A climate change report card for water

Working Technical Paper

6. Assessing future water demand for agricultural irrigation in England and Wales –an updated analysis.

Keith Weatherhead[*], Jerry Knox, Tim Hess and Andre Daccache

Cranfield Water Science Institute, Cranfield University, Bedford, MK43 0AL, UK

[*]Corresponding author: k.weatherhead@cranfield.ac.uk

Summary

Spray irrigation accounts for <2% total annual abstraction in England and Wales, but is concentrated in the driest months, in the driest catchments when resources are most constrained. Most is abstracted and used direct, with relatively little on-farm storage. However, investment in on-farm reservoirs has increased steadily in recent years in response to concerns regarding the reliability of future water. In a dry year, outdoor irrigated cropping accounts for around 150,000 ha; this is a very small proportion of the total cropped area nationally, but nevertheless constitutes a significant component of agricultural output in terms of rural employment and national revenue.

Following a long period of growth, the volume of water being abstracted for irrigation is in decline. Since around 1990, the volumes abstracted have declined at an average rate of 2-3% (of the 2010 value) per annum. However, this partly reflects a recent sequence of wetter summers. Allowing for annual weather variations, the underlying decline in dry year demand was -1.4% per annum, averaged over 1990 to 2010. Extrapolating forward as a compound decline suggests a further reduction of around one quarter (-25%) by 2030. These trends, particularly for important irrigated crops (potatoes), highlight major differences to those reported previously. They suggest that the strong upward growth in water demand until around 1990 has halted and is now reversed. This reflects the increasing yield and hence decreasing cropped areas needed, together with increased efficiency and better scheduling, largely in response to rising energy costs for irrigation and demands for quality assurance. Emerging issues regarding water availability and reliability, and hence greater appreciation of its value, are also likely to have contributed to the change in trend.

Estimates of the magnitude and location of future irrigation demand are essential for strategic planning and management of water resources at national and regional levels. However, demand forecasting is fraught with difficulty, as water use is highly sensitive to assumptions made regarding changes in agro-economic policy, the impacts of climate change on crop growth and future water resources availability. The most recent forecasts (up to the 2050s) used a combination methodology to incorporate the effects of changes in population demographics, consumption and consumer preferences under a range of socio-economic policies. Likely changes in the expected national area irrigated, food consumption per head, the proportion of produce that is home-grown, and the proportion likely to be irrigated as well as changes in climate and crop yield were assessed. Future water demand for arable cropping, potatoes and horticulture were then estimated for four EA defined socio-economic scenarios (sustainable behaviour, innovation, local resilience and uncontrolled demand). The projected changes ranged from +40% to +167% by the 2050s for 'unconstrained' demand in a dry year; in future 'actual' water use will be constrained by water availability and allocation policy, which itself may lead to a relocation of demand. Combined with a probable decline in low-flow (summer) water availability, this indicates major future water resource issues. The figures do need to be interpreted with caution as they are sensitive to model input values. Sensitivity analysis showed demand could change by ±5% for most of the input variables, but 'change in potato yield' could change demand by +20% for some scenarios (and vice versa). The latest forecasts are surprisingly similar to previous estimates given that they have been completely reworked with new independent industry opinion and framed within modified socio-economic scenarios. The projections ignore any impacts of step-change genetic improvements, such as the

introduction of genetic modification techniques and the effects of CO_2 concentrations on crop growth.

In future, climate change is likely to exacerbate many of the current farming challenges, including land suitability for both rainfed and irrigated cropping. However, coping with more immediate economic and environmental risks means the farming sector is less inclined to give climate change the priority it deserves as a business risk. Adaptation will be critical to secure access to the relevant skills, resources and knowledge needed to increase production efficiency, to improve agricultural water management and to embrace new technology as part of the sustainable intensification of UK agriculture.

Introduction

Internationally, agriculture is widely regarded as one of the sectors at most risk from a changing climate (Falloon and Betts, 2010), due to the impact of increased temperatures, reduced rainfall and increased frequency of extreme events, not only in the tropics, but also in humid environments such as the UK (Knox *et al*., 2010a; 2012). Climate change will influence the way crops develop, grow, and yield. Outdoor field crops such as vegetables and potatoes will be particularly sensitive, both directly from changes in rainfall and temperature but also indirectly, since any changes will also impact on the agricultural potential of soils by modifying soil water balances, with consequences for land management, including trafficability and workability. In the UK, climate change will impact on land suitability (Daccache *et al*., 2012), the viability of rainfed production, and hence demand for irrigation.

Although UK agriculture accounts for only a small proportion of the national economy and employment, it occupies almost 75% of the total surface area (Angus *et al*., 2009). It is strategically important in the provision of food, including both cropping (arable, horticulture) and livestock (beef, dairying, pigs, poultry), and provides over half of all food consumed in the UK (Defra, 2010a). As in many countries, UK agriculture has a multifunctional role, sitting at the interface between the natural environment and society, contributing to a range of environmental services including landscape enhancement, leisure and recreation and the provision of non-food raw materials. Since agriculture involves the manipulation of natural ecosystems, it is particularly vulnerable to climate change. But the interactions and feedbacks that exist between agriculture, the environment and society can make risk assessments difficult (Knox and Wade, 2012). In the future, producing food sustainably in a changing and uncertain climate will be a high priority (Defra, 2010b) but climate change is just one of a number of stresses on agriculture. Responses to the threat of climate change will need to be sensitive to ecosystems and the diversity of benefits that agriculture provides, and not just food production. Water resources will be more constrained, and water allocation policy will be a key issue.

Irrigated areas and volumes of water applied

Most agricultural cropping in UK is rainfed and, even in a dry year, only a small proportion (<1%) of land is typically irrigated. Since 1955, the government has published statistics on agricultural irrigation in England and Wales, based on surveys carried out roughly triennially, and most recently in 2010. The latest survey (2010) shows that potatoes constitute the dominant irrigated crop, accounting for 43% of the total irrigated area and 54% of the total volume of irrigation applied. Irrigation of field vegetables has increased steadily, now accounting for 25% of the area and 26% of water use, respectively. In recent years, cereals have also shown a gradual increase in the proportion irrigated, but much less change in water use, probably a response to drier springs and the importance of water for crop establishment. For many farming enterprises, irrigated production is the driving force behind investment, but future changes in water availability and reliability will impact on its potential benefits (Knox *et al*., 2009).

Irrigation water demand and water stress

All abstractions for agricultural irrigation in England and Wales are regulated by the Environment Agency (EA). Most irrigation is abstracted from rivers and streams, and used direct with relatively little on-farm storage. Weatherhead (2006) reported that over half (54%) of all irrigation abstraction was from surface sources (rivers, streams), with groundwater (boreholes) accounting for 41%. However, with an increasing dependence on irrigation for crop assurance, in some catchments irrigation now constitutes the largest proportion of abstraction in dry summers - concerns have been raised regarding its potential environmental impact, particularly where water resources are under pressure (Hess *et al*., 2010). Information on agricultural and horticultural holdings are collected annually by the Agriculture and Horticulture Development Board (AHDB) as part of their statutory duty. In England and Wales, the EA has assessed the availability of water resources for abstraction, with each sub-catchment defined according to resource status, including 'water available', 'no water available', 'over-licensed' and 'over-abstracted' in order of increasing water stress. By combining the AHDB data for the most important irrigated crop categories (potatoes, field vegetables and soft fruit, which account for 85% of the total volume of irrigation water abstracted), with EA data on resource availability, the proportion of holdings currently in water stressed catchments was estimated. This analysis by Hess *et al*. (2010) showed that 10-15% of irrigated holdings were within catchments where additional water could be available during summer low-flow periods for abstraction ('water available'). About half were are in catchments having 'no (more) water available' or were 'over-licensed'. Nearly a fifth were in 'over- abstracted' catchments. This analysis highlighted the challenge facing water resources management and abstraction control – identifying crop sectors and regions where future agricultural water demand is likely to exceed available water supplies. It is therefore important to understand the likely future spatial and temporal variability in demand, the drivers of change and adaptation options to minimise the environmental impacts and economic consequences of water shortages on agricultural productivity.

Forecasting future irrigation water demand

Over the last two decades a number of contrasting approaches have been developed to assess future spatial and temporal changes in agricultural water demand (e.g. Weatherhead *et al*., 1994; Weatherhead and Knox, 1999; Downing *et al*., 2003). In this paper, the most recent forecasts by Knox *et al* (2012) are briefly described; these build on work by Weatherhead and Knox (2008) which formed part of the EA water resources strategy (EA, 2008a). That study considered eight crop categories to match those in the Defra Irrigation Surveys, namely; early and maincrop potatoes, sugar beet, vegetables (grown in the open), soft fruit, orchard fruit, cereals, and grass. Climate impacts were based on projections from the UK Climate Impacts Programme (UKCIP02). The most recent forecasts by Knox *et al.* (2012) used the same crop categories but incorporated data from the latest climate projections (UKCP09). All forecasts were for a 'design' dry year, defined as a year with an irrigation need with a 20% probability of exceedance. It is emphasised that the projections are for demand; actual water use is already constrained in dry years and would be significantly reduced by any increased restrictions on water availability and allocation policy, which may itself lead to a relocation of water demand, depending on where water resources are under pressure relative to the location of irrigated production. Forecasts were made for two periods (i) short to medium term (2010 to 2030s) for a 'business as usual' scenario under current economic and water policy conditions based on underlying trends, and (ii) the medium to long-term (up to 2050s) with projections framed within four socio-economic scenarios. All forecasts were relative to a 2010 baseline. An outline of the approaches used and key findings are summarised below.

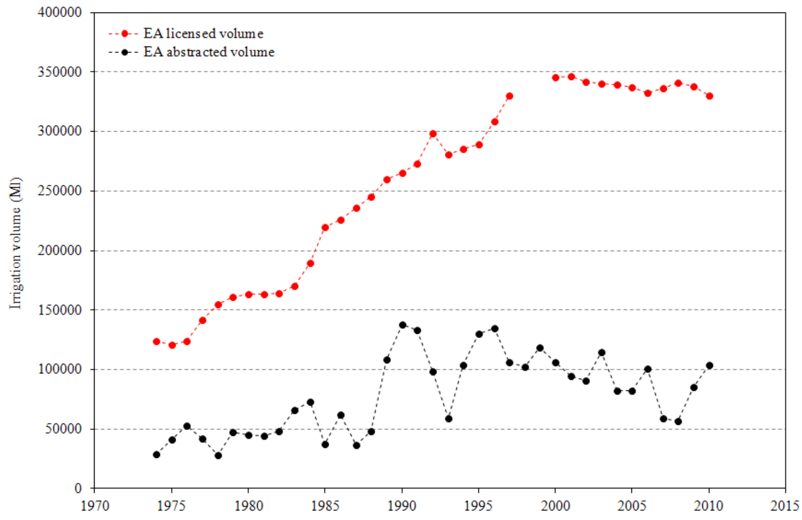
(i) Short to medium term future water demand (2010 to 2030s)

For this projection, an extrapolation based on underlying trends was developed. In England, the irrigated areas and the volumes of irrigation water applied each year vary considerably depending on the summer weather and distribution of rainfall. The data published in government irrigation surveys and reported by the EA on irrigation abstractions therefore partly reflect the weather in each year, and do not directly show the dry year demand in a particular year nor indicate the underlying trends in dry year demand. However, Weatherhead and Knox (2008) developed a statistical approach to analyse these datasets using calculated theoretical irrigation needs (depths) for selected crops as the independent climate variable in a multiple linear regression analysis. This can be used to calculate the underlying growth rate in the areas irrigated and volumes of water applied. Two alternate datasets were used; the first based on annual data from the EA National Abstraction Licensing Database (NALD), which informs Defra ABSTAT data; the second using data from the periodic Defra Irrigation Surveys.

Total volume trends based on NALD/ABSTAT data

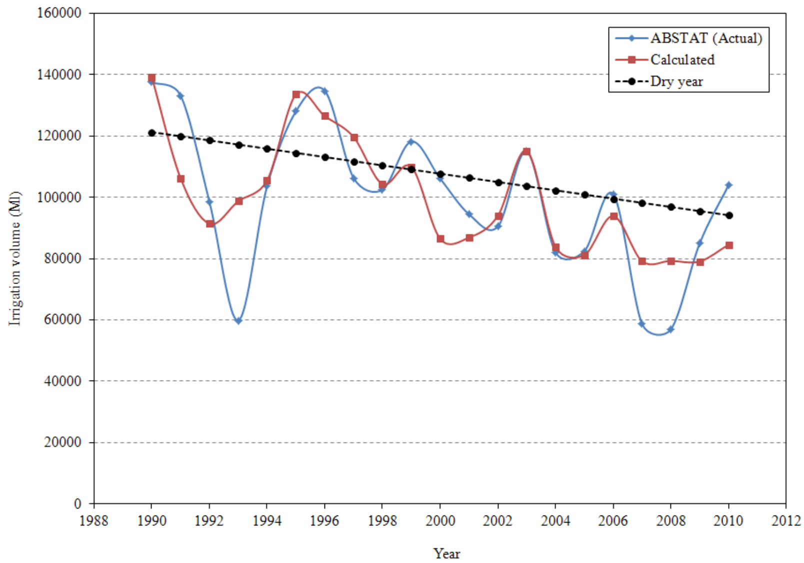
Data on the total volumes of water licensed and abstracted for spray irrigation are available from the EA NALD or in processed format from the ABSTAT files published by Defra. Almost all irrigators abstracting > $20m^3day^{-1}$ are required to have an abstraction licence and flow meter(s) and to return data to the EA on their volumes abstracted. After statistical correction for non-returns and missing data, the aggregated results are published as ABSTAT data, available from the Defra website. Until around 1998, the volumes licensed for spray irrigation were growing steadily at around 10,000 Ml/year, equivalent to around 3% of the 1998 value per annum (Figure 1). Since the late 1990s, however, the total licensed volume has declined slowly, at about 0.3% per annum. This date roughly coincides with the general realisation that many catchments were becoming over-abstracted and changes in licensing policy were underway. This steady decline in the national total does disguise local and regional variation and significant 'churn' with some new licences still being issued and others being systematically reduced and/or relinquished.

Figure 1 Reported licensed and abstracted volumes (Ml) for spray irrigation in England and Wales, 1974 to 2010.



There is much more variation in the volumes reported as actually abstracted (Figure 1), partly due to the weather differences between years. Again, there has been a period of strong growth followed by a decline, though the change in abstraction trend appears to have occurred earlier than the change in licensed volume trend. Since around 1990, the volume abstracted appears to have been declining at an average rate of around 2% to 3% (of the 2010 value) per annum. However, this partly reflects a recent sequence of wetter summers. After allowing for the annual weather variation, the underlying decline in the dry year demand was estimated to be around -1.4% per annum, averaged over the 1990 to 2010 period (Figure 2). Extrapolating that forward alone as a compound decline would suggest a further reduction of around one quarter (-25%) from 2010 to 2030.

Figure 2 Volumes abstracted (Ml) between 1990 and 2010, with the fitted curve allowing for actual weather and the resulting underlying dry year changes.

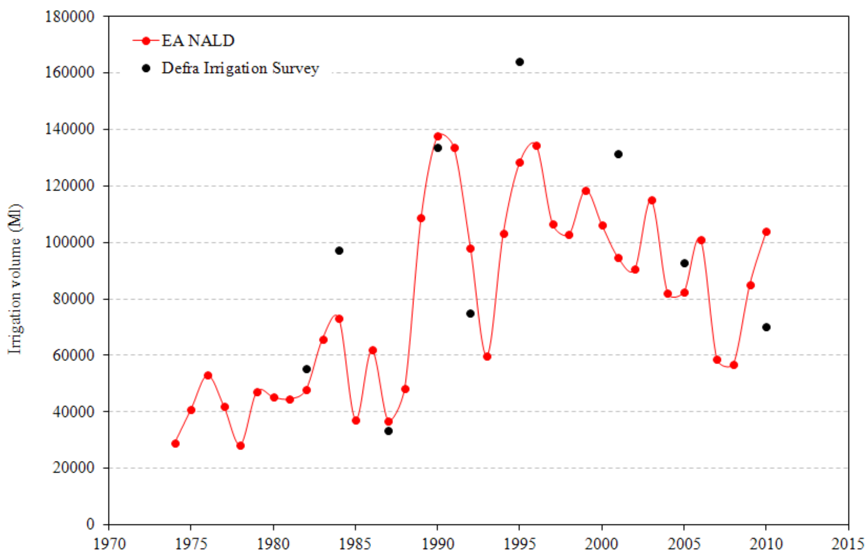


Crop-based trends based on MAFF/Defra Irrigation Survey data

More detailed data on irrigation use for individual crop types is available from the periodic Defra Surveys of “Irrigation of Outdoor Crops”. Since 1982 the main questions have been kept consistent, giving now nine sets of directly comparable data, for 1982, 1984, 1987, 1990, 1992, 1995 (all by MAFF), then 2001 and 2005 (for Defra by Cranfield University), and most recently in 2010 (by Defra). The next survey is planned for 2013. The data is broken down between 8 crop categories, by irrigated area and volume. Other data includes irrigation method, water source, and scheduling method. This data is much richer in content but is less complete, due to its intermittent nature and the lower return rate. The address list is obtained from a trigger question in the annual Defra "Agricultural and Horticultural Cropping" census (“June Census”). That is only a full census in selected years (including 2010). Statistical corrections therefore have to be made for those not included in the June Census, non-returns to the June Census, and non-returns to the irrigation survey. This can be a major source of error for calculating national totals. In 2001, for example, the final returns were estimated to cover only about 40% of the total irrigated area. The survey also only refers to outdoor crops grown on registered agricultural holdings; it therefore excludes glasshouse crops, and landscape and other non-crop irrigation. It does include other water sources outside the NALD/ABSTAT dataset such as mains public supply, rainwater harvesting, water re-use, trickle irrigation and abstractions < $20m^3\ day^{-1}$, though these are relatively minor compared to direct abstraction from surface water or ground water.

The total annual water use data from the Defra Irrigation Survey data shows similar trends to the EA NALD data, but they do not match entirely (Figure 3). This may be partly due to the different ranges of water sources covered and businesses surveyed, the different year end dates (affecting when reservoir recharge is counted), and/or inaccurate returns from water users, but is probably mainly due to the difficulty of correcting for non-returns in both datasets. A detailed discussion of the various survey differences is given in Weatherhead *et al*. (1997). Analyses based on the 1995 to 2010 Irrigation Surveys data appear to show very much faster rates of decline than the ABSTAT abstraction returns; however, their statistical reliability is lower, due to the limited number of surveys. The ABSTAT trend has therefore been used for the total volume abstracted, and the Defra Irrigation Survey data used to distribute that overall trend between individual crop categories.

Figure 3 Comparison of the reported total volumes (Ml) abstracted/applied between 1974 and 2010 based on EA NALD and Defra Irrigation Survey datasets.



The analysis of the irrigation survey data suggests the average depths applied (volume per unit area) have been falling slowly. There has been a underlying decline in both the area of potatoes irrigated and the water applied. The picture is statistically less clear for vegetables, but tends to suggest an overall slow increase in both areas and volumes, but possibly a short-term decline more recently. In contrast, irrigation of sugar beet, grass, cereals and orchard fruit all appear to have been in longer-term decline, but have perhaps seen recent increases. Irrigation of soft fruit (e.g. strawberries) shows a steady decline in both areas and volumes, thought this is one crop where the average depths applied have increased.

These trends, particularly for the important irrigated crops, highlight quite major differences to those derived previously. They suggest that the strong upward growth until around 1990 in the total volumes of water abstracted has reversed. This at least partly reflects the increasing yield and hence decreasing cropped areas needed (particularly for potatoes and some other major irrigated crops), together with increased efficiency and better scheduling. The increasing issues relating to reduced water availability and reliability, and hence a greater appreciation of its value, are also likely to have contributed. It is noted however that these short term forecasts do not include climate change (other than any already occurring), and may therefore be a temporary trend.

(ii) Medium to long term future water demand (up to 2050s)

Water demand forecasts are highly sensitive to the assumed prevailing socio-economic conditions. In this study, four new EA future scenarios were used (‘Innovation’, ‘Uncontrolled Demand’, ‘Sustainable Behaviour’ and ‘Local Resilience’). These reflect updated scenarios previously developed for the EA water resource strategy (EA, 2008) termed ‘Alchemy’, ‘Jeopardy’, ‘Survivor’ and ‘Restoration’, respectively (Burdett *et al*., 2006). In England where irrigation is supplemental to rainfall, many crops are not irrigated, and even for irrigated crops, not all farmers irrigate. Furthermore, many farmers apply less than agronomic demand, because of equipment or water resource limitations, or as a deliberate policy to maximise profit. The methodology for estimating future changes in demand is thus more complex than for say an arid area, where demand is a function of agroclimate. For irrigated cropping, water demand therefore depends on the future area of each crop grown, the proportion of each crop irrigated, and depth of water applied. Each of these in turn depends on agro-economic and technical conditions which will inevitably change, as well as the fundamental agronomic and agroclimatic conditions, which will themselves vary. Hence, the approach developed by Knox *et al* (2012) integrated spatial and temporal information relating to future changes in climate, changes in land suitability (as this influences whether a crop will be rainfed or will switch to irrigated production), and the likely changes in socio-economic conditions and agro-economic policy. These 'externalities' are critical because they influence the extent to which adaptation measures become economically viable, and geographically where they should be promoted. The approach involved a number of discrete stages.

In 2012, a stakeholder workshop was organised to discuss the four EA scenarios and their impacts on irrigation demand. It was important to highlight any 'givens' – these are drivers where it was assumed that there is just one possible future development across all scenarios, or which are already pre-defined. These included (i) climate change where it was assumed that recent developments would continue without any trend breaks, broadly reflecting assumptions underpinning the "Reference Scenario" of the Office for National Statistics (ONS) in its projections for demographics and a relevant scenario from the Intergovernmental Panel on Climate Change (IPCC) for climate change and UKCP09; (ii) population demographics which were already defined under each EA scenario, (iii) consumption patterns and behaviour which were already part of the 'axis of uncertainty' so their status was already given in the EA scenario, and (iv) government interventions in EU and national agricultural policy which were similarly already part of the same 'axis of uncertainty' defined in the EA scenario.

Workshop participants were asked to prioritise a set of 'drivers for change' that would most influence future water demand. Those given highest priority included water use and availability, price and availability of resources, including energy and land, price and availability of staple crops, land use and productivity, global demand for food products, global food markets and environmental quality and biodiversity. Two exercises were then conducted. The first involved a qualitative description of how these 'drivers of change' might impact on agriculture within each EA scenario. This helped to provide an agricultural narrative. The second exercise involved generating estimates of change (direction and magnitude) for five micro-components of demand (MCD), namely, national consumption, the proportion of the crop grown in the UK, yield, the cropped area and proportion irrigated. For each EA scenario, a consensus regarding the direction of change and magnitude of change for each MCD, in each sub-sector (arable, potatoes, horticulture) was then completed.

The MCD outputs were then converted into numeric values, and expressed as '% change factors' (either direct changes or asymptotic to either 0% or 100% for proportions, depending on the variable). These change factors were informed by a review of evidence to identify typical historical rates of change, as they could be indicative of likely future rates of change. For example, crop yields have doubled over the last 40 years, so it would be reasonable to assume that they could double (+100%) again over the next 40 years. In contrast, the future change in national consumption for a particular crop commodity (e.g. vegetables) is likely to be tied to the population growth rate so more conservative increases might be more realistic (e.g. +10 to +20%). This approach helped to weight the outputs from the scenario workshop. For each sub-sector and each EA scenario, the rates of change were mathematically combined to estimate future water use for each sub sector (Knox *et al*., 2012). A summary of each EA scenario and impact on future agricultural water demand is given below.

'***Innovation'*** resulted in a +157% increase to the 2050s, abstracted within environmental constraints. A high technology and knowledge-led society with consumption in a relatively resource intensive manner led to growth in potatoes (+44%), horticulture (+34%), arable (+14%) and other crops (+8%). The high demand increases for potatoes and horticultural crops is due to higher per capita consumption and population growth, but offset by substantial yield increases. The cropped areas are grown under intensive conditions managed by agribusiness with a higher proportion irrigated than at present and scheduled for high yield and quality under a more arid climate.

'***Uncontrolled demand'*** represents a consumption based scenario that results in the largest increase in water demand (+167%). There is no significant change in overall food demand other than to supply the substantial population increase. Potatoes remain the largest abstractor accounting for nearly half all water use (49%); there is also major growth for vegetable irrigation (27%) and nearly a fifth (15%) for arable irrigation to meet increased population food needs.

'Sustainable Behaviour' resulted in a gradual steady growth in demand, rising by around +42% by the 2050s, again concentrated on potatoes (+56%) and vegetables (+27%). This scenario featured low resource consumption and local food production using greener technologies, with lower yields and less emphasis on quality assurance. Diets are more vegetable based than meat, population growth is modest but the decline in imports and lower yields results in significantly more land needed for cultivation. There is little emphasis on GM and new technologies due to the lack of past investment. There is a larger area grown under potato irrigation than at present, but mainly on family farm units rather than large scale agribusiness. Without demands for quality assurance, irrigation is widely used to boost yield.

'***Local Resilience'*** resulted in a similar increase in demand to sustainable behaviour (+40%) due to population growth and climate change, as the population starts to accept lower quality and locally sourced fruit and vegetables. This scenario reflects a society more concerned about the environment than consumption. Consumers want naturally grown, sustainable food. Organic food and free range becomes more accepted. Farming becomes more extensive, non-organic fertilizers are expensive and yields decline. There is high concern for water application efficiency and low wastage, but efficiency falls in terms of productivity per unit of water – 'crop per drop' - due to the lower yields. Moderate population leads to significantly larger land areas under potatoes, horticulture and arable. The proportions irrigated decline slowly, and climate change is partly moderated by relocating crops. The increased areas and the impacts of climate change result in significant increases in water use on potatoes (+55%) and horticulture (+27%).

All these demand forecasts are of course sensitive to the model input values which themselves were derived from the stakeholder workshop. For example, another workshop with different key informants could quite feasibly generate a different set of input values. A sensitivity analysis of the various input values was therefore undertaken. This resulted in a change of ±5% for most of the input model variables. The most sensitive was 'change in potato yield' which could change demand by +20% for some scenarios (and vice versa). The forecasts were also sensitive to model inputs for cereals – current projections could be markedly different if there was large-scale switch from rainfed to irrigated production (the current baseline irrigated area is so small as to make any % changes unreliable). Given current water resource pressures, it would be difficult to imagine a situation where sufficient water was available, but changing economics to justify cereal irrigation could be a real driver. The projections also ignore any impacts of step-change genetic improvements, such as the introduction of genetic modification (GM) techniques and the effects of elevated CO_2 concentrations on crop growth and yield.

Future water demand in agriculture – policy implications

The projected increases have important implications for water management and abstraction policy.

Promoting increased water efficiency

Increasing the “efficiency” of irrigation, say by reducing water use by 10% without impacting yield or crop quality, if feasible, would reduce all demand proportionately, easing some of the constraints on farmers and/or allowing the EA to limit abstraction. The route to higher efficiency is most likely to include further switches to modern application technology (e.g. trickle irrigation, automated solid-set sprinklers, intelligent mobile booms or guns) in appropriate (but not all) situations, and improved scheduling systems and management. The geographical disparity in demand growth and between different crop types emphasises that increased efficiency is more important in some areas than others, and that any policy to promote water efficiency should be appropriately targeted for greatest benefit.

Promoting abstraction licence trading

Water trading is only likely to occur where supplies are constrained, therefore an increase in trading will not in itself alter the ‘unconstrained’ demand. However, it could help to reduce actual shortages in particular catchments by allowing a higher proportion of the licensed water to be abstracted (subject to environmental constraints), and help society obtain a higher benefit from the water through transfer to higher value users. Since trading is likely to be restricted within hydrological units, it would not alter the location of demand, but it might allow irrigators to grow particular crops in more favourable locations (climate, soils, markets) rather than moving to where water is available without trading.

Promoting high flow storage

Increased on-farm reservoir storage would allow more of the water to be abstracted at times of high flow (winter), reducing the impacts of irrigation abstraction at times of major resource constraint. Due to reservoir losses through leakage and evaporation, this policy may actually cause a small increase in total abstraction, but this will be abstraction at times of high flow. Furthermore, storage will help spread out the peaked abstraction in dry years – in most years reservoirs carry water over into the next year. Most reservoirs are likely to be built in areas where water resources are already constrained and where the benefits of irrigation are highest, typically for irrigating high value crops in southern and eastern England. If summer licences have to be surrendered, the water constraints will remain while the abstraction impacts will be reduced. If the winter licences are additional to existing summer licences, the reservoir size and cost will be reduced but there will be less reduction of summer abstraction; however the existence of storage will reduce the costs of imposing summer restrictions or higher “hands-off” constraints, and would allow the water regulator to manage supplies more effectively. These reasons highlight why ‘high flow’ storage is being promoted, but recent winter droughts and many unfilled reservoirs in 2012 highlight the risks of this strategy.

Influencing food quality expectations

Much of the current demand for irrigation water is reportedly due to the demand for high quality skin finish on potatoes, and potatoes remain the dominant water user into the future, suggesting that a policy of influencing consumers might be beneficial in influencing water demand. Beyond about 2020, vegetables become an increasingly important growth sector. Current government heath policy is to promote increased vegetable consumption (e.g. Eatwell Plate campaign) so it is important to consider water policy impacts in the context of other broader government initiatives.

Adaptation options to potential future water shortages in irrigated agriculture

Greater uncertainty in seasonal weather patterns means growers will need to adapt and consider short-term coping strategies as well as longer-term strategic developments to reduce their vulnerability to changing water availability. How they respond will depend to a large extent on their perception of risk and the opportunities that climate change presents to their business. Farmers generally have two adaptation options, (i) to reduce their water needs or (ii) to secure additional water supplies. Options to reduce water needs include investing in improved irrigation technology (scheduling) and equipment to increase application uniformity and efficiency, using weather forecasting to increase the effective use of rainfall, encouraging deeper rooting of crops, introducing lower water use or drought tolerant crop varieties, decreasing the overall irrigated area, or modifying soil structure to improve soil moisture retention. Adaptation options to obtain more water include purchasing land with water, obtaining additional licensed capacity and building on-farm storage reservoirs (individually or shared with neighbours), installing rainwater harvesting equipment, re-using waste water from farm buildings, or switching water supplies to public mains where feasible. Many of these adaptations (e.g. reservoirs) are already ‘no regret’, in that they make sense by solving existing water resource issues, which then contribute to a farms future adaptability. The feasibility of other adaptations (e.g. water harvesting) are farm specific and depend on their technical and economic viability for that particular enterprise.

Water resource impacts

In reality future demand will be strongly influenced by actual water availability. Licences are still available for winter (high flow) abstraction in most catchments, and recent years have seen a significant increase in the construction of on-farm reservoirs for summer irrigation. Though expensive, these provide growers with greater security of supply, and it seems likely that this will become the preferred water resource adaptation for many irrigators. Most reservoir investments have probably been more a response to legislative or other pressures (e.g. supermarkets), rather than purposeful (deliberate) adaptations to any perceived future climate change. Nevertheless they may still prove to be a useful climate change adaptation strategy. Once irrigation water is assured but expensive, it will become increasingly sensible to invest more heavily in water efficiency measures, including better application methods (e.g. drip) and precision irrigation, and scientific scheduling methods will become more widely adopted.

Many responses will have a crop specific element. For example, earlier planting and harvesting in potatoes would reduce water use per unit area, but with some varieties growers might prefer to use the longer grower season to increase yield. There has been a steady increase in average potato yields over the last few decades; with national consumption roughly constant this has led to a gradually reducing area planted and hence reduction in water demand. There will also be some degree of autonomous adaptation even if not planned. For potatoes, this could include earlier planting and harvest dates, changing to better adapted varieties, less dependence on soils with low water holding capacities, crop movement to regions with suitable agroclimate and water availability, and uptake of GM technology.

Water use and land suitability

Recent research by Daccache *et al* (2011, 2012) showed that growing rainfed potatoes in England and Wales will become increasingly risky as the climate changes, and limited to a few favourable areas. In contrast, with irrigation, the land suitability hardly changes, and most of the current rainfed crop could remain at its present location if irrigated. Although only around 1% of water abstraction in England and Wales is used for irrigated agriculture, there is limited prospect of obtaining significant additional licensed quantities for the summer months in the face of competing demands. Many existing licences are unused or underused so some farm of water transfers or abstraction license trading may be an option, though there are environmental arguments against re-activating 'sleeper' licences in water short catchments. Previous research has suggested that irrigated potato production might move north and west as an adaptation to climate change. Given that most of the current locations remain suited to irrigated production, and that future summer water resources may not be reliable even where licenses are available at present, this may be a slow process. Many growers have sizeable investment in fixed assets for potato production, and may prefer to remain near their present locations, renting land from nearby farmers with unused or partially used licences as a preferred adaptation response.

Future water demand and 'non climate' risks

It is important to recognise that UK irrigated agriculture also faces a range of 'non-climate' risks which it is often argued present a greater and more immediate threat than climate change (Knox *et al*., 2010b). These can be categorised into economic, environmental and technological risks, with the majority occurring 'off-farm' and impacting on growers via various national and European agro-economic policy interventions; the increasing burden of environmental regulations; limitations in the availability of finance; fluctuating exchange rates; and the relative power of supermarkets as these affect the operation of markets, including requirements for auditing and traceability.

The most significant economic risks off-farm relate to CAP reform, as it could affect farm income support, compliance requirements and incentives for environmental sensitive farming. Rising production costs for water, energy, labour and fertiliser, coupled with increasing risks associated with infrastructure damage due to flooding are other sources of economic risk. Much depends whether these increased costs are offset by higher commodity prices arising from strong global demand. The main environmental impacts off-farm relate to changes in water availability due to low surface water flows and groundwater levels, increasing demands for water from other sectors, increasing environmental regulation and abstraction control, and the risks associated with GMO cultivation (Knox *et al*., 2010b).

The on-farm risks relate mainly to the control of the use of pesticides and fertilisers (because of their potential impacts on local environments via diffuse water pollution), the risks of new disease and poor soil management. The main technological risks off-farm are insufficient R&D investment in agriculture (Royal Society, 2009), coupled with a lag in technological uptake compared to European neighbours. A decline in the capacity of skills in UK agriculture, as well as the number of people willing to work on the land are also constraints (Spedding, 2009) common to other parts of Europe and North America (IAASTD, 2009). On-farm technological risks relate to the observed widespread deterioration in maintenance of land drains, inadequate staff training and the rising costs of energy on which new technologies are dependant.

In addition, a raft of international drivers will affect UK agriculture including the consequences for world trade, affecting both demand for, and supply and prices of agricultural commodities in global and regional markets and an increased volatility of market conditions. In addition, there are the actions being taken by governments to address climate change effects – with consequences for agricultural markets, including protectionism. There is likely to be greater instability in international food and energy prices, affecting fuel costs and fertiliser use, and greater global water scarcity with consequent impacts on food production especially in relation to food exports to the UK from Southern Europe (Yang *et al*., 2007). There are societal factors too, such as public and political resistance to the use of GMOs that could help to adapt to environmental change; changing dietary preferences towards healthy eating; increasing demand for year-round fresh supplies favouring food imports; and competition for land and water for development and non-agricultural use, such as nature conservation and recreation.

Finally, the irrigated farming sector clearly has a challenging period ahead, trying to maintain productivity whilst controlling spiraling farm costs, particularly in relation to energy, whilst also demonstrating compliance with regulations associated with environmental protection, food safety and bio-security. Coping with immediate economic, environmental and technological pressures means that farmers are less inclined to give climate change the priority it deserves as a key business risk. Climate change, however, is likely to exacerbate many of the current challenges already facing the agri-food sector, including that of securing future access to reliable water supplies.

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References

Angus, A., Burgess, P.J., Morris, J and Lingard, J. (2009). Agriculture and land use: demand for and supply of agricultural commodities, characteristics of farming and food industries and implications for land use. *Land Use Policy*, doi 10.1016/j.landusepol.2009.09.020.

Burdett, L.,Cooksey, E.,Christie, I.,Wehmmey, W.,Chenoweth,J., and Clift,R. (2006). EA socio economic scenarios. Environment Agency Scenarios 2030. Science Report SC050002/SR1. Environment Agency, Bristol, UK.

Daccache, A., Weatherhead, E.K., Stalham, M.A., and Knox, J.W (2011). Impacts of climate change on irrigated potato production in a humid climate. *Agricultural and Forest Meteorology* 151: 1641–1653.

Daccache, A., Keay, C., Jones, R.J.A., Weatherhead, E.K, Stalham, M.A., and Knox, J.W (2012). Climate change and land suitability for potato production in England and Wales: impacts and adaptation. *Journal of Agricultural Science* 150: (2): 161-177.

Defra (2010a). UK food security assessment: detailed analysis. HMSO, London.

Defra (2010b) Food 2030, Department for Environment, Food and Rural Affairs, London.

Downing, T.E, Butterfield, R.E., Edmonds, B., Knox, J.W., Moss, S., Piper, B.S. and Weatherhead, E.K (and the CCDeW project team) (2003). Climate Change and the Demand for Water, Research Report, Stockholm Environment Institute Oxford Office, Oxford.

Environment Agency (2008a). *Water resources in England and Wales - current state and future pressures*. EA Bristol, pp21.

Environment Agency (2008b). *Demand for water in the 2050s – briefing note.* EA, 2008, Bristol, 12pp.

Falloon, P., and Betts, R. (2010). Climate impacts on European agriculture and water management in the context of adaptation and mitigation: the importance of an integrated approach. *Science of the Total Environment* 408(23): 5667-5687.

Hess, T.M., Knox, J.W., Kay, M.G., and Weatherhead, E.K. (2010). Managing the Water Footprint of Irrigated Food Production in England and Wales. In Hester, R.E. and Harrison, R.M. (Eds) *Issues in Environmental Science and Technology* 31: Sustainable Water. pp.185. ISBN: 9781849730198.

IAASTD (2009). Agriculture at the Cross Roads. Global Report. International Assessment of Agricultural Knowledge, Science and Technology for Development. Washington: Island Press.

Knox, J.W., Weatherhead, E.K., Rodriguez-Diaz, J.A., and Kay, M.G., 2009. Developing a strategy to improve irrigation efficiency in a temperate climate: a case study in England. *Outlook on Agriculture* 38(4), 303-309.

Knox, J.W., Rodriguez-Diaz, J.A., Weatherhead, E.K., and Kay, M.G (2010a). Development of a water strategy for horticulture in England and Wales. *Journal of Horticultural Science and Biotechnology* 85(2): 89-93.

Knox. J.W., Morris, J., and Hess, T.M. (2010b). Identifying future risks to UK agricultural crop production – putting climate change in context. *Outlook on Agriculture* 39 (4): 249-256.

Knox, J.W., and Wade, S. (2012). Assessing climate risks to UK agriculture. *Nature Climate Change* Vol 2 June 378 doi:10.1038/nclimate1538.

Knox, J.W., Daccache, and Weatherhead, E.K. (2012) Assessing climate change impacts on land use and agricultural water demand and opportunities for farmer adaptation. Phase I (FFG1129) Final Report to Defra.

Royal Society (2009). *Reaping the Benefits: Science and the sustainable intensification of global agriculture.* RS Policy Document 11/09. pp 77.

Spedding, A. (2009). *New Blood – Attracting the Best People to UK Agriculture*. 62pp. Royal Agricultural Society of England (RASE).

Weatherhead, E.K., Place, A.J., Morris, J., Burton, M. (1994). Demand for Irrigation Water. NRA R and D Report 14, HMSO, London.

Weatherhead, E.K. and Knox, J.W. (1999). Predicting and mapping the future demand for irrigation water in England and Wales. *Agricultural Water Management* 43: 203-218.

Weatherhead, E.K (2006). Defra Irrigation Survey of Outdoor Crops 2005, Cranfield University.

Weatherhead, E.K., and Knox, J.W. (2008). Demand forecasting water resources for agricultural irrigation. Final Report to the Environment Agency. August 2008.

Yang, H., Wang, L., and Zehnder, A.B. (2007). Water scarcity and food trade in the Southern and Eastern Mediterranean countries. *Food Policy* 32: 585–605.