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The impacts of drought in England

R&D Technical Report WT0987/TR

Produced: March 2013

Department for Environment Food and Rural Affairs

Defra’s Water Availability and Quality R&D Programme

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Statement of use

This report is part of Defra's Water Availability and Quality Research Programme. Its objective is to support the Department's work on the management of limited water resources during droughts and in particular to add to its capability to analyse the impacts of management decisions in future droughts.

Dissemination status

Internal: Released Internally

External: Released to Public Domain

Keywords: Water resources, drought, regulation

Research contractor: Vivid Economics
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The impacts of drought in England

Final report prepared for Defra

March 2013

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Acknowledgements

Vivid Economics wishes to acknowledge the advice provided by the Environment Agency and the Department for Environment, Food and Rural Affairs throughout the project.

The assistance given by the following organisations was greatly appreciated: the British Swimming Pool Federation, the Car Wash Association, the British Window Cleaning Academy, the British Trout Association, the Salmon and Trout Association, the Angling Trust, the Centre for Environment, Fisheries and Aquaculture Science, the Canal and River Trust, EnergyUK, Waterwise, the Consumer Council for Water, the Horticultural Trade Association, and the Health Protection Agency.

Halcrow would like to thank the following companies for their assistance with the collection of data: Sutton and East Surrey Water, Anglian Water, Thames Water, United Utilities and Southern Water.

Vivid Economics would also like to thank peer reviewers who have commented on various parts of this report during its preparation.

An appropriate citation for this report is:

Vivid Economics, Kunle Akande and Sajid Hussain of Halcrow Group Ltd, a CH2M Hill Company, J. Knox and Tim Hess from Cranfield University and D.A.P. Hooftman, C. Stratford, S.M. Schafer, M.C. Acreman and F.K. Edwards from the Centre for Ecology and Hydrology (2013), *The impacts of drought in England*, report prepared for Defra, March

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Executive Summary

An inter-disciplinary assessment of the economic impact of the 2011/12 drought in England

Aim

The Department for Environment, Food and Rural Affairs commissioned this assessment to support its work on the management of limited water resources during droughts and in particular to add to its capability to analyse the impacts of management decisions in future droughts.

Method

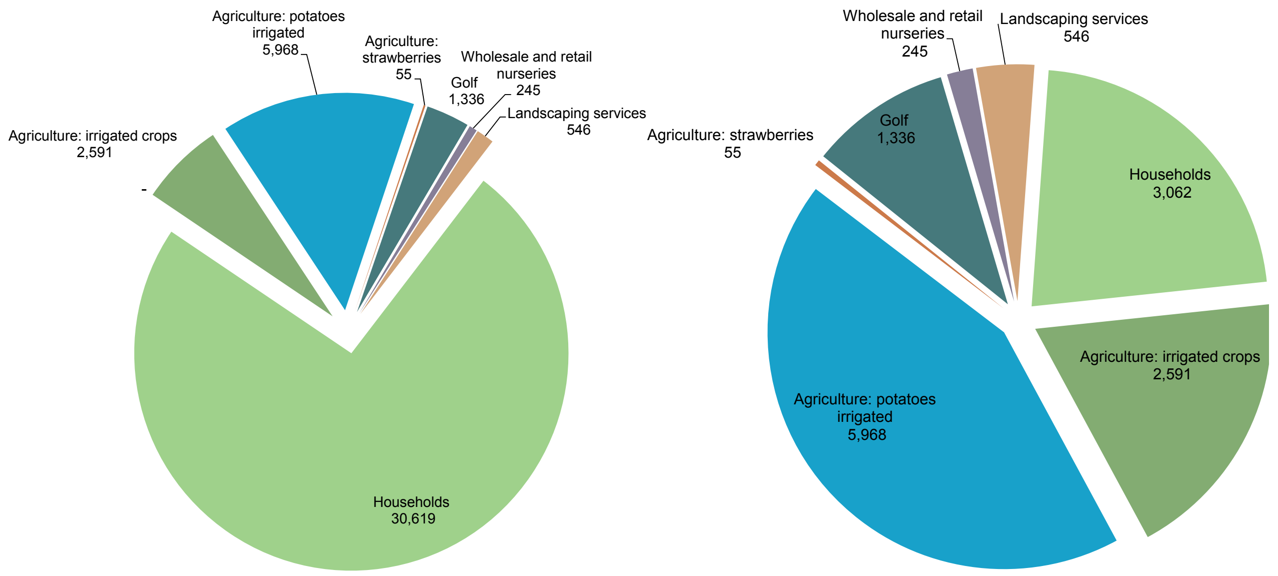
The approach of the assessment was inter-disciplinary, bringing together the expertise of ecologists, engineers, hydrologists and economists. The economic data were collated in a user-friendly Excel model which allows the user to estimate the economic impacts of the 2011/12 drought under different management assumptions, in particular water savings and impacts on turnover and profit for sectors that rely on the supply of water to function. The model also allows the user to compare scenarios for the management of an extended drought, worse than the one experienced in 2011/12, and affecting different regions of England.

The impacts of the 2011/12 drought on the economy

The 2011/12 drought was characterised by two previous dry winters, however its impact was mainly felt in the first half of 2012, when water companies introduced temporary use bans to restrict demand. These restrictions applied in some areas in the second quarter of 2012. As the main target of temporary use bans, households were affected, together with businesses offering services to domestic customers, in particular landscaping services and the horticultural trade. Farmers were encouraged to reduce water use for the irrigation of agricultural crops, and this also had impacts. However, the effect of the drought and of the restrictions on water use in agriculture were not clearly visible, since they were mingled with the impacts of the wet summer that started in the second quarter of 2012. Water savings were an estimated 40,000 megalitres in the second quarter of 2012 and amounted to a cumulative 170,000 megalitres for the period starting from the first quarter of 2011 and ending with the second quarter of 2012.

Figure 1 shows the distribution of water savings in the second quarter of 2012, when they were at their highest level. The left hand side pie chart refers to water use and the right hand side to water consumption, that is taking into account water that is lost though evaporation or otherwise. Households contributed the most to the total savings of water use, but on a consumptive basis, irrigated potatoes were the main contributor of savings. Other sectors contributing to water savings were other irrigated crops, landscaping services and golf.

Figure 1. **Water savings in the second quarter of 2012, Ml: On a use basis households contributed the most to water savings, whereas on a consumptiveness basis irrigated potatoes were the main contributor**



Note: The left hand-side chart presents savings in water use, whereas the right-hand chart looks at water savings on a consumptive basis. Consumptiveness refers to the degree to which the water taken or supplied to a user is not returned directly to a river, groundwater, drain or public sewer, and thus might be lost through evaporation or might take some time to return to an exploitable water source.

Source: Vivid Economics

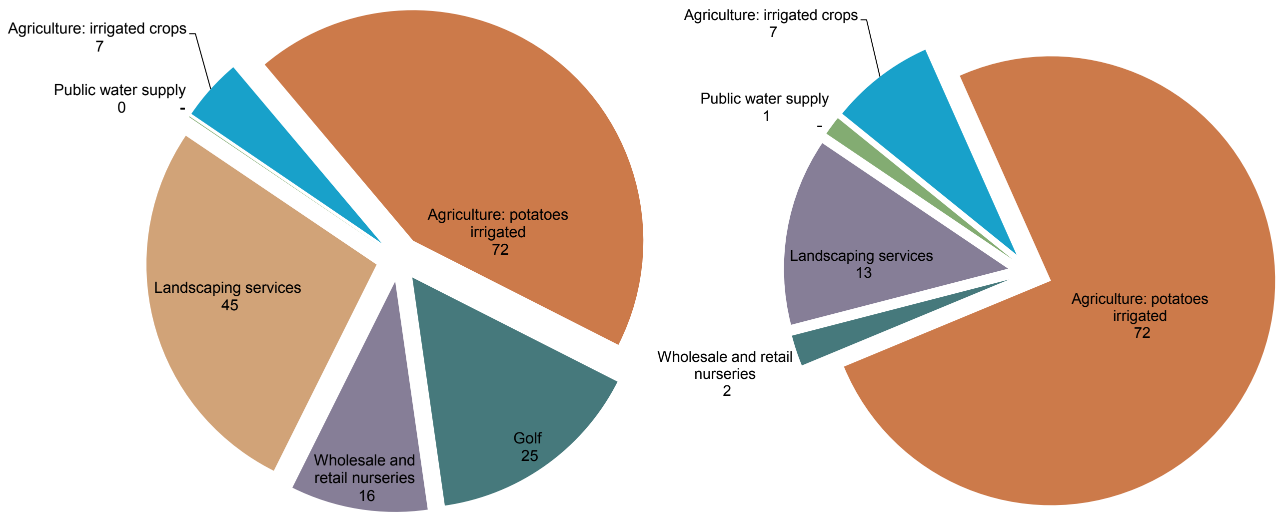
In terms of economic impacts, about £165 million in revenue and £96 million in profit were forgone by some firms and sites in the second quarter of 2012, of which £72 million is attributed to irrigated potatoes. Other sectors to have suffered losses are other irrigated crops, landscaping services, wholesale and retail nurseries, golf and public water supply companies in the South East and Anglian regions.

To some extent in agriculture, farmers in other regions not affected by drought and associated water use restrictions might have benefitted through higher prices and increased output from the costs facing their competitors, offsetting these impacts across the sector as a whole. However, there is a high degree of substitution between home-grown and imported agricultural products and between potatoes and other staples. Activities down the supply chain in food processing could also be affected.

In golf, wholesale and retail nurseries, and landscaping services, it is unlikely that the regional impacts were offset by increases in other regions. These services are mostly local and as such subject to local conditions.

There were no reported impacts on employment because the restrictions were transient. No impacts on recreation or tourism are reported, due to lack of evidence.

Figure 2. **First-round turnover reduction and foregone profit in the second quarter of 2012, GBP million (before considering offsetting increases): contractions in both turnover and profit were highest in the irrigated potatoes sector.**



Note: *The left hand-side chart presents reductions in turnover, whereas the right-hand chart looks at foregone profit. In irrigated agriculture, costs were assumed to be constant, which means that the reduction in turnover translated into an equivalent reduction in profit.*

Baseline profits are not estimated for the golf sector whose profit level is set at zero in the absence of restrictions on water use (private communication from the English Golf Union). Therefore golf does not appear in the right hand side chart.

Source: *Vivid Economics*

The impacts of the 2011/12 drought on the environment

An extensive literature review of the evidence on impacts of drought on the environment accompanies and complements the monetary metrics resulting from the modelling assessment. The impacts of the 2011/12 drought on the environment are not known yet, although some may appear in the long-term monitoring of aquatic ecosystems.

It is a daunting challenge to extrapolate from experimental and observational studies to the effects of drought. Many aspects of the effects of drought on the environment have been studied in only a few experiments and no meta-analyses over multiple studies have yet been conducted, making it difficult to generalise results.

It is known that droughts affect key ecosystem processes in both aquatic and terrestrial ecosystems. The effects of drought are related to the frequency of drought seasons as well as their severity, especially in terrestrial ecosystems. Drought management actions however mainly affect aquatic systems. In most aquatic environments, the level of reduction in water flow, wetted area and loss of connectivity of rivers and wetlands are critical factors. Drought reduces the volume of water in streams and rivers and disrupts horizontal, longitudinal and vertical connectivity.

In many terrestrial systems an important impact is on soil processes, which can be altered, potentially causing current sinks of carbon and nutrients to become sources of emission: the loss of an important ecosystem function. It does not appear that soil moisture in terrestrial systems could be affected by drought management actions, and although groundwater levels could be affected by the management action, the wider ramifications of these fluctuations has scarcely been studied in the UK.

Impacts of alternative management actions on the extended hydrological drought scenario

The extended drought scenario explores the consequences of a drought which continues into a third dry winter. Four management scenarios are considered:

- a **baseline**, which extends the management actions taken during the 2011/12 drought;
- a **priority for the environment** scenario which departs from the management actions taken in 2011/12 by taking action earlier and applies more stringent restrictions on various sectors, for example a full S57 restriction on irrigation in both quarters 2 and 3 of 2012;
- a **priority for the economy** scenario, which also departs from the management actions taken in 2011/12. It delays action and takes no stringent measures, relying more on voluntary reduction in water use in agriculture in the second quarter of 2012 and only partial S57 restrictions in the third quarter as opposed to full restrictions as per previous scenario; and
- a **local consensus** scenario, which assigns gradual and equal reductions to all sectors.

Under the baseline scenario, cumulative water use savings amount to 0.76 million Ml over the two year period starting from the first quarter of 2011 and finishing in the last quarter of 2012. First round foregone profit (before offsetting gains in benefitting sectors and regions) amounts to GBP 1.5 billion.

As expected, the priority for the environment scenario delivers more water savings than the baseline, 0.85 million Ml, however the first-round contraction in profit is highest, at GBP 1.7 billion. The opposite is true for the priority for the economy scenario: water savings cumulate to 0.69 million Ml and first-round foregone profit to GBP 1.4 billion. The local consensus scenario delivers 0.82 million Ml in water savings.

In all management scenarios for the extended drought, the main sectors affected, in terms of first-round profit impacts, are public water supply companies, the electricity sector and agricultural crops, particularly irrigated potatoes. Other sectors that are affected are landscaping services and golf. Smaller sectors such as car washing services and window cleaning contribute little to the overall impact.

1 Introduction

A first of a kind, inter-disciplinary assessment of the recent drought, supplying new data and tools

1.1 Introduction

At the time that this work was conceived, in spring 2012, the south east, and to some extent central England, were heading into the second summer of a severe drought. There was demand for evidence to inform the allocation of limited water resources and for scenarios with which to plan the management of water for the rest of 2012 and beyond.

Fortunately, at about the time this project was scheduled to begin, the drought lifted, and the need became less urgent. This allowed time for engagement with water users over the summer, eager to share their recent experiences, exploring through discussion what might have happened if the rain had not come, and how it might have been handled. This work built on the existing processes of engagement between water users, government and the Environment Agency which yielded a descriptive understanding of the impacts on users.

Conscious that a manager dealing with questions of water resource allocation in times of drought also needs planning tools and quantitative data, Defra wanted to develop an organising framework for assessing options, a fairly comprehensive and reliable body of relevant data, and tools to assist in the complex task of building scenarios and testing options for drought management.

The authors of this report, Vivid Economics, the Centre for Ecology and Hydrology, Halcrow Group and Cranfield University, were asked to create a set of data, modelling and scenario assets for Defra, and then to use them to assess the impacts of the 2011/12 drought and a fictitious extended drought. The authors believe that this is the first time this has been attempted in England, and like all first of a kind work, there are ways in which it could be extended and improved. Nevertheless, for a modest budget, a large amount of stakeholder engagement, data collection, analysis and model building has been delivered, which presents a major advance in the evidence base in this field.

The impact estimates relate to 2012. Had the drought been more severe, the impacts could have extended into 2013.

1.2 Contents of this report

The work spans detailed research, model building and strategic analysis and the structure of this report is designed to give access to all this material.

The priority is to explain the shape of drought impacts and in particular the management actions used to control abstraction and water use during a drought. The main body of the report focuses on this, describing the impact of the drought using estimates of changes in water use and financial metrics. Not all the impacts can be expressed in monetary values or quantified, however, and the impacts on major sectors warrant

further discussion, so there is a comprehensive description of the impacts on plants and animals, together with further detail on the major water-using sectors of public water supply: agriculture and golf.

In order to make these findings accessible, the appendices contain all the discussions of methodology, source data and calculations.

1.3 Definitions

This report spans economics, ecology and engineering and covers specific sector topics in agriculture and public water supply. In some areas, technical language is used for the benefit of brevity and precision, but the authors hope that those who read it will still find the report accessible.

There are just two words which are used in a particular way throughout this report. When water 'use' is mentioned, it refers to the water taken by or supplied to a user. When water 'consumption' is mentioned, it refers to that part of the water taken or supplied to a user which is not returned directly to a river, groundwater, drain or public sewer, and thus might be lost through evaporation or might take some time to return to an exploitable water source.

2 Drought and management scenarios

What might have happened if 2012 had been drier and what action might have been taken

2.1 Drought scenarios

The project considers a baseline drought scenario and an extended drought scenario. The baseline scenario relates to the actual drought event from 2010 to end March 2012, see Figure 1, with the geographical area of drought impact focused primarily on Anglian region and the South East of England. The baseline drought started in 2010 when United Utilities (UU) had hosepipe restrictions. UU was affected relatively quickly in summer 2010 but recovered quickly after six weeks of water use restrictions. The baseline drought is therefore a single season drought in the North West of England but a two season drought (two dry winters) in the East and South East of England.

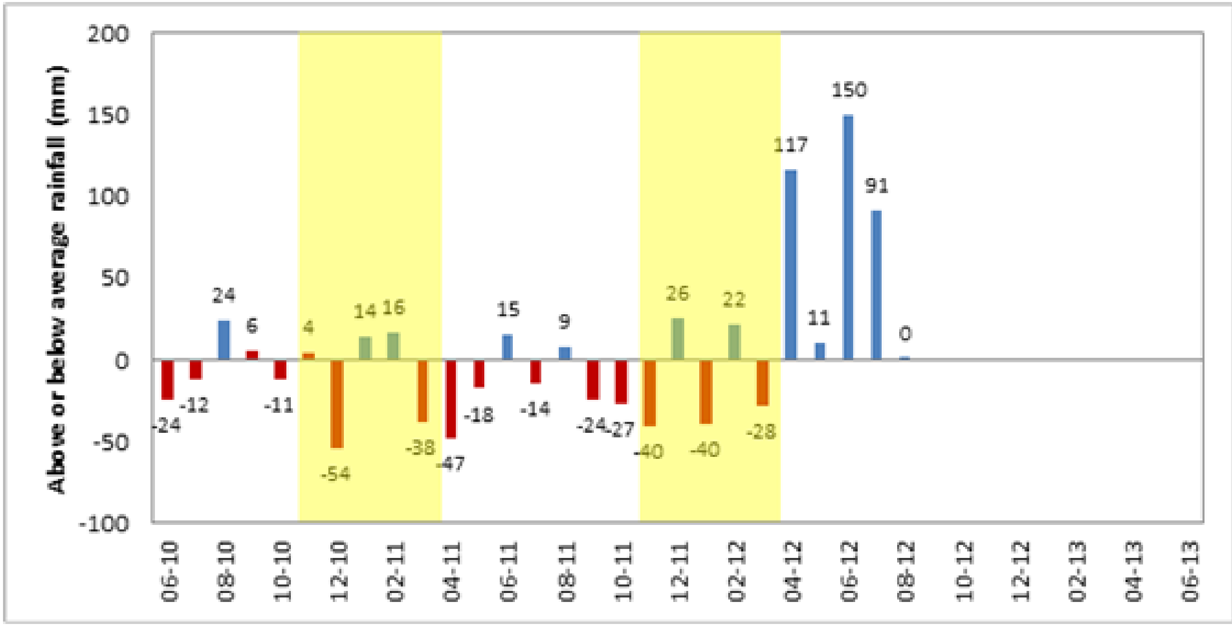
In England and Wales consideration of how sources respond to rainfall over a long period, preferably back to 1920 or earlier, has traditionally formed the basis of planning for water resources needs across the industry to meet household and non-household water demands. This approach is intended to capture a range of different droughts that have occurred; in practice, for most water companies, it identifies six to twenty-four months of below average rainfall as the critical basis – see the rainfall data sets outlined in the Model Handbook Appendix.

For the baseline scenario, thirteen months of below long term average rainfall fell to end March 2012, see Figure 3, resulting in the imposition of temporary use bans (TUBs) by seven water companies in the East and South East of England, and with the activation of water industry drought plans.

Analysis of the Meteorological Office monthly rainfall data from 1766 to date has been carried out to inform the definition of the project's extended drought scenario. Details of the long term average rainfall data, including maxima and minima and previous drought years used in water resources management plans across the water industry, are given in Appendix 1.

The extended drought scenario is a continuation of the baseline drought from the beginning of April 2012 through a serious drought event to June 2013. The extended scenario is a serious, multiple-season drought affecting England. The geographical area of the extended drought impact covers the Anglian region and South East England with an arc of effects extending from Devon through the Midlands to South Yorkshire. The area of impact increases as the summer progresses and by late August 2012, the whole of England and Welsh borders are affected to some degree, although the most serious impacts remain in the South East.

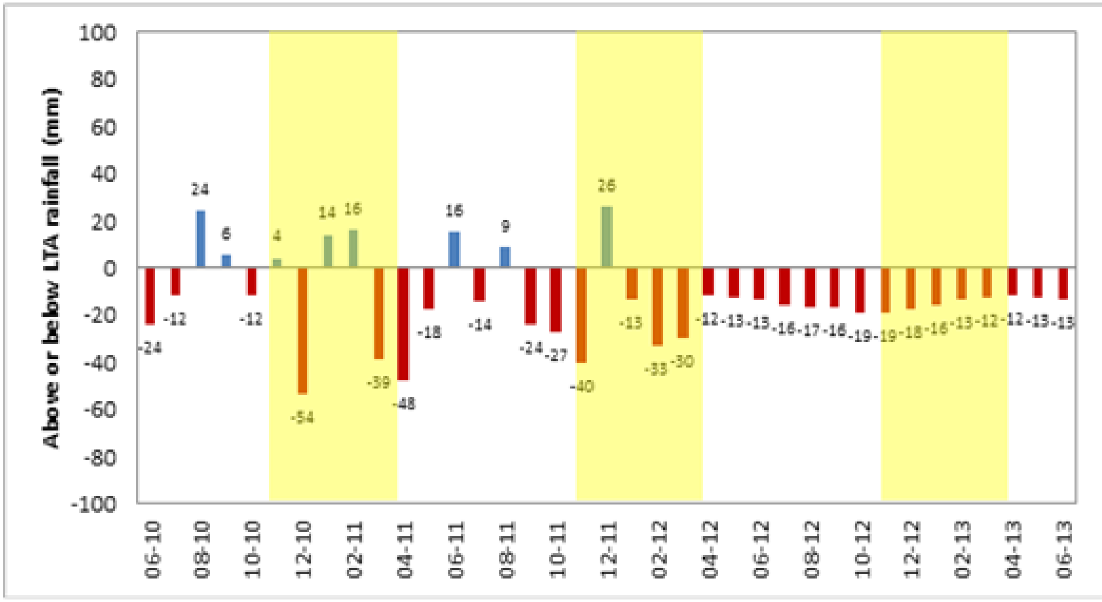
Figure 3. **In England and Wales, from June 2010 to August 2012, most months experienced below long term average rainfall**



Source *Halcrow Ltd*

Analysis of the Meteorological Office rainfall data shows that a drought event associated with 80 per cent of long term average rainfall across England and Wales from April 2012 to June 2013, see Figure 4, would be a serious drought according to the drought classification system described in a paper by the British Hydrological Society (1994) .

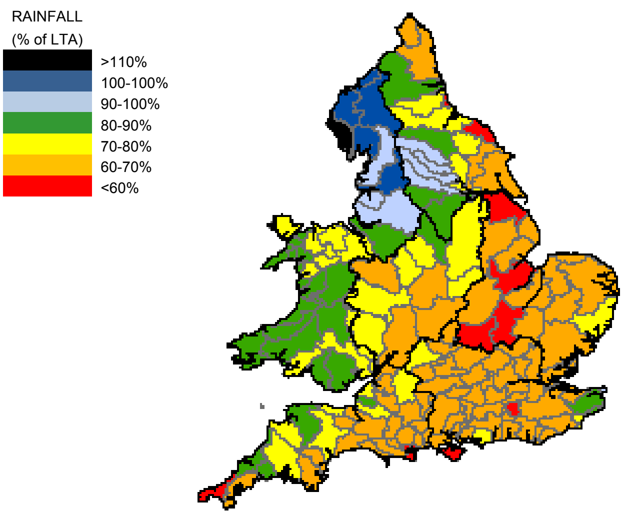
Figure 4. **The extended drought scenario assumes 80 per cent of long term average rainfall for April 2012 to June 2013**



Source: *Halcrow Ltd*

An illustration of the possible geographical coverage of an extended drought scenario, based on actual rainfall data to March 2012 and with 80 per cent of long term average rainfall across England and Wales from April 2012 to June 2013, is shown in Figure 5.

Figure 5. **The extended drought scenario with 80 percent of LTA rainfall across England and Wales from April 2012 to June 2013 would cover most of England, apart from North Western regions**



Source *Halcrow Ltd based on Environment Agency 2012*

2.2 High level discussion of management scenarios

The managers of a drought can choose **when** to act, **what** measures to put in place and **who** to apply them to within the constraints of current guidance and legislation. They may also decide overall **by how much** they wish to curtail abstraction (and in particular consumption), in order to protect the environment and ensure essential supplies can be met in the future. This project explores these four dimensions of management action.

2.2.1 The four dimensions of management action

When. The choice of timing of action can weigh up the costs and benefits of acting in advance, thereby bringing forward in time the shoulder of the drought impact to mitigate its peak impact, or by acting just in time, matching the action to the most up to date drought situation. The former smoothes down the peak of the drought but extends its effect over a longer time period. Acting just in time creates a shorter, more peaked impact, like in the case of the 2011/12 drought. The majority of management actions were taken between January and April 2012; as such the impact was felt mainly in spring 2012.

In the absence of certain knowledge of the future course of the drought, the timing of action can involve some upfront cost in exchange for a potential payoff. In some circumstances, the action could pay off by reducing the intensity of the peak of the drought or by bringing forward the end-date of the drought; however, it could also happen that the drought dissipates and there is little or no payoff. Mathematically, the value of the action is the sum of the payoffs for each outcome multiplied by their likelihood, which is to say that if one knows how likely the scenarios are, then one can calculate fair odds on the bet.

In this study, a baseline case of the actual drought is examined and compared with an extended drought scenario. The aim is to estimate the cost of early action, and the benefits it brings in both scenarios, which might be large in the extended drought scenario and small in the baseline scenario. A full cost-benefit analysis of the option would require the calculation of a probability distribution function for the outturn value of the early action option. This might be feasible, but it is beyond the scope of this work, because this work looks at two discrete scenarios only.

The effect of early management action is to conserve stocks of water in strategic reservoirs and aquifers. Surface waters fed by these sources can benefit directly later in the drought. In contrast, there would be little or no impact on the quantity of water available in rivers fed by surface run-off. Hence, early action is likely to be of greater interest in areas where surface waters are fed by groundwater and reservoirs, or where abstractors rely upon these sources.

Scenarios of 'when'. Two scenarios are possible here. In the first, actions are triggered according to usual practice in the development of a drought. In the second, actions are triggered early at all stages in the progression of the drought, in order to protect stores of water above and below ground. These triggers will relate to the level of groundwater and reservoir sources relative to datum.

What. The measures to be selected can be grouped into supply side and demand side measures. Supply side measures include the drawing of water from different abstraction sources, the transfer of water between

catchments, areas or regions, and the storage of water between seasons. Supply side measures are only available to abstractors, and then only to abstractors with access to multiple sources of abstraction, with networks to connect them together, or land on which, or under which, to store water. In the context of this report, which considers the actions taken by abstractors with legislative powers, water companies and navigation authorities appear to be the only abstractors in the position to readily undertake supply side measures.[1] They can be authorised, or perhaps required to take water during the winter to recharge aquifers or reservoirs, to cease or begin making transfers, or to change the pattern of abstraction to reflect local water availability. They are also likely to have greater scope to initiate new schemes and infrastructure or bring disused sources back into use.

These examples indicate that supply side measures may be used to change the place or timing of abstraction in order to avoid taking as much water from drought-affected areas, thereby reducing the adverse impact of abstraction on other users and the environment.

At the present time, it is possible to give permissions for this storage and transfer to take place, but not to mandate it, and so where the private interest or inclination of the individual is not to carry out these actions, these actions may not happen, even though they may be in the wider interest. Thus, while a water company might choose to store water from one season to the next, or to recharge an aquifer during the winter, it might not be obliged to do so. In the absence of a legal mandate, the water company might choose not to invest in storage because it is, or perceived to be, costly in the short-run. Such a perception could be based on a lack of thorough understanding of costs and benefits. Similarly, it might not be obliged to supply another abstractor with water through its network. One might speculate that the overall resilience of the system to drought could be improved through greater exercise of positive control over actions, but that this would impose liabilities on some parties, affecting their own resilience to drought or costs, and some financial compensation might be justified, for which no mandatory arrangements currently exist.

The demand side measures fall into two groups: voluntary and forced reductions in demand. The voluntary reductions use public communications to persuade users, either of public water supply or abstraction, to reduce their usage. Voluntary action is widely encouraged in the early stages of and throughout droughts. The reduction in usage is brought about both through reduced activity, such as cleaning buildings and vehicles or irrigation, and in greater efficiency of use, through careful use in the home, leakage repair or use of low-flow water fittings.

The forced reductions either cut the amount of water which can be abstracted by a proportion or prohibit abstraction or consumption altogether. Some of these restrictions are encoded in abstraction licence conditions (the hands-off flows provisions); at the same time wide-ranging powers exist to impose wider restrictions.

[1] Other abstractors can take supply side measures that affect them individually or as a sector, for example, farmers with winter storage can protect themselves against a summer drought, however the report focuses on actors with legislative powers that have a broader impact, for example, a water company, through its decisions, affects sectors such as agricultural crops, golf, window cleaning, sectors that rely on mains supply in order to function.

Scenarios of 'what'. A number of scenarios are possible here. One pair would compare voluntary action and unenforceable use bans, to contrast with mandatory enforceable use bans. Another pair would examine greater use of supply side transfers and storage, and then consider greater use of demand side restrictions.

Who. Water is used by households and non-households for a wide range of purposes, examples of which are:

- industrial processes (including power generation) for cooling, where a reduction in water volume would mean that the process capacity has to be de-rated or shut down;
- cleaning, sometimes for essential hygiene or safety purposes, for control of nuisance (such as dust suppression), or for aesthetics of clean vehicles and buildings;
- irrigation to improve the yield and quality of crops (for example scab control on potatoes);
- drinking, by both people and animals, and for food preparation, for both people and animals, within the home and within industry and catering; and
- navigation in canals and rivers, and for fish husbandry.

In many of these examples, there is no alternative to water use, but even where there is no complete substitute, there may be some options for reducing the rate of water use by compromising on output, or increasing other inputs, such as power, or expenditure on irrigation, filtration and recycling systems.

Two authorities can control access to water by type of user or use: the Environment Agency and the water supply companies. In choosing management actions of which user and what uses to restrict, they could take into account merit and economic impact, or political agreements with specific user groups.

Scenarios of 'who'. The scenarios can be set up to compare a burden of use reduction which falls upon households against one which falls upon non-household users. The scenarios might consider an equiproportionate reduction across all users or target reductions at particular uses, for example with the aim of minimising economic cost or by taking account of social preferences.

By how much. The final dimension of management action is the degree of severity of the action taken, perhaps measured by the quantity of water taken out of use and the extent of geographical redistribution of resources. Here, the consideration is between, on the one hand, the costs imposed on water users and the costs of redistribution, and on the other, the damage to the environment.

Environmental protection scenarios might be considered with high, medium or low levels of protection, as evidenced by the levels of flows maintained in rivers.

Scenarios of 'by how much'. A wide range of scenarios are possible here. Taking the recent planned actions as the baseline, a scenario in which environmental flows are more strongly protected, and one in which less protection is afforded can both be seen to be beneficial.

2.2.2 The effectiveness of management actions

Each management action will have an effect on the quantity of water taken from the environment, specific to the groups of water users to which it is applied. As a management action drives changes in practice among users, it acts upon the quantity of water taken, but perhaps not in a wholly effective way. Some users may respond quickly and others slowly, some may comply fully and others only in part. The enforcement of some

management actions may be more effective than others.

For these reasons, the actual effect of management action is not only a matter of what users and uses of water it covers or how consumptive those uses are. The effect is also in the degree of response and compliance that it engenders among users.

For a study such as this, which seeks to build a robust, scientific evidence base for policy making, it would be advantageous to have access to good information about the response of users to management actions. However, droughts are fortunately infrequent and the systems that are in place to capture data have not yet yielded up those insights. The effectiveness of management actions thus remains somewhat uncertain, therefore scenarios are useful assessment tools.

2.2.3 Proposed scenarios

The management actions have been grouped together under four scenario headings, each with its own narrative. These are in addition to a minimum action scenario, where solely supply side measures are taken, with the purpose of protecting public water supply.

The **Baseline** scenario involves just in time action with little supply side preparation, but fairly strict use of mandatory measures in targeted sectors to deliver with some certainty, but not excessive economic cost, a medium level of environmental protection. This reflects current practice in drought management, as observed in the 2011/12 drought.

The **Priority for the environment** scenario places great store in maintaining environmental quality, and so takes early action to mitigate the worst effects of the drought, demands a high level of supply side action and uses mandatory measures both for supply and to constrain demand to be more certain of their effect. Given the higher cost of high environmental protection, cost effectiveness becomes a priority, and the mandatory measures are targeted carefully to keep costs down.

The **Local consensus** scenario creates a spirit of ‘we’re all in it together’ and tries to solve problems as they arise locally. Action starts just in time, triggered by the onset of drought, and involves little supply side effort in preparation or through coordination between areas. High reliance is placed on voluntary measures and where stronger measures are taken, they are applied equally to all sectors, as far as is possible. A balance is struck between the environment and the costs imposed, leading to a medium level of environmental protection.

The **Priority for the economy** scenario makes all the most cost-effective choices, acting early, using voluntary measures where possible, and is reluctant to press on with mandatory measures. Action is targeted carefully to minimise costs and the environment receives the minimum legal protection.

These scenarios are summarised in Table 1.

Table 1. **Summary of proposed management action scenarios**

Aspect	Option	Baseline	Priority for the environment	Local consensus	Priority for the economy
When	Early action		X		X
	Just-in-time action	X		X	
What	Low supply side action	X		X	
	High supply side action		X		X
	Voluntary and quasi-voluntary measures	X		X	X
	Mandatory measures	X	X		
Who	Equi-proportionate reduction			X	
	Targeted reduction	X	X		X
By how much	High environmental protection		X		
	Medium environmental protection	X		X	
	Weak environmental protection				X

Source: Vivid Economics

The options for action in Table 1 merit brief further expansion.

– Early action involves substantially advancing in time all the management actions that are taken, bringing forward actions that could bring benefits later to the point where there was significant risk of drought rather than waiting for the event to arrive.
– The low supply side option involves no re-arrangements of bulk supplies or transfers between water resource zones, nor any tankering between places.
– The voluntary and quasi-voluntary measures are those for which there are no penalties for non-compliance or where compliance cannot be enforced. They include communications campaigns and unenforceable requests to cease specific uses.
– The equiproportionate reduction attempts to spread the burden evenly across sectors, regardless of the distribution of the costs.
– The medium level of environmental protection is the level set today and observed in the recent drought. A higher level of protection involves greater minimum river flows and less temporary loss of wetland area. The lower level of environmental protection involves the lowest flows in rivers and the greatest reduction in extent of wetlands. There are complexities with regard to river flow needs in terms of timing, for example seasonal flows for fish migration; whilst serious impacts (for example fish kills) arise from summer low flows, winter or spring impacts at medium flows may be more

significant for avoiding chronic effects. However, due to the level of inherent uncertainty it would be too difficult to model such complexities here.

3 Water use before and during the 2011/12 drought

Results from data collection and modelling

3.1 Description of water use and consumption

This section presents a series of descriptive statistics for the sectors analysed in this report. The metrics chosen are gross water use, water consumption, turnover and profit. Due to the lack of complete and reliable data, descriptive statistics for gross value added and employment are not presented here, but can be provided by the model if desired.

3.1.1 Water use

In a typical summer quarter, in the absence of drought, the sectors analysed in this report use approximately 2 million Ml across all of England's regions.[2] A summer quarter includes water use for irrigation in agriculture and golf: these only irrigate during the second and third quarters of the year.

Landscaping services and wholesale and retail nurseries are not assumed to be seasonal, as such

Public water supply (PWS) is the biggest user, with distribution input making up 65 per cent of total use across sectors, as per Figure 6.[3] According to data published by the Environment Agency, seventy per cent of this distribution input is abstracted, the balance being made up from upland reservoirs, re-use and other sources.

Households use just over half of PWS distribution input with under a quarter leaking from the pipe network, see Figure 6. This number includes distribution and supply pipe leakage on customers' premises.[4] The remainder is used by businesses, the public sector and other organisations. A number of other sectors of interest, which use some public water supply, are relatively small users. These include window cleaning, landscaping services, non-domestic swimming pools and golf courses.

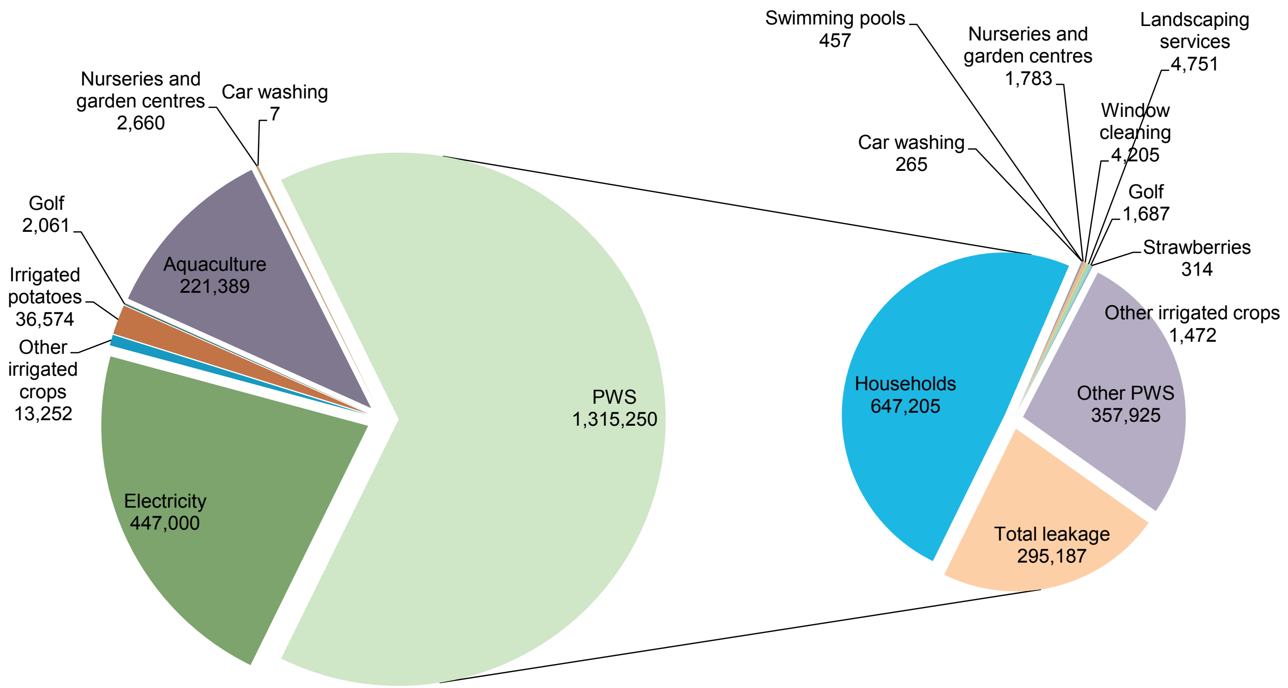
The second biggest user after PWS is the electricity sector, followed by the category freshwater aquaculture. Irrigating crops is fourth in importance of water use, whilst all other sectors are much smaller in comparison.

[2] Based on 2010 data.

[3] Distribution input is the amount of water entering the distribution system at the point of production, that is water delivered plus distribution losses plus distribution operational use. An alternative metric would be deployable output, which is defined as the output of a commissioned source or group of sources or of bulk supply as constrained by the environment, licence restrictions, if applicable, pumping plant and/or well/aquifer properties, raw water mains and/or aquifers, transfer and/or output main, treatment and water quality. Definitions taken from Bristol Water glossary.

[4] Total leakage was 19.7 per cent of distribution input in 2009-10 (average across water companies in England and Wales). Distribution leakage is 14.7 per cent and supply pipe leakage 5 per cent of DI. Source: Halcrow based on water company data.

Figure 6. **Quarterly water use in the absence of any drought management actions, Ml per quarter**



Note: England totals

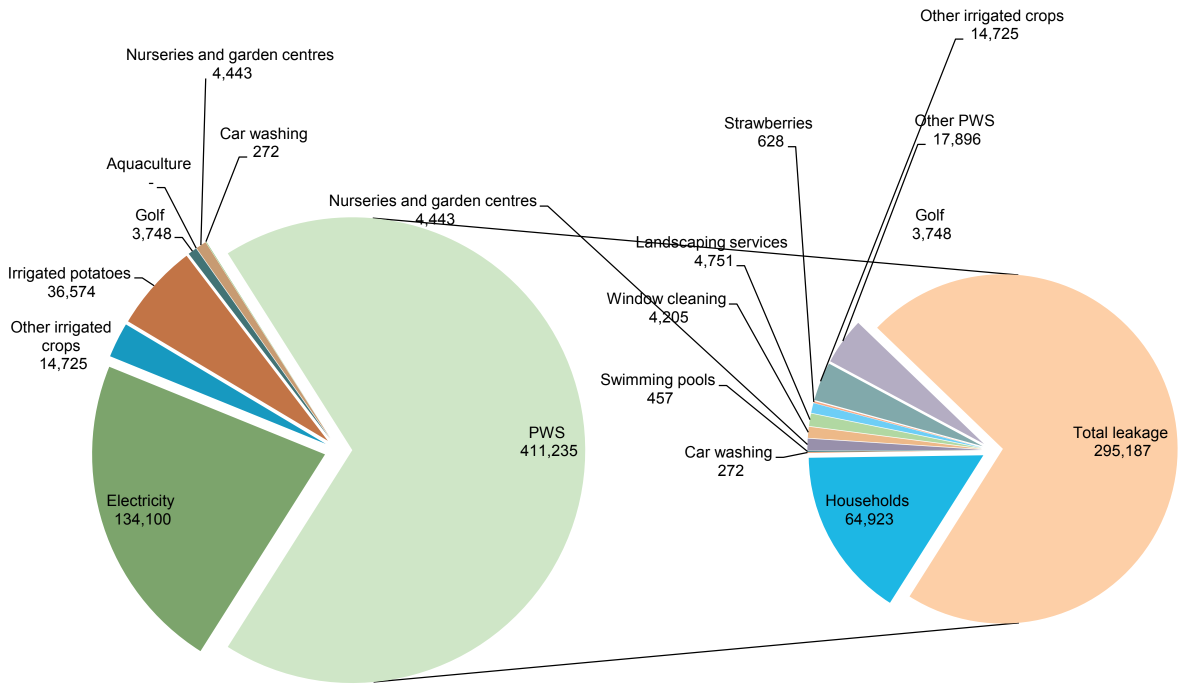
Source: Vivid Economics calculations based on various sources, as described in Appendix 7

3.1.2 Water consumption

Water consumed is the part of the water taken or supplied to a user which is not returned directly to a river, groundwater, drain or public sewer, and thus might be lost through evaporation or might take some time to return to an exploitable water source.

Figure 7 presents quarterly water consumption in England in the absence of any drought management action. A significant difference is seen in aquaculture, which is a non-consumptive water user. PWS is the biggest consumer, with consumption of 0.41 million Ml/quarter, followed by the electricity sector, which consumes a third this amount. Irrigated agricultural crops, golf and horticulture consume all the water they use, as well as water used in the golf and horticulture sectors. The consumptiveness of use is listed by sector in Appendix 7.

Figure 7. **Quarterly water consumption in the absence of any drought management actions, Ml per quarter**



Note: *England totals*

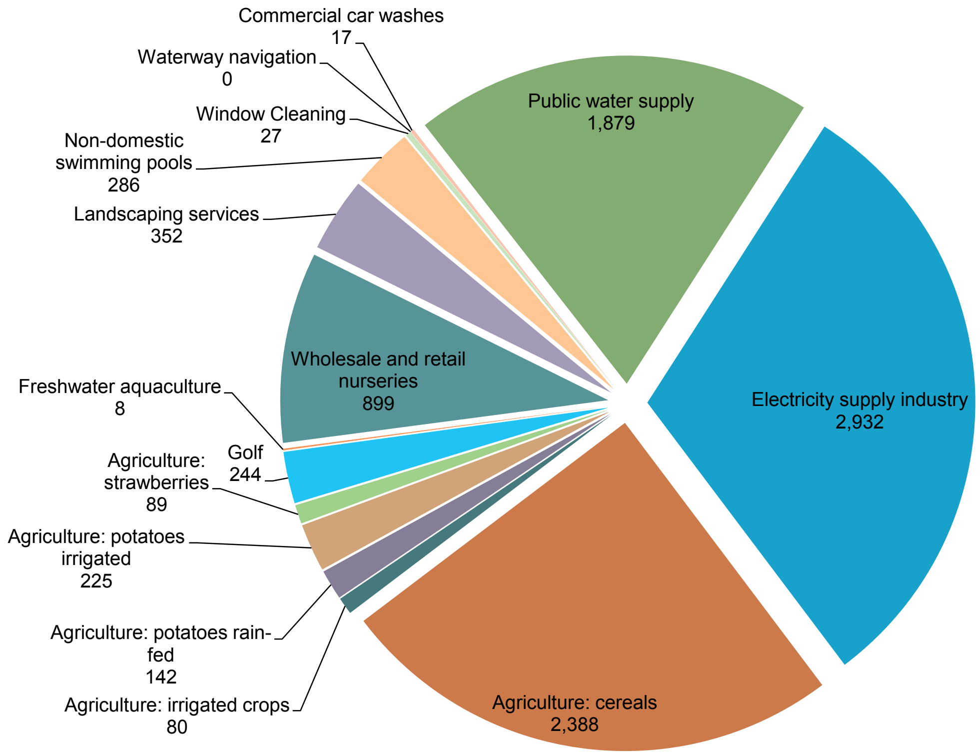
Source: *Vivid Economics calculations based on various sources, as described in Appendix 7*

3.1.3 Economic statistics

Some of the sectors analysed in this report are economically important, as Figure 8 demonstrates. The electricity sector has a quarterly turnover figure of GBP 2.9 billion, cereals GBP 2.4 billion and PWS GBP 1.9 billion. A further important sector is wholesale and retail nurseries. The majority however are smaller sectors, with freshwater aquaculture, for example, generating GBP 8 million, commercial car washes GBP 20 million and golf GBP 240 million in quarterly turnover. Irrigated potatoes generate more turnover than rain-fed potatoes, that is, GBP 230 million compared to GBP 140 million, which probably explains farmers' preference for planting crops in areas with drier soils, where they can use irrigation to adjust the water that reaches the crops.

Cereals, rain-fed crops and aquaculture are affected by drought conditions. These sectors experience direct impacts from lack of rainfall; and in the case of aquaculture, drought impacts can be compounded by drought management actions such as restricted abstraction as a result of HoFs.

Figure 8. **Sectoral distribution of turnover in the absence of any drought management actions, GBP m/quarter**

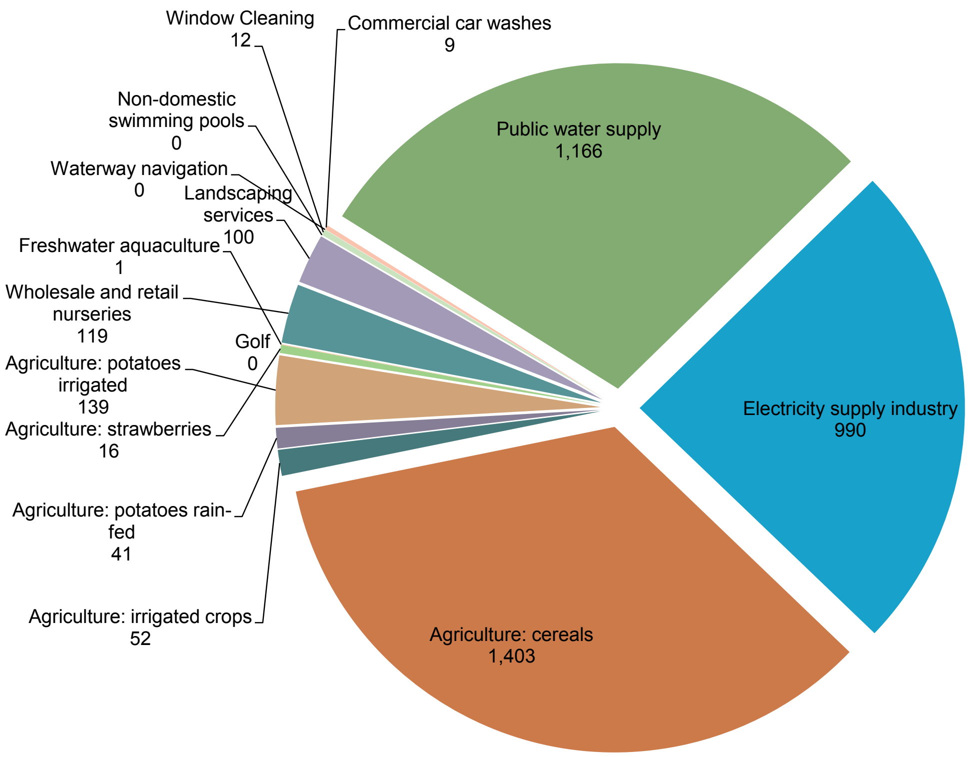


Note: England totals, data for 2010

Source: Vivid Economics calculations based on various sources, as described in Appendix 7

Profits can vary greatly from year to year. These figures are indicative. Cereals generate the highest quarterly profit, GBP 1.4 billion, see Figure 9. PWS generates just under GBP 2.0 billion in profits and the electricity sector GBP 1.0 billion. All other sectors have smaller profits, for example irrigated potatoes a quarterly profit of around GBP 140 million. Commercial swimming pools are usually affiliated to a fitness club or hotel and do not report profits separately. Aquaculture reports near to zero levels of profit under normal conditions. For these low or non-profit sectors a figure of zero profits has been used for normal operations.

Figure 9. **Sectoral distribution of profit in the absence of any drought management actions, GBP m/quarter**



Note: *England totals*

Source: *Vivid Economics calculations based on various sources, as described in Appendix 7*

3.2 Estimated impacts of the baseline drought

3.2.1 Management action taken

The 2011/12 drought was characterised by two dry winters, but it was not felt by water company customers until the second quarter of 2012 (Q2 2012), when some water companies took actions to restrict demand, introducing TUBs. At this time, the Environment Agency encouraged agricultural irrigators to cut their use following which some water companies applied for drought permits to secure river abstractions with one company applying for a drought order to fill one of its reservoirs, see Appendix 1. Table 2 summarises the management actions taken during the 2011/12 drought. Only two Environment Agency regions were affected by management actions: the South East and Anglian. For a more detailed description of the 2011/12 drought, refer to Appendix 1.

Table 2. **Management actions taken during the 2011/12 drought**

Management action	Sectors affected	Start date	End date
PWS communication	PWS, households	Q1 2011	Q2 2012
PWS temporary use bans with concessions	PWS, households, golf, landscaping services, wholesale and retail nurseries	Q2 2012	Q2 2012
PWS drought permits	PWS	Q4 2011	Q2 2012
PWS drought orders (supply side)	PWS	Q4 2011	Q1 2012
EA encouraging voluntary reductions under S57	Agriculture: irrigated potatoes and other irrigated crops	Q2 2012	Q2 2012

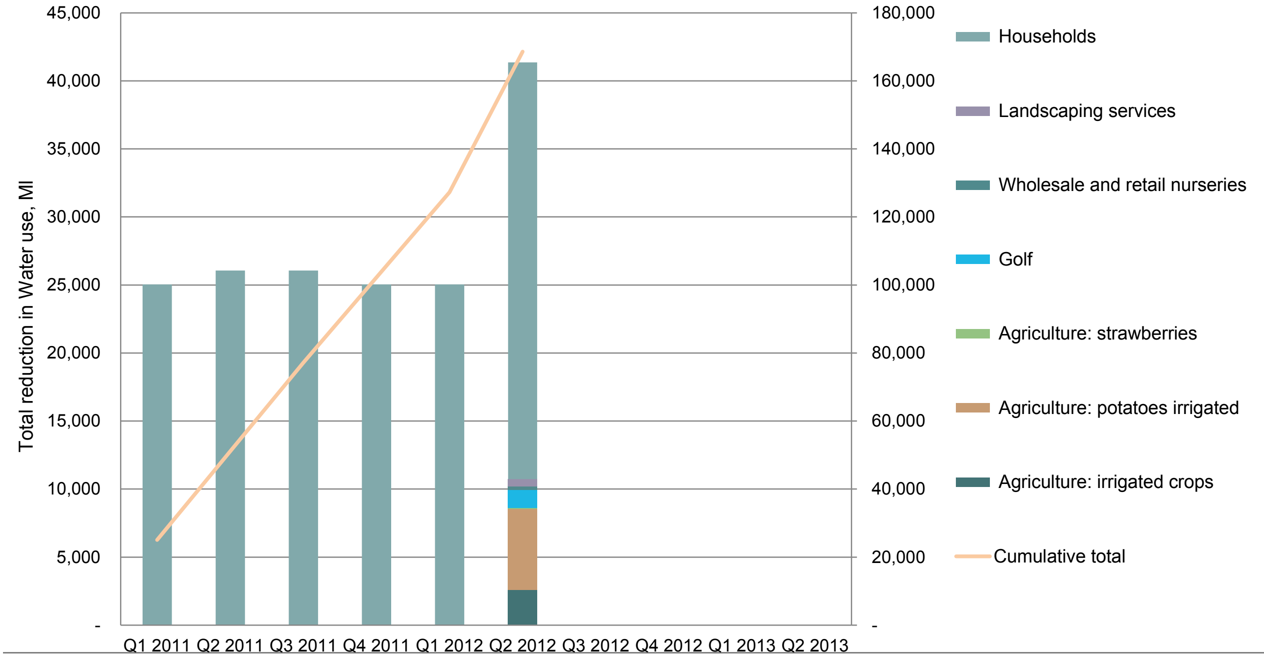
Note: *South East and Anglian regions only*

Source: *Vivid Economics and Halcrow Ltd*

3.2.2 Estimated impacts of the 2011/2012 drought on water use and consumption

The management actions listed in Table 2 proved to be of a short duration because above average rainfall occurred from April and through the summer of 2012. The reduction in water use brought about by the management actions reached around 40,000 Ml in Q2 2012, shown in Figure 10.

Figure 10. **Total reduction in water use, Ml/quarter**



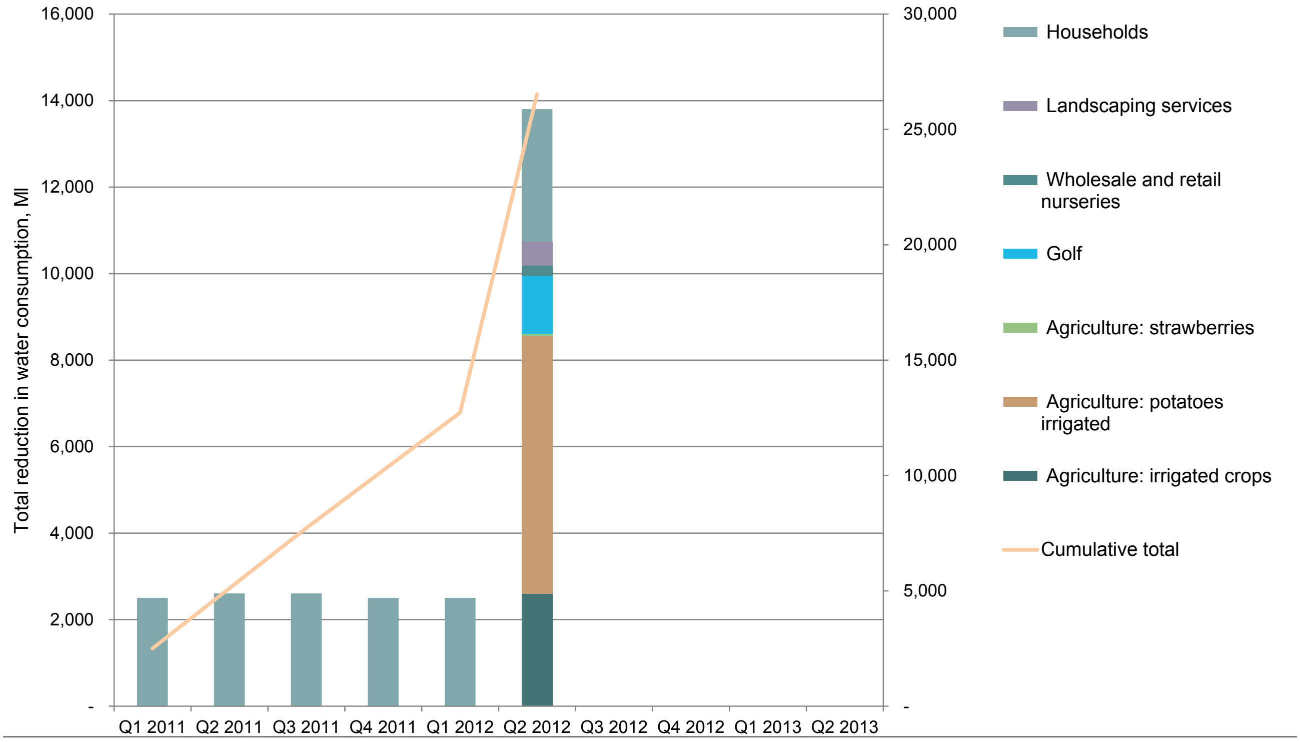
Note: The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

The impacts were short-lived because the management actions began just before the drought ended. Households contributed the most to water savings on a 'water use' basis, followed by irrigated potatoes and other irrigated crops, see Figure 10. In total, it is estimated that 0.17 million Ml was saved, with most contributions occurring in Q2 2012. Households' water savings amounted to three quarters of the total in Q2 2012; irrigated potatoes coming second with 14 per cent.

However, on a 'consumption basis', irrigated potatoes contributed the highest proportion of savings in Q2 2012, 43 per cent. Cumulative water consumption savings totalled 27,000 Ml; households and other irrigated crops each contributing around 20 per cent of the total water savings.

Figure 11. **Total reduction in water consumption, Ml/quarter**



Note: The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

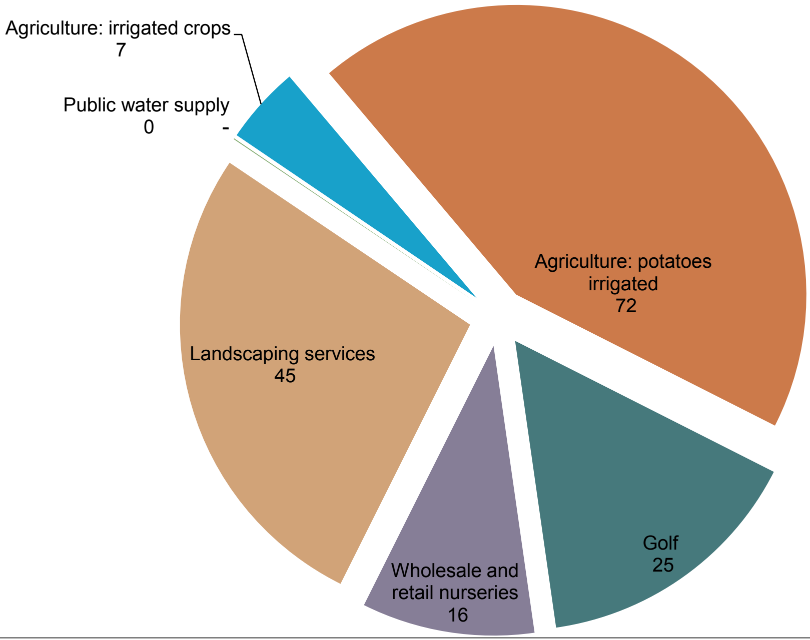
3.2.3 Estimated impacts of the 2011/2012 drought on turnover and profit

Turnover and profit were probably affected only in Q2 2012. The costs to water companies include the exercise of drought permits and orders and bulk transfers between water companies. These costs are shown as occurring evenly across quarters, although there would have been seasonal variation, because information on that variation is not available.

Figure 12 shows the estimated reduction in turnover in the five sectors which experienced drought management actions applied in Q2 2012. These are ‘first order’ impacts on those adversely affected, before considering offsetting gains in other locations and sectors. On this basis, about GBP 165 million in turnover was lost, just under half of which was in irrigated potatoes. Landscaping services lost revenue amounting to about GBP 45 million in turnover and the golf sector GBP 25 million. PWS companies were the least affected, with lost revenue amounting to GBP 0.08 million. Across the six quarters of the drought, that is Q1 2011 to Q2 2012, PWS companies suffered a turnover loss of GBP 0.48 million.

In terms of profits, the greatest first-order impact was faced by irrigated potatoes, with profits cut by GBP 75 million, see Figure 13. This figure is the same as the loss in turnover, because costs were assumed to be unchanged. Other irrigated crops gave up around a tenth as much profit as potatoes. Activities down the supply chain in food processing could also be affected.

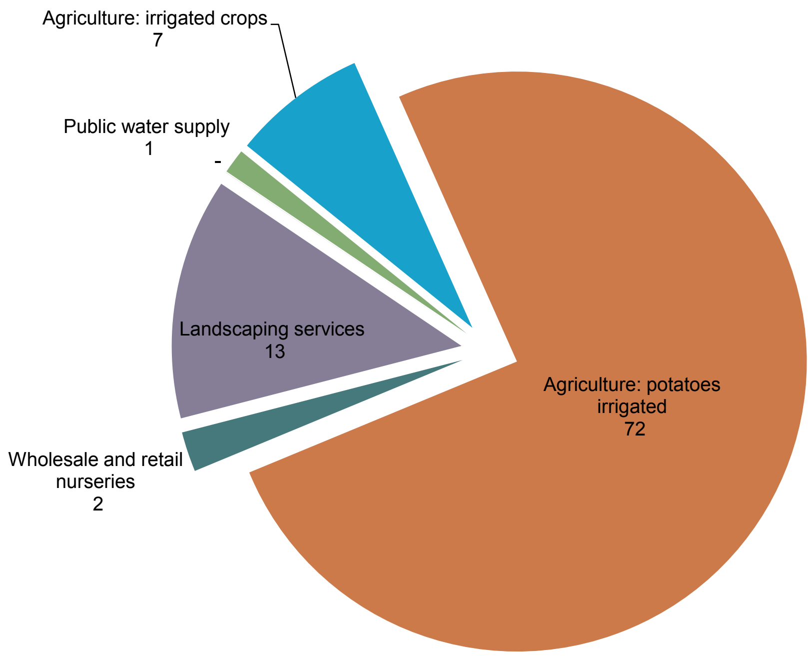
Figure 12. **Reduction in total turnover, GBP m, Q2 2012**



Note: *South East and Anglian regions*

Source: *Vivid Economics based on sources as detailed in Appendix 7*

Figure 13. **Reduction in profit, GBP m, Q2 2012**



Note: *South East and Anglian regions*

Source: *Vivid Economics based on sources as detailed in Appendix 7*

It is likely that reported agricultural losses were not related to the drought, but to the heavy rainfall that started in April 2012. Potato production in 2012 was 24 per cent lower than in 2011, mostly due to a 20 per

cent fall in the average net yield; the Potato Council reported that:

> *'from April, planting progress and crop development were affected by unusually cold, dull and wet conditions across GB. All regions were affected by the difficult conditions but the magnitude of the impact varied crucially on when crops were planted, soil type and topography'* (Potato Council and the Agriculture and Horticulture Development Board, 2012).

The second round impacts on vegetable production would have had some mitigating effect. Potato prices rise when availability is reduced, compensating all growers for the lower yields of some. The higher prices draw in imports of potatoes and raise demand for rice, wheat and other staples. None of these higher order effects have been estimated.

Electricity sector impacts are not quantified in the model. In this particular sector it is likely that reduction in output by one plant which loses the right to abstract water due to HoFs or otherwise would be offset by increases in another, as the electricity supply across the country will always meet demand other than in very exceptional circumstances. The UK is a net importer of electricity and droughts could increase imports (DECC, 2012). The net effect on electricity production, after the reallocation of power supply has been taken into account, is small. However, there could be an impact on profits and prices as the costs of supply from the substitute producer may be higher than for the curtailed producer.

Landscaping services and golf clubs are businesses that are likely to be local. Hence the impacts in one region are not likely to be offset by impacts in other regions.

Wholesale and retail nurseries reported that losses in sales were more likely to have been due to rain than the drought, as such the impacts of the drought, if any, are difficult to quantify.

Interviews and research suggest that there were no employment impacts in these sectors.

There were no quantifiable impacts from Hands-off-Flow (HoFs) conditions. The lack of data prevented them from being used in the modelling of the 2011/12 drought.

Among the sectors not included in the model is the leisure sector that is dependent on waterways navigation. Parts of the canals were closed due to the drought, with likely reverberations on affiliated businesses. More generally, there is no quantitative evidence available on the impacts on recreation and tourism

Of further note is the impact of TUBs on builders of domestic pools; the industry reported reduced consumer demand for new pools and a decrease in maintenance requests for existing pools. Lack of data has prevented these sectors from being included in the model in a quantitative manner. The aquaculture industry was also close to experiencing substantial impacts due to high water temperatures.

No impacts on recreation or tourism are reported, due to lack of evidence.

Taking all of the above into consideration, the impacts of the drought in 2011/12 were likely to have been in the region of GBP 70 million turnover reduction, accruing to public water supply companies, landscaping services and golf. Reductions in profit were somewhat lower than this figure.

4 Impacts of an extended drought

Whilst the hydrological info goes into 2013, the estimates on impacts only cover 2012, as the impacts could have been much more severe had the drought continued into 2013. Beyond April 2012 there is considerable uncertainty surrounding what may have happened in response to the continued hydrological conditions; the report builds on input from water companies and others to inform this decision.

Had the drought continued into a third dry winter, water companies and the Environment Agency would have taken further management actions to restrict demand. The extended drought scenario considers rainfall patterns at 80 per cent below long term average continuing through Q3 and Q4 2012. Section 2.1 discusses the rainfall pattern for the extended drought scenario in more detail.

This section explores the impact of four management scenarios for an extended drought. The rationale for these management scenarios is described in section 2.2.

4.1 Baseline scenario for an extended drought

4.1.1 Baseline management actions for extended drought scenario

The baseline management scenario is an extension of the management actions taken during the 2011/12 drought. It is likely that water companies would have removed the exemptions from temporary use bans awarded to small businesses catering to households, for example, window cleaning, during Q2 2012 and would have kept restrictions in place until the end of the year.

Voluntary S57 restrictions on irrigation would have been replaced with partial restrictions in Q2 2012, followed by full restrictions in the following quarter.

Table 3. **Management actions are extended to Q4 2012 and exemptions removed in the baseline scenario**

Management action	Sectors affected	Start date	End date
PWS communication	PWS, households	Q1 2011	Q4 2012
PWS temporary use bans no concessions	PWS, households, golf, landscaping services, wholesale and retail nurseries, window cleaning	Q2 2012	Q4 2012
PWS drought orders, no concessions	PWS, golf, landscaping services, wholesale and retail nurseries, window cleaning, commercial car washing, non-domestic swimming pools, strawberries, irrigated crops other than potatoes	Q3 2012	Q4 2012
PWS drought permits	PWS	Q4 2011	Q4 2012
PWS drought orders (supply side)	PWS	Q4 2011	Q4 2012
Partial S57 restrictions	Irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q2 2012	Q2 2012
Full S57 restrictions	Irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q3 2012	Q3 2012
Hands-off Flow conditions	Electricity supply, irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries, freshwater aquaculture	Q2 2012	Q4 2012

Note: Anglian, South East and Midlands regions affected

Source: Vivid Economics and Halcrow Ltd

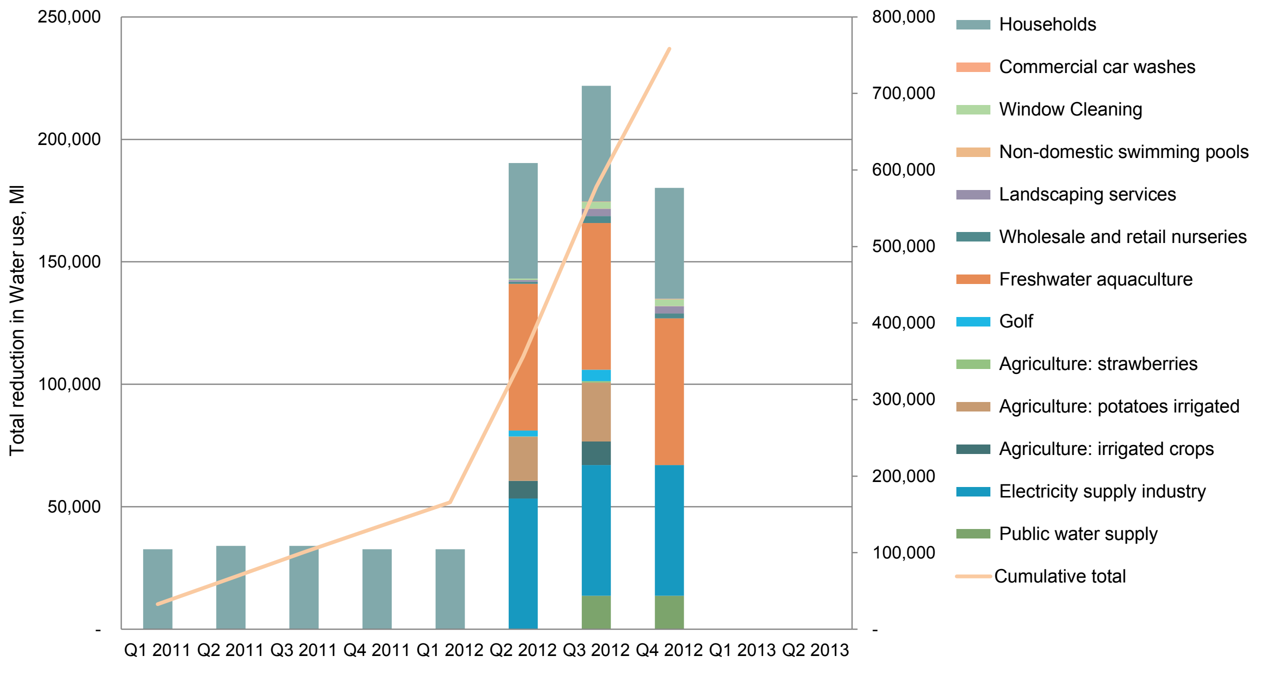
4.1.2 Estimated impacts on water use in the baseline scenario

Under this baseline management scenario of the extended drought, water use savings amount to 0.76 million Ml, see Figure 14. This is equivalent to 6 per cent of the total water use under business as usual, that is water use when no restrictions are in place (based on 2010 quarterly figures). Most savings take place between Q2 and Q4 2012, as the stronger management actions only started in the second quarter of 2012.

Households' water savings contribute around 0.30 million Ml or 40 per cent of the total for the period. Freshwater aquaculture contributes 0.18 million ML or 24 per cent of the water use savings over the period as a result of HoF restrictions.[5] The electricity sector savings from HoF restrictions amount to 0.16 million Ml, or 21 per cent of the total over the same period. Irrigated potato crops and other irrigated crops contribute 0.04 million Ml (6 per cent) and 0.02 million Ml (2 per cent of the total water savings) respectively. Other sectors make only a small contribution, for example, golf, window cleaning, landscaping services and wholesale and retail nurseries accounting for only 1 per cent of the total each.

[5] Assuming HoF restrictions reduce the water abstracted by 50 per cent.

Figure 14. **On a 'use' basis, households and electricity account for the majority of water savings over the period**



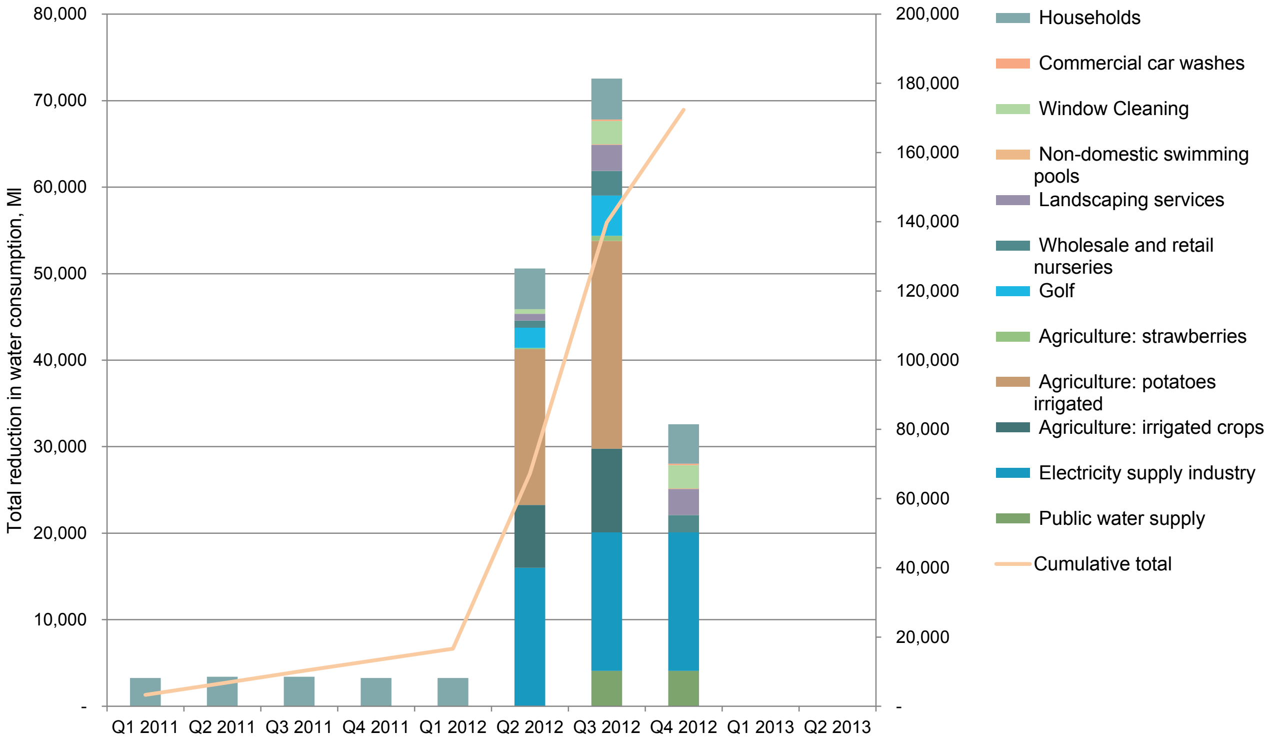
Note: Anglian, South East and Midlands regions affected. Public water supply refers to other PWS sectors not mentioned in the legend. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

On a consumption basis, total water savings over the period would have amounted to 0.17 million Ml. The electricity sector would have been the biggest contributor to water savings during Q2 and Q3 2012, responsible for 0.05 million Ml or 28 per cent of the total. Irrigated potatoes would have accounted for 0.04 million Ml or 24 per cent. Restrictions on water use on irrigated crops other than potatoes lead to 0.02 million Ml of water savings or 10 per cent of the total. Irrigated agriculture includes potatoes and vegetables, and is assumed to be consumptive, so that reductions in use translate fully into reductions in consumption. Rain-fed crops such as cereals are not included in the analysis.

PWS other sectors account for 8,000 Ml or 5 per cent of the savings. Golf, and landscaping services contribute 4 per cent of total water savings each, window cleaning and wholesale and retail nurseries contribute a further 3 per cent each..

Figure 15. **On a 'consumption' basis, electricity and irrigated potatoes account for the majority of water savings**



Note: *Anglian, South East and Midlands regions affected. Public water supply refers to other PWS sectors not mentioned in the legend. The cumulative savings are shown on the right hand axis.*

Source: *Vivid Economics based on sources as detailed in Appendix 7*

4.1.3 Estimated impacts on turnover and profits in the baseline scenario

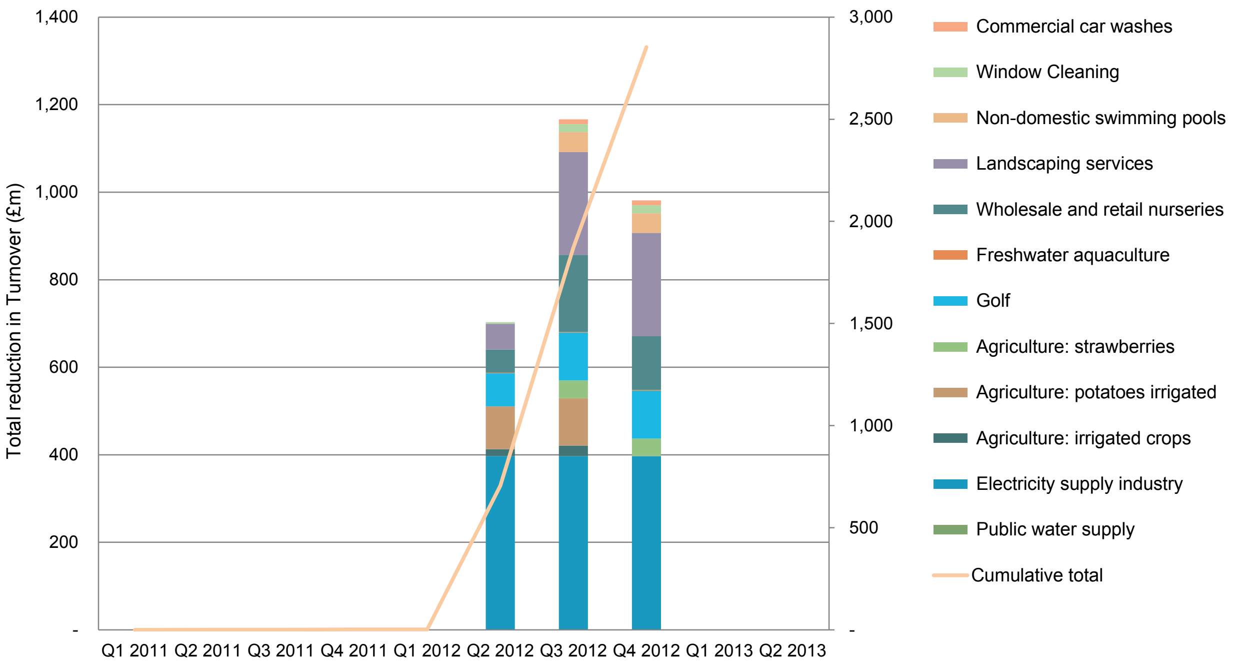
In this scenario, cumulative 'first round' turnover losses amount to under GBP 2.9 billion over the two year period, equivalent to 6 per cent of the total turnover under business as usual.

Impacts are mainly felt in Q2 – Q4 2012. Water companies would also have incurred costs in previous quarters due to a combination of supply side actions such as drought permits and orders and bulk transfers, and demand side actions such as communication campaigns with customers.

The electricity sector has assets incurring the largest absolute reduction in turnover, GBP 1.20 billion or 42 per cent of the total for the period, followed by landscaping services with GBP 0.53 billion (19 per cent) and wholesale and retail nurseries with GBP 0.35 billion (12 per cent), as shown in Figure 16. Note, however, that while some electricity plants would have seen profits fall, plants in other regions not affected by drought would have experienced increases in turnover as their market share of supply would have increased. Thus the negative impacts on the electricity sector in the three regions affected by drought would likely be offset by gains in the regions not affected by drought.

The golf sector in the regions affected by drought loses GBP 0.29 or 10 per cent of turnover. Irrigated potatoes contribute GBP 0.21 billion or 7 per cent of turnover over the period.

Figure 16. **The electricity sector has assets which would have incurred the highest turnover losses, although these would have been made up by other assets, followed by landscaping services which would not have made up reductions by gains elsewhere**



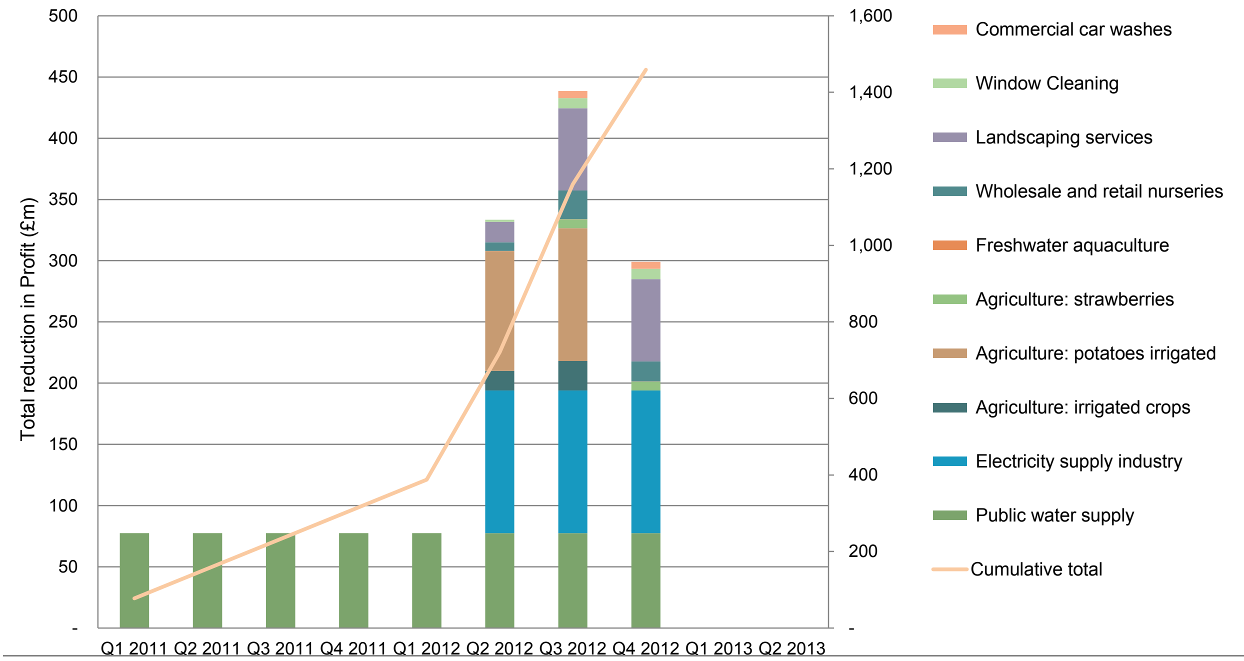
Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

Cumulative first round profit losses amount to just under GBP 1.46 billion over the two year period, equivalent to 7 per cent of the total profit under business as usual. Figure 17 presents the distribution of these results.

PWS companies contribute GBP 0.62 billion or 43 per cent of cumulative profit losses over the period, followed by the electricity sector with GBP 0.35 billion or 24 per cent of the total. Irrigated potatoes contribute GBP 0.21 billion or 21 per cent, with other irrigated crops totalling only 3 per cent of total profit losses. Landscaping services suffer a profit loss of GBP 0.15 billion or 10 per cent of the total.

Figure 17. **PWS companies and the electricity sector would have been incurred the highest profit losses, followed by irrigated potatoes**



Note: *Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.*

Source: *Vivid Economics based on sources as detailed in Appendix 7*

4.2 Priority for the environment scenario

4.2.1 Management actions in the priority for the environment scenario

In this scenario, demand management actions are taken as early as possible in order to protect the environment, see Table 4. Sectors are thus restricted earlier and are subject to more stringent restrictions; for example, temporary use bans with no exemptions are imposed from Q4 2011 to Q4 2012, and full S57 restrictions on irrigation from Q2 to Q3 2012. There is a description of the scenario comparing it to the baseline management scenario in section 2.2.

Table 4. **Management actions in the priority for the environment scenario start earlier than in the baseline scenario**

Management action	Sectors affected	Start date	End date
PWS communication	PWS, households	Q1 2011	Q4 2012
PWS temporary use bans no concessions	PWS, households, golf, landscaping services, wholesale and retail nurseries, window cleaning	Q4 2011	Q4 2012
PWS drought orders, no concessions	PWS, households, golf, landscaping services, wholesale and retail nurseries, window cleaning, commercial car washing, non-domestic swimming pools, strawberries	Q1 2012	Q4 2012
PWS drought permits	PWS	Q2 2012	Q4 2012
PWS drought permits (supply side)	PWS	Q2 2012	Q4 2012
Full S57 restrictions	Irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q2 2012	Q3 2012
Hands-off Flow conditions	Electricity supply, irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q2 2012	Q4 2012

Note: *Anglian, South East and Midlands regions affected*

Source: *Vivid Economics and Halcrow Ltd*

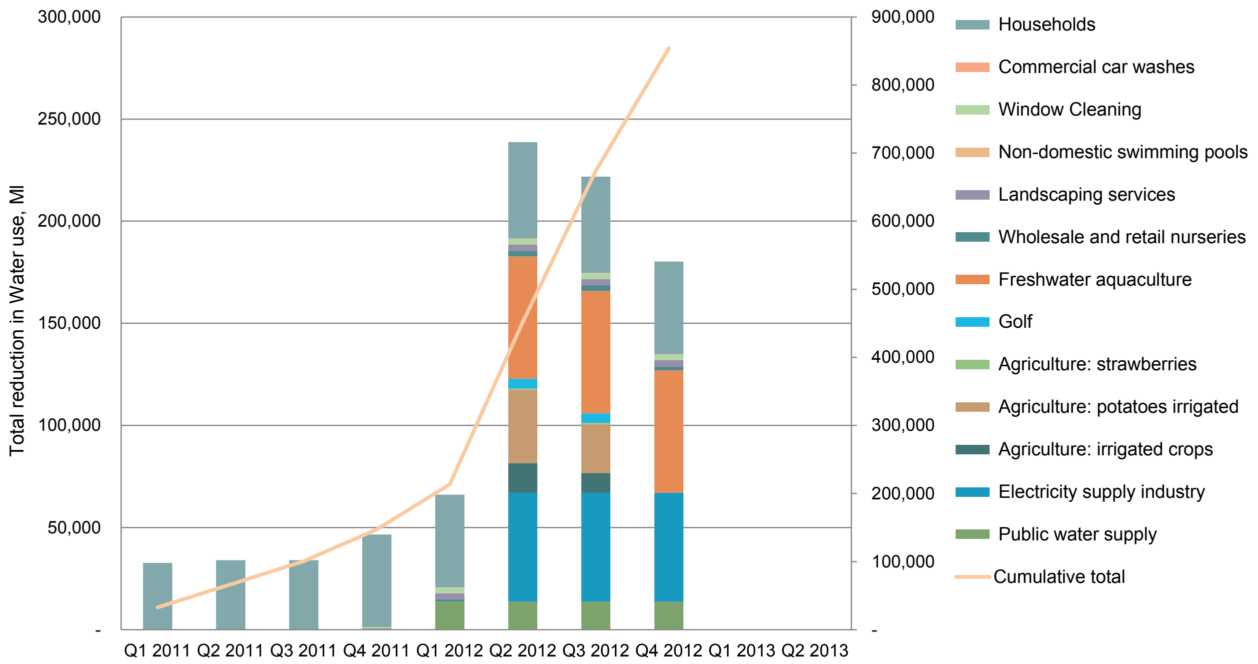
4.2.2 Estimated impacts on water use in priority for the environment scenario

Over the two-year period starting from Q1 2011 and finishing in Q4 2012, the scenario delivers just over 0.85 million Ml of water use savings. This amounts to 7 per cent of the total water use under business as usual, that is water use when no restrictions are in place (based on 2010 quarterly figures).

Households deliver the highest proportion of total water use savings, with 0.33 million Ml (39 per cent of the total for the period) followed by the electricity sector with 0.16 million Ml (19 per cent). Irrigated potatoes contribute 0.06 million Ml of the savings, or 7 per cent of the total. Irrigated agricultural crops combined account for 0.09 million Ml or 10 per cent. Figure 18 shows the quarterly distribution of these results. The greatest water savings are spread over five quarters, due to early action being taken. This is different from the baseline management scenario where water savings mainly occur over three quarters, as Figure 14 shows.

The highest impacts are felt in Q2 2012, where 0.18 million Ml of water are saved (28 per cent of cumulative total for the two year period) and in Q3 2012, where 0.22 million Ml (26 per cent) are saved. These results coincide with, and can be explained by the irrigation season.

Figure 18. **Households contribute the highest water use savings in the majority of quarters, Ml**



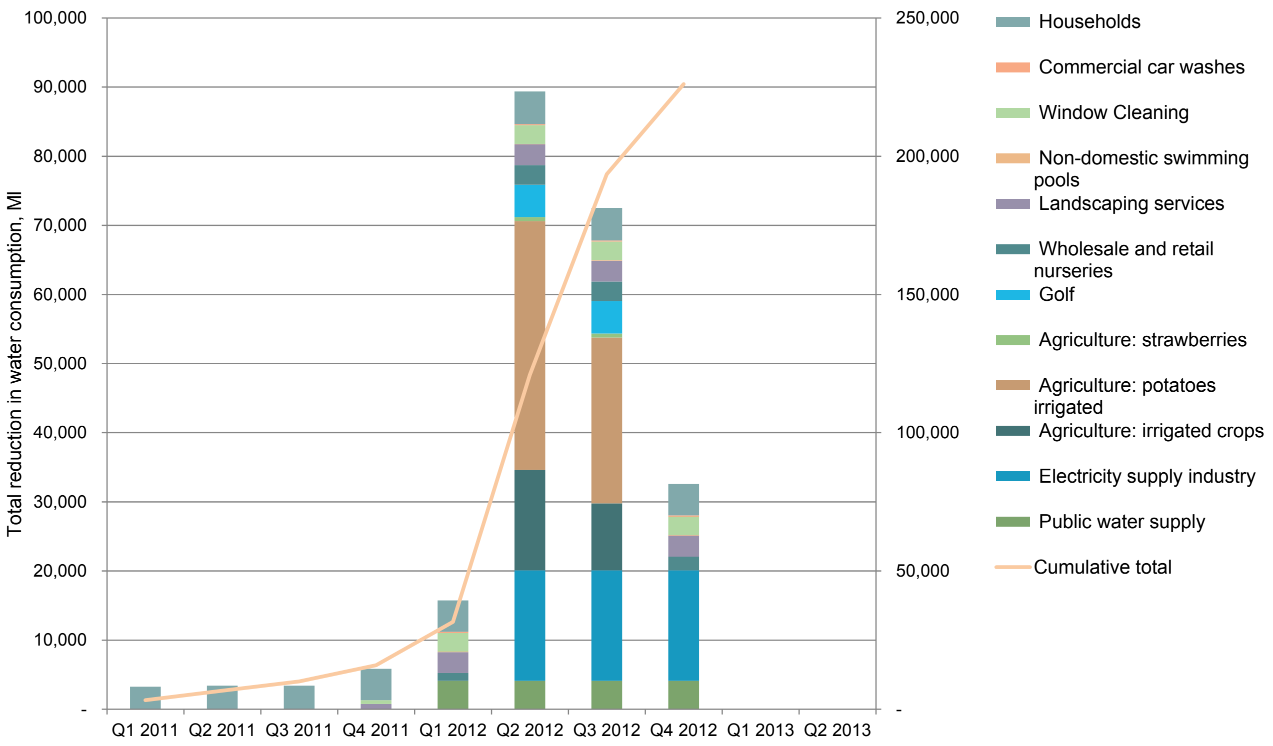
Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

On a consumptive basis, 0.23 million Ml of water is saved under the priority for the environment scenario. Figure 19 shows the distribution of savings. The biggest contributor is irrigated potatoes, with 0.06 million Ml or 27 per cent of the cumulative two-year total water savings. The impacts from this sector are felt during the irrigation season. Other irrigated crops and electricity are also significant contributors to the reduction in total water consumption, with 0.02 million Ml (11 per cent) and 0.05 (22 per cent) respectively. Landscaping services and window cleaning contribute around 0.01 million Ml each, that is 6 and 5 per cent of the total respectively.

As in the case of water use, most of the savings occur during the irrigation season, with 0.09 million Ml (40 per cent) and 0.07 million Ml (33 per cent) of total cumulative savings for the period. These results are due to the fact that water use in agriculture is mostly consumptive in practice and assumed fully consumptive in the model.

Figure 19. **On a consumption basis, Q2 2012 delivers the highest water savings, due to restrictions on irrigation**



Note: *Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.*

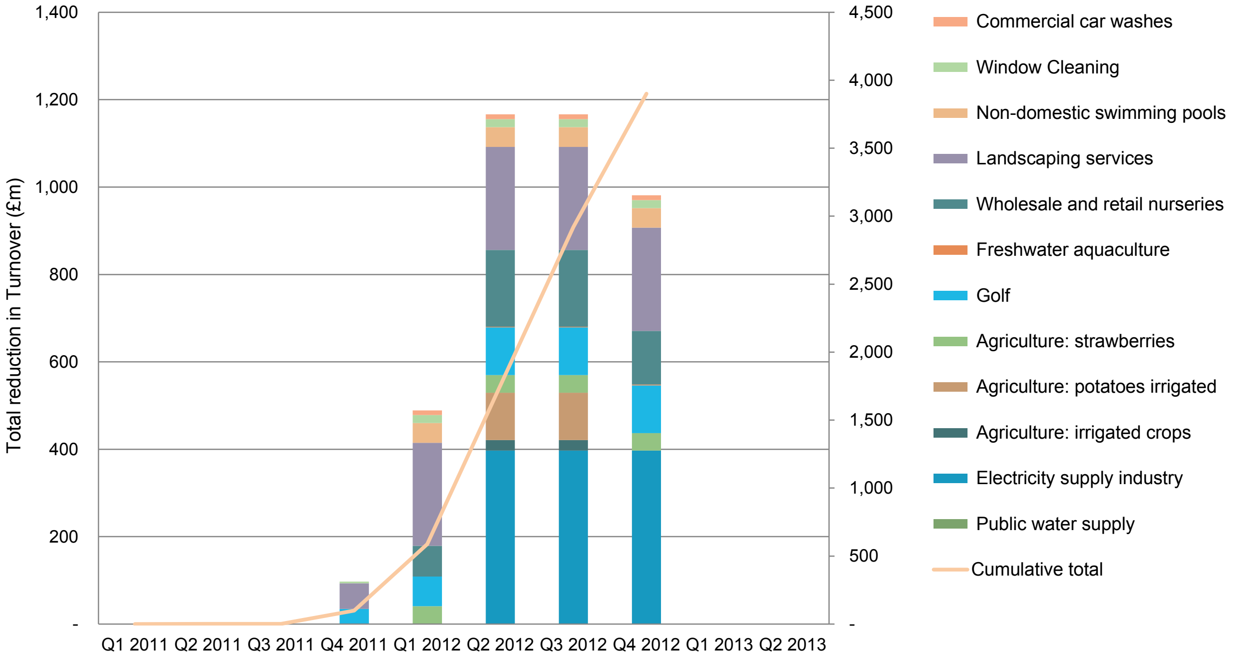
Source: *Vivid Economics based on sources as detailed in Appendix 7*

4.2.3 Estimated impacts on turnover and profit in the priority for the environment scenario

The economic impacts begin in Q4 2011 with 85 per cent of the turnover effects being felt in the last three quarters of 2012. Total turnover reduction amounts to GBP 3.9 billion, which represents 8 per cent of total turnover under business as usual. The electricity sector contributes the largest share of the total turnover reduction, GBP 1.2 billion or 30 per cent of the cumulative total for the period. However, as previously mentioned for the electricity sector, losses in the regions affected by drought are likely to be offset by profits in other regions, although this may elevate the costs of electricity generation and wholesale prices. Landscaping services lose over GBP 1 billion or 26 per cent of the total, followed by wholesale and retail nurseries, with 14 per cent of the cumulative fall in turnover. Both these sectors will not be compensated by increases in output in other geographical areas. Neither will golf, which loses GBP 0.4 billion or 11 per cent of the total and irrigated potatoes contribute GBP 0.2 billion or 6 per cent of the total. Figure 20 presents the loss in turnover for each quarter and cumulatively over a two-year period.

Turnover losses are mainly felt in Q2 and Q3 2012, also in the last quarter of 2012.

Figure 20. **Highest turnover reductions occur in Q2, Q3 and Q4 of 2012, with cumulative turnover reduction of GBP 3,900 million**



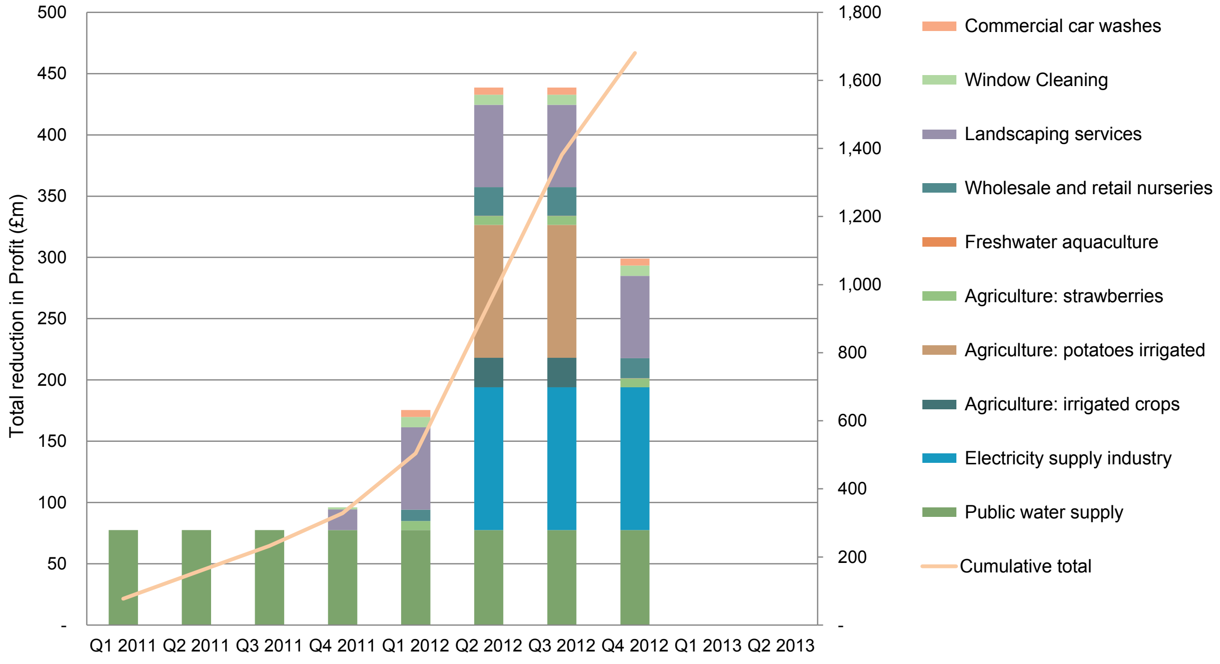
Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

Over the period, GBP 1.7 billion in 'first-round' profits are lost, or 8 per cent of business as usual. PWS companies contribute the most to the cumulative fall in profit over the two year period, with GBP 0.6 billion or 37 per cent of the total. Electricity follows with GBP 0.3 billion or 21 per cent and landscaping services GBP 0.3 billion or 17 per cent. Irrigated potatoes lose GBP 0.2 billion or 13 per cent of the total; irrigated agricultural crops combined lose GBP 0.3 billion or 18 per cent of the total. Figure 21 shows the distribution of these results.

Mirroring turnover, profit losses are mainly felt in Q2 and Q3 2012, also in the last quarter of 2012.

Figure 21. **Highest profit reductions occur in Q2, Q3 and Q4 of 2012, with cumulative profit fall of GBP 1,700 million**



Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

4.3 Priority for the economy scenario

4.3.1 Management actions in the priority for the economy scenario

The priority for the economy scenario delays management action at the expense of environmental impact. The intention is to reduce adverse economic impact on sectors which use water. For example voluntary S57 restrictions on irrigation are encouraged in the second quarter and only partial S57 restrictions are brought in in the following quarter. Drought permits and orders are used earlier, from Q3 2011 to ensure demand for water is met. For more detail on the scenario and how it compares to the other management scenarios, refer to section 2.2.

Table 5. **Management actions are delayed to the benefit of economic sectors reliant on water and at the expense of the environment**

Management action	Sectors affected	Start date	End date
PWS communication	PWS, households	Q1 2011	Q4 2012
PWS temporary use bans with concessions	PWS, households, golf, landscaping services	Q2 2012	Q4 2012
PWS drought orders, with concessions	PWS, households, golf, landscaping services, wholesale and retail nurseries, window cleaning, commercial car washing, non-domestic swimming pools, strawberries	Q3 2012	Q4 2012
PWS drought permits	PWS	Q3 2011	Q4 2012
PWS drought permits (supply side)	PWS	Q3 2011	Q4 2012
Voluntary S57 restrictions	Irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q2 2012	Q2 2012
Partial S57 restrictions	Irrigated potatoes and other irrigated crops, strawberries, golf, wholesale and retail nurseries	Q3 2012	Q3 2012
Hands-off Flow conditions	Electricity supply, irrigated potatoes and other irrigated crops	Q2 2012	Q4 2012

Note: Anglian, South East and Midlands regions affected

Source: Vivid Economics and Halcrow Ltd

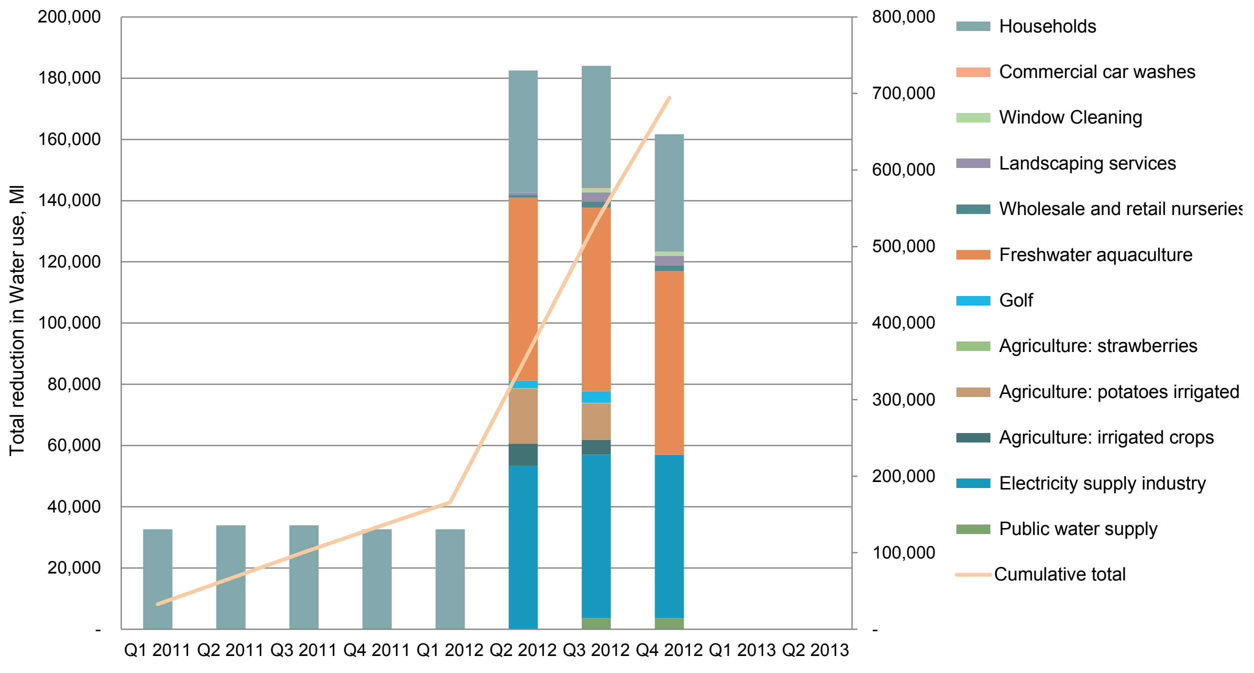
4.3.2 Estimated impacts on water use

In this scenario, there are savings of 0.70 million Ml of water use over the two year period, which amount to 6 per cent of business as usual. As in other scenarios, households, freshwater aquaculture and electricity contribute the most to water savings on a use basis, with 0.28 million Ml (41 per cent), 0.18 million Ml (25 per cent) and 0.16 million Ml (23 per cent of the cumulative total for the period) respectively. Figure 22 presents the distribution of these results.

Irrigated potatoes contribute 0.03 million Ml (4 per cent of the total) and the total for the irrigated sector is 0.04 million Ml (6 per cent of the total). Golf, landscaping services and commercial swimming pools contribute 1 per cent each.

The impacts are mainly felt in Q2 – Q4 2012; only households are affected in prior quarters.

Figure 22. **Total water savings, Ml, 'use' basis**



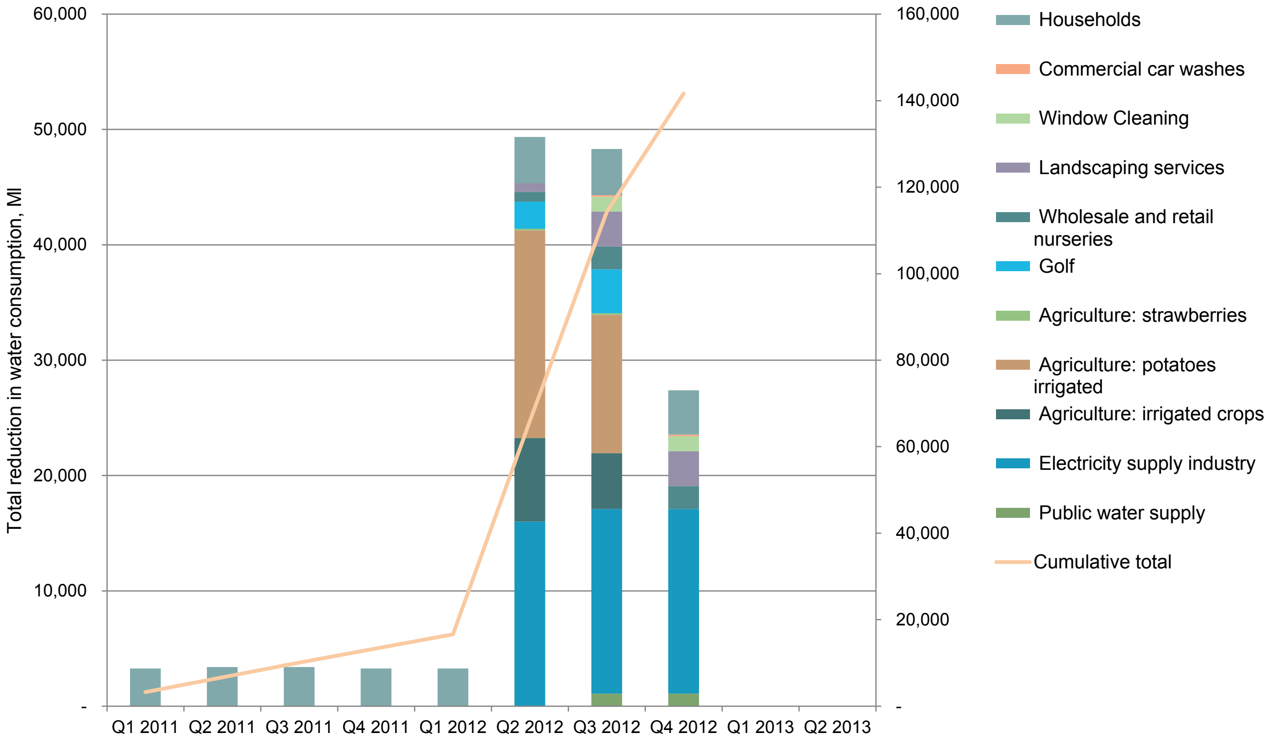
Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

On a consumptive basis, 0.14 million Ml are saved over the two year period, as per Figure 23. The electricity sector is the biggest contributor, with 0.05 million Ml or 34 per cent of the cumulative total. Irrigated potatoes contribute 0.03 million Ml or 21 per cent of the total; the impact is felt most strongly in Q2 2012 where the sector contributes to 30 per cent of the savings for the quarter. Households contribute 0.02 million Ml or 20 per cent of the total.

Mirroring water use, the impacts are mainly felt in Q2 – Q4 2012; only households are affected in prior quarters.

Figure 23. **Total water savings, Ml, 'consumption' basis**



Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

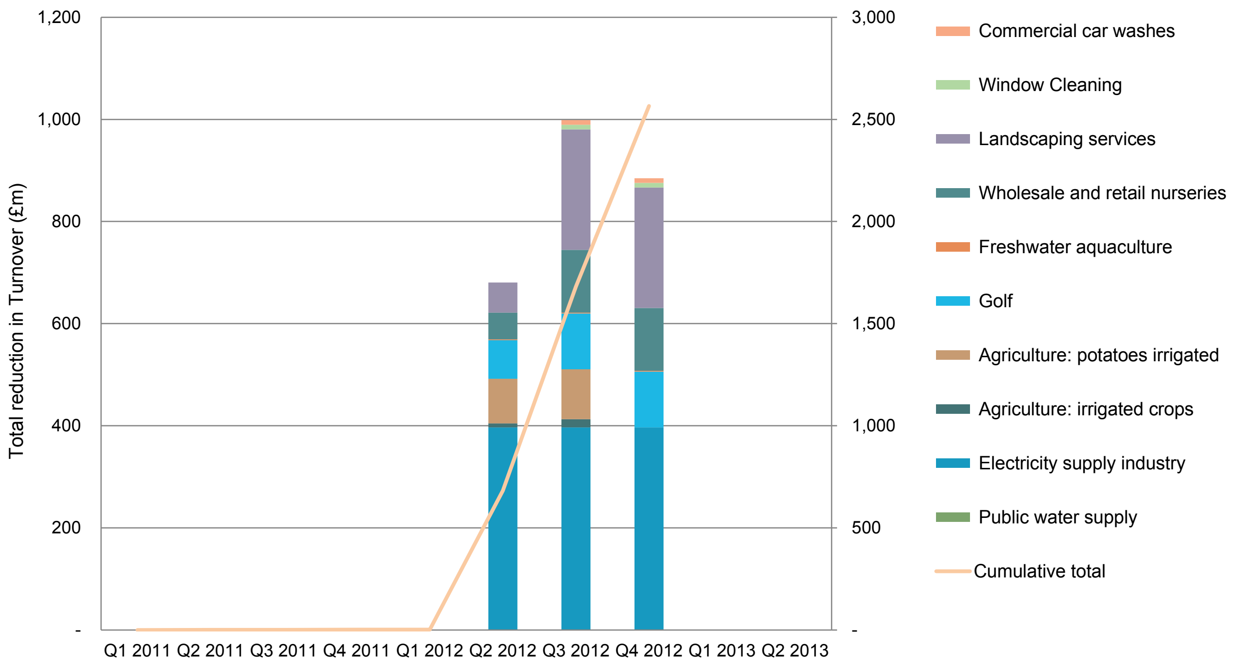
Source: Vivid Economics based on sources as detailed in Appendix 7

4.3.3 Estimated impacts on turnover and profit

Cumulative fall in turnover amounts to GBP 2.6 billion or 5 per cent of business as usual over the two year period. The biggest contributor to the reduction in turnover over the two year period is the electricity sector, with GBP 1.2 billion or 46 per cent of the total, followed by landscaping services with GBP 0.5 billion or 21 per cent of the total and wholesale and retail nurseries with GBP 0.3 billion or 12 per cent, as per Figure 24. As before, losses in the electricity sector are attributed to the regions affected by drought and offset by increased generation in other regions.

Golf loses GBP 300 million, equivalent to 11 per cent of the cumulative total over the period. Irrigated potatoes lose GBP 0.2 billion or 7 per cent. Other irrigated crops, window cleaning and commercial car washing contribute 1 per cent each.

Figure 24. **Impacts are felt more strongly in Q3 and Q4 2012 than in previous quarters, as management actions are delayed**



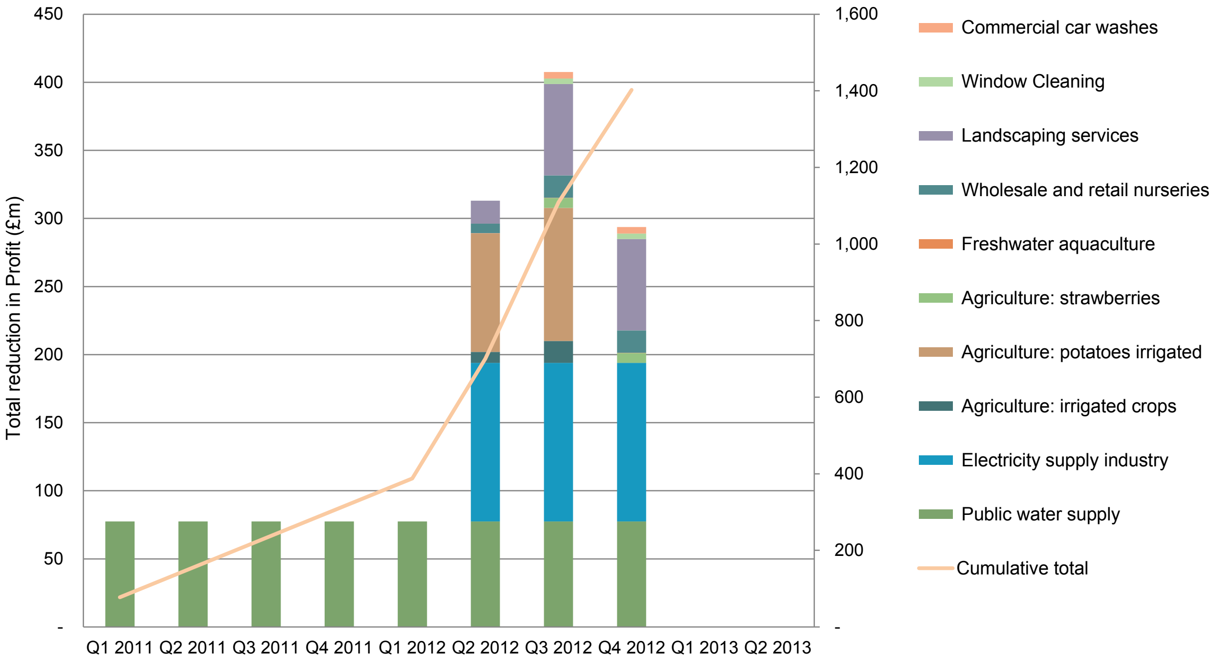
Note: *Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.*

Source: *Vivid Economics based on sources as detailed in Appendix 7*

Cumulative fall in profit amounts to GBP 1.4 billion or 7 per cent of business as usual over the two year period. PWS (GBP 0.6 billion, 44 per cent), electricity (GBP 0.35 billion, 25 per cent), irrigated potatoes (GBP 0.18 billion, 13 per cent), and landscaping services (GBP 0.15 billion, 11 per cent) contribute the most to total reduction in profit over the two year period. Other irrigated crops contribute 2 per cent; strawberries, window cleaning and commercial car washing contribute a further 1 per cent each.

PWS suffers losses from the beginning of the drought, whereas other sectors are only affected in Q2 – Q4 2012, see Figure 25.

Figure 25. **Electricity, irrigated potatoes, PWS and landscaping contribute the most to total reduction in profit over the two year period**



Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

4.4 Local consensus scenario

4.4.1 Overview

The local consensus scenario, defined in section 2.2 , applies equal proportionate reductions in water use for all sectors. The aim is to distribute water reductions across sectors by some simple rule that might be perceived as fair.[6] It would be difficult to implement this equi-proportionate rule using currently available management actions. The assumptions are as follows:

- all sectors are encouraged to reduce water use by 2.5 per cent in Q1 to Q3 of 2011;
- by 5 per cent in Q4 2011, by 7.5 per cent in Q1 2012;
- by 10 per cent in Q2 and Q3 2012; and
- by 15 per cent in Q4 2012.

This distribution of action does not take into account differences in consumptiveness.

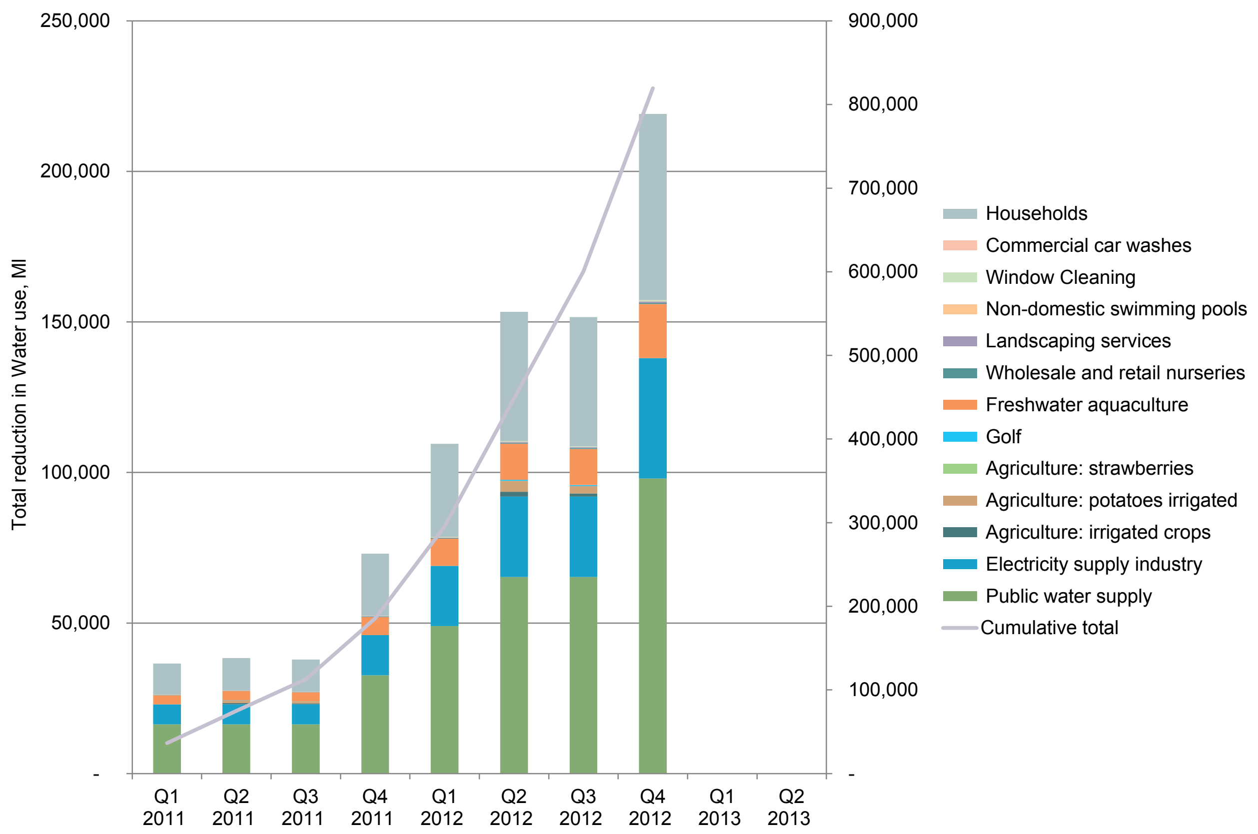
4.4.2 Estimated impacts on water use in local consensus scenario

Figure 26 presents the resulting quarterly reductions in water use, and the cumulative total for the sectors considered. As the highest users, other PWS sectors, households and the electricity sector contribute the most to water savings: 0.36 million Ml (44 per cent of the total), 0.23 million Ml (28 per cent) and 0.15 million Ml

[6] Fairly in this context refers to water use, ignoring differences in consumptiveness between sectors.

(18 per cent) respectively. Cumulative savings of water use are 0.82 million Ml over the two year period, which add up to 4.6 per cent of total water use under business as usual.

Figure 26. **Households and other PWS sectors make the greatest contribution of water consumption savings, followed by the electricity supply industry**

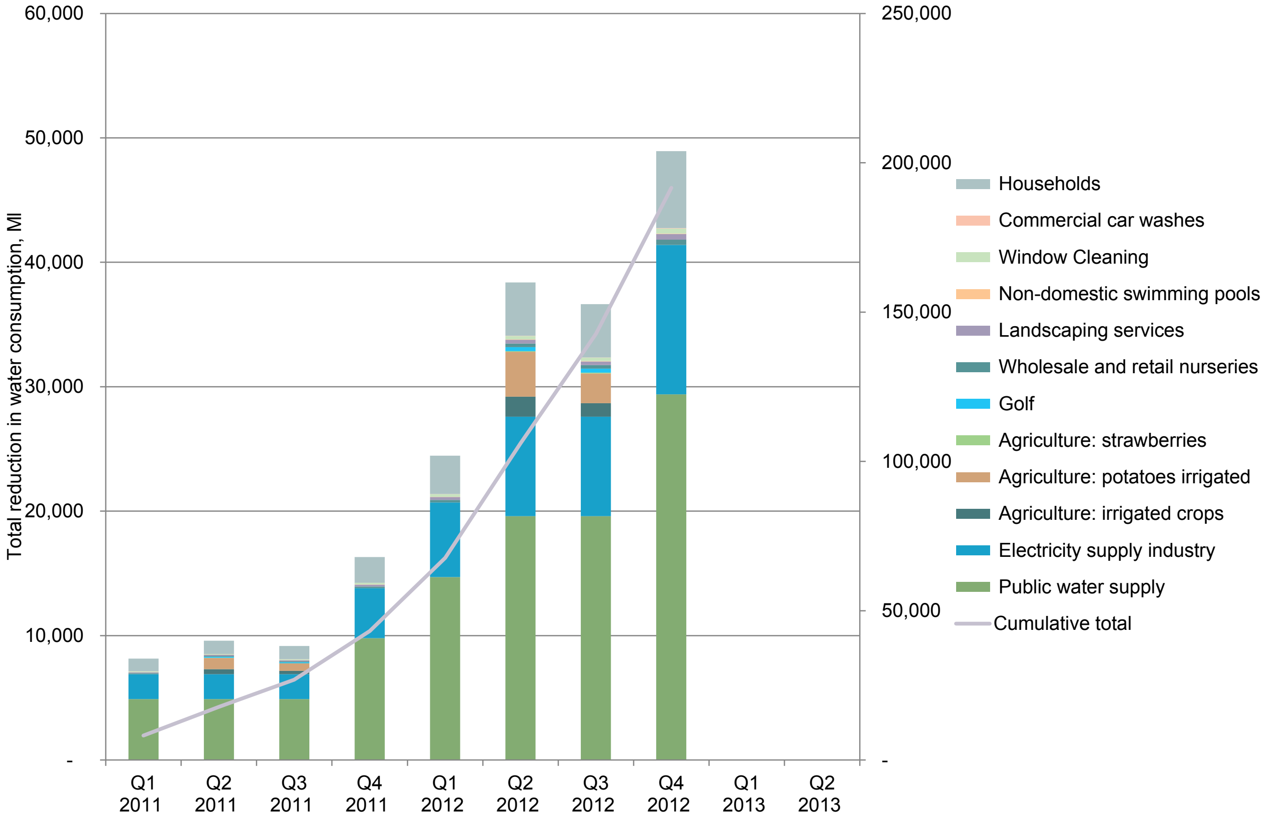


Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

On a consumptive basis, a cumulative total of about 0.19 million Ml is saved. PWS other sectors contribute 0.11 million Ml or 56 per cent of total water savings for the two year period, followed by the electricity sector with 0.04 million Ml or 23 per cent of the total. Households contribute 0.02 million Ml or 12 per cent of the total reduction in water consumed. Agricultural sectors combined are responsible for just 0.01 million Ml or 6 per cent of the savings over the period.

Figure 27. **Households and other PWS sectors make the greatest contribution of water consumption savings, followed by the electricity supply industry**



Note: Anglian, South East and Midlands regions affected. The cumulative savings are shown on the right hand vertical axis.

Source: Vivid Economics based on sources as detailed in Appendix 7

4.4.3 Estimated impacts on turnover and profit in the local consensus scenario

The impacts on turnover and profit cannot be calculated in the local consensus scenario because the scenario does not specify the management actions applied to the sectors. The choice of management actions can affect the economic impacts. The scenario is nevertheless interesting for the purpose of comparing water savings.

4.5 Conclusion

A comparison of the four drought management scenarios shows that the priority for the environment scenario delivers the highest water use and consumption savings (cumulative over the period). As expected, the priority for the economy scenario delivers the least volume of savings on a use or consumptive basis.

Reductions in turnover and profit are smallest under the priority for the economy scenario. The financial impacts are greatest under the priority for the environment scenario, which delivers by far the greatest water savings. Water savings and changes in turnover and profit are summed over the period Q1 2011 – Q4 2012, see Table 6.

Table 6. **The local consensus and the priority for the environment scenarios deliver the greatest water savings while the priority for the economy is the least costly (on a cumulative basis)**

Cumulative figures	Water use savings, Ml	Water consumption savings, Ml	Reduction in turnover, GBP million	Reduction in profit, GBP million
Baseline	760,000	170,000	2,900	1,500
Priority for the environment	850,000	230,000	3,900	1,700
Priority for the economy	690,000	140,000	2,600	1,400
Local consensus	820,000	190,000	-	-

Note: *The regions considered under the extended hydrological drought are South East, Midlands, and Anglian.*

Source: *Vivid Economics*

The only sector to experience offsetting benefits is the electricity industry. As output drops from individual plant, production is ramped up elsewhere in the country or imported from Europe. The benefits accruing to other power plant would partly compensate plant owners for the losses in the drought affected regions. Some customers would experience higher prices as a result.

Agricultural impacts would result from the change in yield (tonnes of product per hectare) or a lower price due to reduced quality. Given that crop planting is decided in advance of drought, it is unlikely that a drought in one area of a country would lead to increased production in another region. Demand could be met by imports, and might push prices up. Imports may not respond so flexibly if the drought is widespread internationally.

Most smaller sectors are of a generally local nature, and so it is unlikely that the benefits would be offset by gains in other regions. A nursery based in the South East would experience economic effects if customers stop buying plants because of a temporary use ban.

It seems unlikely that window cleaners and landscapers would travel out of the drought affected area in order to mitigate the impact. Travel and accommodation costs and lack of established customer relationships is likely to prevent it.

Golf clubs and commercial swimming pools obtain a high proportion of their revenue from annual memberships and customers might not be willing to travel far for these services. Therefore the impacts are most likely to be local and not offset by positive gains in other areas of the country.

Table 7 compares the cost-effectiveness of the management scenarios. Four metrics are available: savings in water use or consumption per unit, combined with profit or turnover reduction. The priority for the economy scenario delivers the most water use savings per unit of turnover lost, which is to be expected given that the

scenario aims to reduce the economic impacts of drought management actions. However, the baseline scenario delivers the highest water use savings per unit of profit change. The differences between these metrics are due to the management actions chosen and their timings.

Table 7. **The highest water savings per unit of turnover occur under the priority for the economy scenario**

	Ml of water use saved per turnover change (Ml/GBP)	Ml of water use saved per profit change (Ml/GBP)	Ml of water consumption saved per turnover change (Ml/GBP)	Ml of water consumption saved per profit change (Ml/GBP)
Baseline	270	520	60	120
Priority for the environment	220	510	58	140
Priority for the economy	270	500	55	100

Note: South East, Midlands, Anglian

Source: Vivid Economics

It is also possible to compare impacts by sector. As above, four metrics are possible; in Table 8 one of the four metrics is presented, water consumption savings per unit of turnover reduction. On this metric, irrigated agriculture delivers the greatest savings, particularly vegetables other than potatoes. Households and other PWS sectors are not included because no turnover or profit estimates are relevant for households and other non-domestic businesses relying on PWS are outside the scope of this work.

When looking at these figures one should bear in mind the size of a sector. It may be that irrigated agriculture delivers the highest water consumption savings per unit of turnover reduction but agriculture is a much smaller sector than electricity supply.

Table 8. **Ml water consumption savings/turnover reduction (Ml/GBP m) are highest for irrigated agriculture**

Sector	Value or range
Electricity supply industry	40
Agriculture: irrigated crops	420 - 500
Agriculture: potatoes irrigated	162 - 277
Agriculture: strawberries	7 - 9
Golf	21 - 24
Wholesale and retail nurseries	16
Landscaping services	13
Non-domestic swimming pools	2
Window cleaning	146
Commercial car washes	16

Source: Vivid Economics

5 Description of drought impacts for selected sectors

The impacts of drought on the environment, public water supply, agriculture and golf

5.1 Impacts of drought on the environment

5.1.1 Introduction

Droughts affect key ecosystem processes in terrestrial ecosystems and aquatic systems. While both are affected by drought, drought management actions have greater impact on aquatic systems.

In terrestrial systems, a drought affects fire-resilience, it alters carbon and nutrient fluxes in soils, it changes the microbial and soil fauna dynamics, and has an effect on plant production. Furthermore, it has been shown to have an impact on the biodiversity of plants, butterflies, moths and beetles. In terrestrial systems, these effects are brought about in two ways: by a lowering of the water tables and by the drying of the top soil layer in which plants are rooted and microbial processes take place. It is possible that the management actions tested in this report could affect the water table in some locations, but it is unlikely that it would have any direct effect on the drying of the top soil layer.

In contrast, in aquatic systems (rivers and wetlands) reduced flows and water levels can result in a reduction in fish biomass, drastic decreases in bird populations, changes in the populations of invertebrates, and altered composition of plant populations. The impacts of droughts vary greatly between catchments, depending on the water body and reach. The impact of drought on stream and river ecosystems occurs principally as a result of the loss of wetted habitat. The resistance of the ecosystem to withstand drought conditions is determined by the morphology of the stream or river bed and channel. Since all of the management actions tested in this report directly affect river flows and levels it is likely that all of the outcomes set out here could occur.

The extensive literature review provided here has been divided into terrestrial, wetland and river ecosystems and focuses mainly on diversity and biomass production aspects of flora and fauna which underpin many other ecosystem services. A full and referenced overview is given in Appendix 3 which includes the methodology of data collection using UK-specific data. Further insight is available from international studies but was outside this scope of work.

In terrestrial ecosystems, altered water flows leading to changes in lower-soil layer moisture, in turn, trigger a cascade of vegetation, microbe and animal responses that are not yet well understood and scarcely studied in the UK. This makes it difficult to assess the changes brought about by the outlined water management scenarios on terrestrial ecosystems. Generally, lengthy periods of drought resulting from reduced summer rainfall over a number of consecutive years have a clear effect on terrestrial species composition,

productivity and ecosystem services. These observations have been found by the majority of experimental and monitoring studies. These investigated summer but not winter droughts. Appendix 3 outlines 67 studies with quantitative data on the effects of drought on terrestrial ecosystems.

Wetlands are a diverse category of ecosystems. Wetland responses to changing hydrological conditions differ greatly and make it difficult to predict the effect of drought or mitigation efforts. Appendix 3 supplements the literature with expert interviews.

For river ecosystems, a wide variety of published studies exist which present a generalised assessment of the impact of drought and varying hydrological scenarios on fish, invertebrates, birds and higher plants. Appendix 3 presents data from 93 studies. For the two aquatic categories, rivers and wetlands, results and findings from an earlier report by the authors are discussed below (Acreman et al., 2012).

5.1.2 Effects of drought on Animals

This subsection presents effects of drought on fish, aquatic and terrestrial birds and butterfly populations. The effects on other terrestrial arthropods and aquatic invertebrates are reported in Appendix 3.

Fish

In aquatic systems, drought has a significant impact on fish stocks, which is proportional to the loss of habitat. A key threshold or factor is the cessation of flow, after which fish become stranded in isolated pools and more prone to depopulation caused by overcrowding and elevated predation rates. Benthic – that is, bottom dwelling fish are more tolerant of low flows than pelagic fish, being more adapted to muddy and more exposed conditions of the remnant pools.

The timing and duration of the drought in the lifecycle of the fish is important with supra-seasonal and winter droughts having a greater effect. Many fish species, for example, Salmonids, live for several years thus the effect of drought can be detected for several years. Recovery of the fish community is relatively rapid when flows return, with high recruitment following the drought. Depending on the rate of population growth, these negative effects of drought on fish populations could still take several years to reverse and might therefore be sensitive to successive droughts. Salmonid populations are reported to be reduced by up to 80 per cent, anadromous returns – that is, returns to rivers after migration– by 40 per cent and recruitment by 90 per cent.

Depleted food resources can affect a fish population heavily; droughts leading to the total drying of stream and river beds cause invertebrate communities to collapse and set-off drastic shifts in invertebrate community composition. This could have a severe effect well beyond the drought as a result of low invertebrate recruitment, for example through egg mortality, slowing the recovery potential of fish populations in following years. However, non-drying reductions in river flows seem to have minor and quickly recoverable/reversible effects on the invertebrate fauna.

Aquatic depending bird populations

The loss of open water causes aquatic dependent bird populations to disperse from degraded or dried up water bodies to other locations; in case of severe and widespread regional drying, bird mortality rises. Avian species affected include ducks, grebes, and semi-aquatic species such as moorhens.

Increased concentration of waterborne pollutants will elevate the risk of direct toxic effects on birds as well as indirectly through toxic effects on their plant and invertebrate food supplies. Furthermore, shrinkage of water bodies exposes nests to terrestrial predators and may thus reduce the safety of roost sites including those of non-aquatic species such as swallows and martins.

The loss of water body and terrestrial vegetation drastically reduces food sources for birds; for example dried up soils provide a less plentiful supply of soil invertebrates for avian species such as snipes and thrushes. Drought causes changes in the fringe vegetation which can lead to a decrease in food plant availability and would have an impact on a wide range of species such as the reed and sedge warblers.

Terrestrial bird populations

Terrestrial bird populations in aquatic ecosystems are known to decline because of reductions in food availability, as is seen in farmland birds. For example, vegetation changes have an impact on herbivore and nesting insects which in turn have an effect on bird densities, showing the complex trophic interactions in terrestrial systems. In general, one or two years of summer drought is sufficient to disrupt invertebrate structures and hence the availability of food sources.

Butterflies

In drought periods, the total abundance of butterflies seems to be at least equal to non-drought years and has even been shown to increase. However, although densities in drought years tend not to decrease, compositional changes in butterfly species are large; and the populations of several species have crashed under drought conditions, such as the Ringlet butterfly and the rare Adonis Blue.

Altered vegetation composition could have a negative effect on butterfly densities, with rare species of butterflies and moths being the most susceptible. The recovery rate of butterfly populations is likely to be highly dependent on the availability of patches of vegetation that can provide a substitute habitat for migrating populations.

5.1.3 Effects of drought on plant communities

Aquatic higher plants

For aquatic flora, drought leads to a gradual shift from fully aquatic to semi-aquatic to terrestrial plants. The intensity of the drought and the extent of the drying of the river bed is a crucial factor; the more that terrestrial plants become established, the more the physical habitat is modified, and thus it becomes harder for the aquatic plant community to return to the pre-drought state. However, there is often little change in total species richness, because plants less adapted to drought are replaced by ones that are better adapted to the dryer conditions. In extreme situations ‘fen blows’ could occur resulting in soil wastage and exposure of the underlying mineral layer. Erosion and loss of the soil carbon and nutrient store creates conditions inimical to vascular plant growth, severely affecting the incumbent wetland plants. In extreme cases, this might lead to wetland destruction and the development of completely new vegetation communities.

Increased pollutant and nutrient concentrations in the remaining water bodies could change the plant species composition towards a more alkaline- and eutrophic-liking vegetation.

Recovery could be slow depending on the extent and severity of the dry period and the site characteristics. The recovery of plant masses can be further limited if fine sediments have been deposited on the river bed during drought as these choke the growth of seedlings. Higher plants are important as a food source and as a habitat for fish and invertebrates; hence changes in composition could affect higher trophic levels.

Aquatic algae

For aquatic algae, the chief effect is a compositional shift towards filamentous algae. At drought onset, low flows and concentrations of nutrients can initially promote algae growth, leading in some circumstances to algal blooming, reducing light to aquatic vascular plant species and shrouding terrestrial plants. Further desiccation and exposure to non-wet circumstances leads to a huge drop in biomass but this recovers extremely quickly when droughts dissipate. Re-wetting often sees rapid recovery of the algal biofilm from surviving cells, cysts, and from propagules in the drift if upstream reaches have remained wet. If remnant pools persist throughout the drought they also act as re-colonisation foci.

Terrestrial higher plants

Among terrestrial plants, the general pattern found across studies is that repeated experimental droughts of two summers or longer do not necessarily lead to large scale species loss in grasslands. However, droughts lead to substantial changes in species composition and altered competitive interactions among species; plant communities tend to homogenise and deep-rooted species become more successful leading to an increased grassification of the vegetation. Most studies observing vegetation changes before and after natural drought events observe that compositional changes are transient and reversible in cases where a drought is followed by non-drought years.

The recovery potential depends on the length of the drought and is poorly understood. Although diversity may not change, the plant densities in general decrease through successive years of drought in grasslands, heath and shrublands. The reproductive output of individual plant species decreases, which suggests reduced insect densities and impacts on higher trophic levels such as birds.

Woodlands

In woods and forests, droughts slow the growth of adult trees and increase mortality rates, especially of young trees. The forest structure recovers after drought, although it can take up to 15 years to regain similar stand demography.

Successive droughts may cause large compositional changes in woodland species as seen in modelling studies and may cause large compositional changes in woodland dwelling species such as epiphytes, bryophytes and soil mycorrihza.

The drying of vegetation, such as woodlands, also heightens the risk of fire. This could result in a decline in abundance and diversity of vegetation and soil flora and fauna as well as a loss of stored carbon.

5.1.4 Effects of drought on soil chemistry and fauna

Aquatic soils

In aquatic soils, a reduction in available soil moisture leads to increased oxygenation of the soil, resulting in microbial oxidation and enhanced activity of aerobic microbes. This in turn leads to increased release of carbon and nutrients through mineralisation of organic matter. A study of nitrous oxide emissions from peat

monoliths found that there was an exponential increase in emissions with a linear decrease in water table elevation.

Terrestrial soils

In terrestrial soils, successive drought years probably change carbon fluxes in soils, although results from various studies are mixed. In the UK, long-term experiments on heathlands, of five to eight years duration, show that repeated drought can change soils from being net carbon sinks to becoming net sources through increasing carbon leakage in ground water and increased respiration of CO_2 into the atmosphere.

Similarly, increasing nitrogen levels in the groundwater indicate N-leaching from the soil and so potential long term negative effects on N-stocks.

For bacteria and microbes dwelling in grasslands and heathland soils the effects of a single drought event seems to be transient and quickly recoverable. In woodlands, experiments involving a succession of dry summers found that they could cause up to 80-90 per cent reduction in soil fauna abundance. The density of worms can be severely affected by drought, changing the aeration and hydrological dynamics of the soils and further exacerbating the effects of soil drying.

5.1.5 Concluding remarks

In conclusion, the biological diversity underlying many services provided by the environment is affected by drought. Furthermore, soil processes can be altered, potentially causing current sinks or carbon and nutrients to become sources of emission: the loss of an important ecosystem function. Tentatively, the level of change in most aquatic environments is related to the intensity of the drought, such as the level of reduction in water flow and connectivity of rivers and wetlands. In many terrestrial systems the effects of drought could be more related to the frequency of drought seasons.

It is a daunting challenge to extrapolate from these experimental and observational studies to the effects of drought. Many aspects of the effects of drought on the environment have been studied in only a few experiments and no meta-analyses over multiple studies have yet been conducted, making it difficult to generalise results.

Drought reduces the volume of water in streams and rivers and disrupts horizontal, longitudinal and vertical connectivity. Therefore, it might be feasible to imagine a mechanism by which drought management actions can affect flows in rivers and water levels in wetlands by lowering water levels and connectivity even further. It does not appear that soil moisture in terrestrial systems could be affected by these drought management actions, and although groundwater levels could be affected by the management action, the wider ramifications of these fluctuations has, as yet been scarcely studied in the UK.

5.2 Impacts of drought on public water supply

5.2.1 Introduction

Halcrow modelling revealed the baseline 2011/12 drought did not have a significant impact on PWS companies and even under the extended drought scenario the impacts are minimal. Of note is the limited extent of available water demand savings and supply gains from management actions.

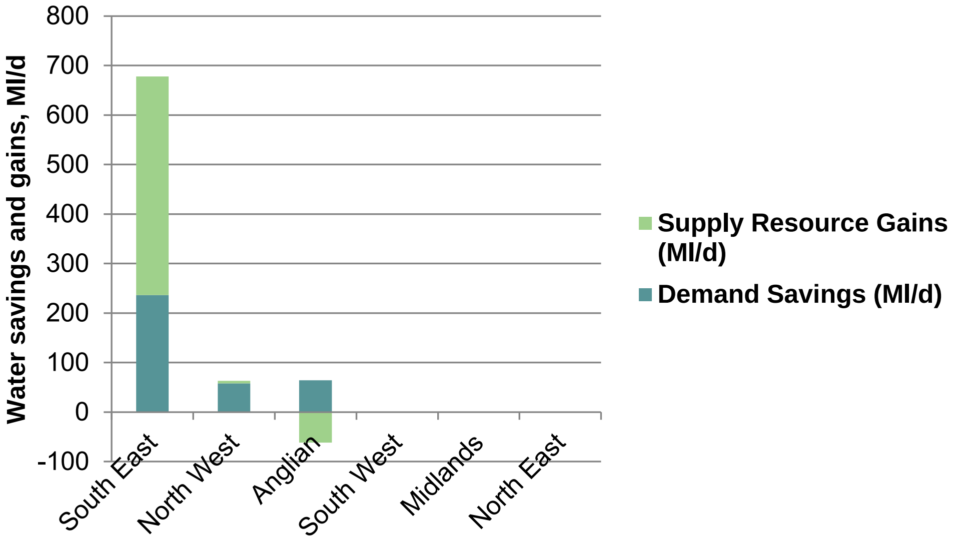
5.2.2 Baseline drought water demand savings and supply gains

The range of demand side drought management measures applied in the baseline drought included media and water efficiency campaigns, leakage reduction and temporary use bans with exemptions (concessions) for particular types of customer and water use category.

On the supply side, the drought management measures applied included the optimisation of existing sources, the use of Drought Permits and Drought Orders for maximising resources, refilling reservoirs or for the compensation of flows to rivers,[7] and inter and intra-zone bulk transfers.

A graphical illustration of the total resource impact of the above demand side and supply side measures for the baseline drought, by project region across England, is given in Figure 28. It shows that the baseline drought impacts were limited to the South East and North West England, with the most significant resource impacts confined to the South East of England. The net resource impact in the Anglian region was small because the region was a net exporter of water resources.

Figure 28. **The most significant resource impacts in the baseline drought are confined to the South East of England**

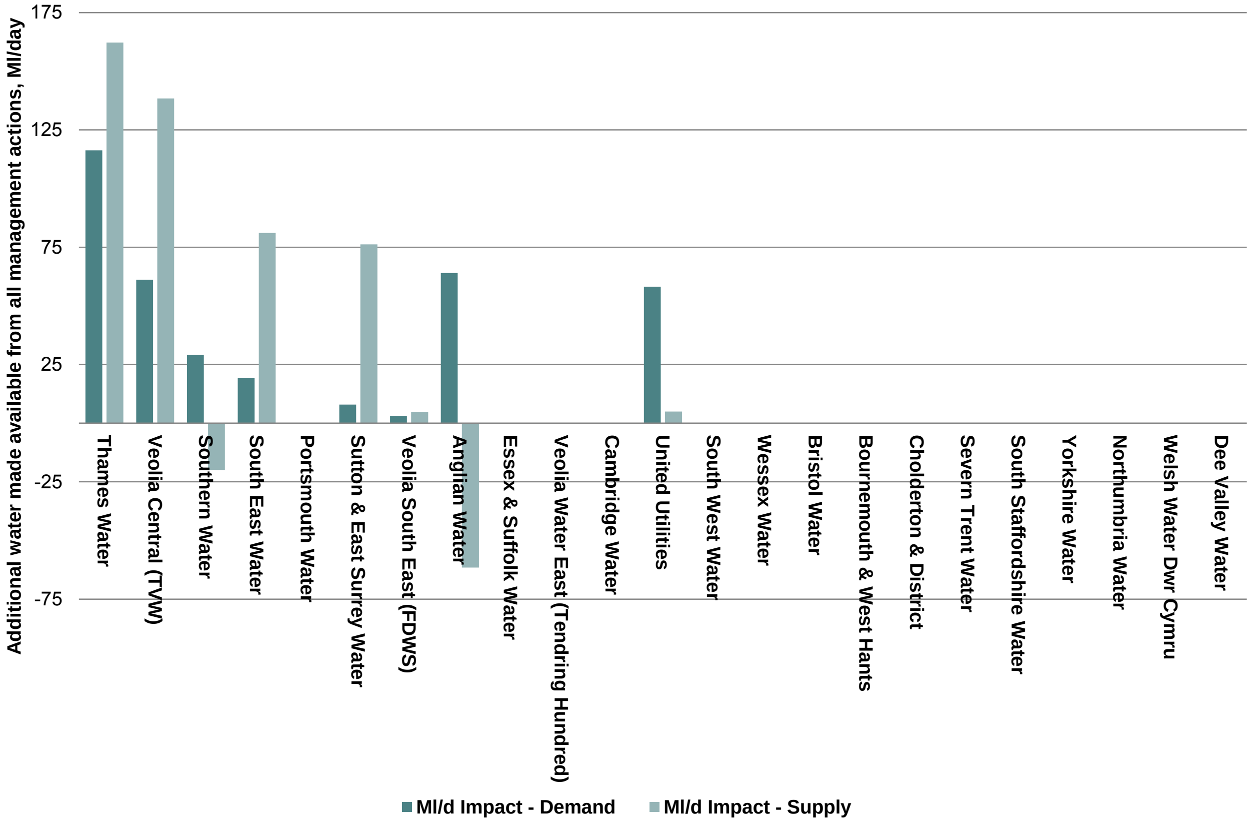


Source: Halcrow Ltd

In most cases in the baseline scenario additional supply outstrips the additional demand interventions, see Figure 29. United Utilities is an exception, having delivered more demand savings than gains in deployable output. Anglian Water and Southern Water were net transferors of water.

[7] Or by agreement with the Environment Agency, for example for additional resources from the lower Thames abstraction sources.

Figure 29. **Additional water made available in the baseline drought, Ml per day**



Source: Halcrow Ltd

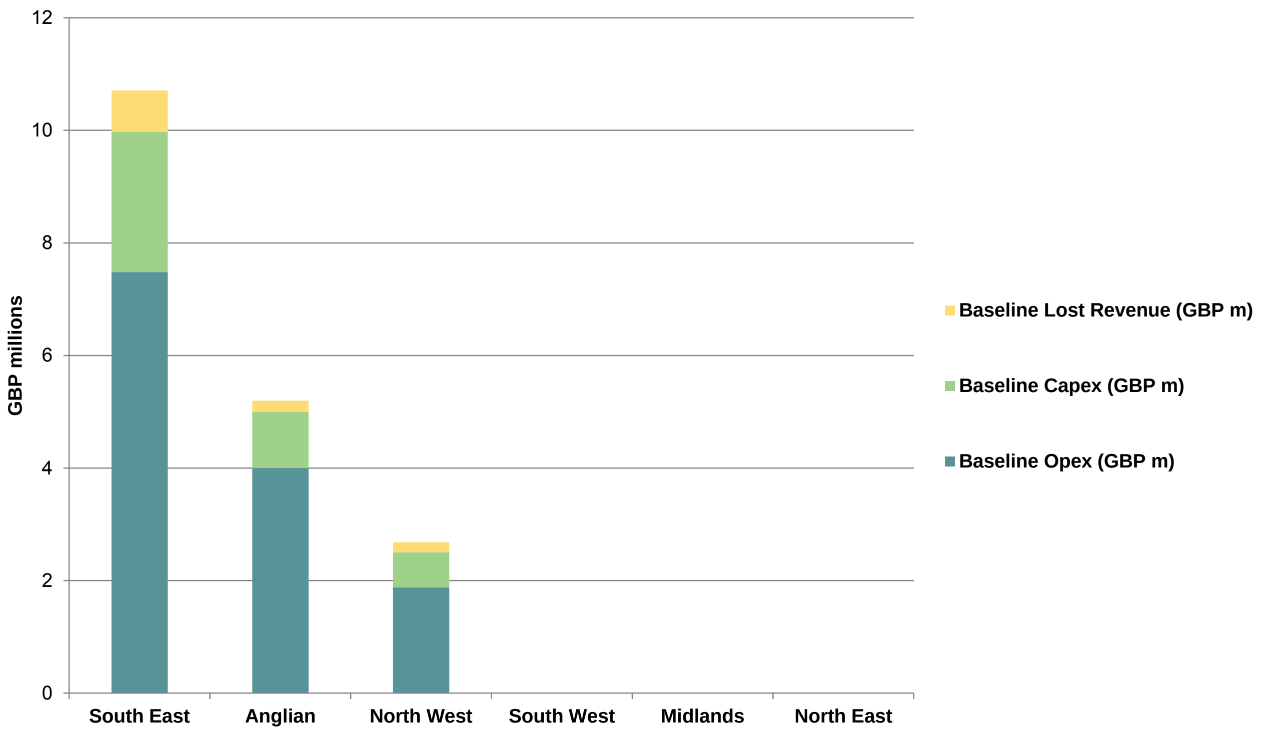
5.2.3 Baseline drought scenario costs

The baseline drought scenario costs are based on data received from each of the companies that were interviewed. Water companies did not record data of costs incurred in response to the drought in any detailed manner. This is mostly because the focus in such instances seemed to be very much towards ensuring sufficient water was made available to service demand.

Most of the companies interviewed did not have a detailed split of costs either by activity or by operating expenditure or capital expenditure category. As a result, Halcrow used its professional judgment to assign costs between capital expenditure and operating expenditure.

The greatest cost impacts are in the South East, whilst some cost impacts occur both for Anglian and the North West, as shown in Figure 30.

Figure 30. **The South East region had the highest total costs under the baseline drought, followed by the Anglian and North West regions**



Source: Halcrow Ltd

5.2.4 Extended drought scenario water demand savings and supply gains

As with the baseline drought, the project's assessment of the resource impacts of the extended drought on public water supply has also made use of published and unpublished information sources available to the project team. The unpublished information sources include company-specific data sets provided on a commercial-in-confidence basis through the project's structured interviews.

The demand side drought management measures considered for the purposes of modelling the extended scenario include, as in the baseline drought, media and water efficiency campaigns, leakage reduction, sprinkler and unattended hosepipe bans, and temporary use bans with exemptions (concessions) for particular types of customer and water use category. Furthermore the extended scenario adds temporary use bans with concessions removed and Drought Direction 2011 measures (formerly known as non-essential use Ordinary Drought Order).

The range of supply side drought management measures applied through the extended scenario consists of the measures taken under the baseline drought plus:

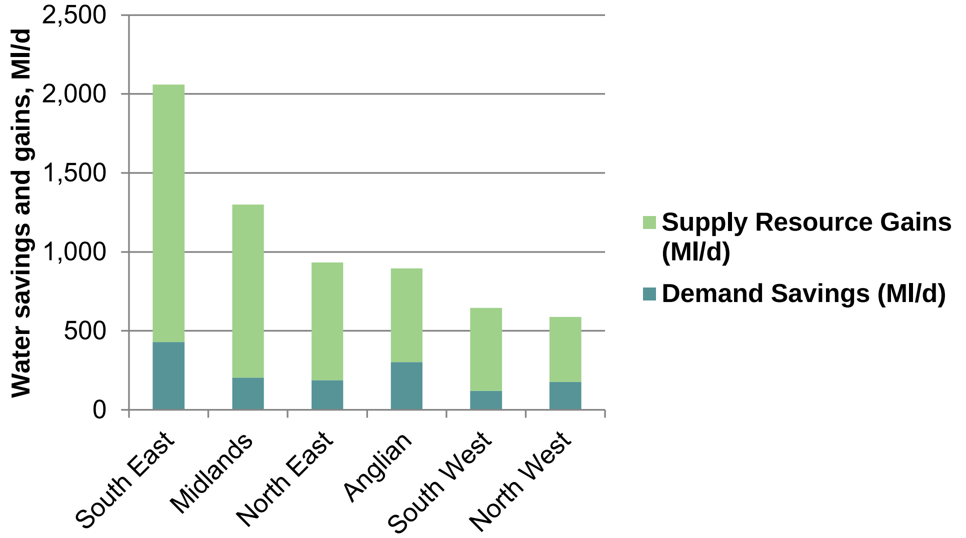
- for groundwater sources, the lowering of existing pumps, re-commissioning of disused boreholes, re-commissioning of commercial boreholes;
- the development of new direct river abstractions and surface water reservoirs; and
- the acceleration of Water Resource Management Plans and/or Drought schemes such as effluent

reuse, desalination, and road tankering.

The water companies interviewed also provided information on third dry winter capital schemes as well as the deployable output of these schemes for the extended scenario. The capital schemes included are listed in Appendix 4.

A graphical illustration of the total resource impact of the above demand side and supply side measures for the extended scenario, by project region across England, is given as Figure 31. It shows that the effects of the extended scenario are more extensive than the baseline drought scenario. The South East delivers the most water demand savings and water supply gains, followed by the Midlands region and the North East.

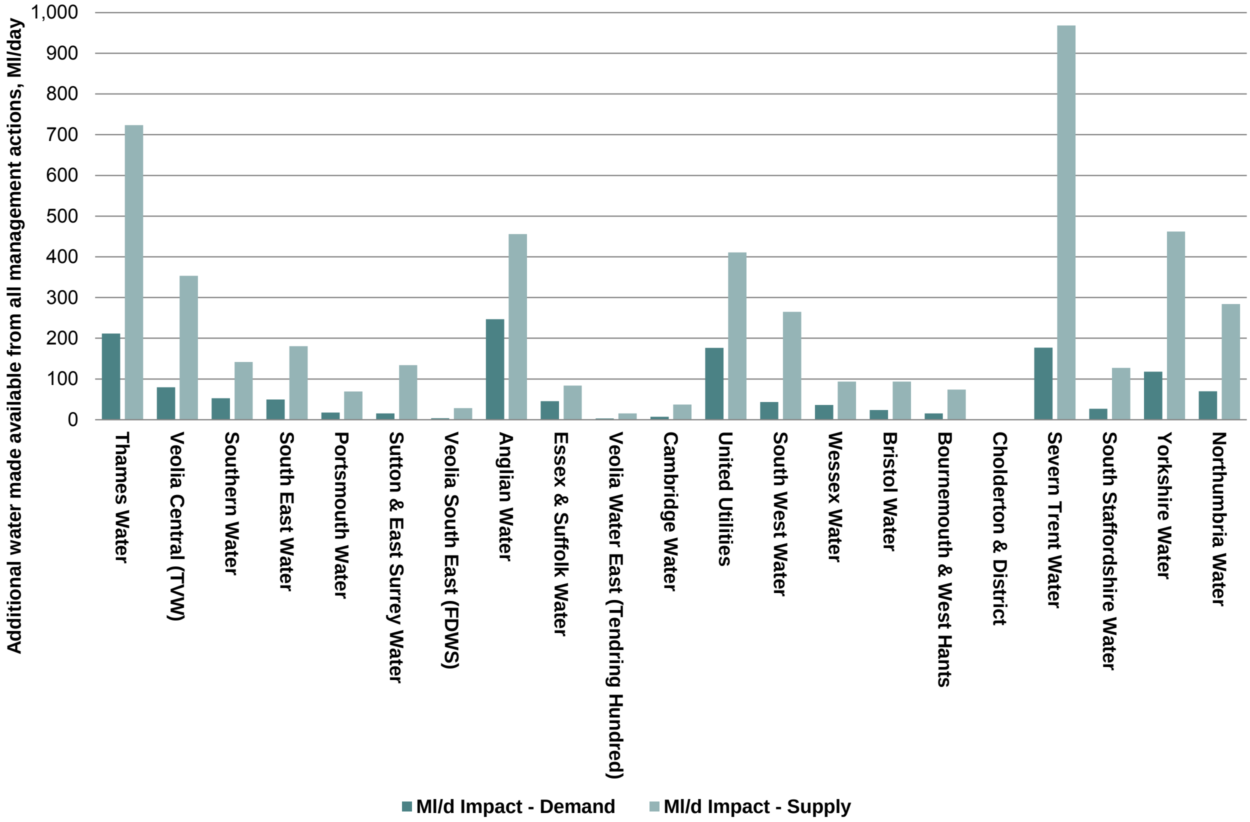
Figure 31. **Under the extended scenario, the South East delivers the most water demand savings and water supply gains, followed by the Midlands region and the North East**



Source: Halcrow Ltd

The amount of additional water provided by each company in the extended scenario is shown in Figure 32. Severn Trent Water and Thames Water deliver the most gains in deployable output. Yorkshire Water, Anglian Water and United Utilities also deliver significant supply side gains in deployable output (DO). For all companies, supply interventions deliver more water than the demand side savings.

Figure 32. **Additional water made available in an extended drought scenario , Ml per day**



Source: Halcrow Ltd

The total water industry distribution input (DI) in England is estimated at 13,970 Ml/d. Demand savings under the extended scenario are listed in Table 9. Communications deliver the most in terms of savings, 3.9 per cent of DI, followed by pressure management at 2.5 per cent. Temporary use bans with concessions save 0.9 per cent of DI and the removal of these concessions a further 0.9 per cent. Drought orders bring further savings of 2 per cent of DI. The cumulative total demand savings from these measures amount to 10.2 per cent of DI, equivalent to 1,491 Ml per day.

Note that the measures highlighted in Table 9 exclude rota cuts and standpipes. Furthermore, the average numbers in the table do not show the peak (or critical period) effects. However, the numbers can still inform high level drought management policies.

Table 9. **Demand savings available from management actions under the extended drought scenario**

Description of management action	**Proportion of distribution input**	**Name given in the model worksheet**	**Proportion of distribution input**
Media/Water efficiency campaign	*1.8% (257 Ml/d)*		
Enhanced media/water efficiency campaign, Leakage reduction (excluding pressure management), Sprinkler and unattended hosepipe bans	*2% (281 Ml/d)*		
PWS communications (sum of the two measures above)	3.9%	**PWS communications**	**3.9%**
Pressure Management	2.5%	**PWS Pressure Management**	**2.5%**
Temporary use bans with exemptions (concessions)	0.9% (130 Ml/d)	**PWS TUBs with concessions**	**0.9%**
Temporary use bans without exemptions (concessions)	0.9% (130 Ml/d)	**PWS TUBs no concessions**	**0.9%**
Drought Directions 2011 driven Drought Orders	2% (281 Ml/d)	**PWS drought orders no concessions**	**1.9%**
		Total cumulative savings	**10.2% (1,419 Ml/day)**

Source: Halcrow Ltd

Gains in DO available from management actions under the extended drought scenario are listed in Table 10. Total water industry DO for England is estimated at 18,460 Ml/d. Capital investment, which includes direct river abstractions and refilling surface water reservoirs, lowering of existing pumps, re-commissioning of disused boreholes, and re-commissioning of commercial boreholes, delivers the most in water supply gains, 17 per cent of DO. Drought orders and permits only deliver 2.75 per cent of DO each. Cumulatively, water supply gains amount to 27.1 per cent of DO.

Table 10. **Gains in deployable output available from management actions under the extended drought scenario**

Description of management action	**Proportion of distribution input**	**Name given in the model worksheet**	**Proportion of distribution input**
Groundwater sources: lowering of existing pumps, re-commissioning of disused boreholes, re-commissioning of commercial boreholes	*5.3% (973 Ml/d)*		
WRMP/Drought Schemes e.g. Effluent Reuse, Desalination, Road Tankering	*10.1% (1,857 Ml/d)*		
Direct river abstractions/surface water reservoirs	*1.6% (303 Ml/d)*		
PWS capital investment (sum of the three measures above)	17% (3,133 Ml/d)	**PWS capital investment**	**17%**
Net bulk transfers	4.7% (863 Ml/d)	**PWS bulk supply transfers between companies**	**4.7%**
Optimisation of existing sources, Drought Permits and Drought Orders for sources, reservoir refill, compensation flows to rivers	*5.5% (1,006 Ml/d)*	**PWS drought orders on supply side** *(half of 5.5%)*	**2.75%**
		PWS drought permits to maximise river abstractions *(half of 5.5%)*	**2.75%**
		Total cumulative savings	**27.1% (5,003 Ml/day)**

Source: Halcrow Ltd

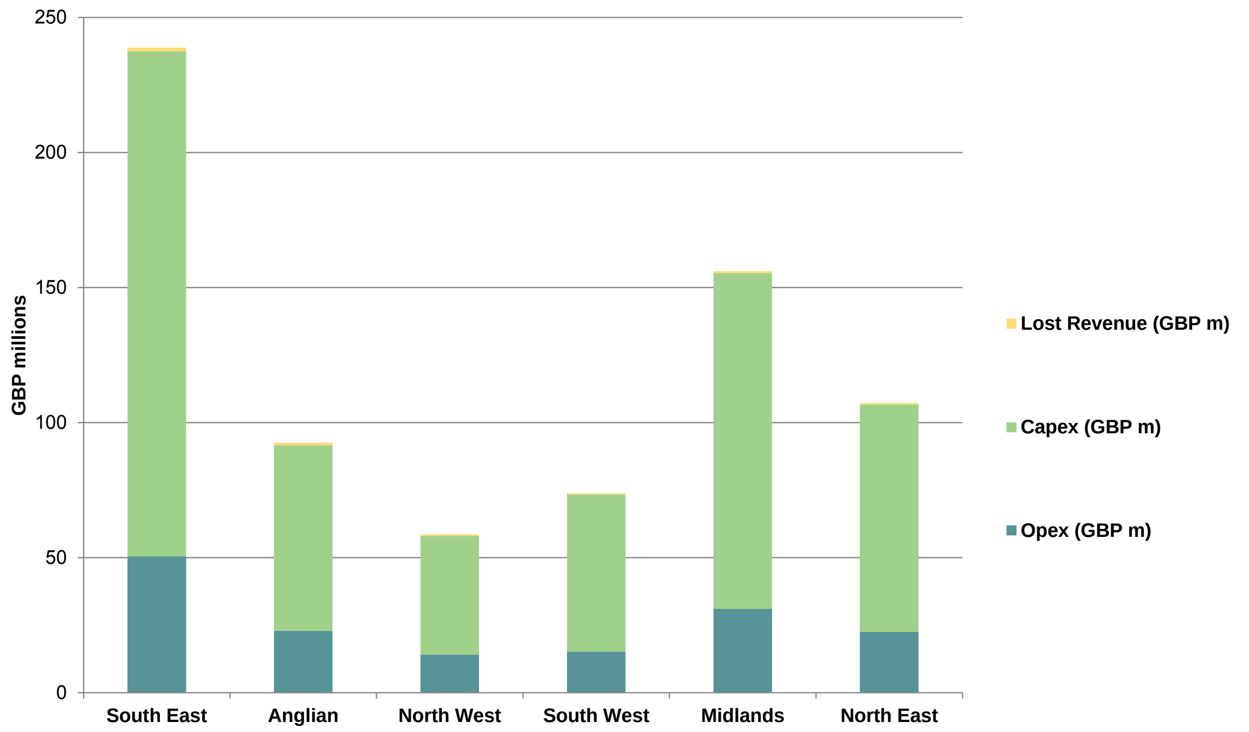
5.2.5 Extended drought scenario costs

For the extended scenario additional operating and capital expenditure is brought in. However, there is a limit to the additional demand side savings available; as such the extended scenario has a greater focus on bringing forward supply options.

Average capital costs per Ml/d were estimated and it was assumed that schemes are brought forward by five years when calculating capital expenditure. Of course, there would be practical constraints in delivering capital projects over a short period of time, given the time taken to prepare, to obtain planning consent, to construct and to commission the project. For operating expenditure, the unit costs per Ml/d from the baseline data were used.

In the extended drought, all regions employ additional expenditure, though the South East faces the highest costs, followed by the North East and Midlands regions. Capital expenditure is greater than operating expenditure because significant investment is brought forward.

Figure 33. **In the extended scenario, water company costs in the South East are the highest, and second highest in the Midlands**



Source: Halcrow Ltd

5.3 Impacts of drought on agriculture

Drought has an impact on agriculture in three main ways:

- reduced rainfall affects the production of rain-fed crops, forage and grazing;
- reduced water resource availability affects abstraction from surface and groundwater resources. This is especially important for the irrigated cropping and livestock sub-sectors as these both rely to a large extent on direct on-farm water abstraction;
- reduced public water supply availability has an impact on all farm businesses, but particularly livestock farming where mains water is used for animal drinking and sanitation and for protected cropping, such as soft fruit, where mains water is often used for irrigation.

Like all businesses, some of the impacts of drought on agriculture may be acute, that is, where lack of water has an impact for the period during which water availability is reduced, but after a short period of recovery, production returns to normal. For example, lack of water for cooling in a dairy milking parlour may mean that milk cannot be stored and would be disposed of as waste until the water supply is reinstated. However, most of the impacts on agricultural systems are chronic and cumulative. For example, dry weather in the spring, or early restrictions on abstraction for irrigation, would affect plant germination and crop development; adequate rainfall or water later in the season will not compensate loss of yield potential. The economic impacts on crop quality could therefore be more significant than any yield penalty. In this way, the

effects of drought on agriculture may extend beyond the end of the drought. The impacts are also sensitive to the timing of the drought in relation to the cropping calendar. Dry weather in the winter may have negligible impact whereas dry weather at the time of germination may result in crop failure and the need to re-seed when the rain has returned.

The impact of the 2011/12 drought on agriculture was complicated by an unusually wet summer. The summer rainfall in England was the highest since 1912 and wet conditions have persisted through the autumn. The subsequent waterlogged conditions exacerbated many of the crop husbandry problems that had been triggered by the drought; delayed harvest by up to four weeks; and harvesting during wet conditions has resulted in soil damage. In some regions, not all crops such as potatoes have been harvested and some may be abandoned. As a consequence, crop yields and quality have been affected by both early drought and subsequent waterlogging and it has been difficult to isolate the impacts of drought from the impacts of waterlogging, although the latter has probably had the greatest impact on harvested yields and crop quality. For these reasons, the material impacts of the 2011/12 drought were difficult to quantify.

The financial impacts on agriculture are sensitive to the geographical extent of the drought (locally) and global market conditions. If drought is confined to a region of the country, it is likely that crops and animal feeds can be sourced from elsewhere; whereas if, as happened in 2011/12, the drought extends across most of Western Europe, alternative sources may be similarly affected and, as a consequence, the prices of crops and animal products may rise.

The study considered impacts on four sub-sectors: irrigated agriculture including potatoes and field vegetables; rain-fed agriculture; livestock; and food and drink manufacture and retail. The key findings are summarised below.

5.3.1 Irrigated agriculture

Water is used in irrigated agriculture to maximise yield and quality of produce when rainfall is insufficient. Irrigating farmers draw water from a range of sources: direct abstraction during the summer from rivers or groundwater; abstraction from on-farm reservoirs that are filled during the winter or high flows; and public water supply. As a result of the unusually dry winter, around 300 irrigators were subject to restrictions to filling winter storage reservoirs and those with summer abstraction licences were unsure if they would be able to abstract. Others agreed a self-imposed voluntary restriction on abstraction. Some growers responded by reducing the planted area of irrigated crops or switching to more drought tolerant varieties, but many were inflexible due to long planning times and contractual commitments. Some with secure water supplies increased the planted area in the hope of high crop prices.

The subsequent wet weather exacerbated the impacts of early drought final yield, depressing them to 10 – 20 per cent below average, and quality was reduced more by the excess summer rain than the spring drought. It is difficult to isolate the material impacts of the 2011/12 drought on irrigated agriculture, but had the drought continued, there would have been widespread and significant economic consequences. Growers would have concentrated water use on a smaller area and some crops would not be irrigated. Overall crop yields and quality would have been reduced and food prices may have risen.

5.3.2 Rain-fed cropping

Rain-fed cropping is not reliant on abstraction and uses modest amounts of mains water for general on-farm use. The main impacts would be from low rainfall in the spring and summer affecting crop yields and quality, but soil degradation and increased pollution could also have resulted from the inefficient uptake of nutrients. There is some evidence that spring cereals on light land were affected by early drought, but the wet summer conditions had a bigger impact on final crop performance.

5.3.3 Livestock

The livestock industry uses water from private boreholes and public water supplies for drinking water and sanitation. Although there were no restrictions on public water supplies in 2011/12, some private boreholes dried up and farmers were increasingly reliant on mains water. In the event, the impact of the water resources drought on livestock sector was minimal, however, had there been restrictions or pressure reductions on main water there would have been a major impact. In an extreme drought, farmers would have to reduce the herd size by slaughtering or selling animals to farmers in regions not affected by drought.

The low spring rainfall resulted in reduced grass growth, limiting the amount of feed for spring grazing or conservation for winter (hay and silage), although the onset of the rains mitigated the impact. Had the drought continued, grazing and forage yields would have fallen. Combined with reduced yields and higher processing cost of grains, it would have significantly increased winter feeds costs.

5.3.4 Food manufacture and retail

Although a number of high water-using food and beverage manufacturers, such as the sugar processors, breweries and soft drinks manufacturers, are direct abstractors and were concerned about potential restrictions on water supply, there was negligible direct impact as the drought did not develop such that restrictions were imposed. An extended drought would have affected domestic ingredient supply and manufacturers would have had to source from elsewhere resulting in higher food prices.

5.4 Impacts of drought on sports turf (golf)

Managed turf areas such as golf courses, sports fields, race courses and stadia are all sensitive to drought stress, even over short periods. In sports-turf, irrigation is used to produce safe, high quality playing surfaces, and in golf it is used as a management tool to maximise playability and bounce (not aesthetics). On racecourses, it is used to control the ‘going’ or soil moisture levels to provide optimum racing conditions, and importantly to minimise rider injury risks.

About half the 2,000 courses in England and Wales are dependent on mains water supply. The dry conditions during autumn 2011 meant that fine turf watering continued for a much longer period than is typical. In 2012, watering started in February and March, much earlier than usual. Greens were hand watered rather than using automated irrigation systems due to frost risks in buried infrastructure.

When drought orders were enforced, water companies imposed ‘non-essential’ use bans on golf clubs. There were no concessionary allowances. Golf clubs responded by reducing cutting and maintenance programmes on fine turf areas; with higher turf mowing heights to reduce drought stress. This led to sub-optimal playing conditions. It is estimated that a third of all clubs were affected, approximately 700 to 1,000, more than in

2006. The industry reported knock-on drought impacts on club business; with reduced visitor numbers, and income from both food and beverage catering (clubhouses) and sales of equipment (professional shops) all reduced. This occurred during the peak season for golf, May to July.

Had the drought continued, the impacts would have been significant. Many golf courses would have lost valuable fine turf areas, which would need re-construction; USGA green construction costs are typically GBP 5,000 per green; on an 18 hole course this is a major cost. Visitor numbers would have declined, due to poorer playing conditions, much as was seen in 2006.

There is still a widespread misconception that sports-turf irrigation is primarily used for aesthetic purposes. All water companies during the drought viewed golf irrigation as 'non-essential'. The golf industry is likely to continue to pursue concessionary allowances for clubs to maintain fine turf areas (greens, tees and approaches) during periods of water scarcity. The majority of clubs do not irrigate fairways – those that do would as a matter of course reduce or stop watering these areas during drought, given their greater resilience to water stress. Clubs could invest in additional storage, but capital investments in new technology and infrastructure such as high flow reservoirs, and upgraded irrigation systems, have been at a low level. The conditions for investing in water conservation measures and/or new drainage infrastructure to cope with higher rainfall peaks are unattractive, given the uncertain economic viability of many golf clubs.

6 Conclusions

6.1 The impacts of the 2011/12 drought

The 2011/12 drought was characterised by two dry winters, however its impact was mainly felt in the first half of 2012, when water companies introduced temporary use bans to restrict demand. These restrictions applied in some areas of England in the second quarter of 2012. As the main target of temporary use bans, households were affected, together with businesses offering services to domestic customers, in particular landscaping services and the horticultural trade. In addition, farmers were encouraged to reduce water use for the irrigation of agricultural crops. The effect of the drought and the restrictions on water use were not easy to estimate once they co-mingled with the impacts of the wet summer that started in the second quarter of 2012.

Water savings were an estimated 40,000 megalitres in the second quarter of 2012 and amounted to a cumulative 170,000 megalitres for the period starting from the first quarter of 2011 and ending with the second quarter of 2012. The economic impacts of the drought in 2011/12 were likely to have been quite small and felt mostly by public water supply companies, landscaping services and golf. Turnover and profits were affected, but the aggregate impacts were small (GBP 70 – 165 million).

The aquaculture industry was reportedly close to significant adverse impacts as the drought affected water temperatures, but heavy rain brought relief in time. Among the sectors not included in the model is the tourism and amenity sector that is dependent on waterways navigation and the navigation sector itself. More generally, impacts on recreation and tourism are not quantified due to lack of available data.

6.2 The additional impacts of an extended drought

The report considered what might have happened if the drought had continued. The hydrological drought was extended into 2013 and the impact estimates estimated up to the end of 2012. There is considerable uncertainty around the response that would have occurred.

Four extended drought scenarios were considered, each involving different management actions and timings. A comparison of the four showed that the choices made could affect the level of water savings obtained and the total level and incidence of the costs of the drought.

On an aggregate basis, reductions in turnover and profit were smallest under priority for the economy scenario, as expected. The financial impacts were greatest under the priority for the environment scenario, which delivered by far the greatest water savings.

However, there is considerable uncertainty around what would have happened in an extended drought.

6.3 The impacts of drought outside a drought-affected region

The electricity sector is affected by drought when its abstraction or discharges are curtailed. The sector carries an amount of headroom in generation capacity and is able to cope with modest reductions in

availability or output from some plant through increases in production from others. In this sector, there is expected to be little impact of drought on output, provided the sector is maintaining a healthy capacity margin (headroom). It is possible that generation costs and wholesale prices would increase if some operating plant became unavailable, and that security of supply would be diminished. This factor might influence the management of electricity generation sector so that less reliance is placed on plant operating in areas affected by severe drought.

Agricultural losses can result from a change in yield (tonnes of product per hectare) and crop quality. These both affect revenue to a farm without the relief of lower costs. Given that crop planting is decided in advance, it is unlikely that a drought in one area of a country would immediately lead to increased production in another region. Any reduction in supply would drive prices up and would be met by greater imports and consumer switching to other food products. Farmers in regions unaffected by drought might benefit from higher prices.

In contrast to agriculture, most of the economically smaller sectors supply services to local markets, making it unlikely that in those sectors the benefits would be offset by gains in other regions. For example, a retail plant nursery based in the South East of England would suffer if customers stop buying plants because of a temporary hosepipe, ban and there is no reason to expect customers in the North West to buy more plants in compensation. That situation might be different for a specialist nursery selling on the wholesale market or delivering by post.

Meanwhile window cleaners and landscapers might be physically able to travel out of a drought affected area, but they would have to identify new customers, would compete with existing businesses and would incur higher accommodation and travel costs. More likely is that they would stay put and adapt as best they can.

Golf clubs and commercial swimming pools, when facing restricted use, would lose income. Their customers would, with very few exceptions, be unwilling to travel to areas without restrictions. In this sector again, other unaffected regions would not gain economically from a drought.

6.4 The effect of drought management measures

In every year there is a chance that the amount of precipitation will be below the long term average. England has experienced periods of a year when rainfall has fallen 10, 20 and even 30 per cent below average. Moreover, there is a chance of this deficit occurring in two or more consecutive years.

Current plans to cope with below average rainfall use a mix of four components: reduced demand, inter-seasonal storage, re-use and transfer. This study of the 2011/12 drought shows that the amount by which demand can be reduced is much less than the amount by which rainfall may be diminished. Except in areas in which there is an ample surplus of water available, demand reduction is not a sufficient option to balance the water account, and the result has been to call upon a mixture of supply side measures and to reduce the water available in the environment. The recent drought has highlighted the limitations of inter-seasonal storage in the face of a winter drought. Inter-seasonal storage is useful, but relies upon winter rain for recharge.

It is evident from the recent experience of drought that the existing management mechanisms are able to cut demand, albeit modestly, and thereby to reallocate water to protect public water supply. There is some uncertainty as to how effective these demand management measures are, in particular the communications campaigns and hosepipe bans used by water companies to reduce household demand. This is partly due to the fact that droughts are uncommon and there is little experience with temporary use bans. Water companies are now reviewing the impacts of their actions in the drought, especially in relation to temporary use bans, and these data may be used to improve the accuracy of future drought planning.

It is not easy to disentangle specific demand measures from the aggregate impact of the actions taken by others such as the government, the Environment Agency, the Met Office and other water companies. The Environment Agency is working with companies on the impacts of demand measures, and along with useful work Thames Water has already done, devising an approach that improve future understanding of the effectiveness of these measures.

There may be more scope for saving water by applying demand management measures over a longer period than by increasing the severity of the controls. If further work proves this concept, then there may be merit in introducing demand controls earlier, and perhaps available supply side measures too, particularly supply side measures such as use of drought permits and orders to fill reservoirs.

Supply-side measures such as drought permits and orders to maximise river abstractions or restrict other abstractors can have a negative impact on other direct abstractors, for example the electricity industry. These impacts happen indirectly, by triggering HoFs, or directly if the water company demands that an abstractor stops taking water. They might, however, if taken early and in a partial manner, avoid more severe impacts later.

Abstractors have shown that some of them can adapt when there is a drought. Farmers have changed the area of irrigated land, a navigation authority has carried out enabling capital works, water companies have brought forward parts of the their planned capital programme, landscape gardeners have shed temporary labour. If the drought conditions were to occur more frequently, there is likely to be further adaptation. The communication between government, water companies, the Environment Agency, abstractors and customers has benefited from greater coordination in this drought than perhaps was the case in previous droughts. All participants have played a role in this and it seems to have facilitated anticipation of control measures and adaptation to the evolving drought situation.

There is a great deal of resilience to short droughts among large, financially robust businesses and large, less specialist, well-integrated wildlife sites. Specialists, be they firms, plants or animals, are more exposed and firms that are financially weak, as is sometimes found in aquaculture, or species that are under other environmental pressures, may not recover well. It is probable that the 2011/12 drought finished in time to prevent the demise of firms or small populations and that environmental and economic recovery was rapid. However, it may be that some choices of management action are more cost-effective than others, and that by alleviating other pressures on some environmental assets, their resilience can be improved.

The most likely permanent damage to businesses would come from temporary use bans because these can inflict severe reductions in turnover in a small number of sectors which are highly dependent on water. These

include window cleaning, tubs and swimming pools and aquaculture. In these sectors, the costs and benefits of use bans can be considered in advance, and the circumstances in which bans will be imposed set out, so that the firms can prepare and adapt. In cases where the water savings are small and the cost-effectiveness is low, restrictions might not be imposed.

These conclusions are offered generically because location is an important factor in determining the impact of drought. This location-specificity makes it difficult for a study which has not looked at individual sites and decisions to report environmental outcomes for general classes of drought management action, or to say anything about the trade-off between financial impacts and environmental impact that has been struck in the recent drought or any scenarios for an extended drought.

6.5 The response of the water industry

Demand management measures appear to be more effective than equivalent supply side measures for short term operational drought management, because demand side measures can be implemented more quickly. When new and more robust evidence on the effectiveness of demand side measures becomes available, it will be possible to state with more certainty how much control these measures give over water demand. At the moment, their effectiveness is quite uncertain. However, supply side measures offer substantial water volumes, if implemented in advance, with a good level of certainty.

In the baseline scenario, the water industry experienced operating cost increases in the South East, Anglian and North West regions. There is no identified impact of the baseline drought scenario on water industry operations in the South West, Midlands and North East regions.

If the drought had continued, there would have been additional costs, mainly in the form of capital expenditure on supply side actions. The supply side actions would have been needed in order to raise deployable output, for example from conjunctive use and effluent reuse schemes. These could have been delivered relatively quickly as preparatory work was already underway within water companies' investment plans.

In the future, water companies might be better able to assess the impacts of a developing drought if they possessed information that enabled them to understand:

- the economic impact of past droughts;
- with more confidence, the level of water savings from customer water use restrictions on annual average demand and peak period demand under drought conditions;
- the value of taking early action.

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Appendix 1 Background to the drought

The management of the 2011/12 drought

Following two unusually dry winters, water companies and the Environment Agency took actions during 2011 and 2012 to manage the drought.

The Environment Agency engaged in an information campaign and encouraged discussions with water intensive sectors. It was involved in the active management of sites, the maintenance of water levels and some isolated fish rescues and aeration. It approved four drought permit applications and encouraged voluntary reductions in irrigation.

Water companies made use of demand side measures such as communications campaigns and temporary use bans; seven water companies have introduced temporary use bans across southern and south eastern England.[8] Temporary use bans were introduced on 5April 2012; three companies lifted them in June 2012, and the remaining four in July.[9]

Other demand side measures included the reinforcement of existing water efficiency activities with communication campaigns and expenditure on leakage reduction with several companies achieving their lowest ever level of distribution losses. There has also been additional use of metering, pressure management and work with commercial customers to reduce their demand (private communication from the Environment Agency).

Water companies have taken actions to manage supply, making use of powers under drought permits and orders; four companies have applied for four drought permits and one a drought order to refill a reservoir. Other supply side measures included bulk supply transfers between companies, full utilisation of peak sources, optimisation of existing operations, transfer of water between supply zones and capital investment in preparation for a third dry winter. The Collaborative Drought Group identified opportunities to share water (private communication from the Environment Agency).

A chronology of the management actions taken by water companies is presented in Table 11.

[8] These companies are: Thames Water, Anglian Water, Sutton and East Surrey Water, Southern Water, South East Water, Veolia Central and Veolia South East.

[9] Thames Water, Anglian Water and Southern Water removed the restrictions on the 13 July 2012, the other four on the 8 July 2012..

Table 11. **Water companies' drought management actions, 2011/12**

Management action	Water company	Timeline
Supply side		
Drought permit for River Nene at Dunsford/ Pitsford reservoir	Anglian Water	25 November 2011 to 31 March 2012
Drought permit for River Nene at Wansford/Rutland reservoir	Anglian Water	13 December 11 to 30 April 12
Drought order for River Ouse/Ardingly reservoir	South East Water	21 December 11 to 31 March 12.
Drought permit for River Medway/Bewl reservoir	Southern Water (extended to dates shown)	28 Feb 12 to 30 April 12
Drought permit for River Eden/Bough Beech reservoir	Sutton and East Surrey Water	27 March to 31 May 12
Demand side		
Temporary use bans	Thames Water, Anglian Water and parts of Southern Water	5 April 2012 to 13 June 2012
Temporary use bans	South East Water, Sutton and East Surrey, Veolia Central and Veolia South East	5 April 2012 to 8 July 2012

Source: Private communication from the Environment Agency

Rainfall data from the Meteorological Office is presented in Figure 34.

Figure 34. **Long-term picture of rainfall data**

2010-12 RAINFALL DATA - TO DATE															
YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total		
2010	75.3	87.2	71	30.1	38.3	42.7	67.9	107.2	86.9	84.2	97.5	34.1	822.4		
2011	94.8	81.2	22.3	11.6	46.5	82	65.2	91.4	57	68.4	52.9	113.6	786.9		
2012	67.6	32.1	30.9	149.9	57.4	160.1	120.5	93.7							
LTA - Long Term Average															
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total		
100%LTA	80.7	64.9	60.8	59.1	64.0	66.5	79.6	82.8	80.9	95.3	92.9	87.4	915.0	100%	LTA
80% LTA	64.6	52.0	48.6	47.3	51.2	53.2	63.7	66.3	64.8	76.2	74.3	69.9	732.0	80%	LTA
70% LTA	56.5	45.5	42.5	41.4	44.8	46.6	55.7	58.0	56.7	66.7	65.0	61.2	640.5	70%	LTA
60% LTA	48.4	39.0	36.5	35.4	38.4	39.9	47.8	49.7	48.6	57.2	55.8	52.4	549.0	60%	LTA
50% LTA	40.3	32.5	30.4	29.5	32.0	33.3	39.8	41.4	40.5	47.7	46.5	43.7	457.5	50%	LTA
Max	176.8	158.6	177.5	142.6	151.8	157.1	182.6	192.9	189.5	218.1	202.5	193.9			
Min	4.4	3.6	5.6	7.1	7.9	4.3	8.2	9.1	8	8.8	17	8.9			
(1766 - 2011)	Based on 246 years of rainfall data														
DROUGHT YEARS															
1920	108.3	43	82	116.5	74.6	66.9	132.4	50.6	71.1	70.9	44.9	92.1	953.3	104.2%	LTA
1921	107.2	10.2	58.5	33.3	46.5	10.3	29.3	93.5	40.9	52.2	70.9	76.2	629	68.7%	LTA
1933	66.9	95.8	75	36.8	55.8	56.6	63.7	33.3	60.6	98.4	46.3	28.5	717.7	78.4%	LTA
1934	78.3	11.9	72.2	75.1	39.6	48.3	45.7	79.1	70.2	82.4	63.4	183.5	849.8	92.9%	LTA
1943	147.1	46.8	26.1	37.5	84.4	59	56	83.7	85.7	85.2	68.5	52.2	832.3	91.0%	LTA
1944	82.4	39.4	11.5	58.8	41.2	61.7	70.2	81.1	104.3	118	155.2	70.3	894.2	97.7%	LTA
1972	100.8	75.6	75.4	69.5	75	71.8	53	35.5	41.5	33.7	108.1	113.5	853.4	93.3%	LTA
1973	46.1	45.8	23	67.6	86.1	61.5	93.5	63.8	75.5	57.5	50.9	68.6	739.8	80.9%	LTA
1975	124.2	32.5	81.9	67.9	50.5	22.1	62.5	51.6	106.5	37.9	73.1	48	758.6	82.9%	LTA
1976	57.8	39.9	48	19	62.1	18.7	30.1	25.2	150.8	154.3	91.7	94	791.5	86.5%	LTA
1984	149.3	60.1	64.8	10.8	64.8	42.8	28.6	56.6	121.3	99.9	151.6	79	929.7	101.6%	LTA
1988	169	64.6	107.3	44.6	65.8	40.2	139	89	72	94.2	50.2	45.7	981.5	107.3%	LTA
1989	49.3	90.5	96.1	88.3	20.7	57.6	38.6	59.4	41.6	103	62.7	149.3	857.3	93.7%	LTA
1990	128.4	143.2	22.5	39.7	23.2	73.8	35.6	47.9	53.6	108.6	68.8	96.3	841.7	92.0%	LTA
1991	97.4	64.3	74.2	70.9	13.7	103	70.7	27.8	64.9	72.1	93.4	49.3	801.7	87.6%	LTA
1992	48.7	44.8	82.2	75.9	51.5	38	89.7	134.6	96.9	90.5	148.5	78.6	979.7	107.1%	LTA
1995	162.6	114.9	70.6	28.1	48.5	20.2	37.6	9.1	123.3	52	82.8	91.1	841	91.9%	LTA
1996	65.9	83.3	43.2	51	58.3	29.6	43.6	79.9	34	87.8	134.3	55.5	766.4	83.8%	LTA
2003	91.2	38.8	36.8	43	70.9	75.6	64.7	21.3	34.7	67.7	116.6	100.3	761.4	83.2%	LTA
2004	122.7	50.2	50.2	91.2	47.5	59.3	74.6	156.5	49.8	154.9	52.8	63.8	973.6	106.4%	LTA
2005	54.2	46.2	55.9	77.7	45.1	55.4	74.3	62.5	68.2	127.4	86.1	72.1	825.1	90.2%	LTA
2006	31.9	57.7	87.8	45.7	111.8	23.9	39.1	89.2	77.6	115.7	108.6	115.7	904.8	98.9%	LTA
2010	75.3	87.2	71	30.1	38.3	42.7	67.9	107.2	86.9	84.2	97.5	34.1	822.4	89.9%	LTA
2011	94.8	81.2	22.3	11.6	46.5	82	65.2	91.4	57	68.4	52.9	113.6	786.9	86.0%	LTA
2012	67.6	32.1	30.9	149.9	57.4	160.1	120.5	93.7							

Source: Halcrow Ltd based on data from the Meteorological Office

Appendix 2 Drought legislation

The Water Act 2003

Under the *Water Act 2003* water companies are statutorily required to prepare, maintain and publish drought plans under section 39B and 39C of the Water Industry Act (WIA) 1991, as amended by the Water Act 2003. In these documents water companies set out how they plan to meet their duties to supply water during drought periods with as little recourse as possible to drought permits or orders: for example, demand management actions such as publicity campaigns, temporary restrictions on water uses under water companies' own powers (*Water Use (Temporary Bans) Order 2010*), leakage control and pressure reduction.

Water companies are expected to consider all drought permits and orders they may require in their drought planning and to carry environmental impact assessments for each option. An application for a drought permit (order) is unlikely to be accepted by the Environment Agency, the Secretary of State or Welsh Ministers, if it was not considered in the drought plan. Table 12 explains the three legislative options for drought management, as laid out in Defra, Welsh Assembly Government, and the Environment Agency (2011).

Temporary use bans powers are also set in law: section 76 of the *Water Industry Act 1991*, amended by the *Flood and Water management Act 2010*. The *Water Use (Temporary Bans) Order 2010* sets out what is or is not to be considered to be covered by the categories of water use listed in the Water Industry Act 1991. The following activities can be restricted under a temporary use ban:

- watering a garden using a hosepipe;
- cleaning a private motor-vehicle using a hosepipe;
- watering plants on domestic or other non-commercial premises using a hosepipe;
- cleaning a private leisure boat using a hosepipe;
- filling or maintaining a domestic swimming or paddling pool;
- drawing water, using a hosepipe, for domestic recreational use;
- filling or maintaining a domestic pond using a hosepipe;
- filling or maintaining an ornamental fountain;
- cleaning walls, or windows, of domestic premises using a hosepipe;
- cleaning paths or patios using a hosepipe; and
- cleaning other artificial outdoor surfaces using a hosepipe.

Table 12. **There are three legislative ways for dealing with drought**

	Basic criteria	Applicant	Authoriser	Duration	Available actions (subject to conditions or restrictions specified on the permit/order)
Drought permits	*'a serious deficiency of supplies of water in any area exists or is threatened* ***and*** *the reason for the deficiency is an* ***exceptional shortage of rain***[1]*"*	water companies	Environment Agency	up to 6 months	take water from specified sources[2] modify or suspend conditions on an abstraction licence held by the water company
Drought orders	*"a serious deficiency of supplies of water in any area, exists or is threatened* ***and*** *the reason for the deficiency is an* ***exceptional shortage of rain"***	water companies	Secretary of State or the Welsh Ministers	up to 6 months	same as the drought permit plus discharge water to specified places modify or suspend discharges or filtering/treating of water held by water company modify or suspend restrictions or obligations to taking, discharging, supply or filtering/treating of water held by others (including Environment Agency) authorise the Environment Agency to stop or limit the taking or discharging of water from/to specified sources or places prohibit or limit particular uses of water under the *Drought Direction 2011*[3]
	"such a deficiency in the flow or level of water in any inland waterway to pose a serious threat to any flora or fauna which are dependent on those waters, exists or is threatened ***and*** *the reason for the deficiency is an* ***exceptional shortage of rain"***	Environment Agency	Secretary of State or the Welsh Ministers	up to 6 months	take water from specified sources discharge water to specified places stop or limit the taking of water from specified sources modify or suspend restrictions or obligations to taking, discharging, supply or filtering/treating of water held by anyone
Emergency drought orders	*"by reason of an* ***exceptional shortage of rain****, a serious deficiency of supplies of water in any area exists or is threatened* ***and*** *the deficiency is such as to be likely to impair the economic or social well-being of persons in the area"*	water companies	Secretary of State or the Welsh Ministers	up to 3 months	same as for ordinary drought orders, except provisions under the Drought Direction 2011, plus prohibit or limit uses specified by water company set up and supply water by means of stand pipes or water tanks in a water company area

	Environment Agency	Secretary of State or the Welsh Ministers	up to 3 months	same as for ordinary drought orders

Note: [1]*There is no legislative definition of 'exceptional shortage of rain'.*

[2]*The act of 'taking' of water usually means abstraction but its definition in the legislation is broader and includes the collection, impounding, diversion or appropriation of water.*

[3]*These uses are: watering outdoor plants on commercial premises, filling or maintaining a non-domestic swimming or paddling pool, filling or maintaining a pond, operating a mechanical vehicle-washer, cleaning any vehicle, boat, aircraft or railway rolling stock, cleaning non-domestic premise, cleaning a window of a non-domestic building, cleaning industrial plant, suppressing dust, and operating cisterns.*

Source: *Defra, Welsh Assembly Government, and the Environment Agency (2011) and Drought Direction 2011*

Appendix 3 The environment

A literature review

Droughts affect key ecosystem processes in terrestrial ecosystems and aquatic systems. While both are affected by drought, drought management actions may have greater direct impact on aquatic systems by drying streams and river beds and by loss of connectivity (Acreman et al., 2012).

In terrestrial systems, a drought affects fire-protection, carbon and nutrient fluxes in soils, microbial and soil fauna dynamics, plant production and biodiversity of plants and of butterflies, moths and beetles. These outcomes happen in two ways, by lowering water tables and by drying of the top soil layer in which plants are rooted and microbial processes take place. It is possible that management actions could affect the water table in some locations, but unlikely that it would have any effect on the drying of the top soil layer.

In aquatic systems, wetlands and rivers, reduced flows and water levels can result in a fall in the fish biomass, changes in the populations of invertebrates and changes to the composition of plant populations. All of these outcomes might be affected by management actions which affect river flows and levels.

Method

The literature covered here focuses on UK studies. It summarises what is known about the effects of drought on terrestrial (semi-) natural ecosystems, wetlands and rivers. This study is UK data specific; the authors do not claim to provide a complete overview of international knowledge. The literature search was divided into terrestrial, river and wetland ecosystems. This chapter contains an executive summary of the findings on these three categories.

The literature search in terrestrial ecosystems used the Web of Knowledge tool and is based on studies carried out in the UK, extended with targeted sources from Denmark, The Netherlands, Belgium and Germany. The searches have yielded over 1,000 results, from which about 450 abstracts have been read, approximately 130 papers were considered of potential interest and downloaded and fully investigated. In the review below, information from 67 papers regarding terrestrial impact is presented.

The literature search on river ecosystems made use of CEH's in-house eco-hydrological references database, which contains more than 2,500 entries, the most important of which was Acreman et al. (2012). In addition, a Web of Knowledge search was carried out. These searches identified 164 papers or reports potentially relevant to the ecological impacts of droughts in rivers, which were further investigated. Data from 93 papers contains some quantification of the impact of drought on river ecology and is included here. The more useful quantifications involve changes in total abundance or total biomass of organisms, though there is also information on loss of biodiversity.

There are fewer specific studies on the effects of droughts in wetland ecosystems. Those that do exist tend to be from more traditionally drought-prone regions such as the Mediterranean and the Murray-Darling basin in Australia. They generally deal with impacts of drought that are not relevant to the UK. A broad sweep of the available literature was conducted using the Web of Science tool where a search for 'drought' and 'wetlands'

generated 702 results. One hundred and eighteen of these were selected on the basis of their titles. The abstracts were read and 20 papers were short-listed: of these only two refer to the UK. Given this shortage of literature, the methodology was changed and interviews were conducted with in-house CEH experts: these are provided below.

The mechanisms of impact

In terrestrial ecosystems, the cascade of changed water flows into vegetation, microbe and animal responses through changes in lower-soil layer moisture is not well understood. This makes it difficult to relate changing water management scenarios directly to terrestrial ecosystems. The few available descriptions depict substantial vegetation changes after changing abstraction regimes, for example, in internationally important British calcareous mires (Harding, 1993; Fojt & Harding, 1995) and in the Herefordshire Hills (English Nature, 1997).

The general picture described below is that the length of drought in number of years of reduced rainfall has a clear effect on terrestrial species composition, productivity and ecosystem services. This is based on the findings of experimental and monitoring studies which investigated summer droughts, being the more photoactive period, but not winter droughts. In fact, in all experiments in which vegetation was shielded from rain, the shields were put in place during the summers only and covers were removed for the winter. The effect of both winter and summer drought combined still remains to be investigated in terrestrial systems.

The risk of fire is known to be heightened by drought from a correlation between increased fire occurrences and decreased natural precipitation, over the period 1976-2008, in the UK Peak District National Park (Albertson, Aylen, Cavan, & McMorrow, 2010). This is corroborated for sites with Nature Conservation Interest in the UK, for which the incidence of fires was reported to be higher in heathlands during the 1976 drought. A total of 118 Nature Conservation sites that were affected in this drought by fires; 58 of these being lowland heaths or peatland sites (Hearn & Gilbert, 1977). Secondary erosion caused by fire departments was a further reported loss of diversity (Hearn & Gilbert, 1977). Similarly such fires were reported during the 2003 drought (Marsh, 2004). Fires cause a decline in vegetation and soil flora and fauna and an increase in carbon loss.

Wetlands are an extremely diverse category. Their responses to changing hydrological conditions differ greatly, which makes it difficult to extract general guidelines on the response of wetlands to drought or the effects of management action. Information on rivers benefits from a wealth of published studies which enables something to be said in general terms about impacts on fish, invertebrates and higher plants. Although there is scarce information on the effect of drought on the function of river ecosystems as a whole, the UK has one of the few experimental drought simulations for rivers (Freeman, Hudson, Lock, & Reynolds, 1993), which shows large shifts in invertebrate and algal community structure and food web structure.

Terrestrial systems

The effects of drier soils are partly understood, while the effects of experimentally lowering water tables on vegetation changes via altered ground water levels is rarely explored in the literature. The evidence comes in two forms, one in the shape of experiments which create drought conditions, the other as empirical work which surveys ecological conditions at normal times and at times of drought.

All the experimental research reduces soil moisture in the upper organic layer by physically shielding plots of land from rainfall by around 30 per cent (Beier et al., 2012; Sowerby et al., 2008; Toberman et al., 2008), with experimental periods of up to 15 years of successive droughts (Fridley, Grime, Askew, Moser, & Stevens, 2011). The empirical research correlates observed rainfall and monitoring results, especially organism density changes, to the natural droughts of 1976, 1995 and 2003.

The amount of information on UK droughts and their impact on animals and birds in terrestrial systems is scarce and relates mostly to invertebrates such as butterflies perhaps because animals tend to be mobile and can escape local drought areas.

Birds

As in aquatic ecosystems, birds are known to decline because of reductions in food availability, especially lowered invertebrate abundances (Fuller et al., 2005; Pearce-Higgins, 2010). Similarly in drying farmland systems, bird abundances declined drastically (Bradbury & Kirby, 2006) and a decrease can be expected in semi-natural habitats. These impacts of droughts are typical examples of how vegetation changes have an impact on herbivore and nesting insects affecting bird nutrition in turn, showing the complex trophic interactions in terrestrial systems. In general, one to two years of summer drought is regarded as enough to disrupt invertebrate food web structures and change interactions among species (Morecroft et al., 2002; Frampton et al., 2000; Staley et al., 2007).

Worms

The density of worms can be severely affected by drought, changing the aeration and hydrological dynamics of the soils even further (Haria, McGrath, Moore, Bell, & Blackshaw, 1998) exacerbating further the effects of soil compaction. During the natural drought of 2003 in the UK, the worm density in a woodland soil decreased by three orders of magnitude, but densities recovered two years after the drought (Eggleton, Inward, Smith, Jones, & Sherlock, 2009). Similarly, in a Danish heathland, worm density and biomass decreased 75 per cent after six years of experimental summer drought (Maraldo, Schmidt, Beier, & Holmstrup, 2008); in an eight-year long Swedish drought experiment, an 80–90 per cent reduction in soil fauna abundance including worms, was found (Lindberg, Engtsson, & Tryggve, 2002).

Butterflies and moths

For butterflies and moths all data is based on monitoring networks. In drought periods, the abundance of butterflies seem to be at least equal to non-drought years (Brereton et al., 2011); Conrad et al., 2004) or even to increase in numbers, such as reported during the 1976 drought (Pollard, 1988; Roy et al., 2001). Correlating 65 years of UK butterfly monitoring to weather patterns offers no strong relationship between precipitation and butterfly occurrence (Pollard & Moss, 1995). This was evidenced in the UK during the mid-90s drought (Morecroft et al. 2002) and during the 2003 drought in The Netherlands (WallisDeVries,

Baxter, & Van Vliet, 2011). Although densities do not decrease, species compositional changes occur in drought years. Several species have been observed to crash under drought conditions, such as the Ringlet butterfly (Oliver, Brereton, & Roy, 2012). The effects of altered vegetation composition, as described above, could negatively affect butterfly densities as knock on effect.

Butterflies and moths which specialise in particular food plants are likely be the most sensitive; a Belgium example showed a transient 85 per cent decline in specialist feeders on *Anthyllis vulneraria* after the 2003 drought (Piessens, Adriaens, Jacquemyn, & Honnay, 2009). In the UK, the resilience of populations after drought of the Ringlet butterfly, *Aphantopus hyperantus*, was shown to be highly dependent on the connectivity of patches of surrounding woodland habitats (Oliver et al., 2012). Similarly, during the 1976 drought, populations of the Adonis Blue (*Polyommatus bellargus*) collapsed in the UK, increasing local extinction risks through lower population sizes and decreasing levels of connectivity (Harper, Maclean, & Goulson, 2003).

Other arthropod groups

For all other arthropod groups, one or two years of summer drought may be enough to at least temporarily disrupt food chain structures and interactions among species (Morecroft et al. 2002; Frampton et al. 2000; Staley et al. 2007). This includes findings concerning the increased prevalence of more drought tolerant carabid beetles (Morecroft et al. 2002) and decreases in density of coleopteran beetles during drought (Masters, Brown, Clarke, Whittaker, & Hollier, 1998). In contrast, in a large field experiment in the UK (1999–2000) no differences were found amount of leaf material eaten by anthropoids between control and drought treatments. Those results could suggest functional groups as such were not changed (Peñuelas et al., 2004).

The impacts of drought on plant communities

Species richness

Among plants, the general pattern found across studies is that repeated experimental droughts of two summers or longer do not necessary lead to large scale species loss in grasslands. They do lead to substantial changes in species composition and altered competitive interactions among species (Morecroft et al. 2002; Morecroft et al. 2004; Jentsch et al. 2011; Grime 2000; Grime et al. 2008; Buckland et al. 2001; Staddon et al. 2003; Silvertown et al. 1994; Silvertown et al. 2006). The driving force behind vegetation composition changes is probably a selective reduction in recruitment and increased mortality among coexisting plant functional groups (Stampfli & Zeiter, 2008). One exception is the 13 year experimental study at Buxton which reported a reversible 25 per cent loss of species diversity (Grime et al. 2008). However, community changes are common; plant communities tend to homogenise and deep-rooted species become more successful leading to an increased grassification of the vegetation (Fridley et al., 2011; Silvertown et al., 2006; Staddon et al., 2003). In UK shrublands, a 15 per cent loss in species richness occurred as a consequence of seven years of experimental drought (Peñuelas et al., 2007).

Most studies observing vegetation changes before and after natural drought events, that is 1976, 1995, and 2003, indicate that these compositional changes can be transient and reversible if the drought is followed by non-drought years (Morecroft et al. 2004; Dunnett et al. 1998; Buckland et al. 2001; Grime 2000; Grime et al. 2008; Faust et al. 2011; Kongstad et al. 2012). However, the change in this recovery potential, with the

length of the drought is poorly understood.

Plant density and biomass

Although diversity may not change, the plant densities in general decrease through successive years of drought in grasslands (Piessens et al., 2009; Morecroft et al. 2004; Bütof et al. 2012) heath- and shrublands (Gordon et al. 1999). Moreover, the reproductive output of individual plant species decreases, which could suggest long-term effects on insect densities and higher trophic levels (Carter et al. 1997; Fox et al. 1999; Peñuelas et al. 2004). These compositional changes in vegetation affect on the mycorrihza community, which is suggested to shift its community structure in synchrony with grassland vegetation (Staddon et al., 2003).

The findings on long-term total plant biomass are mixed. In the short-term during a drought, plants loose photosynthetic activity and have reduced reproductive output (Carter et al., 1997), but there is only a weak correlation between weather and biomass production in the UK, according to 38 years of monitoring (Dunnett et al., 1998). This is supported by many experimental UK studies, ranging from two to nine years of successive summer droughts, which found no loss of total plant biomass (Morecroft et al. 2004; Fox et al. 1999; Sternberg et al. 1999; Staddon et al. 2003; Peñuelas et al. 2004; Gorissen et al. 2004). Even in the 13 years study at Buxton, which suggested a 35 per cent decrease in grassland biomass production, the loss was expected to be fully recoverable when the drought ended (Grime et al. 2008). Moreover, the large German drought experiment (Jentsch et al., 2011) did not detect substantial effects of drought on the biomass production capacity of the vegetation, suggesting effects to be transient.

Woodlands

In woods and forests, droughts decrease the growth of adult trees and increase the mortality rates of younger trees. These results have been found in various experiments and in observations after natural drought (Zang et al., 2011; Thiel et al. 2012; Mountford 2006). The forest structure is expected to be recoverable, although it can take up to 15 years to regain similar stand demography after the 1976 drought (Peterken & Mountford 1996). Successive droughts may cause large compositional changes in woodland species as seen in modelling studies (for example, Lindner, Bugmann, Lasch, Flechsig, & Cramer, 1997) and cause large compositional changes in woodland dwelling species such as epiphytes, bryophytes and soil mycorrihza (Bates, Thompson, & Grime, 2005; Ellis, Yahr, & Coppins, 2009; Shi, Guttenberger, Kottke, & Hampp, 2002).

The impacts of drought soil chemistry

Carbon and Nitrogen

Successive drought years are likely to change carbon fluxes in soils. Short term heatwaves lower respiration rates by 45 per cent from the soil, with recovery times exceeding one month (Gregory et al., 2009). Over the longer term the results are mixed. In the UK, long-term experiments on heathlands, of five to eight years duration, show that repeated drought can change soils from being net carbon sinks to becoming net sources, through increased carbon leakage in ground water and increased respiration of CO_2 into the atmosphere (Sowerby et al. 2010; Sowerby et al. 2008). Similar results were found in a five-year long experimental summer drought experiment in a grassland in Germany, reporting a 35 per cent reduction in carbon fixation rate (Jentsch et al., 2011). However, non-distinctive patterns have been detected in other experiments with

two years of summer droughts in UK and Danish heathlands, in which soil respiration and dissolved carbon content rates were lower in drought plots than controls (Emmett et al. 2004; Maraldo et al. 2008). No differences in decomposition rates were identified in these experiments (Emmett et al. 2004; Toberman et al. 2008). So far, no experimental data describing the recovery potential of these soils after drought has been found.

In the same experiment as above, it was shown that successive droughts may not increase N-mineralization in heathland and grassland soils (Emmett et al. 2004; Jentsch et al. 2011). Still, increasing levels in the groundwater on other experiments indicates N-leaching from the soil and so potential long term negative effects on N-stocks under drought conditions (Schmidt et al. 2004). Hence, changes in N-fluxes remain to be studied further.

Soil dwelling organisms

For organisms living in soils, only short term experiments have been carried out with one exception. For bacteria and microbes in grasslands and heathlands the effects of one drought event seem to be transient. Drought causes large drops in soil organism activity, which is quickly recoverable (Griffiths et al. 2003). Also over multiple-years, a drop in activity seems to be completely reversible (Jentsch et al., 2011) as well as highly dependent on the substrate (Jensen, Beier, Michelsen, & Emmett, 2003).

In woodlands, eight years of successive experimental dry summers caused a 80–90 per cent reduction in soil fauna abundance in Sweden including worms, springtails and mites (Lindberg et al., 2002); similar results were found using a soil moisture gradient in the UK, showing the driest plots to have the lowest bait feeding activity (Simpson, Slade, Riutta, & Taylor, 2012). However, in a shielding experiment in a German woodland no differences were found (Shi et al., 2002).

River ecosystems

General effects of droughts on river ecosystems

This section summarises knowledge on drought and is drawn from Lake (2011), Edwards, Baker, Dunbar, and Laize (2012) and Acreman et al. (2012).

Empirical, scientifically robust data on the ecological effects of drought on river ecosystems are scarce. Many peer-reviewed studies in scientific journals report on a drought but comparisons with a baseline before the drought or after the recovery phase are extremely rare and are limited to cases when drought happens to occur during a long term monitoring campaign.

The ecological impacts of drought at all spatial scales are determined by:

- the seasonal timing;
- the rate of onset, for example, the rate of reduction in flow or the rate of bed drying;
- the intensity, for example, the total reduction in flow or the total extent of drying;
- the duration, for example, one season, several seasons (supra-seasonality), multi-year droughts;
- the frequency of occurrence over long time spans.

At local scales, such as individual water bodies or river reaches, the ecological impacts are influenced by:

- the hydromorphology;
- the flow permanence: normally perennial sites versus naturally intermittent or ephemeral sites;
- the relative natural contribution of groundwater versus run off.

Thus, the impact of drought on river ecosystems is a catchment scale process, yet effects vary strongly at the water body and reach scale.

Summer droughts occur at a time of the year when water resources are naturally most depleted. Many organisms are adapted to summer low flows, particularly the timing of life cycles of fauna and flora. Winter droughts have greater ecological impacts because many plants and animals over-winter as juveniles and may be more sensitive to low flows. Also, winter time is when aquifers normally recharge so a winter drought can evolve into a supra-seasonal drought. Winter floods or high flows are essential for channel morphology maintenance and the flushing of organic matter and fine sediments. There is some evidence that the lack of these flushing flows has an impact in itself.

Drought reduces the volume of water in streams and rivers and disrupts horizontal, longitudinal and vertical connectivity. At the onset of a drought, water flow gradually decreases so that there is a lower volume of water but the amount of benthic wetted habitat remains the same. If the drought persists, and flow continues to decrease, a number of successive steps occur:

- loss of horizontal connectivity: water recedes from the stream margins so that the riparian zone becomes disconnected from the stream system;
- loss of longitudinal connectivity: as flow reduces, the river bed becomes a mosaic of increasingly disconnected trickles, remnant pools and drying patches;
- loss of vertical connectivity: as flow stops and the bed dries, water is lost from the hyporheic zone (shallow groundwater below a water course, if present);

- total desiccation: in severe supra-seasonal droughts, all remnant surface water and hyporheic water may disappear.

The impact of drought on river ecosystems is principally mediated by the loss of wetted habitat, and resilience of the ecosystem is determined by the morphology of the bed and channel. The spatial pattern of drying is dependent on stream bed topography because this governs the hydraulic conditions at a range of spatial scales. Morphologically diverse sites are more resistant to drought because they present a range of bed and channel features which serve to retain water and maintain the amount of wetted and damp habitat, for example: meanders, large boulders, and logs. In contrast a more morphologically homogeneous site such as straightened, channelled and dredged watercourses have fewer of these features, thus drying is likely to occur more rapidly and to be more severe.

The impact of drought is also in part mediated by changes in water temperature. As flow is reduced, air temperature and solar radiation have a greater influence on water temperature, which increases. Higher water temperature causes heat stress to biota but also increases decomposition rates and reduces dissolved oxygen, impairing water quality. Water temperature is also a major determinant of algal blooms. At wider scales water temperature patterns contribute to the geographic distribution of species, including non-native invasive species. Stream and river ecosystems may become increasingly sensitive to heat stress because the temperatures of flowing waters have increased across Europe, in line with climate change scenarios. This may make these systems more vulnerable to drought.

The ecological effects of drought are dependent on certain environmental thresholds being met, in relation to drought magnitude and duration. Although drought is a sustained disturbance, impacts may be disproportionately severe when critical thresholds are exceeded. For example, ecological changes may be gradual while water levels drop but cessation of flow causes abrupt loss of some habitats, alteration of physicochemical conditions in pools, and fragmentation of the river ecosystem. Many ecological responses of plants and animals to drought depend on the rapidity of hydrological transitions across these thresholds, as this shapes a stepped response alternating between gradual change while a threshold is approached followed by a swift transition when habitat disappears or is fragmented.

How plants and animals cope with drought

Droughts are natural phenomena, and flora and fauna have evolved adaptations to cope with drought, but few organisms are adapted to supra-seasonal and multi-year droughts. The main adaptations are:

- avoidance: migration, life cycle timing, early emergence of flying insects;
- resistance: physiological responses to survive desiccation and heat stress;
- resilience: production of desiccation resistant cysts (algae), seeds (plants) and eggs (fish/invertebrates).

Many ecosystems show some degree of resilience to drought because past droughts act as an ecological filter, selecting the more resilient species.

Human activities modify the ecological impacts of drought:

- changes in land use and land cover can affect the severity and duration, as well as the rate of onset of droughts, which all have a strong bearing on the ecological impact. They generally operate by reducing the amount of water stored in the catchment , for example, deforestation for agriculture and

grazing, urbanisation;

- groundwater abstraction may alter the dynamics of rivers and influence the severity of drought and the ecological recovery. In some circumstances abstraction may be used as compensation flows;
- dams have the potential to exacerbate the impacts of drought because they reduce river flow. Conversely, under drought conditions dams and reservoirs can be used to release environmental flows to support the downstream ecosystem;
- channel clearing and re-sectioning, usually to reduce flooding, increases vulnerability to drought;
- invasive species may hinder the recovery of native species from drought;
- climate change is expected to increase the frequency, severity and duration of droughts in Europe.

Drought recovery is a major gap in research. Abiotic changes caused by drought are much better known than abiotic changes that occur when droughts break and recovery sets in. Recovery from drought is strongly mediated via catchments; by water body type, state of the catchment, groundwater levels, and the nature of the precipitation.

If droughts break with a heavy spell of precipitation, large amounts of sediment and nutrients may be entrained and ultimately lost from the catchment (Lake 2011). The re-wetted riparian zones and floodplains release dissolved organic chemicals from the soil and litter which is flushed into river water and can increase microbial activity and reduce water quality (O'Connell et al. 2000; Worall, Burt, and Adamson 2006; Howitt et al. 2007). Soils also accumulate nitrates during drought and re-wetting causes a pulse of these nitrates in streams / rivers and thus an increase in nitrate concentrations and nitrogen loading. Dried bed sediments may also release nitrates on re-wetting. (Watmough et al. 2004; Whitehead et al. 2006; Zwolsman and van Bokhoven 2007). The increased nitrates can stimulate microbial activity, algal activity and macrophyte growth (Baldwin et al. 2005). Re-wetted soils may also release sulphates as sulphuric acid, causing an acid pulse and potentially mobilising metals, which can reach toxic concentrations (Tipping et al. 2003; Eimers et al. 2008).

If organic matter and leaf litter has accumulated on the stream / river bed during drought, there is a pulse of dissolved organic chemicals and nutrients which may be taken up into the food web contributing to recovery (Artigas et al. 2009; Lake 2011). The relative influence of these pulses of chemicals, nutrients and organic matter on re-wetting at the catchment and river reach scales can be a major determinant of ecosystem recovery (Romani, Vazquez, & Butturini, 2006).

Taxon specific effects of drought and recovery

The impacts of drought on fish

As flow drops fish change behaviour and habitat (Elliott, 2006). Initially, fish redistribute at the reach scale, seeking in particular shaded pools (Elliott 2000; Matthews and Marsh-Matthews 2003; Dekar and Magoulik 2007; Pires et al. 2010). Benthic fish are more tolerant of low flows than pelagic fish (Elliott 2006; Lake 2011) but are also affected by the depletion of invertebrates, their main food resource (Hakala & Hartman, 2004). Fish, in particular pelagic fish, can become stranded in remnant pools once a flow threshold is reached. This can increase predation risk from terrestrial animals and increases the risk of parasitism and disease (Magalhaes et al. 2002). The water quality of pools may also be low (Labbe and Fausch 2000; Antolos et al. 2005; Dekar and Magoulik 2007; Magalhaes et al. 2007; Maceda-Veiga et al. 2009). Remnant pools can thus act as an environmental filter shaping the composition of the remnant fauna and the post-drought assemblage (Matthews and Marsh-Matthews 2003; Lake 2011). As the bed dries, deteriorating water

quality in pools means fish will need to attempt migration to a perennial reach or run the risk of being trapped in a pool that may eventually dry out (Magoulick and Kobza 2003; Dekar and Magoulik 2007; Conallin et al. 2010). The timing of drought is important with respect to life cycle. Juvenile fish are more susceptible to predation in remnant pools and eggs may die if fine sediments are deposited during low flows (Hakala and Hartman 2004; Magalhaes et al. 2007). Supra-seasonal drought may prevent the migration of anadromous and catadromous fish, particularly in systems with weirs and other artificial structures, leading to local extinctions (De Leaniz, 2008; Fukushima, 2001; Jonsson & Jonsson, 2002; Vadas, 2000).

As long as wetted areas are available and accessible, fish re-colonisation is rapid because they are highly mobile (Magoulick and Kobza 2003; Elliott 2006). Recruitment is sometimes strongest following a drought year (Keaton, Haney, and Andersen 2005). Recovery from a supra-seasonal drought is less predictable for fish and ranges from rapid recovery to no recovery at all (Lake 2007).

Quantified UK examples

In small Welsh streams, the main effect of the 1976 drought on fish was the complete elimination of that year's juveniles (Cowx, Young, and Hellawell 1984). Though densities of other fish varied greatly with site there was no overall clear pattern of increase or decrease. It seemed that the main driver for mortality was increased water temperature rather than reduced flow. A similar pattern was observed in the river Wye where older salmon were completely eliminated in the 1976 drought (Brooker, Morris, and Hemsworth 1977).

In the 1995 drought, fish life was obliterated in the river Tame, an estimated 20,000 fish were killed in the river Trent, and an estimated 16,500 in the Staffordshire and Worcestershire Canal (Environment Agency, 1996).

Elliott, Hurley, and Elliott (1997) describe the impacts of several droughts on UK sea trout populations in the north west of England. The long-term effects of the droughts on the population densities of females returning to spawn were evident for six year-classes. Considering first the three less severe droughts, that of 1969 had no effect on the 1969 year-class and a minor effect on the 1968 year-class (76 per cent of expected value), but those of 1989 and 1993 had significant long-term effects on the 1988, 1989 and 1992 year-classes (38, 24 and 26 percent of expected values). The long-term effects of the three other severe droughts (1976, 1983 and 1984) were variable, being less marked for the 1976 and 1984 year-classes (62 and 77 per cent of expected values) than for the 1975, 1982 and 1983 year-classes (26, 13 and 19 per cent of expected values). Total egg production in each year-class was 50 per cent less than expected in the six drought year-classes (1975, 1982, 1983, 1988, 1989 and 1992). Elliott (2006) found a relationship with wetted habitat showing that trout density dropped as wetted habitat was reduced but densities of benthic fish increased. Below 20 per cent wetted area, trout were eliminated but benthic fish, the common bullhead, nearly doubled.

The impacts of drought on invertebrates

Reduced flows can initially increase invertebrate density as they are concentrated in the remaining wet habitat (McIntosh, Peckarsky, and Taylor 2002; Dewson, James, and Death 2007), but competitive and predatory interactions intensify and eventually lead to a decline in invertebrates (Wood, Agnew, & Petts, 2000). The response of food resources, in particular algae, to drought conditions can have a strong influence on the response of invertebrates (Smakhtin, 2001). If habitats such as riffles and cascades are lost with drying, invertebrate biodiversity can decrease. If habitat diversity persists then invertebrate species richness is little affected (Ruegg and Robinson 2004; Boulton and Lake 2008).

Channel morphology has a strong influence on how the wetted habitat changes as droughts develop. Heterogeneous reaches provide a variety of flow and depth environments and are more resilient to drought because drying rates are slower and they present more refuges for the biota. However, once drying sets in there is potentially a greater diversity of species to be lost. Comparatively homogeneous reaches have less diversity to lose, but drying is likely to occur more quickly and be more severe thus having a strong impact on biota. In cases where some flow remains, total abundance and richness are similar pre- and post-drought. There is usually a change in community composition as droughts progress, as habitat suitability increases for some species and decreases for others (Everard, 1996).

The rate of drying is important to community structure. In small streams rapid drying acts as an environmental filter to produce a robust set of surviving species. In larger rivers drying takes longer, and may be less extensive, so produces a less stable and specific community. Taxa with preferences for low velocities and fine sediment can dominate during drought years, whereas species with preference for high velocities and gravel would normally dominate (Everard, 1996). Taxa with shorter life cycles are favoured as their exposure to drought is limited (Bonada et al. 2006; Bonada, Rieradevall, and Prat 2007; Dewson, James, and Death 2007). Larger bodied taxa are more susceptible to drought particularly when drying sets in, due to their higher rates of evaporation and their greater requirement for wetted area (Dewson, James, and Death 2007; Ledger et al. 2011). Species specialised in shallower habitats like riffles risk becoming stranded as water levels drop, particularly those with limited motility such as mussels (Gagnon et al. 2004; Golladay et al. 2004).

Due to increasing concentrations of nutrients in the remaining water, especially remnant pools, and physical processes such as the deposition of fine sediments and litter with dropping flows, taxa that are well adapted to low water quality and degraded river conditions are often tolerant of drought (Boulton 2003; Lake 2011). Invertebrate fauna have a low resistance but high resilience to drought (Boulton 2003; Lake 2003; Fritz and Dodds 2004; Bonada, Rieradevall, and Prat 2007). Resilience is substantially mediated by the use of refuges (Boulton 2003; Dewson, James, and Death 2007; Lake 2008; Poff et al. 2010). Invertebrate refuges consist of remnant pools, moist areas (for example, under boulders) (Fenoglio, Bo, & Bost, 2006), the hyporheic zone (Stubbington, 2012; Wood, Boulton, Little, & Stubbington, 2010) or wetted reaches further downstream.

Drift enables some invertebrates to avoid drought and can be the first and strongest response to drought. Active drift of invertebrates increases during drought, whereas passive drift is reduced. Once a flow threshold is reached, drifting is no longer possible (Poff and Ward 1991; Kinzie et al. 2006; Dewson, James, and Death 2007).

Some taxa emerge earlier than they would normally to avoid drought (Stubbington et al., 2009), but some will need wet habitat to lay their eggs. Some have desiccation resistant eggs which serve to delay the next generation until drought conditions have passed (Morrison 1990; Brock et al. 2003; Briers, Gee, and Geoghegan 2004; Harper and Peckarsky 2006). Thus for many insects the true impact of a drought may remain unclear until the following year’s recruitment (Lake 2011).

Non-drifting, low motility invertebrates, for example, worms, molluscs and some crustaceans have to use sedentary refuges (Dewson *et al*. 2007). In the early stages of drying some wet habitat is available under stones and woody detritus (Covich et al. 2003; Golladay *et al*. 2004). In rivers with hyporheic zones, invertebrates may bury in the wet sediment, though this may eventually dry out too. There is some debate

over the use of the hyporheic zone by benthic taxa as a refuge, as this varies greatly between river ecosystems. In some cases there is no hyporheic zone at all (Datry, Lafont, and Larned 2010; Wood et al. 2010; Dole-Olivier, Marmonier, and Beffy 1997; Young, Norris, and Sheldon 2011; Stubbington 2012).

As long as some flow persists, recovery of invertebrate assemblages is usually rapid. If the channel dries completely, recovery will be slower and may be incomplete (Boulton 2003; Acuna et al. 2005; Boulton and Lake 2008). Some insects re-colonise via highly mobile adult flying stages from remnant pools, wetted reaches or other water bodies (the availability of these latter two will be affected by the spatial extent of the drought; Fritz and Dodds 2004). Drought favours species with good coloniser traits, such as multi-voltinism, but for many insects re-colonisation may not take place until the following year (Hynes 1958; Hynes 1961; Morrison 1990; Ruegg and Robinson 2004; Bonanda, Rieradevall, and Prat 2007). Thus the timing of drought in terms of animal life cycles is crucial in determining the speed of recovery (Boulton, 2003). Re-colonisation also occurs from surviving individuals in remnant pools (Suren et al. 2003; Fritz and Dodds 2004; Boulton and Lake 2008) and the hyporheic zone (Dole-Olivier, Marmonier, and Beffy 1997; Stubbington et al. 2009; Wood et al. 2010; Dole-Olivier 2011; Young, Norris, and Sheldon 2011; Stubbington 2012). Re-colonisation can also occur from drought resistant eggs (Boulton, 2003).

The recovery trajectory is similar in perennial and intermittent streams. The first colonists have short life cycles and are usually small bodied, then species richness increases as bigger, longer-lived taxa re-appear, with larger predators usually returning last (Lake 2007). For supra-seasonal droughts, the pre- and post-drought communities can be different if key species such as grazers and shredders are lost and the trophic structure has changed (Lake 2011).

Quantified UK examples

In the Little Stour river in Kent (Wood & Petts, 1999), species richness was reduced by 26 per cent at the height of a drought but recovered by the next year. This ranged from no effect to, for example, 30 per cent reductions for snails. Stubbington et al. (2009) state an approximate reduction of 20 per cent in invertebrate abundance during the 2006 groundwater drought in intermittent chalk streams, but populations recovered with the return of flow, partly because of a deep hyporheic zone which acted as a refuge. Wright et al., (2002) found no impact on species richness of several droughts, though there was species turnover.

Ledger & Hildrew (2001) observed rapid re-colonisation of a dry stream bed by invertebrates; from after 3 days of flow, 665 invertebrates m^{-2} had been attained. The total numbers of invertebrates peaked 38 days after rewetting when a density of 2,185 larvae m^{-2}, similar to pre drought conditions. Wood et al., (2000) dealing with 1992 and 1996 droughts indicated in both cases an invertebrate reduction of 20 per cent with characteristic traits of a shift and a rapid recovery in the Little Stour. Extence (1981) studied the 1975/1976 drought in the River Roding and observed a 40 to 60 per cent reduction in the abundance of aquatic snails, but many other invertebrates such as leeches and midge larvae increased from 5 per cent to over 100 per cent.

The impacts of drought on aquatic higher plants

Effects of drought on macrophyte plants usually consist of a shift from an aquatic community to a terrestrial community, dependent on duration and severity of the drought (Westwood, Teeuw, Wade, Holmes, et al. 2006; Westwood, Teeuw, Wade and Holmes 2006; Holmes 1999). Thus there is often little change in total species richness, because plants less adapted to drought are replaced by ones that are better adapted.

Shifts in the plant community can modify channel morphology, particularly when combined with the deposition of sediment and plant litter (Franklin, Dunbar, & Whitehead, 2008). As aquatic plants die with drying, organic material is deposited on the bed and river margins which can act as a source of moist habitat patches, providing some refuge for other biota (Lake 2011).

The impact on plants has knock on effects because they are a source of food for some invertebrates, and more importantly, provide habitat for invertebrates as well as cover for juvenile fish (Wright et al. 2002). Plants use a range of strategies to resist drought: changes in osmotic physiology, cell turgor, stomata opening and leaf orientation (Romanello, Chucchra-Zbytniuk, Vandermer, & Touchette, 2008; Touchette, Iannacone, Turner, & Frank, 2007). Plants can also avoid drought through propagules and seeds which allow the plants to re-establish from a seed bank stored in benthic sediments which remain viable for several years. These seeds do not always germinate immediately on rewetting so seed banks provide a refuge from supra-seasonal drought (Brock et al., 2003). However, some systems recover rapidly, waterborne stream flora for example re-establishes itself soon after inundation (Holmes 1999; Wright et al. 2002; Westwood, Teeuw, Wade, Holmes, et al. 2006). Recovery of plant assemblages can, in part, be limited if fine sediments have been deposited on the river bed during drought (Franklin et al., 2008). Holmes (1999) found that some plant communities shifted permanently after drought, and never returned to pre-drought conditions but that this was dependent on site characteristics and on the pre-drought community structure, making generalisations and predictions difficult.

UK quantified examples

In a chalk stream during the 1976 drought, Wright and Berrie (1987) observed that 96 per cent of the stream bed was covered in fine silt. This reduced the plant populations with reductions in plant cover ranging from 40 to 100 per cent. On the river Lambourn, Wright and Symes (1999) observed that plant cover was reduced by just fewer than 60 per cent during the 1976 drought and that full recovery had taken place by the following year. In more degraded streams and rivers, the impacts of drought are less obvious. Wright et al., (2002) observed no significant change in plant species richness in the River Kennet during the 1976 drought and assumed this was because the community had already felt the impact of other factors so that diversity was low in this system.

The impacts of drought on aquatic algae

In the UK, only a few deep, wide, slow flowing rivers have significant planktonic algae, that is, floating in the water column. It is known that these can bloom when flow is reduced or temperature increases, so may bloom during droughts. The dynamics are poorly understood because of the catchment-wide influences that operate in this type of larger river. Though an important source of food in river ecosystems, attached algae have not been studied with regard to drought. However, as many grow on higher plants, there is a clear route of impact if higher plants are reduced by drought.

Most streams and rivers are characterised by algae that attach to stones, plants and debris. At drought onset, low flows and higher nutrient concentrations can initially promote algal growth (Wade, Whitehead, Hornberger, & Snook, 2002). Low flows cause a shift from assemblages dominated by diatoms to assemblages dominated by filamentous green algae; there is thus a net increase in algal biomass (Suren et al., 2003). Once flows decrease past a threshold, the higher concentrations of nutrients and elevated temperatures can lead to algal and bacterial blooms leading to eutrophication (Kinzie et al., 2006). As the wetted habitat decreases, biofilms become exposed and desiccation starts to occur (Ledger, Harris, Armitage, & Milner, 2008); at this stage there is a shift back to assemblages dominated by diatoms (Caramujo, Mendes,

Cartaxana, Brotas, & Boavida, 2008).

Algal biofilms resist desiccation using extracellular mucilage layers, and the formation of cysts provides an avoidance strategy (Stanley, Fisher, & Jones, 2004). Remnant pools may also provide refuges (Robson & Matthews, 2004). The rate of drying is critical, rapid drying kills algal cells and impairs desiccation-resistant strategies (Ledger & Hildrew, 2001). Re-wetting often sees rapid recovery of the algal biofilm from surviving cells, cysts, and from propagules in the drift if upstream reaches have remained wet. If remnant pools persisted throughout the drought they also act as sources of re-colonisation.

The only adequate before-after drought data for the UK is provided by (Ledger & Hildrew, 2001). This describes the complete loss of filamentous green algae with drying, and its replacement by a diatom dominated community. The algal community recovered within one month of re-wetting with most of the recovery occurring within a few days. An important aspect was that the drought broke with a spate, sloughing off the diatom biofilm and promoting re-colonisation.

Wetland ecosystems

There are few specific studies on the effects of droughts on wetlands (Acreman et al., 2012; Edwards et al., 2012). Those that do exist are mostly from more traditionally drought-prone regions such as the Mediterranean and the Murray-Darling basin in Australia and tend to deal with impacts of drought and levels of drought that are not particularly relevant to, nor foreseen, in the UK.

Initially, a broad sweep of the available literature was conducted alongside the information already available in Acreman et al. (2012). A Web of Science search for ‘Drought’ and ‘Wetlands’ generated 702 results. Of these, 118 were selected on the basis of their title. The abstracts of the 118 papers were read and 20 papers were shortlisted for this study: only two are from the UK.

The following provides a summary of the studies that were available. The hydrological preferences of various wetland plant communities were studied in (Wheeler, Shaw, & Tanner, 2009). This work also attempted to quantify the extent to which a vegetation community can withstand non-ideal conditions. Green, amber and red zones are defined for each community studied, and these relate to different water levels at different times of the year with green being optimal conditions, amber being sub-optimal and red being non-favourable.

Freeman et al. (1993) carried out experiments in a gully mire in Wales to look at the impact of lowered water level conditions, that is, artificially simulating drought. A significant increase in soil temperature at 10 cm depth was detected in the lower water level condition, and the implication of this is that increased microbial activity is likely to occur. This could lead to substantial mobilisation of materials that would normally remain sequestered within the peat. The average difference in water table elevation between the control (non-lowered water table) and experiment (lowered water table) was 5 cm.

Given this shortage of UK-based peer review literature it was decided to go beyond the few available studies and use expertise available within the Centre for Ecology and Hydrology instead. To do this, interviews were conducted with an in house specialist respectively for birds, vegetation, invertebrates and soils. Each specialist was asked for a summary of effects of drought in the UK in their specific topic area. Below, a summary is provided of those interviews describing the main environmental effects.

Impact of drought on wetland birds

Input from Dr. Shelley Hinsley, Centre for Ecology and Hydrology.

As the area of open water in the wetland reduces and is finally lost, there is a loss of aquatic species, for example, ducks, grebes, and of semi-aquatic species such as moorhen. Reduced viability of fringing vegetation could have an impact on the range of species, such as the reed warbler, sedge warbler, as well as other species, by damaging their food supply. Shrinkage of water bodies exposes nests to terrestrial predators and may also reduce safety of roost sites, including non-aquatic species such as swallows and martins. There may also be reduced availability of aquatic invertebrates, for example, mayflies, and in the extreme may result in fish mortality. Reduced connectivity between water features will also result in an increased risk of mortality and loss of body condition, if species are forced to disperse from a degraded or dried up water body.

Increased concentration of waterborne pollutants will increase the risk of direct toxic effects and the risk of loss of plant and invertebrate food supplies. This could also cause a possible loss of cover. Increased turbidity in the remaining open water could decrease hunting success in visual pursuit predators, for example, grebes.

A reduction in available soil moisture, due to both a greater depth to the water table and increased evapotranspiration demand at the surface, will have direct effects on vegetation which will in turn reduce food supply for herbivores and cover for nests and roosting. There will also be knock-on effects on invertebrate prey species. Less frequent delivery of nutrients to the surface and oxidation and subsequent loss of organic soil will only exacerbate these vegetation related issues.

As the soil dries to the point of becoming impenetrable there is a direct effect on bird species, for example, snipe and thrushes, feeding on soil invertebrates as their prey become inaccessible. This may also leave the soils less able to absorb water and re-wet, resulting in long-term habitat damage.

Impact of drought on wetland vegetation

Input from Dr. Owen Mountford and Dr. Chris Preston, Centre for Ecology and Hydrology.

With a reduction or loss of open water there should be an at least temporary increase in the proportion of drawdown species, mainly annuals or ephemerals with a ruderal strategy, that colonise the drying soil. This open habitat will also be colonised by competitors with a strategy for rapid vegetative spread, for example, rhizomatous and stoloniferous grasses such as *Agrostis stolonifera*, assuming they are part of the vegetation surrounding the open water. In the open water areas, there will be an adverse impact on species of permanent water, however, probably having little impact on species of shallow water and moist soils that are adapted to withstand fluctuating water levels. In prolonged drought scenarios those species can be affected as well. These conditions may be good for ephemeral species which are adapted to complete life rapidly on exposed mud.

If the drought results in increased concentration of waterborne pollutants, there could be some impacts upon terrestrial wetland plants through increased nitrogen, phosphorous and potassium levels, increased alkalinity and high pollutant levels, favouring those species adapted to eutrophic or alkaline conditions. These chemical changes are also likely to favour various algae which may produce ‘blooms’ under drought conditions in receding pools, reducing light to aquatic vascular plant species and shrouding terrestrial plants.

Highly eutrophic groundwater will affect the soil microbial biota, altering nutrient dynamics and availability for vascular plants. There is a suppression of wetland microbial activity during drought, leading to reduced consumption of inorganic nutrients. The direct stress of drought on vascular plants leads to reduced release of dissolved organic carbon, further reducing microbial activity.

A reduction in available soil moisture and a deeper water table could make the plants unable to abstract water from the soil and reach their wilting point, closing stomata and unable to perform gaseous exchange: should this continue, a permanent wilting point may be reached followed by death. The impact on plant assemblages will be to disadvantage shallow-rooted species and those without physiological adaptations to drought, altering the community structure. At least temporary effects on wetland species of marshes and swamps would be expected, but it is uncertain whether these would be affected more permanently; this depends on extent and frequency of droughts.

In a long-term study of fen hydrology and vegetation, Large *et al.* (2007) found that the vegetation communities at Newham Bog in Northumberland recovered gradually in the period from the dry conditions of 1994, 1995 and 1996, each equating to a 1 in 50 drought event, to the wetter conditions experienced from 1997 to 2002. The suggestion from this work is that an assisted natural recovery can help to limit the negative impact of drought.

Impact of drought on wetland invertebrates

Input from Dr. Miles Nunn and Dr. Dave Spurgeon, Centre for Ecology and Hydrology.

For mosquito species which lay their eggs in permanent water bodies a reduction in open water would decrease available habitat and might increase competition between larvae to a sufficient level to negatively affect adult abundance. For species which lay their eggs on land and wait for water levels to rise, prolonged drought would result in eggs starting to die and may lead to a reduction in mosquito abundance. However, reduced connectivity between water features may enhance mosquito larval survival since many species prefer isolated water features that may have a reduced number of predators.

A reduction in available soil moisture is likely to have an impact on the survival rate of adult mosquitoes as survival is related to air moisture which will have a relationship with soil moisture. In general reduced moisture will decrease adult survival, though effects will be different for individual species.

As soil becomes impenetrable, soil invertebrates such as earthworms and springtails will move to deeper soil layers or enter diapauses. This has negative impacts on survival and reproduction of the relevant soil species resulting in longer term declines in population size; fragmentation rates of deposited leaf litter; access of bird and mammal species to suitable food source potential during times when they have young; and soil porosity as burrow structures are lost, but not formed.

With continued loss of soil structure, soil microbial communities become inactive. This affects rates of carbon mineralisation, rates of cycling of key nutrients including nitrogen and phosphorus, potential for degradation of complex organic chemicals including deposited air pollutants and pesticides, and soil food webs and energy flows.

Moorcroft *et al*. (2002) studied the effects of the 1995 drought on various UK insect and plant species.

Although this did not focus on wetlands it is possible that some of these results are applicable to wetland systems, at least in medium intensity and duration drought events. In the case of more severe droughts, particularly those where soil structure is affected, the results may not be applicable. In general, similar numbers of carabid beetles increased as decreased over the drought period, however the decreasing species tended to be associated with lower temperature and wetter soils. It may therefore be the case that drought conditions could increase beetle populations in the short term.

Impact of drought on wetland soils

Input from Dr. Emma Sayer, Centre for Ecology and Hydrology & The Open University; Dr. Owen Mountford and Dr. Chris Preston, Centre for Ecology and Hydrology.

A reduction in available soil moisture will lead to increased oxygenation of the soil leading to microbial oxidation and enhanced activity of aerobic microbes. This in turn will lead to increased release of carbon and nutrients through mineralisation of organic matter, and large losses of carbon and the potential for large pulses of nutrients to leave the system.

Greenhouse gas fluxes from wetlands, particularly methane and nitrous oxide, have been studied in the UK. The results indicate that carbon flux from peatlands is likely to decrease under climate change (Freeman et al., 2002; Worrall et al., 2007b), largely due to a reduction in water logging and subsequent methanogenesis. A study of nitrous oxide emissions from peat monoliths (Dowrick et al., 1999) suggested that there was an exponential increase in emissions with a linear decrease in water table elevation.

Oxidation and subsequent loss of organic soil is especially notable where drought leads to vegetation death exposing the organic soils and accelerating oxidation and loss. In an extreme situation ‘fen blows’ have been a characteristic of the drained wetlands of eastern England resulting in soil wastage and exposure of the underlying mineral layer which may not be so conducive to growth of crops and wetland vegetation. Erosion and loss of the soil carbon and nutrient store creates conditions inimical to vascular plant growth, severely affecting the obligate wetland plants. In extreme cases, this might lead to wetland destruction and development of completely new vegetation types, if any at all.

Appendix 4 Detailed impacts of drought on PWS

Approach

The water company drought plans (DPs) accessible to the project team during 2012 contain a range of demand side and supply side information directly related to the project's baseline and extended drought scenarios. In these plans, the potential savings in demand from demand side management actions are estimated as a proportion of peak period distribution input (DI) or water demand values, by reference to one or a combination of the following UKWIR documents: UKWIR 2011, UKWIR 2007, UKWIR/EA 2006, EA/UKWIR 1998, and UKWIR 1996.

In order to develop the project's data sets for economic modelling, we used the Environment Agency's Head Office Drought Plan and water situation reports, with information on stages of drought and the associated national and regional regulatory actions, to check the provenance of the water company's generalised drought plan information.

The water industry sector covers the activities of 23 water companies. The most complete and consistent information source for water demand as distribution input is the report Security of Supply, Leakage and Water Efficiency 2005-06, produced by Ofwat in 2006 for the water industry. The report was compiled following the 2003-06 severe, multi-season drought that seriously affected the South East of England.

The Ofwat distribution input information dated November 2006 was updated with detailed information from the water companies interviewed during the project. The companies interviewed were Thames Water, Anglian Water, Southern Water, Sutton & East Surrey Water and United Utilities, see Appendix 6. The detailed information provided by the interviewees incorporates factors that relate annual average distribution input values to peak period and monthly values.

Of the water companies interviewed, Thames Water provided a detailed, company-specific data set for the baseline scenario and for any drought scenario such as the extended scenario. Thames Water's drought management actions are linked to the lower Thames control diagram and the lower Thames operating agreement. These data sets were informed by the Thames Water's in-house research and development activities related to estimating the impact of drought management actions on water demand and consumption. Thames Water provided data sets for the London water resource zone, which is typical of highly urbanised water supply areas, and for the Thames Valley zones, which are typical of largely rural water supply areas across England.

The information on demand savings from Thames Water was re-expressed as a proportion of annual average distribution input values based on the volume of water saved during the drought periods of interest for the:

- London zone (urban area);
- Thames Valley zones (rural areas); and
- a notional mixed urban/rural zone. The notional mixed zone has been used to infill missing gaps in the project database of water company drought plan information.

For the demand side actions, the representative urban, rural and mixed urban/rural percentage savings in water demand as a proportion of distribution input have been used to compute and graphically represent the potential demand savings across the 23 water companies of England and Wales.

The most complete and consistent information source for deployable output (DO) or yield of water company sources is the Environment Agency's Review of Water Company Yields document dated March 1998. This was updated with detailed information from the water companies interviewed through the project and by reference to the latest data sets from the water companies' published Water Resources Management Plans accessible during 2012

For the supply side actions, water company information from structured interviews were expressed in terms of changes to company total deployable output associated with each of the 23 water companies.

Capital schemes for extended scenario

The water companies interviewed also provided information on third dry winter capital schemes as well as the deployable output of these schemes for the extended scenario. The capital schemes included are:

- greater conjunctive use of resources and distribution reinforcements – additional transfer pipelines and pumps;
- optimisation of existing sources;
- borehole commissioning works including construction of satellite boreholes;
- lowering of existing pumps at groundwater sources, re-commissioning of disused boreholes and commercial boreholes;
- cut off channel to Stoke Ferry under Drought Order utilising the Great Ouse Groundwater scheme;
- Thames Region's West Berkshire Groundwater scheme;
- additional regional bulk transfers such as: the Anglian Water resource "bumping" from Yorkshire Water, from Yorkshire Water to Severn Trent Water, Severn Trent Water groundwater resource introduced into the River Trent, River Trent to Pitsford (water storage) transfers;
- Thames Water's Deephams reuse scheme, Anglian Water's Flag Fen reuse scheme;
- additional resource to Trent-Witham-Ancholme scheme;
- additional resource available at Cadney to Anglian Water;
- desalination schemes;
- use of tankers to augment local supplies;
- preparatory work associated with the use of Kielder reservoir resource as a potential raw water transfer source from north to south as a longer term option.

For the capital schemes, it is assumed that deployable output and yield gains from some of the schemes, for example the conjunctive use schemes and the effluent reuse schemes, can be claimed relatively quickly as work is already underway to develop these schemes as part of the implementation of water company's investment plans promoted through statutory Water Resources Management Plans. In addition to the published information sources and information from structured interviews, we also carried out limited deployable output modelling to validate water company information on the potential savings as percentage of distribution input and potential deployable output gains and the validity of some of the suggested third dry winter schemes.

Appendix 5 Detailed impacts of drought on agriculture and sports turf

Table 13 lists the variables and values relevant to the cereals sector. Winter wheat is the reference crop for the sector.

Table 13. **Winter wheat was used as a reference crop for the cereals sector**

Baseline variable	Suggested value	Comment	Reference for data source
Crop yield (t/ha)	7.7	Based on 20 year average annual wheat yield in UK from Defra cropping census data. Also coincides with data reported in Nix (2011) on average 2011 yield for winter grown milling wheat	(DEFRA, 2011) (Nix, 2011)
Price (GBP/t)	134	Derived from Nix (2011) yield and output data	(Nix, 2011)
Output (GBP/ha)	1,032	Data reported in Nix (2011) on average GM in 2011 for winter grown milling wheat	(Nix, 2011)
Gross margin (GBP/ha)	606	Data reported in Nix (2011) on average GM in 2011 for winter grown milling wheat	(Nix, 2011)
Cropped area (ha)	Wheat England (1,817,000) Total cereals England (2,594,000)	As reported in Defra cropping census (2012) Data relate to 2012 cropping year	(DEFRA, 2012a)

Source: Cranfield University

Table 14 lists the variables and values relevant to the irrigated crops. Onion is the reference crop for the sector.

Table 14. **Onions (dry bulb autumn sown) were used as a reference crop for the irrigated crops sector (excluding potatoes)**

Baseline variable	Suggested value	Comment	Reference for data source
Water use (m^3/ha)	1,500	Assumes crop grown on low available water holding capacity (AWC) soil in a reasonably arid part of England (agro-climate zone 4). Data taken from EA Optimum Water Use for industry and agriculture report (EA Water Resources R&D Project W6-056/TR	(Rees et al., 2003)
Proportion water use which is abstracted (%)	100	Field vegetable crops in England are predominantly irrigated using water that is abstracted direct, with or without on-farm storage. PWS mains water is not used.	Authors expert knowledge
Consumptive ness	100	Irrigation is predominantly consumptive and applied to increase crop yield and quality. Most lost through crop evapotranspiration (ET)	Authors expert knowledge
Crop yield (t/ha)	41	Normal or average season yield for 2011 as reported in Nix (2011)	(Nix, 2011)
Price (GBP/t)	100	Normal or average season price for 2011 as reported in Nix (2011)	(Nix, 2011)
Output (GBP/ha)	4100	Normal or average season output for 2011 as reported in Nix (2011) based on yield and price	(Nix, 2011)
Gross margin (GBP/ha)	2651	Normal or average season Gross Margin for 2011 as reported in Nix (2011)	(Nix, 2011)
Cropped area (ha)	Onions England (14,000) Total cropped area of field vegetables in England (106,000)	Based on data from latest 2012 Defra June Cropping census survey About 30% of the total cropped area is irrigated.	AHDB HGCA (2012) (DEFRA, 2012a)

Source: Cranfield University

Table 15 lists the variables and values relevant to rainfed potatoes.

Table 15. **Potatoes rainfed in a design dry year**

Baseline variable	Suggested value	Comment	Reference for data source
Crop yield (t/ha)	40	Taken from Table 4-8 (Weatherhead et al., 1997) for rainfed maincrop potatoes in a 'design' dry year but modified slightly based on expert opinion.	(Weatherhead et al., 1997) Expert opinion
Price (GBP/t)	100	Taken from Table 4-8 (Weatherhead et al., 1997) for rainfed maincrop potatoes in a 'design' dry year but modified slightly based on expert opinion.	(Weatherhead et al., 1997) Expert opinion
Output (GBP/ha)	4,000	Derived from estimated crop yield and price data above.	Expert opinion
Gross margin (GBP/ha)	1,161	Calculated based on variable costs (GBP 2,839) given in Nix (2011) for maincrop potatoes grown under a medium production levels	Expert opinion (Nix, 2011)
Cropped area (ha)	57,035	Based on regional industry data from AHDB PCL (Potato Council) for 2009	(AHDB PCL, 2010)

Source: Cranfield University

Table 16 lists the variables and values relevant to irrigated potatoes.

Table 16. **Irrigated maincrop potatoes in a design dry year**

Baseline variable	**Suggested value**	**Comment**	**Reference for data source**
Water use (m^3/ha)	2,400	Assumes maincrop potatoes grown on low available water holding capacity (AWC) soil in an arid part of England (agroclimate zone 6). Data from EA Optimum Water Use for industry and agriculture report (EA Water Resources R&D Project W6-056/TR	(Rees et al., 2003)
Proportion water use abstracted (%)	100	Maincrop potatoes in England predominantly irrigated using water that is abstracted direct, either with or without on-farm storage. PWS mains water not used.	Authors expert knowledge
Consumptive ness	100	Irrigation predominantly consumptive and applied to increase crop yield and quality. Most lost through crop evapotranspiration (ET)	Authors expert knowledge
Crop yield (t/ha)	51	Data from AHDB Potato Council industry statistics for production of 8 maincrop potato varieties grown in 2010	(AHDB PCL, 2011)
Price (GBP/t)	145	Based on averaged industry price data from AHDB PCL (Potato Council) for maincrop potatoes (M Piper) for three different market sectors (chipping, prepack and processing) in 2009.	(AHDB PCL, 2010)
Output (GBP/ha)	7,395	Derived from estimated crop yield and price data given above.	Expert opinion
Gross margin (GBP/ha)	4,556	Calculated based on variable costs (GBP 2,839) given in Nix (2011) for maincrop potatoes grown under a medium production levels	Expert opinion (Nix, 2011)
Cropped area (ha)	64,199	Based on regional industry data from AHDB PCL (Potato Council) for 2009	(AHDB PCL, 2010)

Source: Cranfield University

Table 17 lists the variables and values relevant to strawberries.

Table 17. **Irrigated strawberries in a design dry year**

Baseline variable	**Suggested value**	**Comment**	**Reference for data source**
Water use (m^3/ha)	1,000	Based on strawberry benchmarking water use data from farmer survey conducted by Mark Else (EMR) under Defra project (WU0122)	Knox et al (2012)
Proportion water use abstracted (%)	0.50	There is no known data on the relative proportion of strawberries irrigated using direct abstraction and mains water. Industry estimates suggest a roughly equal split	Authors expert knowledge
Consumptive ness	100	Irrigation predominantly consumptive and applied to increase crop yield and quality. Most lost through crop evapotranspiration (ET)	Authors expert knowledge
Crop yield (t/ha)	22	Based on strawberry benchmarking water use data from farmer survey conducted by Mark Else (EMR) under Defra project (WU0122) Reported yields range from 18-23 t/ha (Nix, 2011)	Knox et al (2012) (Nix, 2011)
Price (GBP/t)	3,000	Normal or average season price for 2011 as reported in Nix (2011) Reported price ranges from 2500-3000 GBP/t	Nix (2011)
Output (GBP/ha)	66,000	Derived from estimated crop yield and price data given above.	Expert opinion
Gross margin (GBP/ha)	12,000	Estimated from reported range in GM for strawberries on raised bed system reported in Nix (2011). Reported GM ranges from 3200-13550 £/ha	(Nix, 2011)
Cropped area (ha)	3,000	Based on data from the 2010 Defra June Cropping census	(DEFRA, 2010)

Source: Cranfield University

Appendix 6 Interview summaries

List of interviews conducted

Table 18. **List of organisations contacted and interviews arranged**

Sector	Organisations contacted	Response	Interview date
Water supply			
	Thames Water	Accepted interview	19/09/2012
	Sutton & East Surrey Water	Accepted interview	10/09/2012
	Anglian Water	Accepted interview	18/09/2012
	United Utilities	Accepted interview	21/09/2012
	Southern Water	Accepted interview	04/10/2012
Agriculture and sports turf			
Rain-fed crops	Home Grown Cereals Authority (HGCA)	Accepted interview	21/09/2012
	NFU	Accepted interview	20/09/2012
Irrigated agriculture	UK Irrigation Association (UKIA)	Accepted interview	19/09/2012
Irrigated crops: potatoes	Potato Council (PCL)	Accepted interview	19/09/2012
	McCain Foods	Accepted interview	21/09/2012
Irrigated crops: field vegetables	Horticultural Development Co (HDC)	Accepted interview	19/09/2012
	G's Fresh	Accepted interview	19/09/2012
Livestock	English Beef and Lamb Executive (EBLEX)	Accepted interview	21/09/2012

	DairyCo	Accepted interview	21/09/2012
Food & beverage manufacturing	Food, drink and retailers (IGD)	Accepted interview	21/09/2012
Sports turf	BIGGA	Accepted interview	20/09/2012
	England Golf	Accepted interview	20/09/2012
Other			
Energy	Energy UK	Accepted interview	31/08/2012
Aquaculture	British Trout Association	Accepted interview	31/08/2012
	Centre for Environment, Fisheries & Aquaculture Science	Accepted interview	03/09/2012
Pharmaceuticals manufacturing	Association of the British Pharmaceutical Industry	Declined interview	
Commercial swimming pools	British Swimming Pool Federation	Accepted interview	30/08/2012
	Chartered Institute for the Management of Sport and Physical Activity	Willing to answer a few questions via email if needed	
Commercial car washing	Car Wash Association	Accepted interview	23/08/2012
Commercial window cleaning	Federation of Window Cleaners	Declined interview	
	British Window Cleaning Academy	Accepted interview	25/09/2012
Waterway navigation, angling, boating	Canal and River Trust (formerly British Waterways)	Accepted interview	12/09/2012
	Association of Pleasure Craft Operators	Declined interview	
Health	BMA	Declined interview	
	Health Protection Agency	Accepted interview	31/10/2012

Local government	Local Government Association	Provided LGA response to National Drought Group and suggested contacts with individual councils	
Water saving appliances	Waterwise	Accepted interview	03/09/2012
Chemicals manufacturing	Chemical Industries Association	Unavailable for interview next few weeks but answering key questions via email	
Households	CCWater	Accepted interview	06/09/2012
Amenity horticulture	Horticultural Trades Association	Accepted interview	10/09/2012

Source: Vivid Economics, Halcrow Ltd and Cranfield University

Interview summaries

Water companies

Introduction

Structured interviews have been conducted with four of the five representative water companies nominated for interviews.

The interviews have enabled the project team to gain useful insights into the vulnerability of different types of water resource zones (WRZs) to single season and multiple season drought events, and obtain first hand operational and planning viewpoints on characteristic drought management responses under the project's baseline and extended drought scenarios.

The interview discussions focussed on five areas related to the project's assessment of drought impacts in England and Wales. These are: vulnerability of WRZs to drought events, modelling of drought impacts, costs and financial liabilities associated with drought events, baseline drought impacts and lessons learnt and extended drought impacts and potential measures. Information gained through the interviews and information expected are summarised in below.

Costs of drought management responses

The scale of operating expenditure (OPEX) and capital expenditure (CAPEX) associated with the water company's drought management responses is directly linked to the vulnerability, expressed as level of drought resilience, of water company resource zones (WRZ). This is in turn linked to the mix of sources within a WRZ and the susceptibility of different source types to single season or multiple season droughts. An example is pumped storage into reservoirs, making use of drought permits to extend the reservoir refill

period beyond the period stipulated in abstraction licences. This involves operational expenditure to cover the costs of obtaining a drought permit, the cost of pumping, and enhancements to the linked water transfer infrastructure.

Significant parts of the water industry are vulnerable to the project's baseline and extended drought scenarios. Most of the existing water supply systems are robust to one to two dry winters but not three dry winters. There have been a number of historical droughts, see Appendix 2, that have affected the existing water supply systems, notably during the 1920s, 1930s, 1940s, 1970s, 1990s and more recently in 2005-06 and 2011/12. All of the historical droughts were characterised by a prolonged period of around six to 24 months of below average rainfall and they form the basis for planning water resource needs of most systems. This historical record of drought puts section 2.1 into context. Each of these periods of exceptionally low rainfall has affected water supplies to various extents, with some affecting parts of the supply areas more severely than others. Whilst groundwater sources are thought to be relatively secure against historical drought events, the surface water reservoirs and river intake sources are considered to be more vulnerable.

With the exception of Thames Water, water companies have generally not carried out economic modelling of drought impacts. This could be due to the current lack of a specific requirement in the current guidance and legislation for the assessment of the economics of drought management responses. Some form of economic modelling of a non-essential use drought order for London has been carried out and reported by NERA for Thames Water (NERA: 2006, 2012). Copies of the NERA reports, received via Defra, have been made available to the project team.

Each water company's direct cost for implementing a drought plan under the baseline scenario is around GBP 1–4m. Under the extended scenario, a third dry winter with use of a drought order for non-essential use bans, this rises to around GBP 2–8m.This reflects the increased costs of environmental monitoring, communication actions, cost of permits, additional leakage control costs, bulk supply costs and consultancy fees.

Indirect costs associated with loss of revenue from water demand restrictions have generally not been monetised or estimated. In addition, there are revenue impacts, which reflect a water company's current level of meter penetration and are treated as transfers rather than costs in a cost-benefit analysis.

Since privatisation in 1989, a number of companies have implemented large capital investment programmes to improve the resilience of their water supply systems against severe drought events with a commitment for further future investments to improve the robustness of their supply system in the event of a third dry winter after the baseline drought event. There has been no change in water company practices as a result of the 2011/12 baseline drought, but the baseline drought has reinforced the need for some strategic mains resilience schemes focussed on the WRZs most vulnerable to serious droughts.

Exposure to liability for payment of compensation for restricted supplies under provision of Schedule 9 of the Water Resources Act 1991 varies according to the requirements under provision Q of water company licences applicable to different types of restrictions and the specific categories of water use within agreed levels of service to customers.

Water resource savings from demand side measures

The greatest savings that can be expected from water company's communication actions and customer water use restriction measures are directly related to the customer levels of service. The following water resource savings from demand side measures-related points were established from the interviews conducted to date.

With the exception of Thames Water, water companies have generally not carried out sophisticated direct modelling of water savings from customer water use restrictions. Water companies may argue that there is currently no specific requirement in current drought planning guidance to do so. However, Thames Water has undertaken some in-house stochastic analysis that provides input to its calculation of deployable outputs.

Communication actions within the company's drought plans were fully implemented in concert with the other neighbouring water companies. These include media campaigns and related stakeholder engagement.

Demand side measures include: implementation of temporary water use restrictions (TUBs) with neighbouring water companies, increased leakage reduction through customer-owned pipes and related demand side water transfer infrastructure and enhanced water efficiency measures.

Implementation of TUBs is thought, by two water companies interviewed, to be resource intensive. An issue with the implementation of TUBs is the restriction of all customers, or phased restriction of some categories of customers, over the course of a developing drought event. The contention is that a staged implementation of TUBs would have enabled an improved understanding of the impact of demand restrictions on customers in a progressive fashion, although the need for a common message to all customers is recognised.

Four of the five water companies interviewed have carried out a review of the baseline 2011/12 drought to assess the impact of the implementation of TUB on water demand. A range of savings from three to five per cent has been observed with the level of distribution input associated with period of TUB restrictions. It is generally agreed that the impact on peak demand could be up to 10 per cent of distribution input based on historical analysis of the 2004-06 drought across South East England (UKWIR, 2007).

Under the extended drought scenario communication actions within the company's Drought Plans might be co-ordinated with neighbouring water companies for effectiveness. Media campaigns on water efficiency and using water wisely would be enhanced. Activities associated with customer and regulatory/stakeholder liaison could also be enhanced over and above the baseline scenario levels.

Then, a further TUB could be introduced to include exempted activities and potentially all commercial activities, removing concessions under the baseline scenario. Leakage reduction activities might be intensified as appropriate, by deploying extra find and fix gangs, and through mains replacement and infrastructure renewal solutions. Drought Orders (Drought Direction 2011) would be used as a basis for non-essential use bans. Extensive pressure reduction schemes could be introduced in parts of the distribution network to minimise supply and reduce leakage. This could lead to low pressures in public water supplies in contravention of DG2 performance standards. This measure could affect the efficiency of heating systems, cooling and washing systems, as well as running the risk of back siphoning and infiltration. Emergency drought orders could be used as a basis for rota cuts and standpipes.

Note: water companies were not asked how much revenue was lost due to specific water demand measures introduced.

Water resource gains from supply side measures

There has been no change in deployable output as a direct result of the 2011/12 drought. However, there could be a downward revision to deployable output under the extended drought scenario, with consequences for capital investment planning. Note that, depending on the levels of service and the security of supply offered by a particular water company, this would be dependent on the supply side measures undertaken. It is conceivable that there would be no deployable output impacts without the supply side measures. Supply side enhancements that could be used by water companies include: the use of satellite borehole sources to support vulnerable groundwater sources, lowering of pumps to maintain source yields, re-commissioning of unused company and commercial sources, intra zonal transfers, use of drought permits or drought orders to relax abstraction licence constraints, and reduction or cessation of existing bulk supplies to neighbouring water companies.

Most supply side enhancement measures would be used in response to local water resource problems. Estimates of additional resources that might be available are therefore water company area specific and could be up to 10Ml per day for the water companies interviewed. For the baseline scenario, supply side measures included conjunctive use of resources, use of a drought permit to extend the period of pumped storage reservoir refill, consideration of bulk supplies from neighbouring water companies, full utilisation of any headroom in peak licence entitlements and careful management of any incidental water quality issues.

Under the extended drought scenario, water companies will commence additional conjunctive use of resources where feasible, apply for new drought permits/drought orders with careful management of any incidental water quality issues related to borehole turbidity at groundwater sources and algal bloom at reservoir storage sites. They may also use mobile desalination plants, units which could provide an additional 20Ml per day, set up inter-regional transfer or tankering schemes.

Further information requested from water companies interviewed

Table 19 lists the data and information requested from water companies during or after the interviews. It will be used to estimate the impacts of drought on public water supply.

Table 19. **Further information requested from the water companies interviewed**

	Information
Costs of drought management responses	baseline scenario OPEX and CAPEX information, including construction of satellite boreholes, water transfer/distribution reinforcements, and demand side actions such as leakage reduction and pressure management
	extended scenario OPEX and CAPEX information, including any water supply area specific considerations for the scaling up of the baseline OPEX and CAPEX to meet the extended drought scenario
	the expected value of schemes that are being undertaken specifically in response to the historic droughts
	cost benefit assessment information for drought-related capital schemes
	revenue impacts split by household and non-household customers for the baseline and extended scenarios
	legal status of customer rebate provision due to water restrictions under the authority of a drought order
	unit cost of supply of water
	activity breakdown of the estimated direct cost for the implementation of the company's drought plan under a third dry winter scenario
Water resource savings from demand side measures	information on the types of businesses that make up the water company's non-household customer base
	discussion on pressure reduction and management activities under the extended scenario
Water resource gains from supply side measures	design capacity of drought resilient schemes (this will be used to estimate additional water resources deployable in extended drought scenarios)

Source: Halcrow Ltd

Agriculture and sports turf

Semi-structured telephone interviews were conducted with ten key organisations from a range of sub-sectors spanning the UK food and farming industry. These included both irrigated and rainfed crop production, beef and dairy cattle, vegetable cropping and processing, and the food and drink and retail sector. One interview was conducted with a representative of the sports turf sector. The aim of the interviews was to capture qualitative and quantitative evidence on the business and economic impacts of the recent drought.

Irrigated agriculture and horticulture – interview with the UK Irrigation Association

Water is used in the irrigated agriculture and horticulture sectors to maximise crop yield and quality in high value fruit and vegetable production, over and above that from rainfed cultivation. In national terms, irrigation constitutes a small proportion, one or two per cent, of total water abstraction, but it is concentrated in the driest catchments, in the driest years and at times of year when water resources are most constrained. Many of the crops irrigated are shallow rooting and sensitive to short spells of drought, particularly during germination and development periods when water stress can incur significant financial penalties on final

crop yield and prices.

In 2011/12, the drought had a number of crop specific and regionally focussed impacts, both direct and indirect. After an unusually dry winter, when many (around 300) experienced abstraction restrictions to filling their winter storage reservoirs, the continued dry conditions between January and March 2012 created further problems as growers tried to plan their planting programmes and match these to available water supplies for summer irrigation, as well as considering any potential consequences that any changes might have on supply contracts. Those with filled winter storage reservoirs were generally relaxed about the situation; in contrast, those relying on direct summer abstraction were increasingly nervous. Regular evidence was presented by the UKIA to the National Drought Group on the impacts to irrigators as the drought developed.

There was anecdotal evidence that some growers in drought affected regions cut back on their planted areas by around 10–20 per cent. However, most were committed to their planting programmes, since capital and operational costs for irrigated production are largely fixed and crop rotations provide limited flexibility to switch to less water demanding crops and/or cereals. Many growers had also ordered their seed long before the drought took hold, which committed them to planting. The lead-in time for planting programmes on high value crops such as potatoes and field vegetables is generally around 4 months as seed has to be ordered and crop rotations, rented land and so on, arranged. Earlier drought warnings would help farmers to develop coping strategies for pending drought conditions but would not result in major changes in crop type. For potatoes, there was evidence of some varietal changes regionally to cope with expected drought conditions.

There were some areas where irrigation for pre-planting was used to improve seedbed conditions for crop germination and establishment. Growers also changed to more drought tolerant varieties, where soils/agro-climate and their contract conditions allowed.

The subsequent wet summer conditions exacerbated many of the crop husbandry problems that had been triggered by the drought. The warm temperatures and high rainfall meant farmers used much larger quantities of foliar sprays to reduce crop disease. Wet conditions delayed harvest by up to four weeks and harvesting during wet conditions resulted in soil damage, mainly soil surface compaction.

Farmers were generally positive about the communication of drought information and regular updates received from the EA on local water resource status, and the need for voluntary restrictions in some catchments. Significant progress on such drought alerts to the farming community has been made since the last major droughts in 1995 and 2003.

In terms of other impacts, there was evidence of an upturn in new equipment sales during the winter as many growers prepared for the pending drought conditions, which ultimately did not materialise, although the investment costs then had to be borne by a lower yielding crop.

An extended drought would have caused widespread and significant economic consequences for farms and agribusinesses. Partial and total restrictions on irrigation abstraction would have had an impact on crop yields and prices. Those with storage reservoirs would have benefitted most, due to higher crop prices being commanded for premium produce. Rainfed as well as irrigated crops would have suffered. The 2011 spring drought again highlighted the risks for cereal germination and crop establishment. Irrigation is increasingly

being used on cereals, due to its current high market price.

An indirect benefit is that the drought has undoubtedly raised awareness of the importance of water for national food crop production.

Individual growers and agribusinesses are giving greater thought to investments for improving water security and reducing supply risks. Winter (high flow) storage reservoirs are being widely favoured, either with grant aid but often without. The values (benefits) of irrigation justify investment where resources are unreliable.

Growers are also giving greater thought to working together, acknowledging the business benefits of collective action by either joining existing water abstractor groups (WAGs) or forming new ones. At present, a number of new groups are in formation. Farming businesses are acutely aware of the risks of drought-induced concern up the supply chain and the risks to supply contracts. It seems unlikely that growers will develop drought contingency plans to cope with future droughts. The wet conditions that prevailed and persisted meant any long term memories of the drought and its potential impact on business were quickly washed away.

Livestock

The main impact of the drought was on the supply of grazing and forage. The impact varied across the country. There were two impacts: direct impacts of reduced rainfall on farm water supply and indirect impacts of dry weather on forage and feed.

Direct impact of water supply. The livestock industry uses water from the public water supply and private water supplies. Some farmers have private boreholes, which probably fall below the minimum abstraction rate for licensing, so would not be 'cut-off', but much comes from public water supply. The English Beef and Lamb Executive (EBLEX), were not aware of any restrictions of water use, although it is known that some private water supplies (boreholes) dried up.

In the event of a more severe drought, public supplies for use on livestock farms would presumably be subject to restrictions before domestic customers, and would have a major impact. It is difficult for livestock farmers to respond to short-term restrictions as alternative water supplies, for example, farm ponds, are also likely to be unavailable.

Restrictions in water supply would result in less water available for animal drinking and cleaning of animals and housing, with a potential biosecurity implication. In an extreme situation, farmers would need to reduce herd size by slaughtering or sale of stock to farmers in regions of the country with more water available.

Indirect impact on grazing, forage and feed. The dry weather in the spring resulted in reduced grass growth, reducing the amount of grass for grazing and conservation. The first silage cut in the spring is very important as it tends to have the highest quantity and quality, so reduced grass growth would lead to a reduction in the availability of winter feeds and increased costs of providing alternative feeds. There is no quantitative evidence on the impact of reduced spring grass growth.

Had the dry weather continued, the impact on grazing and forage production would have been much greater.

The impact of drought on cereal production would have increased supplementary feed costs. In reality this has happened as a result of the wet weather and drought overseas in grain producing regions.

Other impacts include: lack of good quality grazing at the time of livestock breeding, when animals benefit from ‘nutritional flushing’, which can lead to reduced animal fertility; reduced growth rates of growing cattle and lambs and a potential increase in animal diseases and parasites, heat stress and sunstroke.

The livestock sector is increasingly aware of its vulnerability to drought. The sector is particularly trying to reduce its vulnerability to fluctuating feed costs by increasing the use and flexibility of home-grown feeds. There is increasing interest in alternative forage species that are more drought resistant, such as chicory, red clover or cereals that have the flexibility to be sold as a grain crop or used for whole crop silage. Farmers are increasingly aware of the need for water efficiency in all areas, particularly with regard to reducing the costs of water and fuel.

Food and drink manufacturing and retail – interviews with the Food and Drink Federation and the Institute of Grocery Distribution

The impact of the 2011/12 drought on the food and drink manufacturing sector was negligible as the drought ended before significant impacts occurred. Many businesses were expressing concern around the end of March and participated in discussions with water companies but were kept well briefed by the Environment Agency on the situation as it unfolded.

The impact of drought on the food manufacturing sector could be seen in three areas: supply of food ingredients, water as an ingredient to processed food and drink and water used in manufacturing processes (sanitation, cleaning, cooling).

Ingredient supply. Food and drink manufacturers generally do not rely on a single source for ingredients so will purchase from a range of domestic and global suppliers dependent on price, subject to its meeting minimum quality standards. The sector is flexible in this respect. As such, the business had contingency plans for sourcing from other areas, in some cases overseas, had there been a disruption of the UK supply chain.

The retail sector was potentially more vulnerable as retailers tend to have direct relationships with producers of, for example, fresh produce. There were some examples of retailers sourcing produce from overseas to compensate for domestic supply, but the impacts of the wet summer were greater than the drought, so it is difficult to estimate the drought impacts on supply.

Water as an ingredient and water used in manufacturing processes. Almost all food and drink manufacturers use mains water as an ingredient and in their manufacturing operations. As far as is known, none were subject to restrictions in the 2011/12 drought. However, the sector is vulnerable to any disruption in water supply, as most food and drink manufacturing businesses operate non-sop production lines that cannot be easily started and stopped. Businesses do not have the ability to change operations, labour, management or supervision at short notice, therefore any disruption to supply may have a more than proportional impact on production. Water is critical to food hygiene. It is difficult to draw water of adequate quality from other sources and there are few opportunities for storage of water in sufficient quantities and

quality to buffer against mains water restrictions.

There is an understanding in the industry that the food and drink industry would have priority over other non-essential uses and would only have supplies restricted in extreme cases.

Some large water using businesses are direct abstractors, such as breweries, meat processors and sugar refiners, and some were asked to make voluntary reductions in water abstraction in the spring of 2012, but there is no evidence that they did so, or on whether these actions were necessary.

The unusual weather conditions in the spring caused a change in consumers' purchasing habits, leading to changes in the demands on the food manufacturing industry. For example, an increased demand for chilled foods in the spring required manufacturers to change productions lines and employ more staff.

Had the drought continued, the impacts may have been much more significant. A reduction in supply of ingredients could have resulted in some food manufacturing companies not being able to meet supply contracts. An increased cost of raw ingredients could have inflated food prices.

Restrictions on water use in the business would have caused some to temporarily cease production or even cease production completely until restrictions were lifted.

Water has generally had a low priority in the food and drink manufacturing sector and water availability has been taken for granted, however, the sector has been looking to reduce water use and improve efficiency for a number of years (for example, the Federation House Agreement) and this is continuing. There is a steady increase in water recycling, water capture and storage in the sector. This results in cost savings for many.

Globally water is increasingly being seen as a supply chain risk at senior level within organisations and is gaining more attention. Some businesses were concerned about the potential impacts had the drought continued.

General agriculture, horticulture and livestock

Dry conditions in early 2011 brought mixed fortunes depending on cropping mixes and location, with real hardships in some commodities in some catchments. Early season conditions were favourable for vegetable and potato planting and the dry weather was beneficial for soft fruit production. By June 2011, the irrigated crop sector in Eastern England was facing difficulties, as irrigation demand intensified and available supplies rapidly depleted. But as often happens, farmers were saved 'just in time' by a prolonged rainy spell.

For rain-fed cereals, yields at harvest were average, saved by late season rainfall. However, for non-irrigated crops on light land, for example wheat, barley, oil seed rape and outdoor herbs, and shallow rooting crops, for example peas and linseed, the situation in May was critical and some trees in orchards were under stress. These crops did not sufficiently recover and resultant yields and quality were poor.

Following a dry winter, the situation steadily deteriorated in early 2012 with the irrigation sector facing acute difficulties. Many farmers were unable to fill their reservoirs during winter 2011/12 and combined with dry conditions forecast for the start of the planting season, some had to re-assess the areas they could plant and

irrigate with confidence; as a consequence cropping changed in drought affected areas. The dry planting conditions also had an impact on cropping decisions for those who would later rely on summer abstraction.

The farming sector developed good working relationships with the EA to mitigate the impacts of the drought. For example, around 400 groundwater abstractors in East Anglia agreed a self-imposed 20 per cent voluntary restriction of licensed volumes to avoid or delay more formal restrictions and potential irrigation bans. Water abstractor groups (WAGS) played a key role in fostering farmer collaboration in managing limited resources at catchment and sub-catchment level.

From March 2012, livestock farms felt the impact in two ways: grass-based systems suffered from early drought-restricted grazing, and housed livestock farmers noted the impact of reduced pressure in public water supplies, feared the threat of supply shortages if drought orders were implemented, and faced the risk of their private borehole supplies failing due to low aquifer levels. For businesses growing 'rain-fed' crops and forage outside of areas affected (south and east) these were no longer in drought after March due to several weeks of steady rain. Heavy and prolonged rainfall coupled with EA flexibility for filling reservoirs relieved the situation and most if not all farm reservoirs were full by mid-July.

The impacts of a third dry winter are discussed in the paragraphs below.

Irrigated crops. In March 2012 the irrigated crop sector faced a perilous growing season. Despite the considerable amount of risk planning and management, for example reduced plantings to match crop need to water availability, it seemed likely that water would run out before the vegetable harvest began with significant (but uncalculated) impacts on yield and quality of fruit and vegetables. Huge numbers of abstractors would have been served with hands-off flow and Section 57 restrictions limiting access to water; although active management by farmers and the Environment Agency aimed to stretch supplies as far as possible. Depending on growing conditions in exporting countries, this could have had a notable impact on UK food supplies and consumer prices.

The longer term anxiety was farming's ability to secure sufficient surface abstraction during autumn and winter 2012-13 to re-fill reservoirs should drier conditions prevail, combined with record low aquifer levels and very high soil moisture deficits. By starting the 2012-13 farming year in a position of 'no water available', many small rural businesses would have faced difficult long term management decisions.

Livestock. A reduction in grass, silage and hay yields and availability could have significantly increased the need for beef and dairy producers to source additional fodder, leading to higher costs.

The indoor rearing of pigs and poultry could have experienced welfare issues relating to continued low pressure in public water supplies, possible public water supply shortages, or interruptions of supply and loss of private borehole supplies due to low aquifer levels and the need to source alternative supplies from elsewhere, possibly a water company.

Rainfed crops. The consequences on cereals and combinable crops are difficult to analyse because of the considerable amount of rainfall which buffered any drought impact. However, it is likely that a continued lack of rain would have resulted in patchy germination linked to lack of moisture in early growth stages and hence more disease. Yields in some varieties could have been reduced due to poor germination and crop

development in the early stages.

Lessons can be learned in several areas, each is discussed briefly: abstraction licence flexibility, collaborative water management, efficiency messages, business planning messages, water abstractor groups, working with non-agricultural users and vertical integration on water issues through the food supply chain.

Abstraction licence flexibility. The EA permitted the filling of farm reservoirs at times of high river flow outside the defined abstraction period. This proved invaluable, gave confidence to farmers that the EA would support their needs when environmentally possible and reflected an increasingly constructive partnership between the sector and water regulator.

Collaborative water management. In managed systems such as the Fens, the Environment Agency, Internal Drainage Boards (IDBs) and farmers worked together to ensure ditch levels remained high to provide water for irrigation without compromising land drainage and flood protection. This approach relied on high levels of mutual confidence and was the foundation on which farmers took day-to-day decisions regarding abstraction.

Efficiency messages. The Environment Agency and farming organisations (NFU, UKIA, CLA) co-ordinated their messages to emphasise the importance and need to use water resources wisely. Clear and consistent messaging was critical, despite the complexity of the message as rain continued from April 2012.

Business planning messages. The EA improved the quality and timeliness of its information to farmers on the severity of the drought based on current information regarding aquifer and surface water levels, SMD, reference to historic events and Met Office forecasts. This was useful for planning farm risk management strategies.

Formation of water abstractor groups. These have existed in some catchments for many years and act as a forum to share information, foster collaboration and as an important single point of contact for Environment Agency communication. Since the drought, new groups have formed in catchments at highest risk of drought.

Working with non-agricultural users. Farmers liaised with other users in some high risk catchments, especially water companies, to understand how they used water and identify opportunities to collaborate on managing limited supply. In future, water companies should ensure that all drought plans undertake an assessment of farming needs, especially regarding the impact and mitigation of impact on housed livestock.

Better vertical integration on water issues through the food supply chain. There is a need to encourage better vertical integration in the food supply chain, among packers, processors and retailers, to help organisations understand better the water management issues at catchment level and to identify mutual dependencies.

Other issues that were discussed include: the support needed for farming to build resilience to extreme events as well as changes in long-term climate; the role of the food processing sector in promoting water stewardship messages to consumers as well as supporting growers; and, the opportunities for water sharing between water companies, farming and the environment. Recent experiences have exposed farmers to a

higher risk in securing water supplies. Summer water shortage is becoming more common and exposes the vulnerability of farming.

Potato production

Irrigated potatoes constitute the most important crop in England and Wales, in terms of irrigated area and total volume of water applied. Irrigation is used to increase yield and quality, particularly for scab control, for potatoes destined for the fresh pre-pack retail market. It is critical for producing tubers of the right size, colour, skin finish and shape with minimal disease defects. Potatoes for processing into chips and crisps are also irrigated to maximise yield.

Overall, the direct impacts of the drought were limited, as the persistent and heavy rains which followed masked many of the impacts that might ultimately have resulted. There was also a sense of relief that prevailed immediately after the drought ended which rapidly diluted any underlying concerns that had been developing during Feb-March 2012.

For many growers, the scope to modify cropping practices in response to the drought, for example planted areas, varieties, was limited given that contracts for retailers and processors are typically set the preceding year and for two years. However, at an industry level there was evidence that planting programmes and varieties were modified slightly to suit regional drought conditions, so that more drought tolerant varieties were targeted to regions where drought severity was greatest.

The capacity for individual growers to change planted areas was limited, and evidence from a grower workshop held in Norfolk suggested that most growers did not change planting areas, but those that did reduced areas by around 10 per cent. A number of growers reported increasing planted area to capitalise on potential market shortfalls in supply.

Material impacts arising from the drought included delays in planting, poorer crop establishment, with consequent knock on effects at harvest, complicated by rainfall. The agronomic impacts of the combined drought and wet summer have led to harvested yields being reduced by an expected range of 10 to 20 per cent, with tubers being smaller in size, and having more common scab defects. Thus the drought has indirectly led to greater variability in crop quality and overall reduced yields. A larger proportion may be sold on the free market where the quality criteria are lower.

A spatial analysis of drought risks relative to Environment Agency defined resource stress is given in Figure 35.

The drought has also raised questions about the viability and desire of growers to tie into long-term contracts where they might default more frequently. Growers are less confident about weather patterns, how production might fare under drought, and what their crop will ultimately be worth, so more growers could potentially switch to growing potatoes for the free market.

Had drought conditions persisted, irrigated potatoes would have suffered from abstraction restrictions. Growers would have allocated their reduced water allocations to a smaller cropped area to maximise yield and quality, but other areas could have been abandoned to rainfed production. Overall, yields and quality

would have felt the impact severely. Only growers with guaranteed water supplies, such as storage reservoirs, would have benefitted from the drought conditions.

For rainfed potato production, depending on the geographical extent of the drought, yields would also have been reduced. This would have had an impact on the supply chain for both processing and pre-pack sectors. Some processors and retailers would have needed to have sought alternative supplies from overseas to buffer shortfalls in UK stocks, increasing dependence on imports. Consumer prices for potatoes would have increased.

There would also be subsequent debate over the societal benefits of irrigating potatoes for scab, since this skin imperfection is aesthetic yet requires large amounts of water to be controlled.

Many lessons have been learned from the recent drought. There is now much greater awareness of climate and rainfall variability, which growers and the industry now acknowledge will have a greater impact on their future planning strategies.

The timing of demand for irrigation, the ‘window’, is likely to change, with an extended season to cater for dry springs and autumns. Additional irrigation for crop establishment and to reduce damage during lifting when harvesting will have implications for abstraction regulation.

Growers and the industry are likely to reappraise available water supplies and their reliability, and re-evaluate the relative risks of potato production.

Supply chains might source or reallocate contracts to growers in less vulnerable water stressed areas or seek confirmation that irrigation supplies are more robust, for example, with access to winter storage.
The industry will encourage growers to make better use of rainfall and modify soil management practices accordingly.

Climate uncertainty is creating new problems for managing risk. The drought impacts are not fully understood and better knowledge of risks to production is needed to improve contingency planning. There is an opportunity to influence growers much more as a result of the drought, particularly with regard to supply chain risks.

Further investment in new equipment such as storage reservoirs to improve efficiency and water conservation is likely. More growers are now better equipped to irrigate and cope with drought and some varieties of crops are better adapted to such conditions. In potato growing for example, more drought tolerant varieties such as Desiree, Harmony, Maris Piper, Safari, Sapphire, Sovereign, Tobina and for pre-pack markets, more scab tolerant varieties are now being grown, for example Sovereign, Lady Clare, Estima, Inca Bella, Melody.

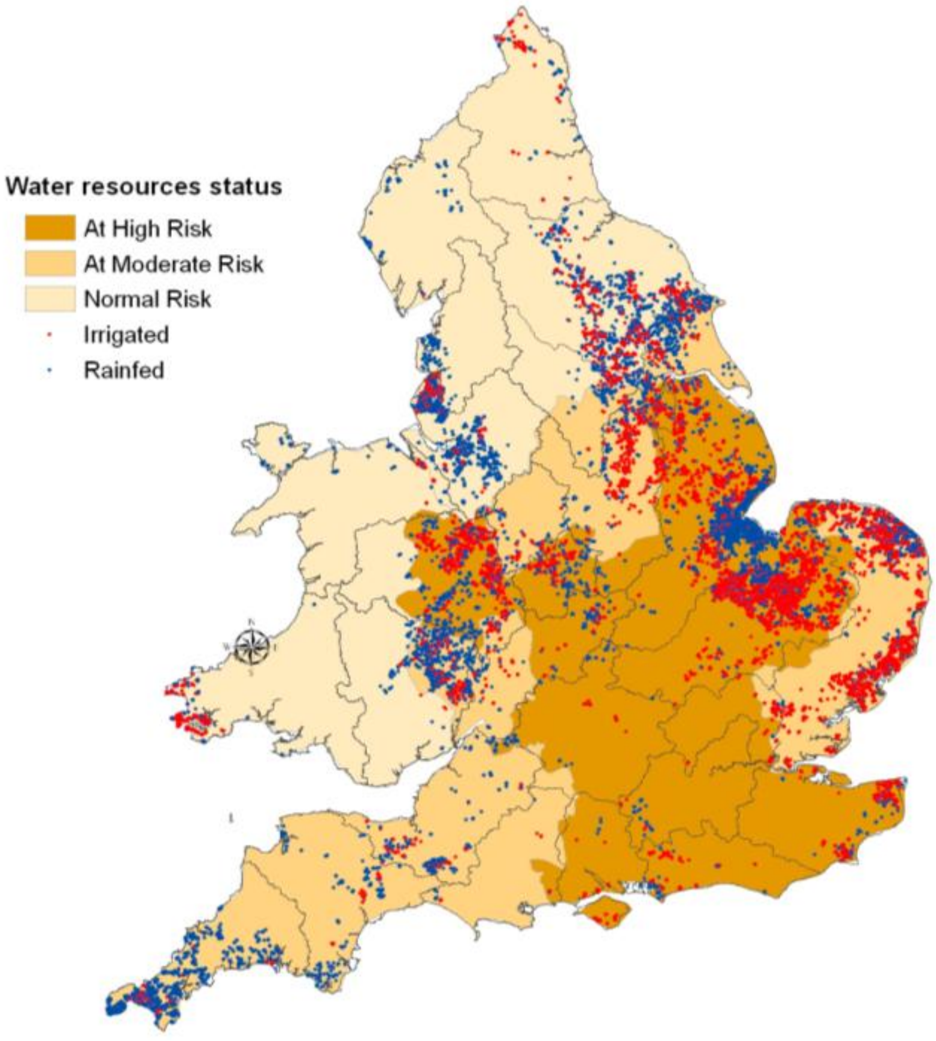
Areas of potato production

Assessing potato production drought risks

Knox et al (2012) estimated that over half (56 per cent) of all irrigated potato fields were located within areas

classified by the EA as being ‘high’ risk, and a third (32 per cent) were at ‘moderate’ risk, see Figure 35 and Figure 36.

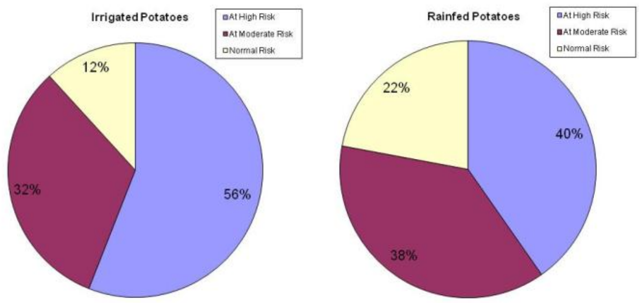
Figure 35. **Spatial distribution of irrigated and rainfed potato cropping in England and Wales relative to EA water resource risk in 2012**



Note: *Red markers indicated irrigated fields and blue markers rainfed fields.*

Source: *Knox et al. (2012)*

Figure 36. **Over half of all irrigated potato fields were located within areas classified by the EA as being 'high' risk**



Source: Knox et al. (2012)

Cereal production

The drought did not have as great an impact on cereal crops as it did on other crops, such as potatoes and field vegetables, since the rain came at the right time in the growing season. In fact too much rain became a bigger problem for cereal growers. There was sufficient water in the soil for crop demands. However, as crops developed in the spring their demands increased and with regular rainfall crop yields were largely unaffected. The dry soil surface was a problem for nitrogen applications, and experience from the dry spring in 2011, when there were severe delays in nitrogen uptake, is encouraging more farmers to apply nitrogen earlier.

Material impacts included increasing costs of production from higher fertiliser application, declining yield and quality, soil degradation and water pollution. All these impacts have economic impacts on farm businesses, which will require larger capital investment in the longer term. Rainfall at the end of May and June was beneficial to most crops, allowing uptake of nitrogen and boosting yield prospects during the grain fill period. The exception was barley on light land in the driest regions which had started the ripening phase prior to the rain arriving.

The soil moisture status and its potential impact on yield was an over-riding concern, and impacts from weeds, pests and disease were small in comparison. There was considerable uncertainty about yield depending on soil type, local rainfall and crop management.

Other impacts included increased manure and fertiliser applications as a response to reduced nutrient uptake, reduction in water quality which increase their cost of production.

An extended drought would have caused major yield losses. As the cereal cropped area expands onto less suitable land, it is likely that more cereal crops will experience drought effects, particularly in the main wheat growing areas in eastern England. A stressed crop uses resources inefficiently and consequent returns on inputs would have been much lower.

There was little that could be done to manage the drought for cereal growers in the short term, as irrigation is not a widespread option yet. However, after recent experiences of two dry springs many cereal growers are reconsidering the benefits and costs of cereal irrigation.

Some farmers with spare capacity have the potential to irrigate. For example, one farmer in Norfolk irrigated barley in March and the yield increased to nine tonnes per hectare, while the UK five-year average yield is 6.3 tonnes per hectare, equivalent to more than EUR 600 per hectare extra income at today's price. In the long term, investing in improved water use efficiency and drought tolerance in UK winter wheat varieties is likely to prepare the industry for more frequent drought events in the future.

Field scale horticulture and salad production

The UK field vegetable sector is valued at approximately GBP 690 million per annum in sales and covers an area of over 130,000 ha. Irrigation is essential.

Growers are familiar with climate uncertainty in horticultural production, as it can have major impacts on many of the short season crops that are typical in this sector.

By mid-March the drought had started to create concern in the supply chain and some retailers were clearly reacting to widespread media coverage of the drought in a disproportionate way. Growers continued to manage and monitor the situation carefully and fine tune planting programmes to match water availability. By early spring, some of the early plantings were starting to suffer, but there was more concern over the impact of the drought on planting and maturity programmes to ensure the time of crop availability could meet peaks in consumer demand.

Growers who had rented land were in discussion with landlords regarding how summer water allocations might be split or reallocated were drought conditions to continue, and partial bans on abstraction enforced. The 'rented land' scenario in horticulture limits optimisation of resources under conditions of water scarcity - an important issue for future drought planning.

In terms of production, most growers followed their original planting programmes, although some reduced their cropped area by 5 to 10 per cent. This avoided having to reduce cropped areas later in the season if drought conditions continued and water supplies ran out. This would have had expensive consequences on the agribusinesses involved.

Planting programmes were modified slightly to reallocate short season crops to geographical areas where it was felt that the drought risks and their impacts might strike soonest. Longer term crops were allocated, within constraints of cropping rotations, onto land where the longer-term drought risks were considered to be less significant. Matching crop growing periods to drought risk was a sensible strategy but ultimately not needed, given the onset of the summer rains.

There was also evidence of discussion between growers to consider options for sharing and/or trading water, where farms were not likely to be fully committed on their resources.

Many horticultural crops actually benefit from periods of low rainfall where supplemental irrigation is then used to manage soil moisture conditions more actively to provide optimal growing conditions. But extremes in drought and then excesses of rainfall created much greater problems, notably crop variability. This is a major problem for field-scale horticulture where crop consistency and uniformity are of paramount

importance for supplying premium quality, consistent supplies into the major retailers and processors. In 2012, the cumulative effect of drought and rainfall masked any direct impacts of the drought on crop yields and prices, but overall the evidence shows that yields are generally reduced, and crop variability is significantly higher.

Other impacts were noted. The uncertain weather conditions created additional problems for growers managing planting programmes to match expected supplies to demands. Had weather conditions changed dramatically during the summer, that is back to drought, then this would have created temporary shortfalls in supply due to planting programmes and much slower rates of crop growth during the wet weather. Matching supply to demand is a major challenge for short season, short shelf-life products.

Had drought conditions persisted, there would have been major impacts on growers dependent solely on direct summer abstraction. Partial or total (Section 57) bans on abstraction would have had an impact on crop development, growth and yield. Those with winter storage reservoirs would have been less exposed to these impacts, although most growers only have storage capacity to meet a limited proportion, say up to 50 per cent, of their total seasonal water needs.

In terms of lessons learned and outlook, as in previous drought years, this drought highlighted the business risks for growers dependent on direct summer abstraction. There is evidence that storage reservoirs are now a priority adaptation measure to cope with future increased water scarcity.

It is evident that a divide exists between the long term view of growers and the shorter term perspective taken by retailers and the supply chain. The recognition that water is a key determinant in providing high quality, continuous supplies of produce to the major multiples is still not yet fully appreciated.

Sports-turf (golf)

Managed turf areas such as golf courses, sports fields, racecourses and stadia are sensitive to drought stress, even over short periods. In contrast to agriculture where irrigation is used to maximise crop yield and quality, the main objective of sports-turf irrigation is to produce safe, high quality playing surfaces. In golf, watering serves to maximise playability and bounce. On racecourses, it is used to control the ‘going’ or soil moisture levels to provide optimum racing conditions, and importantly to minimise rider injury risks.

About half the 2000 courses in England and Wales are dependent on mains water supply. The impact of the 2011/12 drought on the golf industry had important agronomic and economic outcomes. The dry summer conditions during autumn 2011 meant that fine turf watering continued for a much longer period than would typically have been undertaken. The season over which irrigation is now required is stretching. In 2012, watering recommenced in February and March, much earlier than normal. Greens were hand watered rather than using automated irrigation systems due to frost risks in buried pipe infrastructure.

When TUBs were enforced, all relevant water companies imposed ‘non-essential’ use bans on golf clubs. There were no concessionary allowances. Golf courses responded by reducing cutting and maintenance programmes on fine turf areas; with higher mowing heights to reduce drought stress on turf. This led to sub-optimal playing conditions, leading to a downturn in the number of players. It is estimated that a third of all courses were affected, approximately 700 to 1,000, many more than in 2006. A spatial analysis of drought

risks relative to EA defined resource stress is given in section Figure 37.
There were also knock-on drought impacts on club business; with reduced visitor numbers, income from both food and beverage catering (clubhouses) and sales of equipment (professional shops) were all noticeably down. This occurred during the peak season for golf, May to July, so were likely a combined response to the rain and the sub-optimal playing conditions.

Had the drought continued, the impacts would have been significant. Many golf courses would have lost valuable fine turf areas, which would then needed re-construction; USGA green construction costs are GBP 5,000 per green; on an 18 hole course this would constitute a major cost. Visitor numbers would have declined, due to poorer playing conditions, much as they did in 2006. Without good quality playing surfaces, courses have limited alternative means for generating income and a number of courses would have closed. Economic losses would extend well beyond any period of restrictions. Relatively small quantities of water would be required, but with important social and economic benefits.

There is widespread misconception that sports-turf irrigation is primarily for aesthetic purposes, and hence 'non-essential' during drought periods. All water companies during the drought still viewed golf course irrigation as 'non-essential' despite its importance for business sustainability, for example in rural areas, golf courses are important local employers. The lesson learned is that the water companies still view golf as a 'non-essential' use, despite the high value of water to this sector. The golf industry will continue to pursue concessionary allowances for golf couses maintain their fine turf green areas during periods of water restriction. Without any concession, golf courses will need to consider investing in alternative sources to buffer the impacts of future droughts. Most golf course irrigation is for greens and tees only, so full fairway systems are the exception. Under drought conditions, course managers usually leave fairway grass cutting heights higher (less stress) and focus limited water resources on the fine turf on greens and tees and approaches.

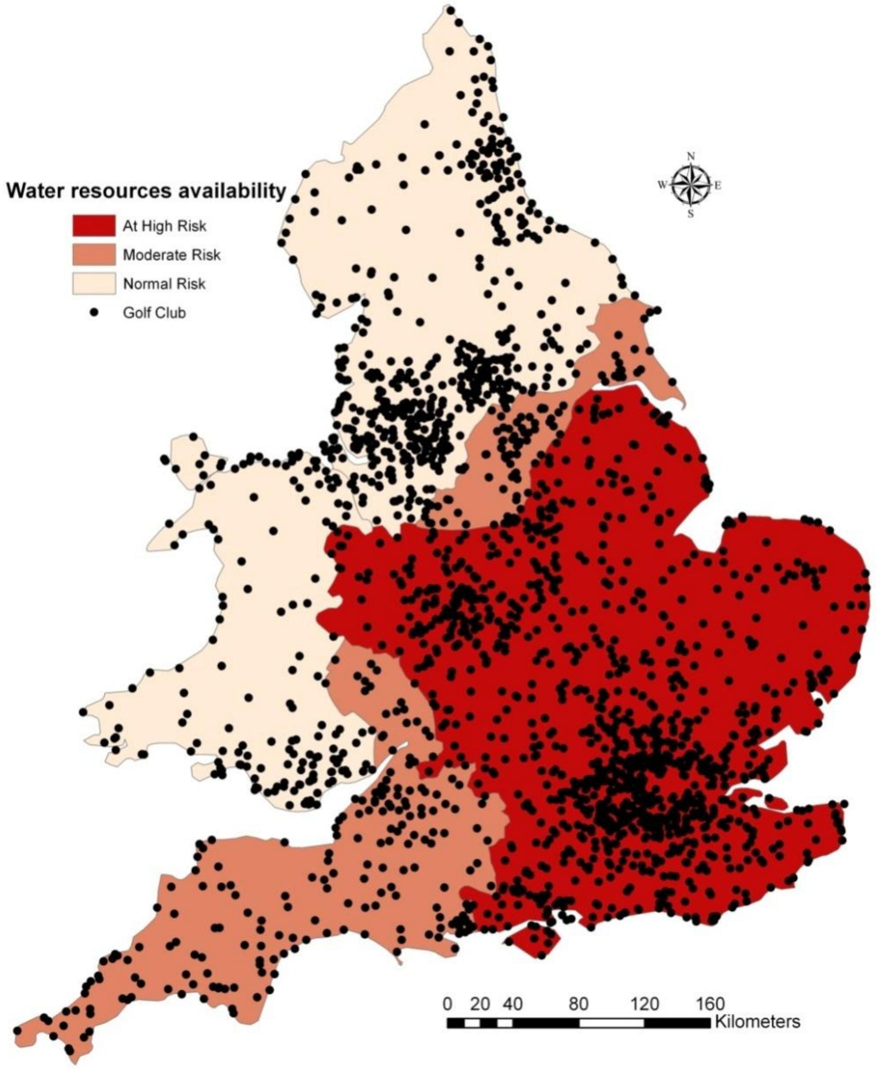
Recurrent droughts and floods have had serious ramifications in the golf industry. Capital investments in new technology and infrastructure such as winter fill reservoirs, improved irrigation systems, are currently at a very low level. The incentive for investing in water conservation measures and/or new drainage infrastructure to cope with higher rainfall peaks is low, given the current economic uncertainty and viability of many golf courses.

Golf course locations

Assessing golf course drought risks

There are approximately 2000 golf courses in England and Wales. The majority irrigate only the fine turf areas (greens and tees) covering 1-2 hectares on a typical 18-hole course. By combining information on golf courses location with water resources' risk data from the EA, the number of golf courses in areas of drought risk has been estimated. The analysis suggests that over half (55 per cent) of all golf courses were located in areas classified by the EA as being 'high' risk, and 14 per cent were at 'moderate' risk, see Figure 37.

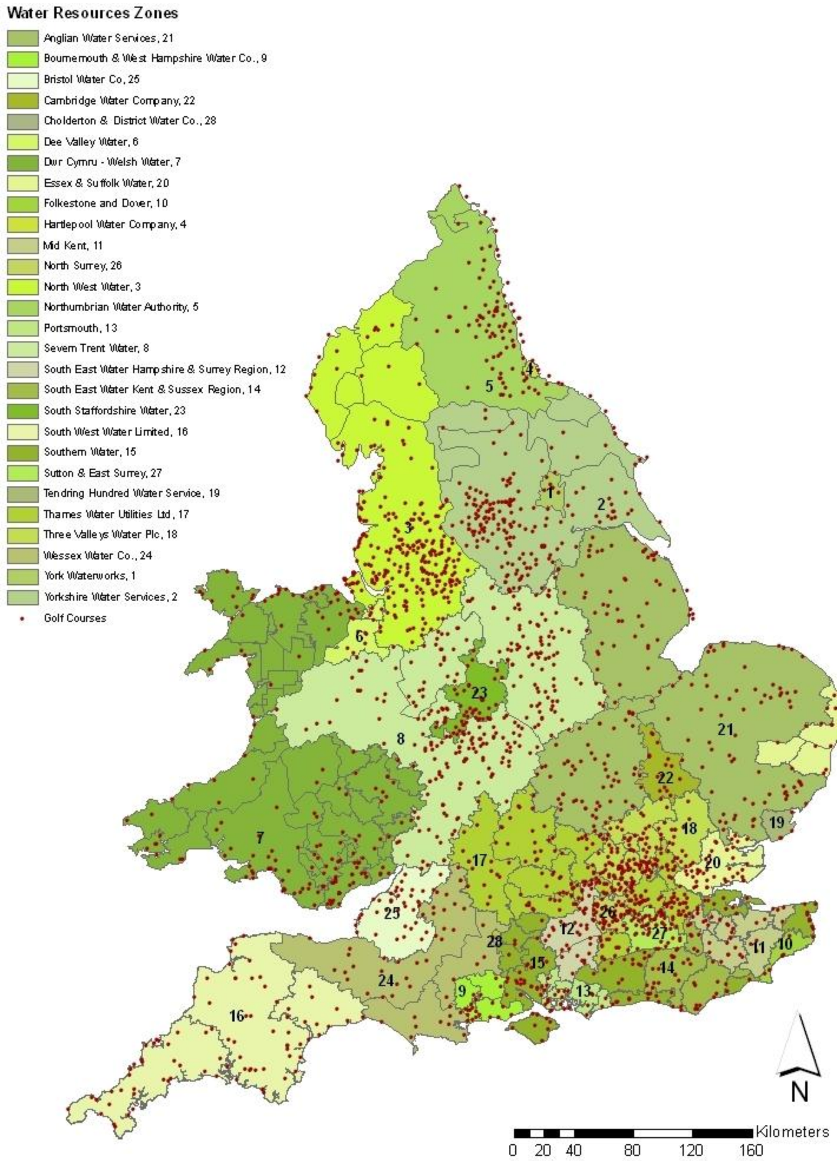
Figure 37. **Spatial distribution of golf courses in England and Wales relative to EA defined water resource/drought risk in 2012**



Source: Knox et al. 2012

Nearly half of all golf courses are dependent on mains water supplies for irrigation (Knox et. al., 2009). By combining information on golf courses location with data on water resources zones for water companies where drought orders or hosepipe bans were enforced on 5th April 2012, the number of courses subjected to 'non-essential' bans has been estimated, see Figure 38. The analysis suggests approximately 15 per cent of all golf courses were in drought affected 'hosepipe' ban areas in April 2012.

Figure 38. **Spatial distribution of golf courses in England and Wales relative to water company water resources zones (WRZ) in 2012**



Note: *Veolia Water Central and Veolia East replaced Three Valleys Water and Tendring Hundred Water Service, more recently (June 2012) acquired by Rift Acquisitions.*

Source: *Knox et al. 2012*

Other sectors

Energy sector

The energy sector is an important abstractor of water; which is used for cooling in thermal power stations and for hydropower generation. Other forms of cooling are available, for example air cooled condensers, however, these cool water less efficiently, which has a direct impact on the overall electricity generating

cycle efficiency. Indeed, the use of water for cooling has, for the past few decades, been determined by national regulators as the Best Available Technique, in most cases, for minimising the impact of power generation activities on the environment, when taken as a whole, provided the localised residual effects on the aquatic environment are judged acceptable on a case-specific basis.
During the recent drought, there were no direct impacts reported at sectoral level. If the drought had become more serious, there would have been a gradual reduction in output at thermal power stations. In this situation, the cost per MWh of electricity produced would have gone up due to the fact that efficiency falls when a plant is running at part load. Therefore, if a power generation company has a portfolio of stations, as do the majority, with contracts in place to generate, they may choose to switch load to a sub-set of stations rather than run stations at part load. These would be less preferred, on economic grounds, in the absence of the abstraction restrictions.

The former Association of Electricity Producers produced a report in 2010 on climate change adaptation measures, which included a high level discussion on the effects of drought. The report analysed all stations that had potential licence restrictions (hands-off flows) and concluded that even if all were constrained, there would not be an interruption to electricity supply, even if those power stations were forced to shut down. If all stations in the thermal fleet had hands- off flows (not all power stations currently have them), then the conclusions would have been different. Water abstraction reforms might result in more restrictions being added to current licences.

Water availability and uncertainty over licence conditions affect investment decisions. It could be that with lower environment flows and increased restrictions on abstraction, further development in the industry is driven towards estuaries and coastal areas; however, there are risks associated with this strategy, such as losing the benefit of existing infrastructure, higher grid connection costs and planning approval difficulties. European legislation to protect the marine environment could add a further layer of complications.

The industry feels that in the future there should be more information provided by the Environment Agency on the evolution of drought; power stations with hands-off flows on their abstraction licences in particular need to know if drought conditions are likely to worsen, as contracting for power generation is done in advance. To facilitate this, information provided by the Environment Agency on predicted flows should be improved and made more accessible.

Households – Consumer Council for Water

Survey evidence suggests that households did not change their lifestyles significantly after the introduction of temporary use bans; around sixty per cent of respondents declared they were not using less water than usual (Ellison, 2012). There is no indication that households have made direct changes in investment as a result of the drought.

During the drought, affected households proved to be understanding. The consumer body does not know how customers would react to more extreme interventions or their willingness-to-pay to avoid them, although there is some research from NERA for Thames Water on this topic. Emergency plans are not publicly available, and there are concerns that rota cuts not only reduce convenience but also affect water quality. Furthermore, a return to standpipes is difficult to imagine.

According to survey evidence, fifty-two per cent of interviewees believe that water companies could do more to fix leaks, and forty-six percent believe water companies should capture and manage water resources more effectively (Ellison, 2012, graph on page 30). Current levels of leakages are a concern. According to the same survey, seventy-seven per cent of interviewees consider the leaks from water pipes to be the major cause of drought, alongside lack of rainfall over the last one or two years. Seventy-six per cent believe that water companies not capturing water and storing rain water effectively are further causes of the drought (Ellison, 2012, graph on page 16). The consumer body believes that water companies can explain to customers how they make investment decisions and regulators can explain leakage targets and state whether they are challenging enough.

The government, regulators and the industry should do more to raise public awareness of water issues such as pressure on supply resources, quality, conveyance, efficiency and savings. Communication is important, specifically the clarity of messages and the ‘language’ used around drought, which could be more engaging. Coordinated action between the water companies, other sectors and the government should become a feature. The need for coordinated action was a lesson from the 2005–06 drought, during which water companies acted inconsistently across regions; specifically, water companies in the South East took different approaches to restricting use. This time round, WaterUK stepped in to act as a coordinator and the information conveyed to households was more consistent and clearer. However, some variations in the concessions granted by water companies remained. In some cases, where companies moved to align their approaches they moved away from the approach they had consulted on in their draft drought plans, so their plans would now need to be revised.

The drought management framework could be made clearer in the future. Little is known about emergency plans, the timing of actions, the seriousness of the situation, or the actions taken by water companies and the Environment Agency at each stage of the drought. The National Drought Group is a new feature of drought management, which has the potential to work well in the future. However, the consumer group feels there was not much information publicly available about its members, the group’s function or its remit and there appeared to be some delays in getting it up and running.

Waterways navigation

By way of a historical exemption, no licences for surface water abstraction are required for waterway navigation, thus restrictions such as hands-off flows imposed by the Environment Agency do not affect the industry. It is likely the exemption will end at some point in the future, however the date is not known. Groundwater sources, on the other hand, are licensed but none have hands-off flow conditions, just daily and annual maxima.

In March 2012, restrictions on navigation were voluntarily imposed by the Canal and River Trust. Such restrictions are planned in advance, based on modelling and projections; in the case of the current drought, phased restrictions were deemed appropriate. The restrictions imposed differed by area. Some were time-based, curtailing times of use; in other parts they were less severe. The expectation was to reduce traffic by deterring some boat owners from navigating the canals and to encourage lock sharing. Lock use is one of the main activities that uses water. Collected data shows that restrictions did indeed reduce the use of locks. Whether this implied fewer boat movements or more lock sharing remains unknown.

Boating trade operators were in favour of the introduction of early restrictions to keep open the possibility of

continued operation during the summer, which is their main trading season.

Industry members reported lower bookings this year, however anecdotal evidence suggests many holiday sectors have seen lower bookings, thus it is unclear to what extent the boating industry was affected by the drought itself. Some boatyards suffered from reduced demand for their services, particularly where access was restricted due to navigation closures.

If the drought had continued, further restrictions on navigation would have been imposed, followed by more canal closures. Back-pumps at some locks can be used to save water, however they are not very effective where boat movements are not the main source of water losses. Reservoirs could be refilled by pumping water, however if the drought had continued, water might not have been available. Other measures, such as leakage reduction, are costly – up to GBP 1m per km. The Canal and River Trust has experienced costs of around GBP 0.75m for pumping, has brought forward some expenditure on projects, and has worked harder to reduce leakage. Overall costs were probably around GBP 1m including contractors and increased day-to-day operational costs. Costs to customers and users on the other hand are difficult to estimate.

Trout farms

Trout is farmed widely in the UK, particularly in central and southern Scotland, the south of England and North Yorkshire. The activity depends upon a clean constant water supply. Water may be abstracted from a river or groundwater and may be partially re-circulated. Almost all water in use is non-consumptive and in the majority of instances it is returned close to the abstraction point, although some farms might return it more than 500m away.

Trout is the most affected sector because of its reliance on fresh water flows; other fish farms, such as coarse and ornamental, are not so dependent on constantly flowing water.

Trout are cold blooded fish which are greatly affected by water temperature. Around 16,000 tonnes of rainbow trout are produced in Britain each year, with around 75 per cent farmed by table producers. About a third of trout farmed in the UK is grown for restocking.

There are a few recirculation farms, half a dozen producing tilapia (fully enclosed recirculation). These farms rely on PWS and boreholes, thus there are minimal impacts from droughts. In farms with recirculation systems, less freshwater needs to be abstracted; for example, for trout farms, recirculation could lead to up to seventy-five per cent reduction in abstraction, depending on the level of built-in filtration. The downside is the high capital and energy cost; given the industry is only marginally profitable, it might not make business sense to invest in recirculation unless the capital costs were subsidised. The cost of a recirculation system depends on the size of the farm, the level of filtration and how much the farmers can undertake themselves (for example, a small farm could implement a crude system for several thousand pounds whereas a big farm could spend hundreds of thousands or millions of pounds).

No members were seriously affected by the recent drought, although some did experience difficulties. It is possible that some trout farms were a week away from suffering serious effects had it not rained. In a more serious drought, if abstraction were restricted, farmers would have to depopulate to maintain farms stocks at

a viable level, or might have had to slaughter the stock entirely. The consequences for the business are long-lasting – it takes about 14 to 18 months to restock a farm and grow the fish to a marketable size.

Different types of fish are highly substitutable in the retail trade and it is unlikely that trout would be imported in the case of a shortage. Nevertheless, there is an import market for trout products both from EU and non-EU producers.

There are mitigation measures available to farmers in times of drought, such as aerating the water or adding liquid oxygen. This type of equipment is already in place and used in summer in most sites. However, aerators may be noisy and potentially bear a high electricity cost; furthermore there is evidence to suggest they stress the fish. Liquid oxygen is very expensive. Generally, water-saving investments are difficult to implement as margins in the sector are already slim; the profit per fish is single figure pence. Levels of profitability have been low for some time, thus businesses have no significant cash reserves. Some farmers have significant credit lines at banks or suppliers and many rely on private finance (for example inheritance or mortgages taken on their homes). If farms had to slaughter stock, some would go out of business.

General impacts on fish

The drought resulted in some fish kills, which could have affected some anglers. The subsequent floods in 2012 made the effects of the drought on all biodiversity, including fish, complex and difficult to disentangle. In reduced flows, such as the second dry winter in 2011/12 migratory fish arrivals into the rivers are reduced because there are no spates flows to encourage upstream migration or migrating fish are confined to less optimum river reaches for spawning, thus impacting overall recruitment. There is a paper on reduced recruitment (David Solomon, published work, EA document R&D publication, tracking salmon in SW, 1999).

The Environment Agency's fisheries monitoring data does not specifically collect data on the impact of droughts, and the routine monitoring data lacks the resolution to determine population level impacts.

Angling

With regards to the impact of the drought on angling, there has been some evidence of problems over the spring of 2011 and the months leading to April 2012:

- as reservoir and river levels fell, access became problematic in some places and some reservoirs would have been closed to fishing;
- low levels in reservoirs, flows and volumes in rivers may have caused fish distress; and
- anglers reported decreasing participation.

A specific example of impact is the River Dove in Derbyshire where it has been reported that ticket sales fell in summer 2011.

Horticultural trade

The retail value of the horticultural industry is about GBP 5bn, which includes around GBP 1.5bn in plants, the remainder in plant products such as pots. Landscaping is split into domestic and commercial.

Temporary use bans are a great concern for the horticultural trade, which consists of plant growers, garden

centres, retailers, landscaping businesses and manufacturers of garden products. During the 2005/06 drought, retailers saw a reduction in demand for their products of more than 20 per cent due to the introduction of temporary use bans. Retail sales are about 12 per cent down this year, but this is ascribed to rain, not drought.

In 2006, the main concern raised by horticulturalists was that water companies were inconsistent in their approach to introducing temporary use bans; a particular sector could be affected in some regions but not in others. The Horticultural Trade Association lobbied for a phased introduction to water restrictions, based on research conducted in conjunction with Waterwise, having suggested, for example, watering plants on alternate days. The approach was included in the UKWIR *Code of Practice*.

No plant growers were affected during this drought, but some came close. If the drought had continued, plant growers would have suffered. Contracts between retailers and plant growers operate on a system of reserves: the retailer reserves a number of plants for next year, but there is no contract or obligation, so reduced sales hurts both grower and retailer.

Some nurseries went out of business this year due to poor sales. Retailers that are more likely to suffer because they are less diversified. With regards to landscaping services, an estimated GBP 24m worth or orders were cancelled and a further GBP 126m postponed; and around GBP 65m worth project leads were lost. Had the hosepipe bans continued, around GBP 140-170m pounds in revenue might have been lost.

A traffic lights system for drought, like the one used in Australia, would be beneficial. If a drought is announced in time, retailers and households can start saving water early and the water savings may even avoid or delay the introduction of temporary use bans.

Recycling, collecting rainwater from roofs and more efficient irrigation are operational practices that garden centres and nurseries can and do engage in – but these are not linked to concessions in the event of temporary use bans. Other mitigation options include sales of more drought tolerant plant varieties and trickle irrigation.

Energy saving appliances

There was an increase in demand for water saving appliances, especially for water butts; some retailers sold out. There was further evidence of a low level background increase in sales of shower heads, however it is not known if it was drought related. In the UK water companies do not follow a staggered approach to drought as in Australia; combined with long lead times this results in products not being marketed, produced and retailed in time.

Waterwise suggested the Meteorological Office might provide drought forecasts, as is common practice in countries such as Australia and France. Furthermore, there is evidence of drought management information being more visible and/or more user-friendly abroad; for example France had temporary use bans this year as well, however there was an informative website giving explanations, the departments concerned, who to contact, what to do, and an interactive map.

According to Waterwise, during the drought, water companies may have cut back on water efficiency

programmes to fund drought programs. This could happen if water companies do not have a contingency budget for drought.

The water efficiency manufacturing industry does not appear to receive the same level of support in the UK as in other countries. Manufacturers and entrepreneurs often choose to relocate their business to the US where there is more government support (government procurement) and easier access to finance. A further example was provided by Waterwise to illustrate the point above: some shower devices manufactured in the UK met the carbon emissions reduction target (CERT) but an additionality clause prevented them from being brought to market.

Swimming pools

Businesses were affected in some areas and there were variations in impacts. When a temporary use ban is imposed, legislation allows for a new domestic pool to be built and filled with water, however subsequent re-filling is not allowed; as a result, some new building contracts were cancelled after the introduction of temporary use bans in spring 2012. A domestic swimming pool would contain, on average, 75,000 litres of water.

The servicing and maintenance of a pool involves backwashing the filter, a process which necessarily results in water loss; subsequent refilling is then required, however temporary use bans meant that hosepipes could not be used to refill a pool, effectively preventing households from servicing their swimming pools. Up to 1,000 litres are required to top up a domestic pool after backwashing filters, depending on the size of the pool, and on average, backwashing needs to be done fortnightly. Commercial pools service the pool more frequently, even daily, due to the much larger number of people using it every day. Hot tubs on the other hand are considered a bathing facility and can still be refilled during a temporary use ban. Hot tubs that are chemically treated can last up to a month and use about 1,500 litres when refilled.

Under the UKWIR *Code of Practice*, swimming pools with covers to prevent evaporation would have been considered exempt from domestic water restrictions. However, the water companies took three to four weeks to agree to the *Code of Practice*, which effectively meant that refurbishment services were affected for up to a month.

If the drought had continued, with pool owners prevented from topping up, at some point water levels would have fallen below the filter level and the pool would have had to close. Moreover, non-essential use drought orders could potentially close swimming pools that are not open to the general public, that is pools that may only be used by paying members of an affiliated club or organisation.

Car wash businesses

Petrol stations possess the majority of car wash businesses in the country even though many petrol stations have closed over the last decades. Hand car washes have experienced the biggest growth in recent years; however many of them are unregulated, which causes great concern to the industry for two main reasons: water use is not metered and unregulated flows from waste water may damage the environment.

Around half the car wash businesses in the UK operate on recycled water. They use around 0.25 m^3 per day,

whereas a car wash that does not operate on recycled water would typically use around 2-3 m^3 per day. Ninety-seven per cent of car wash businesses rely on public water supply, with the remaining three per cent abstracting water from their own boreholes. There is no need for an abstraction licence because water use per day is smaller than 20 m^3. In the event of a water shortage, boreholes are not affected by drought directions although this could change in a severe drought, for example, if the minimum volume for licence exemption were lowered. The cost of a borehole is around GBP 15,000 and can be up to GBP 30,000 if the borehole is deep; however, with businesses seeing a steady decline in demand over the last 10 years, this option is not always attractive.

During the 2005-06 drought, drought orders were imposed and car washes were told to use no more than 25-28 litres per car wash. In the past, that was feasible because, with older technology jet-washes, water pressure and time could be adjusted. However, with newer technology, for example buy-time jet washes, it is not so easy to control the customer’s use of water. Roll-over washes include a high pressure initial rinse which consumes around 70 per cent of water in a wash. Customers have a preference for this part of the wash, however in times of water shortage this step could be omitted. Also, lower quality water could be used if necessary. In spring 2012, the Car Wash Association was lobbying for an agreed fresh water usage of not less than 30 litres per wash.

Car wash businesses cannot insure against a drought order. Two investments are available to car washes to help protect businesses from water shortages: drilling a borehole, the cost of which was mentioned above, and switching to a technology that recycles water, which would require GBP 10-12,000 initial cost for equipment, then GBP 2-3,000 maintenance costs per year for non-recycled-water car washes.

In 2005/06 there was no noticeable reduction in demand as a result of drought orders, and in 2012 the sector experienced a slight increase in demand with the introduction of temporary use bans.

The Car Wash Association raised a similar issue to other industries interviewed: water companies could communicate more and further in advance. Drought conditions, likelihood of worsening and implications could be conveyed to a non-technical audience.

Window cleaning sector

During the recent drought, five out of the seven water companies that imposed temporary use bans agreed concessions for window cleaners catering to domestic households. The other two form part of Veolia, which did not exist in its current form in 2006 and thus was not involved in the public hearings. In these hearings, water companies discussed, assessed and agreed concessions for window cleaners using water-fed poles on grounds of health and safety.

The window cleaning industry is affected by the perceptions of its customers. Anecdotal evidence suggests some households may have been reluctant to hire window cleaners because it was not clear to them that window cleaners were exempted from the bans.

If the drought had continued, resulting in non-essential drought orders being imposed, water cleaning businesses would have been seriously affected. The loss of income would have been felt instantly. Most window cleaners are self-employed and rely on ad-hoc business.

In terms of consumption, water-fed poles use 1-1.5 litres per minute. Most window cleaners carry their own tank with them filled with water that has been treated and purified overnight. When there is a drought, window cleaners use water-fed poles for windows on high elevations only, and buckets for ground level windows.

Health impacts of drought

When determining the health impacts of drought, the ‘context’ of a drought is very important: the impacts of drought on populations are heavily dependent on the adaptive capacity of exposed populations. Droughts are complex events and determining their health impacts is not straightforward.

- They can be associated with other extreme events such as heatwaves, where heat itself has an impact, or wildfires, which have impacts such as airborne pollution.
- In contrast to an extreme event such as flooding, the vast major of health impacts appear to be ‘indirect’ impacts, that is, impacts resulting from impacts of the drought, rather than ‘direct’ impacts of the drought itself. This can be compared to a flood, in which there are both direct and indirect health impacts: a direct impact for example is drowning and an indirect impact are the mental health impacts from the recovery process. There may be direct impacts of drought but these would be very difficult to identify but could include injuries and dust-related diseases.

The complexity of droughts means that just because health impacts have not been identified does not mean they do not exist: examining the impacts is challenging.

One issue considered during the recent drought is the potential for health impacts of reductions in private (non-Public Water Supply) drinking water. A large proportion of people use private drinking water; for example, there may be around 7,000 bores supplying private drinking water in Yorkshire. Drought means that there is a higher risk of water-borne diseases from bores.

In a recent review, the HPA looked at the quality of evidence on water shortages and extreme events and found an absence of robust evidence-based scientific studies on water shortages in extreme events (Health Protection Agency and Drinking Water Inspectorate, 2012).

Water is critical for health and life and medical uses of water are some of the most valuable. If water were absent or very scarce, health care would have to be made to work in very challenging conditions. The closure of Gloucester hospital after flooding provides a recent example of the serious impacts of hospital closure. One issue is that it is very difficult to agree how much water individuals should have in an emergency and the available evidence base that could inform these decisions is not particularly strong. The Sphere guidance on minimum standards in humanitarian response can provide some guidance on water needs.

Conclusion

The drought affected some sectors more than it did others, for example irrigated agriculture and horticulture suffered more than food and drink manufacturing and retail. However, there is evidence to suggest the drought ended just in time, and had it continued, serious impacts would have been felt by all the sectors that

were interviewed, possibly with the exception of food and drink manufacturing and retail, who have priority over non-essential uses as defined by water companies. It is apparent that the wet summer had an equal or more negative impact than the drought in sectors such as irrigated agriculture and horticulture, and horticultural trade.

During April and June/July, seven public water supply companies imposed temporary use bans on non-essential uses of water. In addition, four of them applied for drought permits and orders to refill their reservoirs. Water companies are vulnerable to drought, with the majority of the infrastructure robust to one or two dry winters, but not more. The cost of implementing their drought plans ranged between GBP 1m to GBP 4m, and had the drought continued with a third dry winter, the costs would have doubled to reflect the increased costs associated with environmental monitoring, communication actions, cost of permits, additional leakage control costs, bulk supply costs and consultancy fees, as mentioned in section 2.1.

Other main actors during the drought included the Environment Agency, which among other things liaised with farmers to encourage voluntary restrictions; it also indirectly had an impact on some sectors through the automatic use of hands-off flow or level restrictions. The Canal and River Trust independently imposed restrictions on navigation in the hope of preserving canals for the summer period, which is the principal season for boat operators.

Agriculture was not the only sector involved in discussions with the Environment Agency. Others engaged with the Environment Agency, Defra and/or water companies, as relevant include car washing and window cleaning.

A distinction can be drawn between the impacts of the drought itself and the effects of management actions taken by water companies or the Environment Agency. For example, a prolonged lack of rainfall would affect most crops, whether irrigated or not, independently of management actions taken by water companies or the Environment Agency. If farmers are prevented from irrigating their crops when they need it most, through the use of a S57 spray irrigation restriction for example, the management action would add to the magnitude of the impact. The main impact of temporary use bans were felt by households, golf clubs and swimming pool repair and maintenance businesses. The window cleaning sector noted that customers' perceptions of what constitutes an acceptable use of water were a problem. The lack of rainfall affected agriculture, horticulture and livestock rearing. No mandatory restrictions were imposed on agriculture through the use of Section 57 irrigation bans, however, some abstractors in East Anglia agreed to voluntary restrictions of licenced volumes to avoid or delay more formal restrictions.

Communications from the Environment Agency were perceived as good by affected sectors that interact with the agency directly. Farmers are a case in point. However, when it comes to sectors that deal with water supply companies, the general feeling was that a more staggered communications approach, starting at an earlier date, would have been beneficial. The majority of the sectors feel that the drought was handled better this time than in previous years, but looking to the future there still are issues to be addressed, such as consistency in approach by water companies or the phasing in of restrictions.

The drought prompted various sectors to think about long-term options, be they changes in practice or financial investments. More farmers for example have been persuaded of the benefits of joining a *Water Abstractor Group* and investing in winter storage reservoirs; most growers today only have limited storage

capacity. Long-term investments to protect against the impacts of drought are not always cost-effective for businesses running on small margins, such as trout farms. Furthermore, in sectors such as window cleaning, there might not be any investments that offer protection from the effects of drought.

The definition of 'non-essential' use can cause problems for some sectors. These sectors argue for a phased approach to temporary use bans that is consistent across all regions. Golf course operators, for example, receive no concessions from temporary use bans while window cleaners receive concessions from most water companies that imposed temporary use bans, but there were some exemptions. Car wash operators are affected by non-essential use drought orders, under which water use is first restricted to a certain quantity per car wash, and in a severe drought, might be banned altogether. Taken together, these businesses are generally local, and small, with no bearing on the macroeconomics of the region or country, but the impacts can be felt strongly by the people involved.

Appendix 7 Model handbook

Overview

The drought model is a spreadsheet tool that lets users compare the economic impacts of drought across sectors and in aggregate under a range of different management actions. It is a six-region, sixteen-sector model of England that reports the impacts of a baseline drought or more severe drought over the period 2011-2014, with the geographical scope of drought and its management chosen by the user. Table 20 shows the sectoral and regional coverage of the model. It uses EA regions and covers sectors of the economy that can impose or be subject to management actions in the event of a moderate or more severe drought. Together these sectors comprise more than 90 per cent of abstractions in England (DEFRA, 2012b). All monetary values are in 2010 pounds the inputs and outputs are quarterly.

The model calculates the changes in water demand, turnover, profits, gross value added and employment by sector that are estimated to result from the management actions selected. These changes take into account the interactions between management actions where multiple actions are applied to a sector. Sectoral impacts are aggregated to provide an overall estimated impact for each metric. The model draws on a wide variety of data sources to create a more detailed quantitative picture of water use in small water-intensive sectors than has hitherto been available. Official ONS data is used where available and combined with other published data, the outputs of in-house models (for PWS and agriculture) and information provided through interviews conducted for the project.

The model can be used to provide quantitative inputs for the discussion of the following important questions:

- for a drought of a given level of severity, how does the *choice* of management actions affect the amount of water available and the aggregate and sectoral costs of management actions?
- for a drought of a given level of severity, how does the *timing* of management actions affect the amount of water available and the aggregate and sectoral costs of management actions? Would a phase-in of drought orders across sectors be preferable to employing all measures at once?
- which management actions will save the most water?
- which management actions are the most cost-effective?

In all cases, the model provides estimates relative to a drought of a given level of severity with no management action. For example, the reductions in water demand for a baseline drought are percentage changes relative to the water which would be consumed in a baseline drought in the absence of management action.

Table 20. **The drought model is a six-region, sixteen-sector model of England**

Sectors	EA regions of England
Public water supply	
Electricity supply industry	
Agriculture: cereals	
Agriculture: irrigated crops	
Agriculture: potatoes rain-fed	Anglian
Agriculture: potatoes irrigated	Midlands
Agriculture: strawberries	North East
Golf	North West
Freshwater aquaculture	South East
Wholesale and retail nurseries	South West
Landscaping services	
Non-domestic swimming pools	
Window cleaning	
Commercial car washes	
Households	

Source: Vivid Economics

In order to make the model tractable given the timeline and resources available for this project, a number of simplifications have been made which should be kept in mind when interpreting model outputs:

- management actions are applied identically in all drought-affected regions. In practice, the severity of drought, and hence the management response, could differ across regions;
- there are no 'legacy effects' in the model, that is, the recovery when management actions are removed. In practice, recovery to pre-drought levels of output after more substantial management actions are lifted could take time, especially if, in the case of aquaculture or horticulture, stocks take time to re-establish;
- with the exception of water companies, business and consumers do not undertake investments which reduce their water consumption during a drought or for future droughts.[10] In practice, with actual or expected quantity constraints on water becoming more frequent, some water-sensitive businesses in particular may consider undertaking investments in capital that improves water efficiency. Over time, if the amount of such investment is large relative to sectoral water consumption, the model will overestimate water demand and potential savings from that sector. This suggests that the model should be updated after a period of around 5 years;
- we assume that households' and businesses' level of compliance with actions such as voluntary restrictions and TUBs is independent of the severity and duration of the drought. In practice, a longer

[10] There are two cases, nurseries and strawberry production, in which operational changes through substitution between sources of water during a drought is relevant. All other sectors either rely solely on either Public Water Supply (PWS) or direct abstraction so have no simple way of replacing water if one of these sources is restricted. Given that this possibility for substitution only applies to a small number of actors, this possibility is ignored.

and/or more severe drought could result in a somewhat higher level of compliance with management actions. However, in the absence of information on the likely size of these effects we assume a uniform response;

- the number of reported economic metrics has been restricted to the most important of those for which some robust data are available and the response to management actions (as opposed to drought itself) could be material. The main implication of this is the absence of price estimates: given the focus on a UK-specific drought and the fact that the UK can import goods, price impacts for traded drought-affected goods and services would be expected to be small. Moreover, many non-traded drought-affected goods are more likely to have to restrict production altogether, for example window cleaning, or have many substitutes if production was affected, for example, trout, so that price impacts in these sectors would also be small.
- there is no real growth over the model horizon (2011 to 2014). In practice the overall level of economic activity, and hence water demand, would be expected to increase over this period. However, as the focus of the model is on changes from a baseline, we have excluded this small change in the baseline over time.

This handbook has three more sections. The next section provides a step-by-step guide to using the model. The section on model structure provides further details about the way that the model estimates the impacts of management actions. The final section provides details of the data sources and methods for each sector.

How to use the model

Users make five choices on the model's Control sheet and can choose from reports on five different metrics on the Impacts sheet.

On the Control sheet, users select:

- the drought scenario: baseline or extended drought, discussed further below;
- the regions affected;
- the management actions applied: up to nine at one time;
- which of the potentially affected sectors these actions should apply to, and the start date and duration of each management action.

These choices enable the user to construct and compare a very wide variety of overall management regimes. Table 21 describes how to make each of these selections.

Table 21. **Users make input selections using simple tick boxes and hand selector tools**

Input	Method of selection	Further user information
Drought scenario	Drop-down menu	
Regions affected	Tick boxes	
Management actions	Drop-down menu	
Start and finish dates of management actions	Drop-down menu	
Eligible sectors covered by action	Type '0' or '1' in the 'select sectors' section to exempt or cover eligible sectors	If 1 is not explicitly typed in cell the sector will be exempted, so please check that all cells are filled with 1 or 0 rather than just left blank
Select metric	Drop-down menu	Results are shown in the 'Impact drought-affected areas' sheet
Select quarter	Drop-down menu	This provides a sectoral breakdown of impacts for a single quarter, shown in the 'Sectoral impact 1' and 'Sectoral impact 2' sheets

Source: Vivid Economics

The Control sheet has features to make selections clearly visible. A summary table at the top of the Control sheet shows which management actions have been applied and their duration.

The 'Impact drought-affected areas' ('Impacts') sheet presents the impacts for all drought-affected regions in aggregate for one of five selected metrics (water use, turnover, GVA, profit, and employment. The following information is then available:

- three summary tables, showing the absolute and percentage change and the absolute level of the selected metric by sector and over time;
- nine supporting tables showing the absolute reduction in each metric for each of the selected management actions; and
- a time series of the absolute change in the selected metric showing sectoral contributions to the overall change.

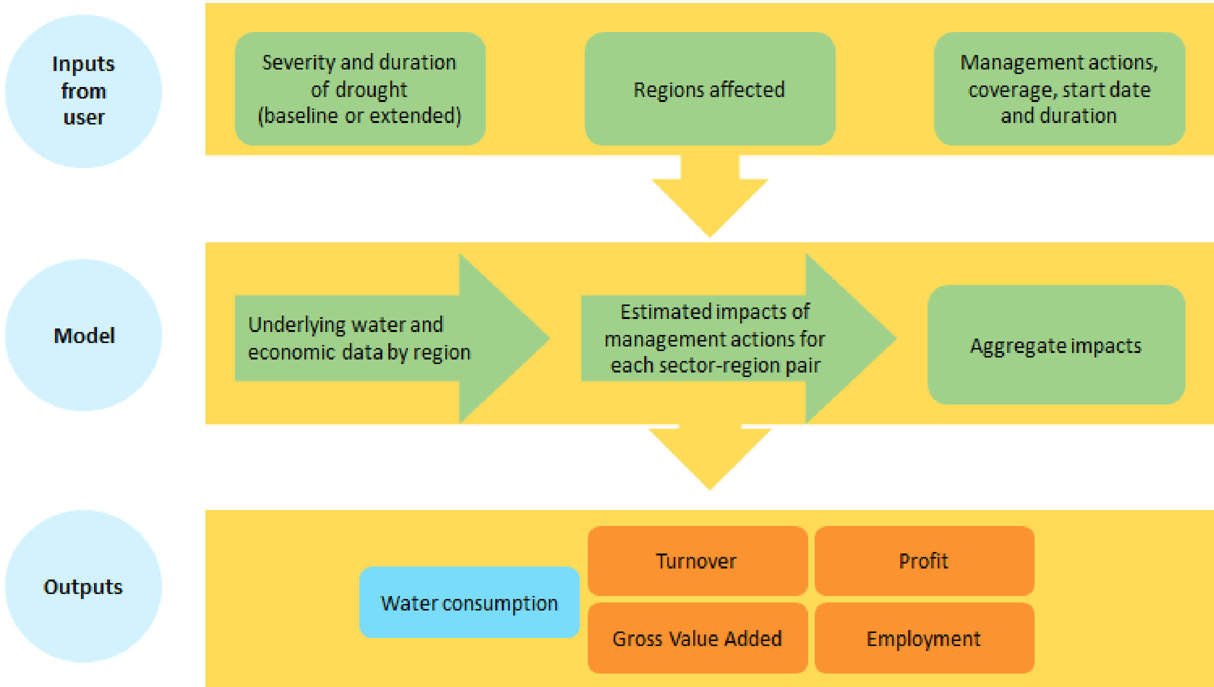
To compare two sets of outputs, the user should copy-paste the values into a separate sheet. This has been done for three scenarios in the 'Output tables extended drought' sheet; results for the three extended drought scenarios considered in the main body of the report have been added here.

The model is quite flexible and many inputs which are not part of the standard user selection can be altered by users in the back end of the model if desired; the main exceptions are the number of sectors and the time horizon. For example, estimates of the consumptiveness factors for water consumption by sector, sectoral responses to a given management action, and any of the underlying assumptions behind the specific sectoral baselines can be altered if desired. The model does not use any programming code (for example, Visual Basic) so alterations only involve changing values in cells, or formulae in the workbooks. In contrast, altering the number of sectors and the model horizon from those established with the Steering Group would require the entire model to be re-written.

Model structure

The model takes underlying water and economic data by sector and region and applies estimated changes in water consumption and economic data to project the impacts of a user-selected combination of management actions. Figure 39 summarises the model structure, showing the inputs, basic model structure, and outputs. The rest of this section discusses the elements of the model shown in this figure in more detail.

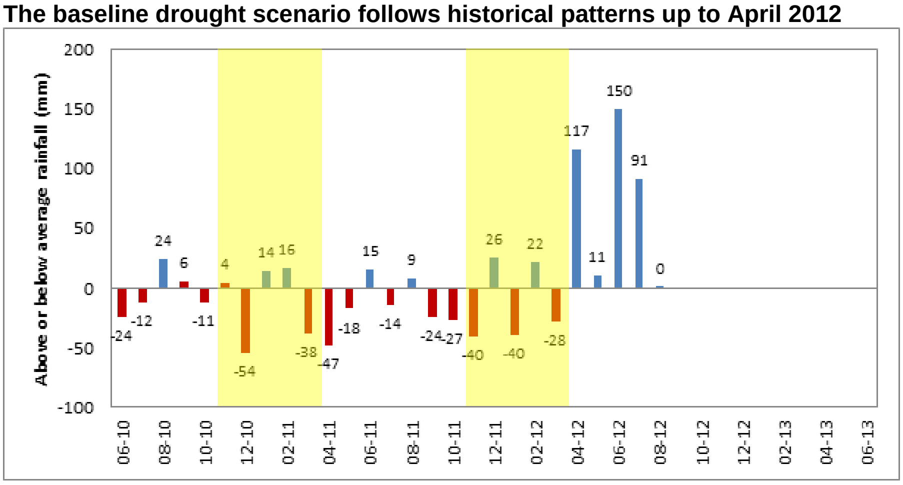
Figure 39. **The drought model is a simple quantitative tool allowing users to investigate drought management in England**



Source: Vivid Economics

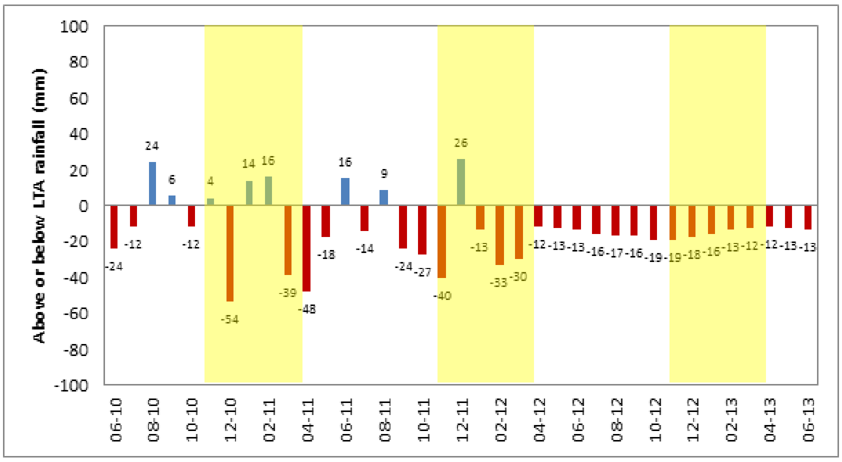
The model includes two drought scenarios, a baseline drought modelling the 2010-2012 drought and an extended drought where drought continues into the winter of 2012-13 during which rainfall is 80 per cent of its long term average. Both scenarios abstract from wet winter of 2012, assuming historical average conditions. The rainfall patterns associated with each drought scenario are shown in Figure 40 and Figure 41. The results presented in Section 3 for the baseline and extended drought use these scenarios and an approximate actual and an assumed geographical distribution for the droughts, respectively. When using the model themselves, users can reproduce and investigate these geographical distributions, or investigate the impact of the baseline or extended drought on other regions of England. As discussed in the first section of this Handbook, we assume that households' and businesses' level of compliance with actions such as voluntary restrictions and TUBs is independent of the severity and duration of the drought. In the model, the only actions undertaken by businesses which vary automatically between the baseline and extended drought scenarios is the level and nature of the response by Public Water Companies (PWCs), discussed in Section 5.2.

Figure 40. **The baseline drought scenario follows historical patterns up to April 2012**



Source: Halcrow Ltd

Figure 41. **The extended drought scenario assumes long term average rainfall for April 2012 to June 2013 is 80 per cent of its long term average**



Note: *Actual rainfall data from June 2010 to March 2012*
Source: *Halcrow Ltd*

The model is based on EA regions of England and ONS regional-level economic data has been incorporated by mapping from ONS to EA regions. Water data are generally available for EA regions, while official regional economic data use ONS regions. The two systems are similar but not identical. Table 22 shows the map between EA and ONS regions used in the modelling. When an ONS region is split between multiple EA regions, economic metrics are allocated to the EA regions based on the weights shown in brackets in the right hand column.

Table 22. **The drought model applies the follow map between ONS to EA regions to create a model based on EA regions**

EA region	Map between ONS region/s and sub-regions and EA region	ONS regions in EA region; proportion of economic activity from each ONS region mapped to EA region in brackets
Anglian	East of England – Hertfordshire + Northamptonshire +Lincolnshire	East (0.76); East Midlands (0.3); Yorkshire and the Humber (0.06)
North West	North West	North West (1.0)
North East	North East + Yorkshire and the Humber – Northern Lincolnshire	North East (1.0); Yorkshire and the Humber (0.94)
Midlands	West Midlands + Gloucestershire + East Midlands – Lincolnshire - Northamptonshire	West Midlands (1.0); East Midlands (0.7); South West (0.13)
South West	South West - Gloucestershire	South West (0.87)
South East	London + South East + Hertfordshire	London (1.0); South East (1.0); East (0.24)

Note: *As they are both small relative to the model, the part of Wiltshire in the Midlands EA region, and the part of Gloucestershire in the South East EA region are excluded from these regions.*

Source: *Vivid Economics based on http://www.environment-agency.gov.uk/aboutus/organisation/35673.aspx, http://www.environment-agency.gov.uk/static/documents/Business/Local_Authorities.pdf and ONS NUTS data.*

The sectoral coverage of the model ensures that it comprises the bulk of the economic impact of the most recent drought as well as sectors likely affected by a more severe one. The sectoral coverage of the model is a refinement of the list of sectors for further consideration based in the *List of materially affected sectors* report prepared for Defra in August 2012, with some sectors (such as Waterways navigation) excluded due to lack of necessary data.[11] Of course, in an emergency drought situation more severe than those within the scope of this work, all sectors of the economy would be affected in some way. Estimates in the model use inputs from official statistics, published reports and interviews conducted for the project. Smaller sectors such as window cleaning draw more heavily on interview responses. Full details of data sources and methods by sector are provided towards the end of the Handbook.

The model reports turnover, profits, gross value added and employment, with the reported metrics varying by sector depending on data availability and robustness. Turnover is the value of total sales and

[11] The Canal and River Trust provided the consortium with a great deal of useful information and data, however some data necessary for including the sector in the model was not available. While canals can be large abstractors in some local areas, they currently lie outside the EA abstraction licensing regime, so that excluding the sector does not exclude a large user subject to management actions. For further details see interview summary in Appendix 6.

work done. Gross value added by a sector is the contribution of the sector to Gross Domestic Product, which is broadly measured by turnover minus the value of intermediate inputs used in production. Profit is defined as the gross operating surplus or loss remaining after all labour costs have been subtracted from GVA. Where available, baseline data comes from ONS Annual Business Survey (ONS, 2012a); further discussion of the ONS definitions is available here.

As employment impacts are generally unlikely to result in reduction in sectoral employment measured on a 'heads' basis, the model reports 'potentially affected employment' rather than changes in employment. As discussed in Section 3, the main pattern of impacts we would expect from a short drought not materially affecting the UK's agricultural trade partners is a temporary reduction in profits, as fixed and some variable costs remain constant while turnover is reduced. In some sectors, for example some agricultural activities, producing a drought-affected output requires a similar amount of labour inputs as production in a normal year: crops still need to be planted, irrigated, and so on. In other sectors, for example landscaping, even if lower demand and/or a management response means that fewer labour inputs are required, in many sectors and business types labour is likely to be 'hoarded' rather than laid off in the short to medium term, so that employment impacts are felt first through a reduction in hours worked.[12]

Management actions and drought impacts are chosen and reported at quarterly frequency; in most cases the underlying sectoral data is annual. For all economic metrics, all underlying data is annual and has been transformed into quarterly data by applying an equal proportion of annual output to each quarter. In some sectors (all irrigated agricultural products and golf, total annual water demand has been apportioned to only the quarters in which water is used in substantial volumes, that is the spring and summer quarters. There is a seasonal element to landscaping services and wholesale and retail nurseries, however these sectors function year round, as such the water use and impacts have not been seasonally adjusted.

Water use is split between sources and users so that the impacts of drought management can be clearly accounted for. There are two points to note about water use by sector in the model. First, water can be obtained by direct abstraction or the Public Water Supply, and some modelled sectors, for instance, golf clubs, nurseries, strawberries, draw large proportions of their water from both. The proportion of use from each source by sector is included in the model. This means that reductions in water use in response to management of either abstracted or PWS water are translated correctly into overall sectoral reductions in water use.

Second, as some modelled sectors serve households using household water, adjustments to sectoral water consumption are necessary to avoid double-counting. Some window cleaning and landscaping work is conducted for households, so overall sector water demand is split between household and businesses.

The management actions have been developed in discussion with the Steering Group and reflect the actions legally available to the Government or water companies during a drought similar to those in the model. In addition to the 'no action' option, these actions are:

[12] Exceptions to this are sectors such as aquaculture where a continuous supply of water is essential to production and restrictions restrict water below a critical threshold. In this case, specialist businesses would likely shut down and employment effects could be relatively rapid.

- PWS implementing capital investment;
- PWS drought permits to maximise river abstractions;
- PWS bulk supply transfers between companies;
- PWS drought orders on supply side;
- EA encouraging voluntary reductions in spray irrigation;
- Hands-off flow conditions;
- EA partial s57 restrictions;
- EA full s57 restrictions;
- EA drought orders;
- PWS communications to customers;
- PWS TUBs with concessions;
- PWS TUBS no concessions;
- PWS drought orders with concessions;
- PWS drought orders no concessions; and
- PWS pressure management.

The estimates of the percentage impact of each management action on water use in each sector have been derived using a combination of sectoral modelling, calculation and expert judgement. These estimates are collected in the last section of the model, sheet titled 'Data array', beginning in cell Q2 for the baseline drought and AI2 for the extended drought, which differs only with respect to PWS investment as discussed above. The principles and approaches used to derive the estimates can be summarised as follows:

- impacts of actions on the Public Water Supply were determined by Halcrow using modelling which is discussed in the next section;
- for demand side changes in PWS, these overall figures from Halcrow were decomposed into reductions made in the water-sensitive industries included in our model and the rest of PWS;
- across measures, voluntary measures have the smallest proportional effect, while Hands-off Flow (HoF) conditions can restrict water use significantly for those affected, while full S57 restrictions on irrigation and drought orders effectively stop abstraction in most affected sectors and reduce abstraction in electricity generation

The consortium judges that there is generally medium confidence about the *ranking* of these impacts and (with some exceptions) reasonable confidence about the *level* of these impacts. There is high confidence in that the sectors affected by each action is correct, and reasonable to high confidence in the ranking of impacts across management actions for a given sector, and on impacts across industries for a given management option. There is more variation in the confidence around the proportional changes in water use for a given action. For more stringent actions which legally curtail abstraction or specific activities, we can be reasonably confident that the vast majority of these activities would effectively cease. For other 'intermediate' or voluntary measures the scale of the impact is more difficult to gauge. Finally, for two sectors (electricity generation and aquaculture) estimates for the impacts of HoF conditions have low confidence as they depend entirely on the proportion of licences in each sector which have HoF conditions and -no information on these proportions could be obtained for the project-.

The impact on agricultural products is also difficult to estimate, as crop yields depend on a variety of factors, one of which is the timing of irrigation. Cranfield University estimates that up to 100 per cent of the potential irrigation benefits would be lost if total bans on irrigation were imposed from the start of April or May in a 'design' dry year. Table 23 presents the full picture.

Table 23. **Monthly distribution of potential irrigation benefits that would be lost if total bans on irrigation were imposed (from the start of a given month) in a 'design' dry year, potato crops**

	April	May	June	July	August	September
Loss in benefit (%)	100	100	77	45	18	0

Source: Cranfield University

The model accounts for the interactions between management actions when multiple actions affect a given sector. Different management actions can be applied to a sector simultaneously, and when this occurs it is necessary to consider their overall impact. In many cases, the simple assumption that actions are additive (that is, the impact of the actions is the sum of the impact of each action if it were applied independently) is appropriate. For example, golf courses tend to be either abstractors or PWS users, so the overall sectoral impact of a simultaneous application of (say) enforcing HoF conditions and TUBs would be additive. In other cases, the overall impact is certain or likely to be less than additive. In these instances we model the overall impact as the maximum of the individual impacts. In many cases, the set of actions is unlikely to occur simultaneously in practice or selected by a user so this is included for correctness, for example, the impact of applying but partial and full S57 restrictions simultaneously would not occur in practice. In other cases the combination of management actions is realistic, for example a simultaneous increase in communications from water companies coupled TUBs.

The estimated changes in economic metrics resulting from each management actions have been derived either from sectoral modelling or simple rules about the implications of the estimated changes in water demand. The changes in economic indicators in the Public Water Supply and irrigated agriculture sectors were determined by Halcrow and Cranfield University, respectively, using modelling discussed in the next section. For other sectors, the model assumes a simple one-to-one relationship between water and turnover, profits and GVA. That is, a 50 per cent reduction in water availability leads to a 50 per cent reduction in turnover, profits and GVA.[13] Exceptions to this are car washing and landscaping services which draw on the specific sources discussed in the next section.

[13] In the case of nurseries this is scaled down to reflect the fact that not all of the business is reliant on plant sales and therefore significant volumes of water: for example, in the event of management actions an on-site café could continue to operate even with reduced business.

Data and assumptions by sectors[14]

Electricity

Water consumption

Annual abstraction for the electricity supply sector by EA region for 2010 from (DEFRA, 2012b).

Economic metrics

2010 Turnover and GVA for the electricity supply industry calculated by scaling down regional data for the 'electricity, gas, steam and air conditioning supply' industry by the national share of the electricity sub-sector in the larger industry. All data come from the ONS Annual Business Survey (ONS, 2012a). 2010 Profit calculated as the difference between GVA and total employment costs for the 'electricity, gas, steam and air conditioning supply' industry by region and scaling down as per turnover and GVA. National-level 2010 employment in the electricity sub-sector allocated to each region assuming that shares of employment are equal to regional shares of turnover (more disaggregated ONS employment data for the industry are unavailable).

Golf

The data on turnover and profits come from personal communication from the English Golf Union and the data on regional water use from Cranfield University.

Fish farming

Water consumption

Annual abstraction for freshwater aquaculture by sector by EA region in 2010 come from (DEFRA, 2012b). The sector listed in the Environment Agency classification is 'fish farming, cress growing and amenity ponds'; based on research conducted by WRAP on freshwater use in the UK, the proportion of water consumption in 'fish farming, cress growing and amenity ponds' represented by freshwater aquaculture is 88 per cent (Kowalski, Lynn, Weylen, & Bujnowicz, 2011).[15] Thus the Environment Agency's abstraction figures have been adjusted accordingly.

Economic metrics

2010 Turnover and GVA for the freshwater aquaculture industry are calculated by combining regional 2010 shares of aquaculture (freshwater and marine combined) from the ONS Annual Business Survey (ONS, 2012a) with the total value of freshwater aquaculture in 2009 (Jeffery, 2011). 2010 Profit calculated as the difference between estimated regional GVA and total employment costs for the freshwater industry, with some missing regional employment cost data estimated by assuming that share of employment costs in GVA

[14] PWS and Agriculture are covered in separate appendices

[15] Aquaculture plants such as watercress represent 12 per cent of water consumption.

is equal to the national ratio for the freshwater aquaculture industry. The total national-level 2010 employment figure for the freshwater aquaculture sub-sector was allocated to each region based on the assumption that shares of employment are equal to regional shares of turnover.

Wholesale and retail nurseries

Water consumption

Water consumption from abstraction and PWS calculated using a sample of water consumption in 2006-07 by source for 29 nurseries provided by the HTA and multiplying by the number of nurseries in England from the First Franchise website.

Economic metrics

This sector uses data from the 2010 ONS Annual Business Survey (ONS, 2012a) for the industry 'retail sale of flowers, plants, seeds, fertilisers, pet animals and pet foods in specialised stores' as a proxy for the wholesale and retail nurseries industry. 2010 turnover calculated using sub-regional 2010 output at basic prices and applying the national industry ratio between output at basic prices and turnover to sub-regional output. 2010 profits calculated from sub-regional GVA assuming employment costs in GVA are equal to the national proxy industry average in all regions. National-level 2010 employment in the overall industry allocated to each region assuming that shares of employment are equal to regional shares of turnover.

Landscaping

Water consumption

The sector is assumed to use only PWS. Total freshwater consumption per year in England is estimated as the product of:

- the number hours per day spent watering during a job;
- water consumption per hour during watering periods;
- days worked per year;
- employees in the landscaping sector engaged directly in landscaping.

Hours per day spent watering are taken from a consultation response from the Horticultural Trade Association et al. (2012); water consumption per hour from a hosepipe from South West Water (2010); employees assumed to work 250 days per year; employees in the landscaping sector assumed to be 80 per cent of employment in the sector.

Economic metrics

This sector uses data from the 2010 ONS Annual Business Survey (ONS, 2012a) for the 'landscape and service activities' sector. 2010 turnover calculated using sub-regional 2010 output at basic prices and applying the national industry ratio between output at basic prices and turnover to sub-regional output. 2010

profits calculated from sub-regional GVA assuming employment costs in GVA are equal to the national industry average in all regions. National-level 2010 employment in the overall industry from the ONS Business Register and Employment Survey (ONS, 2012b)allocated to each region assuming that shares of employment are equal to regional shares of turnover.

Non-domestic swimming pools

This part of the model calculates water and economic metrics for the operation of non-domestic swimming pools, which are split roughly one-third each between commercial, education and local authorities. These estimates to not cover any changes in demand for the construction of domestic or non-domestic pools as a result of drought management, or water consumed in domestic pools.

Water consumption

Pools are PWS users; annual consumption is equal the total volume of pool water replaced per week in cleaning and maintenance. This is equal to the recommended fraction of water replaced per week (10 per cent),[16] multiplied by the volume of non-domestic pool water. The volume of non-domestic pool water is the product of estimated average pool depth taken from Sport England (2011) multiplied by area of water covered by each non-domestic pools by ONS region.[17]

Economic metrics

Non-domestic pools are split roughly one-third each between educational, local authority and commercial pools. The first of these would generally not earn material income nor pay material proportional costs specifically linked to the pool. The final third would likely earn higher incomes and profits than the middle third for a given pool size. For simplicity, we use available data on indicative income, costs and profits for community pools for the sector as a whole. Turnover by region calculated using indicative income for a community swimming pool from Sport England (2012) multiplied by unpublished figures for number of non-domestic pools per region from Sports England. GVA by region calculated using sum of indicative operating surplus and staff costs for a community swimming pool from Sport England (2012) multiplied by unpublished figures for number of non-domestic pools per region, personal communication from Sports England.

Window cleaning

Water consumption

The sector is purely a PWS user; as most of the sector use ‘water-fed poles’ to clean windows this section models consumption based on that technology. Total freshwater consumption per year in England is estimated as the product of:

[16] Caromal UK website, confirmed by personal communication.

[17] Unpublished data provided by Sports England, personal communication.

- the proportion of businesses solely (70 per cent) or mostly (20 per cent) using water-fed poles;
- water consumption per hour when using a water-fed pole;
- hours per working day spent cleaning windows;
- days per year in full-time work
- employees in the sector.

The first three of these are taken from the interview conducted with the British Window Cleaning Academy (BWCA) conducted for this project. Employees assumed to work 250 days per year and employment is taken from the BWCA website.

Economic metrics

This sector uses data from the 2010 ONS Annual Business Survey (ONS, 2012a)for the window cleaning services sector. 2010 turnover calculated using sub-regional 2010 output at basic prices and applying the national industry ratio between output at basic prices and turnover to sub-regional output. 2010 profits calculated from sub-regional GVA assuming employment costs in GVA are equal to the national industry average in all regions. National-level 2010 employment in the overall industry from the ONS Business Register and Employment Survey (ONS, 2012b) allocated to each region assuming that shares of employment are equal to regional shares of turnover.

Commercial car washes

This part of the model calculates water and economic metrics for car wash businesses using mechanical car washes. This represents approximately 50 per cent of the car wash business, according to the Car Wash Association; the other half of the sector (hand car washes) is likely to contain a reasonable proportion of businesses which are difficult to regulate and hence may be unlikely to respond to management actions applied to the sector.

Water consumption

Total freshwater consumption per year in England is the product of:

- the number of businesses;
- freshwater per wash; and
- washes per year per business.

Number of businesses is the sum of approximate number of stand-alone car washes and estimated number of petrol stations with car washes (calculated using total number of petrol stations from the retail marketing survey conducted by the Energy Institute and proportion with car washes.

Freshwater per wash depends on the type of equipment and whether or not the business recycles water. We assume that half of petrol station car washes and all stand-alone businesses recycle water and that the other

half of petrol station car washes are split between ‘high pressure roll-over’ and ‘brush roll-over’ systems. Water consumption figures are taken from (Washtec, 2011).

The number of car washes per year per business was taken from an Excel model provided by WashTec: *Car Wash Economics v2.62*.[18]

Economic metrics

These were taken from the WashTec *Car Wash Economics* model. Turnover is average of turnover for a business with ‘full’ and no capital investment. Profits are average of profits for a business with ‘full’ and no capital investment. The definition of profits implicit in the model is revenues minus capital depreciation, business rates and operational costs.

Households

Water consumption

Household water consumption in 2009-10 by region was calculated from Public Water Company data on per household consumption for metered and unmetered households and number of households of each type. This data was supplied by Halcrow. Household consumption excludes PWS leakage, which is accounted for separately in the model.

[18] The model can be requested at Marketing@WashTec-uk.com.

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Company Profile

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