 'stream water crowfoot' only grows when flow rates are strong. The plant is also sensitive to water quality because when water is enriched with N and P algae flourishes and smothers Ranunculus as it is trying to grow. Lack of weed growth in the stream reduces the number of invertebrates, leaving less food and cover for fish, with knock on consequences across the food web. In addition stream water crowfoot and starwort takes up space in the water course, channelling water in to fast flowing sections. A bare river channel supports a much lower biodiversity than one with good macrophyte growth.

As climate change takes hold temperatures are predicted to rise and, in fact, the EA research on temperature patterns across the southern UK already show temperature increases (Orr et al, 2015). Increased temperatures lower the saturation levels of DO and this reduces the capacity of the river to naturally reaerate. The higher temperatures also affect fish populations as certain species (e.g. trout) prefer cooler waters. Another often neglected water quality impact is that caused by atmospheric deposition of pollutants. There are high levels of Nitrogen in the atmosphere due to industrial and vehicle pollution and this nitrogen is deposited on soils, trees and plants across the catchment. This extra N will eventually be flushed into the rivers during rainfall events which again exacerbates the nutrient levels in the river system.

So, all these effects mean that water quality improvement, via catchment management, is a complex and difficult task. However, some progress has been made in recent years with the installation of phosphorus stripping equipment at the Marlborough sewage treatment work (STW). This has effectively removed about 80% of the phosphorus. Also reduced fertilizer use should have an impact and new cropping techniques such as cover crops could help as well. Reintroducing wetland areas along the banks would create more 'residence time' for natural denitrification to occur. Some of these ideas are evaluated in section 6 of this report.

3 River management and its problems

Starting with an overview of the local community concerns about the condition of the river historically this section explores river management through to present day efforts to improve river flow and water quality.

3.1 Local concerns

Concerns about over abstraction, low flows and water quality in the Kennet have been ongoing since the 1920s with concerted active campaigning to protect the river since the early 1990s[2].

One of the earliest documented episodes of the impact of drought and abstraction was written by G K Maurice in Blackwoods Magazine January 1947. The article, entitled 'The Passing of a River - an obituary' describes in detail changes to the river observed since the first boreholes were sunk. Residents of the Upper Kennet in particular are acutely aware of river levels and conditions and anxious to see abstraction and pollution reduced to protect the river's ecology.

Particular concerns have been raised by the local understanding that a proportion of the water abstracted from the Kennet is exported to Swindon and the treated effluent is discharged into a different sub-catchment, so is lost to the River Kennet completely. This is known as consumptive abstraction.

3.2 Addressing abstraction

Local residents are very pleased with the proposed reduction in the abstraction licence at Ax-

[2] The history of abstraction and low flows in the River Kennet is outlined in the report 'Reducing the impact of abstraction on the River Kennet' 2012 by John Lawson for ARK.

ford and the Og, which will come in to effect in March 2017. The new licence restricts the quantity of water that can be exported from the catchment to 3 Ml/d during low flow periods. The licence restriction is not in force all year round, only when the flow at Knighton gauging station drops below an agreed level.

Local residents have campaigned vociferously for over 20 years, through Action for the River Kennet (ARK), to get the abstraction reduced. Their campaign has amongst other things included a BBC Panorama programme, speaking at the Houses of Parliament, and appearing in court. They suspect that if it had not been for this concerted and noisy pressure the Kennet could still have remained on the waiting list.

The Environment Agency (EA) has established a mechanism, called the National Environment Programme (NEP), to work closely with water companies to identify where abstractions may have an adverse impact on the environment. Water companies are then expected to submit proposals for how to address the impact. In many cases reductions in water company's current abstraction rates have been needed to mitigate adverse impacts on the environment.

In 2005, an investigation was conducted to assess the impact of the Axford abstraction on the local groundwater regime and the flow in the adjacent River Kennet. The investigation concluded that the Axford abstraction has an impact on local groundwater regime and the River Kennet, which can potentially affect the ecology of the river. Consequently, the Environment Agency reduced the licence from 13.1 Ml/d peak and 11.1 Ml/d average to 6 Ml/d peak and average. This licence reduction will need to be addressed by new infrastructure to supply water from other sources. Currently a scheme to increase transfer of water from Farmoor Reservoir to Swindon is well underway, a new pipeline linking North and South Swindon is due to be completed in March 2017.

Thames Water building a pipeline

3.3 Remaining issues

According to the local Rivers Trust Action for the River Kennet (ARK) measures to reduce the impact of abstraction are very welcome, but they have focused on the Axford and Og boreholes while the earliest concerns from residents were in relation to the boreholes at Canning's Hill and Clatford. ARK believe that the upper Kennet boreholes have an detrimental impact on the ecology of the chalkstream and have produced a report showing that the abstraction above Marlborough causes the river to dry up for an additional two weeks each year and up to eight weeks in some years. If the existing licences were fully used the winterbourne would be dry for about 30 days longer each year on average and up to 80 days longer in some years. ARK has had the report peer reviewed and submitted it to the Environment Agency and Thames Water in 2012 but they are still waiting for a response from the Environment Agency.

3.4 Historical structures

As a result of human impact over hundreds of years the River Kennet is a highly managed river system. Water meadow systems, mills and industry have left a series of control structures, like weirs and sluices in their wake, and although nowadays their role is largely redundant they impact the way the river is able to flow from its source to the confluence with the Thames.

There is no prescribed or coordinated management regime for control of weirs and river levels. Where the river is managed by employed river keepers, sluices are regularly altered to ensure good flows for Ranunculus growth whilst keeping side streams full of water. Publicly owned structures are rarely altered and privately owned structures are altered on an ad hoc basis usually to avoid flooding, or to retain water in reaches at risk drying during low flows. This can exacerbate problems of for fish when river levels drop in low flow conditions because they get trapped in isolated pools. Each structure has an impact on ecology either because it impounds water upstream, holding back flow and creating deep slow moving sections, or because it creates a barrier that fish can't swim over. The Kennet Catchment Partnership are working to reduce the impact of redundant structures by removing them, altering them to create fish passage or getting agreement from the structure's owners to allow more flow to pass over them. Local volunteers - organised and equipped by ARK (the local Rivers Trust) - the Environment Agency, Natural England and river keepers are working hard to improve river habitat by planting vegetation in the margins, improving flow characteristics and planting in-stream plants.

4 Future demand and droughts

This section accounts for the group's considerations of the potential implications of future water needs on the River Kennet. Research in the MaRIUS project provided information that enabled the Kennet ECG to consider some possible consequences of future demand scenarios on the Kennet given its role as a water supply source and to also think about the broader impacts on the Thames water supply system. We used a scientific computer model to represent the water supply system across the Thames and modelled a number of scenarios with different population growths in order to assess the vulnerability of the flows in the river to increased resource demand.

4.1 Future demand scenarios

Three different demand scenarios were assessed based on projected changes in population and per capita consumption (PCC). There is a lot of uncertainty surrounding how these numbers may change; PCC of water is gradually decreasing overall currently, but population is expected to increase significantly, particularly in the south east.

To reflect this, we considered three different future demand scenarios based on forecasts in the Thames:

1. No population or consumption changes in future, demand remains the same as currently.
2. 0.3% annual growth based on Thames Water report on annual average demand for a dry year forecast for 2015-2040 (WRMP14).
3. 1% annual growth to reflect a more severe demand growth scenario.

Thames Water supplies water to six Water Resource Zones (WRZ) including London, SWOX (Swindon and Oxfordshire), SWA (Slough Wycombe and Aylesbury), Henley, Kennet and Guildford (Figure 5). Table A in Appendix 1 presents the demand for each of these six WRZs for 2015-2040 (Scenario 1). Table A-1 displays demands based on Thames Water report (Scenario 2) and Table A-2 suggests the extreme demand growth (Scenario 3) for each WRZs in 2015-2040.

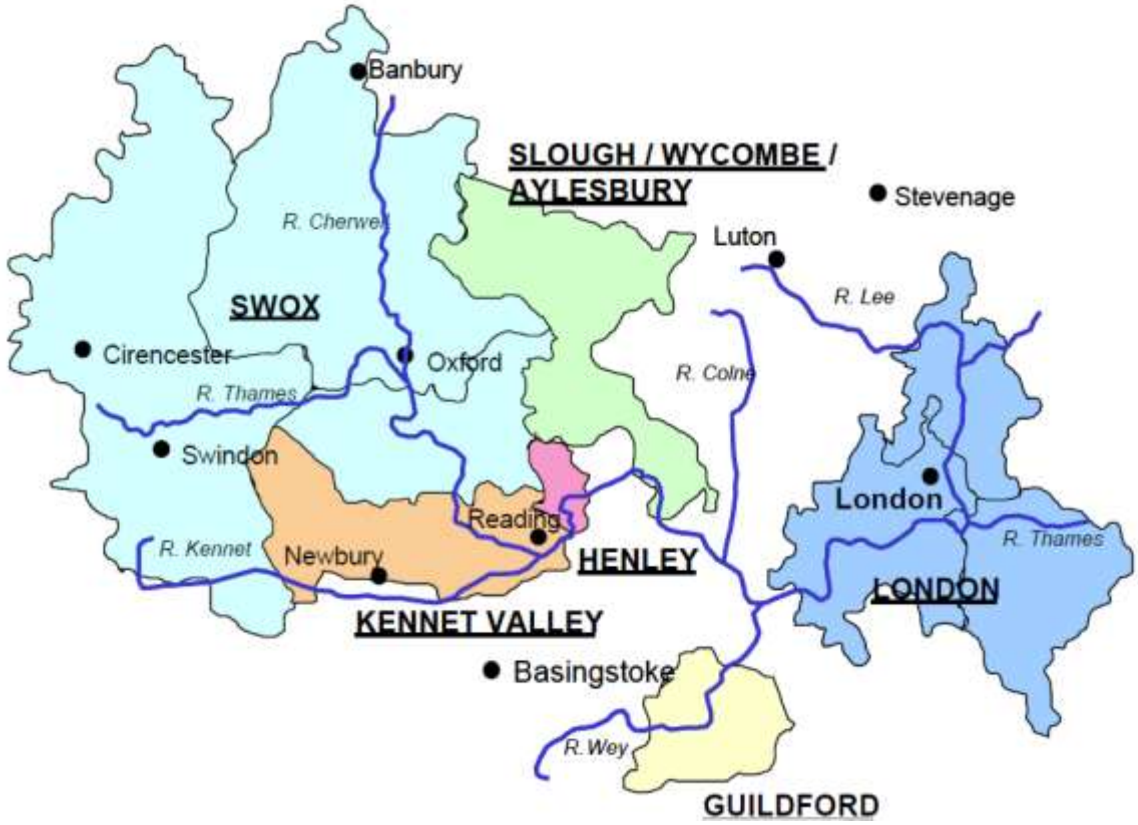

Figure 5 Water Resource Zones (WZR).

4.2 Modelling the water supply system

Thames Water and Affinity are the two main water companies supplying water to the Thames region. The River Kennet is in the SWOX water resource zone, in the domain of Thames Water and so the Kennet ECG mainly focused on the Thames Water's supply system. Thames Water has two main abstractions on the River Thames, one on the upper Thames, near the Farmoor reservoir, and one on the lower Thames. There is a large network of pipes and reservoirs which facilitate water supply to all water resource zones in the region. For instance, SWOX gets 40% of its sources from surface water through the Farmoor reservoir and 60% from groundwater abstractions.

The simulation model (WATHNET) helps us to understand how changes in one source, or one part of the system, e.g. introducing a new pipeline, can impact on the whole system. The Thames basin water resource system was developed in WATHNET and validated against output from the Thames Water model for the period

1920-2010, where the model was found to replicate similar reservoir levels and WRZ demands. The model was then run with modelled inflows for 1971 – 2012 with the three demand scenarios described above. This time period was chosen as it included a number of major droughts in the Thames basin (e.g. 1976 and 1995-1997).

4.3 Drought and demand

The main aim of a water supply system is to supply safe and reliable water to users with no or minimum environmental damages. In this study we defined reliability as frequency of imposing restrictions on demand consumption. Based on an agreement between Thames Water and the Environment Agency there are four levels of restrictions which will come into effect depending on the storage levels in the Lower Thames reservoirs.

Once each level is reached, actions need to be carried out by Thames Water:

1. Level 1 triggers an intensive media campaign.
2. Level 2 imposes sprinkler/unattended hosepipe ban and enhanced media campaign.
3. Level 3 imposes temporary use bans and implementation of Drought Direction 2011.
4. Level 4 an Emergency Drought Order would be put in place.

The reliability of the water supply system was measured based on how often each of these restriction levels were imposed for the three proposed demand scenarios. Figure 6 below presents the number of imposed restrictions (level 1 to level 4) for each demand scenario (a table of these figures can be found in Appendix two)

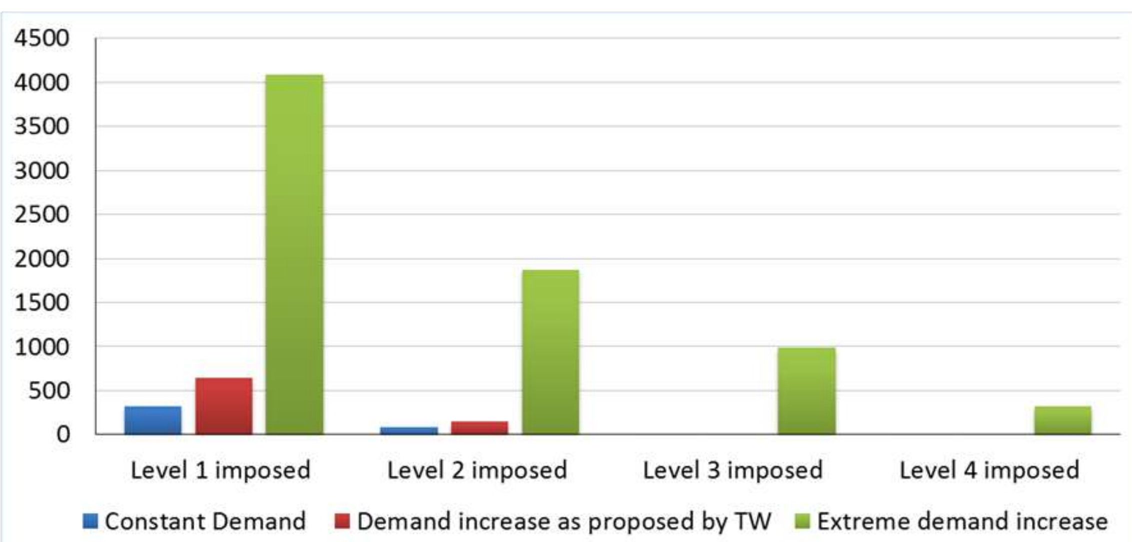

Figure 6 Number of imposed restrictions (in days) for each demand scenario from the 41 years modelled.

In Figure 6, we see that for the constant demand scenario in blue, a level 1 restriction (i.e. intensive media campaign) would have been triggered for 323 days out of the 41 years modelled. As we would expect, once you increase the demand placed on the system this sharply rises to 648 and 4090 days (or approximately 4 and 28% of the time) where there would be an intensive media campaign to reduce water usage. A similar trend is found for level 2 restrictions which would impose sprinkler and hosepipe bans. Significantly, no level 3 and 4 restrictions were imposed in the constant demand scenario but this increased to 989 days and 323 days for the extreme demand scenario based on the model simulations. Although, the population increases in the extreme demand scenario are much higher than is currently projected and these results are based on existing infrastructure, these results do not include the effect of future climate changes which could include more extreme droughts compared to the historical record. These results demonstrate the sensitivity of the Thames water system to different future demand scenarios and indicate that future water demand and population growth needs to be carefully monitored in order to ensure a resilient water supply.

Algae smothering macrophyte growth

Healthy macrophyte (Ranunculus) growth

5 Infrastructure and the built environment

Good water management in existing and new developments can improve river water quality, by reducing polluted runoff into rivers. Better water management can improve aquifer levels and resilience to drought by promoting infiltration to groundwater, treating storm water as a resource and reducing water consumption.

ARK and Thames Water have been working with local residents since 2012 to reduce water consumption in the Kennet Valley and in Swindon. This has been done by retrofitting homes with water saving devices. Uptake rates are between 1 in 3 and 1 in 4 households. Only around 40% of households in the area are on a water meter, so the incentive to save water is not always financial and the project demonstrates that there is an appetite for water efficiency in the community.

Marlborough and the surrounding villages have been part of a water efficiency programme, linked to Save Water Swindon. The Care for the Kennet approach emphasised the positive environmental impact of using water wisely, in contrast to the Save Water Swindon campaign, which focussed more on the potential to reduce water and heating bills. The projects have been reviewed by Claire Hoolahan in her PhD thesis: *Reframing water efficiency: Designing approaches that reconfigure the shared and collective aspects of everyday water use*[3]

During the campaign (which is still going on, now called 'Water Matters') more than a quarter of homes have fitted water saving devices into existing kitchens and bathrooms, the work has been funded by Thames Water and promoted by Action for the River Kennet. It demonstrates that there is an appetite to be more water efficient.

Volunteers working on the river

[3] A summary of the PhD thesis can be accessed at: https://www.academia.edu/29048262/Reframing_water_efficiency_Designing_approaches_that_reconfigure_the_shared_and_collective_aspects_of_everyday_water_use

6 Combined effects of drought, abstractions, increased housing and agricultural impacts (cover crops)

A major issue for the upper Kennet river system is the impact of low flows on water quality, as described in section 2. This is because low flows reduce the dilution of pollutants entering the river system, raising the concentrations of nutrients such as nitrogen and phosphorus, and enhancing the risks of algal blooms in the river system. There are quite frequent droughts in the Kennet region as the natural rainfall is low. A few months without rain can deplete the groundwater levels, which in turn depletes the river flows. In order to assess the effects of environmental change, abstractions and mitigation measures on water quality in the upper Kennet, the integrated catchment model INCA (Whitehead et al, 1998, 2013) has been applied to the river system. The model is dynamic, daily and process based so that it represents the key flow and chemical interactions occurring in the river system. Appendix 3 in this report gives a brief summary of the INCA Model.

6.1 Effects of drought and abstraction

The Kennet groundwaters have always been a source of fresh water either from individual wells for houses or from deeper wells that extract water for public supply. In total there are 64 groundwater supply abstractions in the upper Kennet catchment and no surface water abstractions. A percentage of each of the groundwater abstractions is returned locally to the River Kennet (usually around 40%) so taking this into account we can consider the current actual abstraction rate. This equates to an instream flow reduction of 707,652 m^3/year or 0.03 m^3/sec. These flow impacts seem small but Q90 (flows which are exceeded 90% of the time) are 0.12 m^3/sec in the upper Kennet, so the abstraction losses (assuming that all the groundwater abstractions have a direct impact on the streamflow in the river) would amount to a 25% reduction in the low flows which could have a significant water quality with subsequent ecological impacts. However, droughts can have a bigger effect than these abstractions, with rainfalls in certain years falling by 50% to create serious low flow conditions. The combined effects of drought and abstraction will create a worst case situation.

In order to evaluate drought and abstraction, the INCA model has been set up for the upper Kennet (Appendix 3). A set of flow and water quality scenarios have been evaluated to assess impacts on nitrogen and phosphorus, and hence ecology. Figures 7, 8 and 9 show the simulation of flow, nitrate and phosphorus for the upper Kennet at Mildenhall over 5 years (2002-2007).

This time period is used to illustrate some wet periods (winter 2003/4) and long dry summers (2005/6). The blue line represents the flow and water quality driven by the actual rainfall over 2002-2007, whilst the green line represents a scenario situation. So the green line in Figures 7, 8 and 9 shows the effects of a severe drought when rainfall is halved over the upper Kennet catchment. As might be expected, reducing the rainfall reduces the water flux into the river and this reduces the flows, as shown in Figure 7. This reduction in flows also affects water quality. Interestingly nitrogen during the drought is lower (Figure 8) and this is because there is less agricultural runoff, as the dry soils, soak up the rainfall. Also there are lower velocities in the river and hence longer residence times. These longer residence times mean that there is more time for biochemical reactions to take place in the river sediments. These reactions remove nitrate. However, at the end of the drought, stored nitrogen in the soils can be released resulting in a large pulse of nitrate in rivers. The major effect of decreasing flows is to reduce the dilution of point source pollutants in the river. In the upper Kennet, effluents from STWs at Fyfield and Marlborough impact the river and, as shown in Figure 9, the phosphorus levels rise during low flow periods, as there is now less water to dilute the effluent from the point sources. Since the river ecology is very sensitive to phosphorus concentrations, these increases are significant and can trigger algal growth.

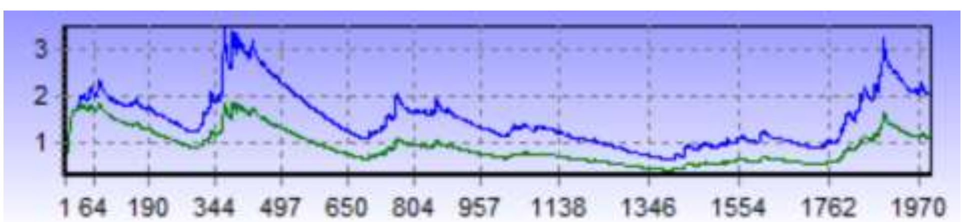

Figure 7 Simulated Flow (m^3/sec) at Mildenhall 2002-2007. Blue line shows actual flows, Green line shows drought/abstraction effects.

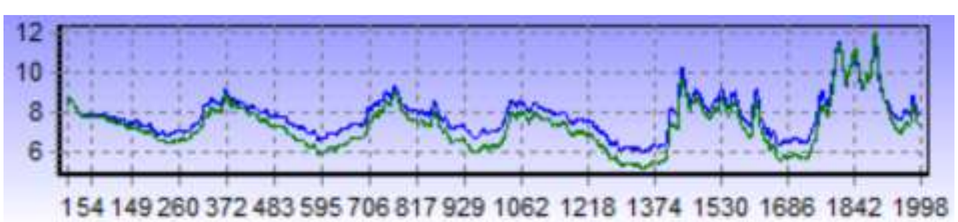

Figure 8 Simulated Nitrate (mg/l) at Midenhall 2002-2007—green line shows drought effect.

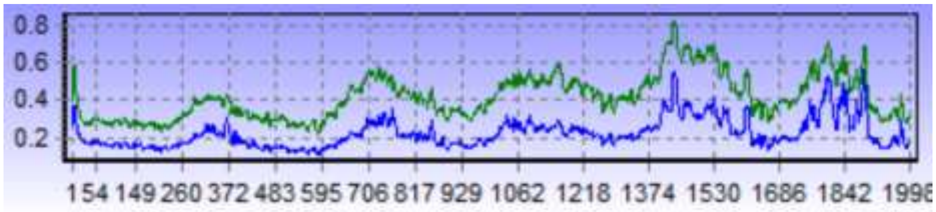

Figure 9 Simulated Phosphorus (mg/l) at Mildenhall 2002-2007 —green line shows effect of drought/abstractions.

6.2 Effects of population growth and agricultural change

The Marlborough population has doubled since the 1950s and there are plans for additional housing in the area. The extra people need additional water supplies thereby increasing pressure for abstraction/supply and also their effluent flows back into the river, via the STWs, exacerbating the pollution issues. Figure 10 shows the effects of a 30% increase in population in the upper Kennet and, as shown, the point sources increase and hence raise the phosphorus concentrations in the river. As far as agriculture is concerned they are many ideas for mitigation the effect of intensive agriculture, including buffer strips along the stream, reducing fertiliser application rates or introducing cover crops to effectively remove nutrients from the soils, thereby reducing their availability for runoff. Figure 11 shows the effects of an agricultural strategy for nitrogen assuming a cover crop is planted that effectively reduces N flux from the soils by 35% or by reducing N fertilizer applications by 35%. As might be expected the effect is to lower nitrate concentrations in the river, although this will take time to work, as there is significant nitrate stored in the groundwater aquifers and this will take time to deplete.

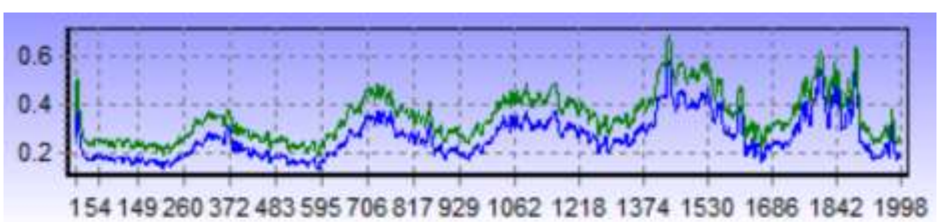

Figure 10 Simulated Phosphorus (mg/l) at Marlborough, 2002-2007—green line shows effects of 30% extra housing.

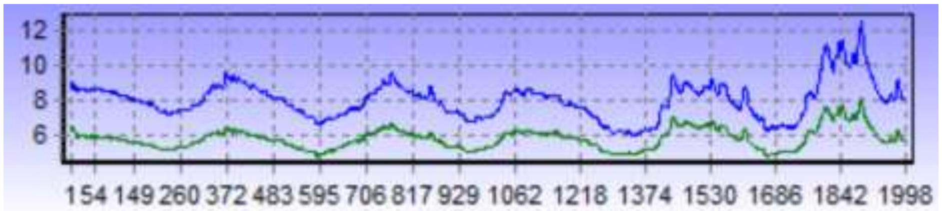

Figure 11 Simulated Nitrate (mg/l) at Mildenhall, 2002-2007—green line shows effects of cover crops or reduced fertiliser applications.

6.3 Climate change impacts and long term mitigation

In a study of the likely future impacts of climate change on hydrology and water quality in the River Kennet, Wilby et al (2006) and Whitehead et al, (2006) have shown that summer flow rates in the river are likely to fall in the future as drought periods becoming more extreme. Winter rainfall is expected to increase and these changed seasonal patterns are still anticipated in more recent studies (Arnell et al., 2015). The lower summer flows will decrease the dilution of diffuse runoff from farms and point sources thereby increasing nitrate concentrations (see Figure 12 below). The research suggests that nitrate concentrations will increase into the future unless any other actions are taken. A series of adaptation strategies have been investigated using the model to see if it is possible to mitigate the effects of climatic change. For example, introducing cover crops or reducing agricultural fertiliser use by 50% in the catchment has the biggest improvement (dotted line below), lowering nitrate concentrations to levels not seen since the 1950s. Reducing atmospheric sources of Nitrate and Ammonia by 50% does reduce the nitrate by about 1 mg/l compared with the climate effects (see grey line) but is a much smaller effect. Constructing water meadows along the river would be more beneficial, significantly slowing down the rising levels of nitrate (see dashed/dotted line). However, a practical proposition might be a combination of all three approaches to reduce fertiliser use by 25%, reduce deposition by 25% and to construct some wetland areas along the river system. This generates significant reductions in nitrate in the river (see black line).

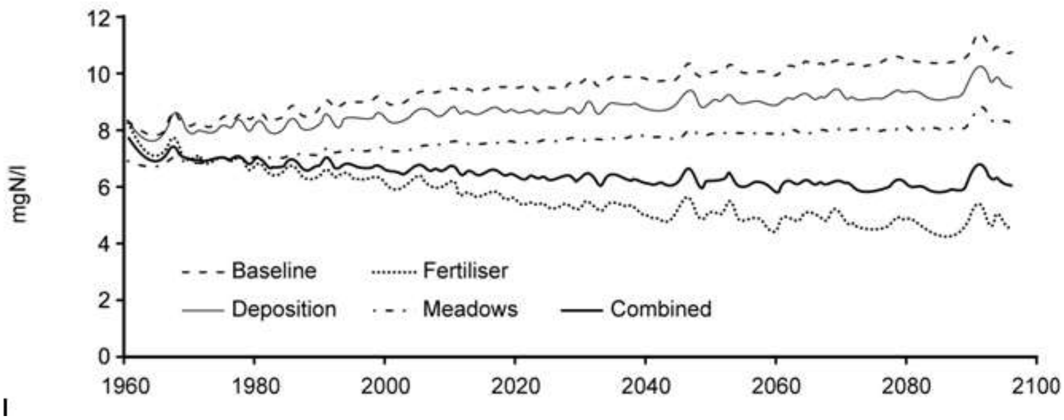

Figure 12 Simulating the effects of climate change from1960-2100 on Nitrate concentrations in the River Kennet together with a set of adaptation strategies.

7 The potential for greater reliance on local knowledge

There are different regulatory and policy frameworks that impact on the management of the Upper Kennet. Water quality, which has been examined in this report, is predominantly addressed through the Water Framework Directive (WFD). The WFD incorporates notions of local community involvement with catchment management and in the Upper Kennet there is an active Catchment Partnership, hosted by Action for the River Kennet. Catchment Partnerships bring together local organisations with an interest in the river environment, partly financed by the Environment Agency, they have been charged with producing catchment management plans to demonstrate how Water Framework Directive aims will be achieved. Some active partnerships also run regular practical river maintenance, provide advice for farmers on water friendly farming techniques, as well as education for schools and groups about the water environment. These activities are not funded by the Environment Agency, and the partnerships have to find their own funding to run them. Local volunteers are also monitoring the health of the river by taking part in Riverfly surveys and Water quality testing, thus, residents can continuously observe how flows impact the river's health.

In contrast drought management and planning does not involve local communities, CPs and

CMPs. The MaRIUS project included a study of the regulatory framework for drought in the UK, which centres on national organisations and the water industry. Figure 13 of the drought planning system in England by Bettina Lange and Christina Cook is published on the MaRIUS Dashboard that presents project findings (http://www.mariusdroughtproject.org).

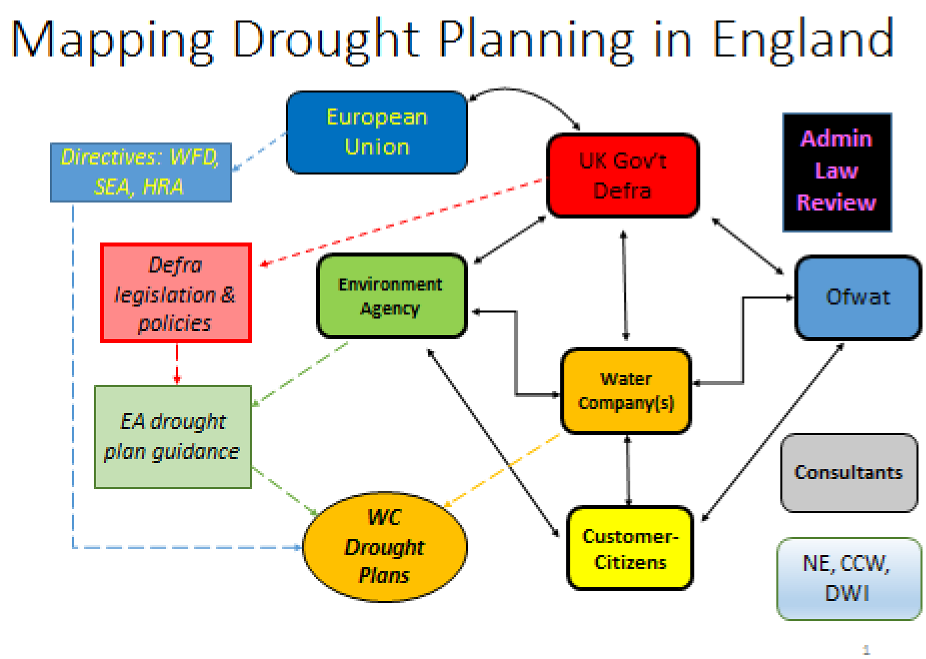

Figure 13 Actors, documents and institutions in English drought management.

Lange and Cook explain the figure as follows: The key actors in the governance space for drought planning in England are Defra, Ofwat, the EA, water companies, customer-citizens, and consultants. Other actors include Natural England (NE), the Consumer Council for Water (CCW) the Drinking Water Inspectorate (DWI), and the European Union (EU). Actors are represented by round-cornered rectangles. Square-cornered rectangles represent legal and policy institutions and the oval represents documents, in this case drought plans, produced by water companies as mandated by legislation and pursuant to soft law guidance. The solid black two-way arrows between the actors represent relationships between actors and indicate a flow of information between them. The dotted arrows between actors and legal and policy institutions indicate which actors lead the development of particular legal or policy institutions. The dotted arrows between the legal and policy institutions suggest a relationship between them. For example, the EA drought plan guidance is derived from the Defra legislation and policies and, in turn, the EA guidance provides a structure to the mandatory drought plans. The black box represents administrative law review processes which can overturn decisions made by government ministries and agencies. Water companies are at the centre of the map because they are the main abstractor of water from the natural environment.

It is clear from Lange and Cook's map that there is minimal overlap between drought planning and river management, which they also discuss in a journal article (Lange and Cook 2015). However, by deploying scientific knowledge and tools from the MaRIUS project in combination with local knowledge, the Kennet ECG has developed a link between drought planning and river catchment management. By considering water quality in the Upper Kennet under different flow conditions the Kennet ECG placed scientific drought knowledge in local context. This enabled understanding of what could happen locally during droughts and low river flows and how local river management practices could improve resilience to droughts. This link between a local catchment and drought management would not have been made without the combination of scientific and local knowledge brought about by the Kennet ECG.

8 Conclusions and recommendations

The Kennet ECG took its departure in knowledge about local conditions constituted in direct experience of the river. This local knowledge guided our application of scientific computer simulation models to explore impacts of different factors on the river flows and water quality.

The groundwater abstraction that has been a major issue in the past is going to be reduced by replacement of the chalk aquifer as a key water source through a new pipeline from Farmoor reservoir to Swindon, hence, the outlook has improved. In order to ensure that the situation for the Kennet actually improves and that future development is prevented from having negative impacts it is critical to integrate the river in local and regional planning and decision making. This environment is very sensitive and the risk of deterioration remains, as can be seen in the Riverfly data collected by citizen science volunteers showing steep declines as low flow means that most of the water in the upper Kenner is effluent from sewage treatment works lacking phosphate stripping.

Local measures to improve water quality identified in this report include two changes in agricultural practice: reducing fertiliser use and using cover crops that can absorb nutrients from the soil, thereby preventing leakage into the river. A third measure is to allow for land use in the catchment that facilitates construction of water meadows and small wetlands that contribute to reducing the amount of nutrients in the water. There are possible co-benefits of Sustainable Urban Drainage Systems (SuDS) techniques that slow surface water flows and encourage infiltration to mitigate flooding. Such measures can range from the creation of green infrastructure across several sites to small rain gardens improving infiltration in a small area.

Local measures can also promote water quantity, i.e. keeping river flows at a level that can sustain the ecology. One important forward looking measure, often overlooked, is to require water efficiency measures in new developments. In some other local areas (e.g. the catchment around Poole Harbour) local authorities have created supplementary planning guidance which stipulate that new houses must meet water efficiency targets set by the Code for Sustainable Homes levels 4 and above, and which also reduce the Nitrogen entering the river network (in the case of Poole it is to protect the Special Area of Conservation of Poole Harbour.)[4] A second measure, already pursued to some degree, is the retrofitting of existing buildings to reduce water use. The work currently being undertaken to address the historical structures in the river, that impact negatively on flows, should be supported. A new measure is local monitoring of the impact of changes to abstraction regimes and the new pipeline. This would give the local community access to information that Thames Water and the Environment Agency could be unwilling to share.

The Kennet ECG has produced knowledge that connected the local understanding of the river with scientific analyses of climate change, water supply and demand and land use in the past, present and possible futures. The geographical specificity of this knowledge makes it possible to draw on it to inform the Area Neighbourhood Plan that is currently under development. Potentially the plan could incorporate some recommendations for how to ensure that the River Kennet is considered in the local development process.

[4] http://www.poole.gov.uk/planning-and-buildings/planning/ldp/spds/nitrogen-reduction-in-poole-harbour/

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10 APPENDICES

APPENDIX 1 TABLE A

A-1 Thames Water demand scenario

Demand (ML/d)

Year	London	SWOX	SWA	Henley	Kennet	Guildford
2015	2017.36	262.55	134.57	13.07	100.1	44.36
2016	2023.59	263.55	134.94	13.13	100.52	44.42
2017	2030.65	264.71	135.26	13.19	100.95	44.49
2018	2036.65	265.98	135.55	13.24	101.36	44.57
2019	2043.48	267.24	135.84	13.29	101.77	44.65
2020	2050.32	268.42	136.1	13.34	102.17	44.74
2021	2057.21	269.53	136.35	13.38	102.55	44.82
2022	2064.32	270.55	136.62	13.41	102.92	44.91
2023	2071.65	271.48	136.9	13.43	103.26	45
2024	2079.13	272.33	137.2	13.46	103.6	45.1
2025	2086.73	273	137.52	13.47	103.93	45.2
2026	2094.59	273.7	137.84	13.48	104.27	45.3
2027	2102.7	274.29	138.17	13.49	104.61	45.4
2028	2111.05	274.82	138.52	13.5	104.96	45.5
2029	2119.58	275.36	138.87	13.51	105.3	45.6

2030	2128.3	275.91	139.24	13.53	105.65	45.7
2031	2137.21	276.46	139.6	13.54	106	45.8
2032	2146.3	277	139.99	13.56	106.37	45.92
2033	2155.53	277.65	140.39	13.58	106.73	46
2034	2164.91	278.26	140.77	13.59	107.1	46.14
2035	2174.48	278.89	141.18	13.61	107.48	46.25
2036	2184.16	279.53	141.58	13.63	107.85	46.37
2037	2193.96	280.18	142	13.65	108.24	46.49
2038	2203.91	280.84	142.42	13.67	108.63	46.61
2039	2215.39	282.25	143	13.71	109.23	46.87

A-2 Extreme demand scenario

Demand (Ml/d)

Year	London	SWOX	SWA	Henley	Kennet	Guildford
2015	2017.36	262.55	134.57	13.07	100.10	44.36
2016	2037.63	265.19	135.92	13.20	101.11	44.81
2017	2058.11	267.85	137.29	13.33	102.12	45.26
2018	2078.80	270.55	138.67	13.47	103.15	45.71
2019	2099.69	273.26	140.06	13.60	104.19	46.17
2020	2120.79	276.01	141.47	13.74	105.23	46.63
2021	2142.11	278.79	142.89	13.88	106.29	47.10

2022	2163.64	281.59	144.33	14.02	107.36	47.58
2023	2185.38	284.42	145.78	14.16	108.44	48.05
2024	2207.34	287.28	147.24	14.30	109.53	48.54
2025	2229.53	290.16	148.72	14.44	110.63	49.03
2026	2251.93	293.08	150.22	14.59	111.74	49.52
2027	2274.57	296.02	151.73	14.74	112.86	50.02
2028	2297.43	299.00	153.25	14.88	114.00	50.52
2029	2320.52	302.00	154.79	15.03	115.14	51.03
2030	2343.84	305.04	156.35	15.19	116.30	51.54
2031	2367.39	308.11	157.92	15.34	117.47	52.06
2032	2391.19	311.20	159.51	15.49	118.65	52.58
2033	2415.22	314.33	161.11	15.65	119.84	53.11
2034	2439.49	317.49	162.73	15.80	121.05	53.64
2035	2464.01	320.68	164.36	15.96	122.26	54.18
2036	2488.77	323.90	166.02	16.12	123.49	54.73
2037	2513.79	327.16	167.68	16.29	124.73	55.28
2038	2539.05	330.45	169.37	16.45	125.99	55.83
2039	2564.57	333.77	171.07	16.62	127.25	56.39

APPENDIX 2 TABLE B

Number of days	BAU operations Constant Demand	Demand increase as proposed by TW	Extreme demand increase
Level 1 imposed	323	648	4090
Level 2 imposed	89	144	1874
Level 3 imposed	0	2	989
Level 4 imposed	0	0	323

Number of years	Constant Demand	Demand increase as proposed by TW	Extreme demand increase
Level 1 imposed	9	12	26
Level 2 imposed	1	4	20
Level 3 imposed	0	1	17
Level 4 imposed	0	0	11

APPENDIX 3 THE INTEGRATED CATCHMENT (INCA) MODEL

The INCA Model-- short for INtegrated CAtchment Model—is the result of several NERC, EA and EU funded projects over many years and is a dynamic computer model that predicts water quantity and quality in rivers and catchments. As shown in Figure 3.1, the primary aim of INCA is to represent the complex interactions and connections operating in catchments and to also address the scaling up issue.

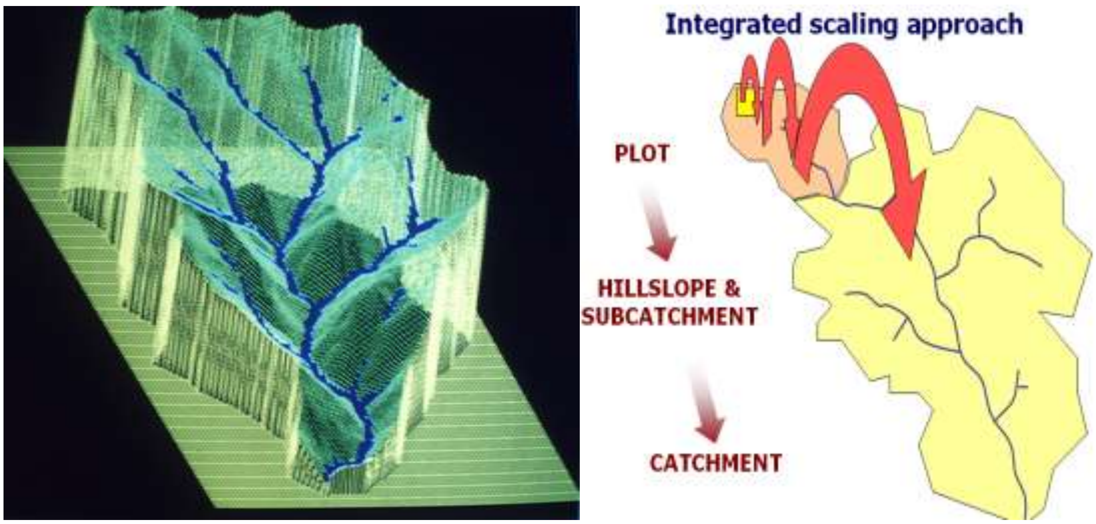
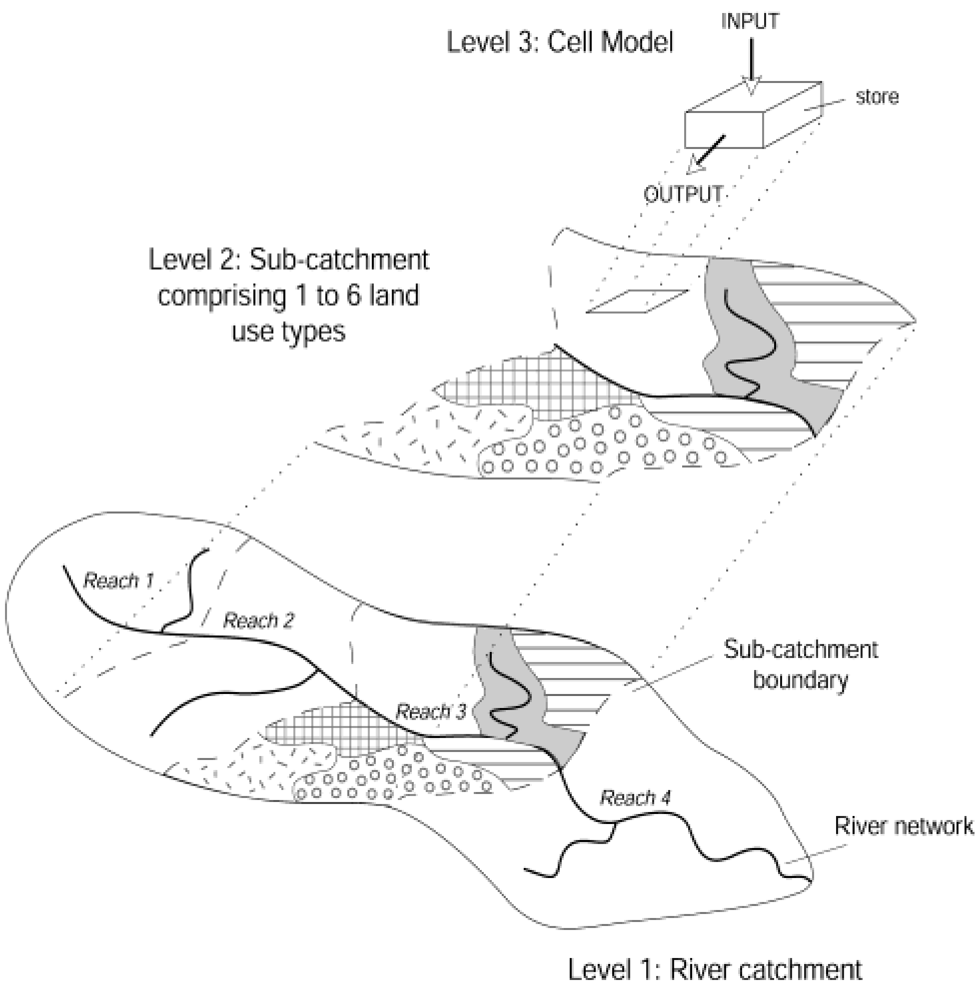


Figure 3.1 Catchment Linkages, Connectivity and Scaling issues

The philosophy of the INCA model is to provide a process-based representation of the factors and processes controlling flow and water quality dynamics in both the land and in-stream components of river catchments, whilst minimising data requirements and model structural complexity (Whitehead *et al.*, 1998a, b). As such, the INCA model produces daily estimates of discharge, and stream water quality concentrations and fluxes, at discrete points along a river's main channel (Figure 2). Also, the model is semi-distributed, so that spatial variations in land use and management can be taken into account, although the hydrological connectivity of different land use patches is not modelled in the same manner as a fully-distributed approach. Rather, the hydrological and nutrient fluxes from different land use classes and sub-catchment boundaries are modelled simultaneously and information fed sequentially into a multi-reach river model, as shown in Figure 3.2.

The INCA model was originally tested on 20 catchments in the UK and over 40 catchments across the EU and around the world. The major applications of INCA have been published to date in two special volumes of International Journals, namely, Hydrology and Earth System Sciences, 2002, 6, (3) and Science of the Total Environment, 2006, 365, (1-3) and in many other publications.

The INCA models have been designed to investigate the fate and distribution of water and pollutants in the aquatic and terrestrial environment. The original version of INCA has been extended to create new versions for N, P, Sediments, carbon, ecology, organics, pathogens and a range of metals. The models simulate flow pathways and tracks fluxes of pollutants in terrestrial and aquatic ecosystems. INCA has been designed to be easy to use and fast, with excellent output graphics. The model system allows the user to specify the semi-distributed nature of a river basin or catchment, to alter reach lengths, rate coefficients, land use, velocity-flow relationships and to vary input pollutant deposition loads.



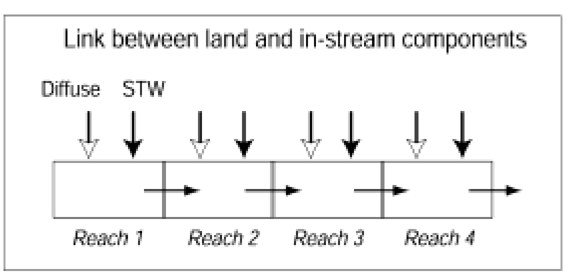


Figure 3.2 The integration of the landscape delivery and in-stream components of INCA. At level 1 the catchment is decomposed into sub-catchments. At level 2, the sub-catchments are sub-divided into 6 different land use types. At level 3, the soil chemical transformations and stores are simulated using the cell model. The diagram shows the link between the land-phase delivery and in-stream components at level 1: the diffuse inputs from the land-phase are added to the effluent point-source inputs and routed downstream.

INCA setup for the River Kennet system

The Kennet is a major tributary of the River Thames (see Figure 3.3), the principal river in the south east of England. The Kennet flows broadly west to east, with a catchment area of about 1200 km^2 and a main river length of about 40 km. Altitude varies across the catchment from 215 m.a.s.l. (the source of the Kennet near Avebury) to 40 m.a.s.l. (the confluence of the Kennet with the Thames at Reading). The catchment is approximately 80 km from the south coast at the English Channel and about 100 km from London and the Thames estuary and the southern North Sea. Land-use within the Kennet catchment is predominantly rural, with an underlying geology predominantly of Cretaceous Chalk.

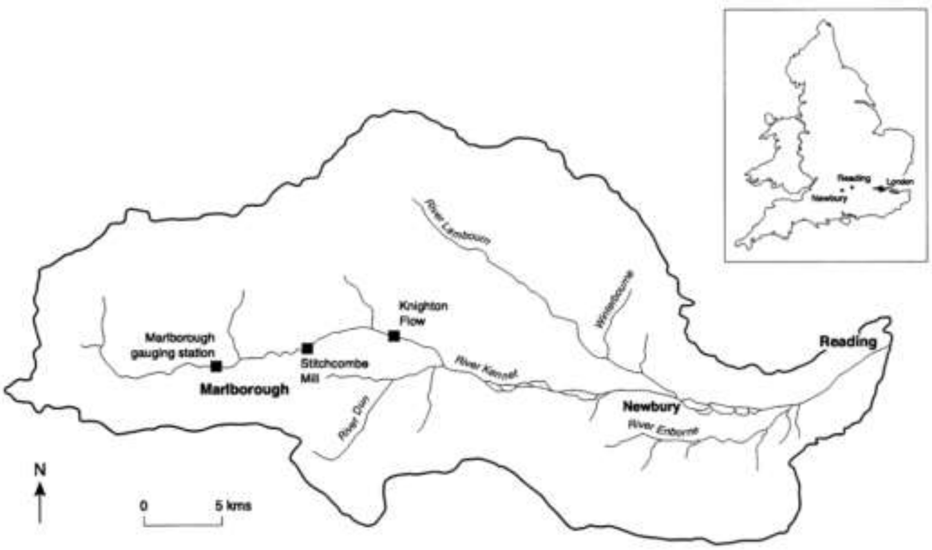


Figure 3.3 Map of the River Kennet.

This study focuses on the upper reaches of the Kennet, around the market town of Marlborough. The upper Kennet catchment is defined as the area draining into the Environment Agency gauging station at Knighton and receives runoff from two tributaries, the Og and Aldbourne. At Knighton (105 m.a.s.l.), the catchment area is 295 km^2, equating to approximately 25% of the total catchment area of the Kennet. The annual average rainfall for the upper Kennet is relatively low for the UK at 787 mm and, with high evaporation at around 520 mm, only about 34 % of the rainfall is converted to river flow. Owing to the highly permeable nature of the bedrock, the Kennet is primarily groundwater fed. Thus, the hydrograph response to rainfall is highly damped with a base-flow index of 0.95 for the upper Kennet. Starting downstream of sewage treatment works on the east of Marlborough the upper River Kennet is designated a Site of Special Scientific Interest (SSSI) in recognition of its outstanding chalk river plant and animal communities with growths of water crowfoot and wild brown trout. Hence, there is keen interest in protecting the high conservation value of the river. In the last decade, there have been concerns about perceived ecological deterioration of the river, particularly poor growth of *Ranunculus* downstream of Marlborough, accompanied by unsightly growth of epiphytes. Attention has focused on the effects of protracted droughts in the 1991/2 and 1996/7 hydrological years and declines in water quality associated with reduced dilution of effluent from Marlborough Sewage Treatment Works (STW). Table 3.1 shows the INCA reach set up of the Kennet with details of sub catchment areas, reach lengths and the land use across the Kennet Catchment.

Table 3.1 List of Reach Boundaries, Areas, Length and Land Use Percentages for the Kennet.

Reach boundary	Reach length (m)	Sub-catchment area (km^2)	Land use class percentages					
			Forest (%)	SvegUG (%)	SVegGNF (%)	SvegF (%)	Arable (%)	Urban (%)
1 Source	6250	24	0	0	13	4	83	0
2 Avebury	4500	34	0	0	0	3	97	0
3 Fyfield	8000	51	2	0	0	10	88	0
4 Clatford	1750	5	0	0	0	0	100	0
5 Marlborough	3000	24	13	0	4	13	62	8
6 Glebe House	2250	77	1	0	0	4	92	3
7 Mildenhall	500	1	0	0	0	0	100	0
8 Stichcombe	1500	2	0	0	0	50	50	0
9 Axford	1000	2	0	0	0	50	50	0
10 Ramsbury	4000	24	4	0	0	4	88	4
11 Knighton	2500	57	2	0	0	4	92	2
12 Chilton	3500	13	0	0	8	0	92	0
13 Hungerford	1750	6	0	0	0	17	83	0
14 Hampstead	10 000	208	12	0	7	7	73	1
15 Newbury-GS	4000	18	0	0	17	33	22	28
16 Newbury	1750	266	4	0	8	3	88	2
17 Thatcham	4500	18	11	0	17	17	22	33
18 Woolhampton	5000	12	8	0	8	25	59	0
19 Padworth	4000	159	17	0	21	18	43	1
20 Ufton Bridge	3000	13	0	0	77	8	15	0
21 Theale	3250	23	13	0	35	9	39	4
22 Burghfield	3250	5	0	0	20	0	20	60
23 Fobney	2000	2	0	0	0	0	0	100
24 Berkerley-Rd	2250	95	8	0	40	4	31	17
25 Thames Confl	2250	3	0	0	0	0	0	100

The six land uses are forest, short vegetation ungrazed (SvegUG), short vegetation grazed not fertilised (SVegGNF), short vegetation fertilised (SvegF), arable and urban areas.