

**Mapping of water supply-demand deficits with climate change in
Scotland: land use implications**





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Executive Summary

Background to research

The supply-demand balance is a key measure of water resource sustainability. This balance is highly uneven across Scotland with much of the demand for water in the drier east. Agricultural irrigation is increasing in many areas, linked to land use change and requirements for high-quality produce. Better knowledge of the water balance can help secure its multiple benefits, including food security, energy crops, and the natural environment. A changing climate has implications for both water supply and demand but previous assessments have not included the influence of land use.

Objectives of research

This project compared the current situation with future patterns for the 2050s based upon climate change projections. It therefore provides a first-order estimate of changes in the water balance, highlights 'hotspot' catchments where the deficit may become problematic, and makes recommendations for further research to address knowledge gaps.

Key findings and recommendations

- UK climate change projections identify that summers will be warmer and most likely to be drier, leading to reduced supply, drier soils and lower river flows.
- Extrapolation of current crop water demands to the 2050s suggests that water stress could become a severe issue for some areas of East Scotland.
- Demand projections are based upon potatoes as the major irrigated crop.
- In the absence of inter-basin transfers, some small catchments in East Scotland are highlighted as particularly vulnerable.
- Estimated additional irrigation demand in the 2050s for potatoes and similar crops is up to 100mm at some locations (the highest values average values are currently ca. 170mm). Volumetric increases are projected to be up to 50ML per km².
- Summer runoff is projected to decline throughout most of Scotland, with decreases of over 50% in some areas. Reduced river flows at this time of year mean less water would be available for abstraction.
- These results have implications for long-term planning of water infrastructure; implementation of the regulatory framework; and abstraction licensing to meet environmental flow requirements.
- The estimates are made for average years and do not include extreme years when drought conditions may become more prevalent.
- Groundwater resources have not been included. This area needs further research. Further work should also use a wider range of scenarios to establish a more robust approach to future uncertainty.

Key words: climate change; water; supply; demand; sustainability; Scotland.

1.0 INTRODUCTION

The balance between water supply and water demand is a key measure of sustainable resource use. In the drier parts of the UK, including some areas of Scotland, the balance is in deficit during the summer and additional abstraction is required from rivers and lakes. However, unregulated over-abstraction can cause damage to ecosystems and biodiversity by reducing water flows and levels, reducing habitat quality and causing related problems such as oxygen depletion. Abstraction is therefore regulated through licenses, with a specific remit to maintain ‘environmental flows’ as a key indicator of ‘good ecological status’ required by the EU Water Framework Directive.

Agriculture is a relatively minor component of water demand compared to industrial and household demand but this component is increasing in many areas due to the increasing requirements for high-quality produce from agriculture and horticulture (Dunn et al., 2004). In addition, water demand for crops occurs during the summer months when resources are at their lowest, with little of the water returned to the soil. These demands are particularly evident during dry years when some catchments can already experience severe problems. On a hot dry day in summer, there can be more water abstracted for irrigation in some catchments than for public water supply.

Climate change is anticipated to lead to changes in both the supply of water (from precipitation and evapotranspiration losses) and in water demand as temperatures increase. The present study has evaluated these changes with a specific focus on land use issues because these have been neglected in previous studies. By analogue, related work on water quality in Scotland has suggested that the indirect effects of climate change through its influence on land use change may be equal or even greater than the direct effects of seasonal climate patterns (Dunn et al., 2012). These land use changes are associated with potential improvements in land capability as climatic constraints are relaxed and new agricultural opportunities develop, with some evidence that this shift is already occurring (Brown et al., 2008, 2011). Climate change will combine with other drivers, such as global changes in commodity prices, to influence future patterns of land use change, in conjunction with national and/or EU policy priorities, such as the renewed emphasis on issues of ‘food security’ or ‘energy security’ (including bioenergy crops).

There has been substantially more research on the impacts of climate change on supply-side issues compared to the demand-side. Hence, several studies have investigated the relationship between climate change and river flows or deployable output (e.g. Prudhomme et al., 2012; Charlton and Arnell, 2011). Fewer studies have investigated water demand issues, a notable exception being the CC:Dew study which mainly focussed on resources in England and Wales (Downing et al., 2003).

In the recent UK Climate Change Risk Assessment (CCRA), the changing balance between supply and demand was highlighted as a key risk in the Water sector (Rance et al., 2012), with important land-use implications also highlighted for Biodiversity and Ecosystem Services (Brown et al, 2012) and Agriculture (Knox et al, 2012). However, no additional country-specific analysis of the supply-demand balance was available for the CCRA Scotland report (Wallingford, 2012).

For England and Wales, it was projected that climate change could lead to an increase in spray irrigation demand by 34% (central estimate; within a wider scenario range of -9 to +76%).

In Scotland, Scottish Water have a programme of research to assess the impact of climate change on supply and demand, which is used to develop appropriate adaptation strategies, including planning new infrastructure, and to inform the regulatory process through Resource Management Plans. However, these procedures do not yet factor in changes in land use change.

The present study is a pilot project that aims to scope and provide initial information that can be used to bridge this knowledge gap. It combines spatial data on land use, climate, soils and hydrology for all of Scotland with the aim of identifying 'hotspot' areas that require further investigation. The emphasis is on crop-based enterprises in which the dominant use of water is direct abstraction for irrigation of field crops, with most water abstraction currently applied to the higher-value crops, notably potatoes and vegetables. The recent trend of increasing demand for potato irrigation is expected to continue over the next 10 years¹ whilst water for irrigating vegetables is projected to become an increasingly important use of water in the next 10 years (Knox et al., 2012). Other rain-fed crops, notably cereals, are not currently irrigated but also have an important water requirement related to yield performance. It should also be noted that a significant proportion of water use by livestock occurs, but this is mainly in the west of Scotland and is fairly evenly distributed throughout the year².

¹ Potato growers are under pressure from supply chains to guarantee premium quality tubers with a significant amount of water use being to control the negative effects of common scab (*Streptomyces scabies*) (Stalham and Allen (2001)).

² Most water use in livestock farming is for drinking, but water is also used for washing down of plant and machinery, particularly within dairy enterprises.

2.0 METHODOLOGY

2.1 Water Supply: baseline and future

Water supply was calculated using a water balance model applied to all of Scotland at a spatial resolution of 1km^2 (Dunn et al., 2012). The water balance model is driven by inputs of climate data (precipitation and potential evapotranspiration: PET) derived from a standard UK Met Office baseline climatology at 5km resolution (Perry and Hollis, 2005). Simulations were initiated using historic data from the standard meteorological baseline period of 1961-90. Actual evapotranspiration (AET) (including interception losses) was calculated from the PET rates as a function of both land use and soil moisture status. A range of land use factors, varying from 0.85 (bracken) to 1.4 (forestry) were applied to calculate a weighted value for the AET for each 1km^2 cell, according to the proportion of land uses within each. In addition, under conditions of moisture stress, when the simulated soil moisture drops to less than 70% of the field capacity, the AET is reduced according to a linear function.

The water balance model calculates water storage and drainage from the soil to surface and ground water bodies as a function of soil moisture conditions. Soil hydrological properties, including field capacity and saturation water content, are based on a database of properties for Scotland and control the thresholds for runoff occurrence. Weighted mean values for each were calculated at the 1km^2 resolution according to the proportion of different soil types as calibrated by runoff and baseflow parameters of the Hydrology of Soil Types (HOST) classification (Boorman et al., 1995).

Future projections of climate change were evaluated through modification of the 5km baseline climate data by applying monthly change factors to the climate variables (delta change method). Future climate data were obtained from the regional climate model used in the 2009 UK climate projections (UKCP09 projections) (HadRM3) (Murphy et al., 2009) which provide detailed multiple model runs under different diagnostic conditions of major model uncertainties (perturbed physics ensemble – PPE). The delta change method allowed downscaling of the climate data to a 5km resolution.

2.2 Water Demand: baseline and future

Current cropping patterns were obtained from detailed analysis of the IACS (Integrated Agricultural Census System) database for Scotland using 2010 as the reference year. Water demand was estimated using indicator crops to calculate typical water requirements for similar groups of crops. Hence, the full list of IACS registered crops were classified into 3 groups with similar types of water use characterised by an indicator crop: (i) potatoes (ii) cereals (iii) grassland.

The water demand for each of these indicator crops was estimated by comparing the local climatic component (as defined by potential soil moisture deficit: PSMD) against the local storage capacity of the soil (as defined by available water capacity). The empirical rules for the indicator crops were taken from the Land Capability for Agriculture (LCA) classification guidelines (Bibby et al., 1982) as updated and refined in digital format by Brown et al. (2011) – see Figure 1. The baseline climate data were derived from the same UK Met Office 5km climatology as used with the supply-side assessment (Perry and Hollis, 2005).

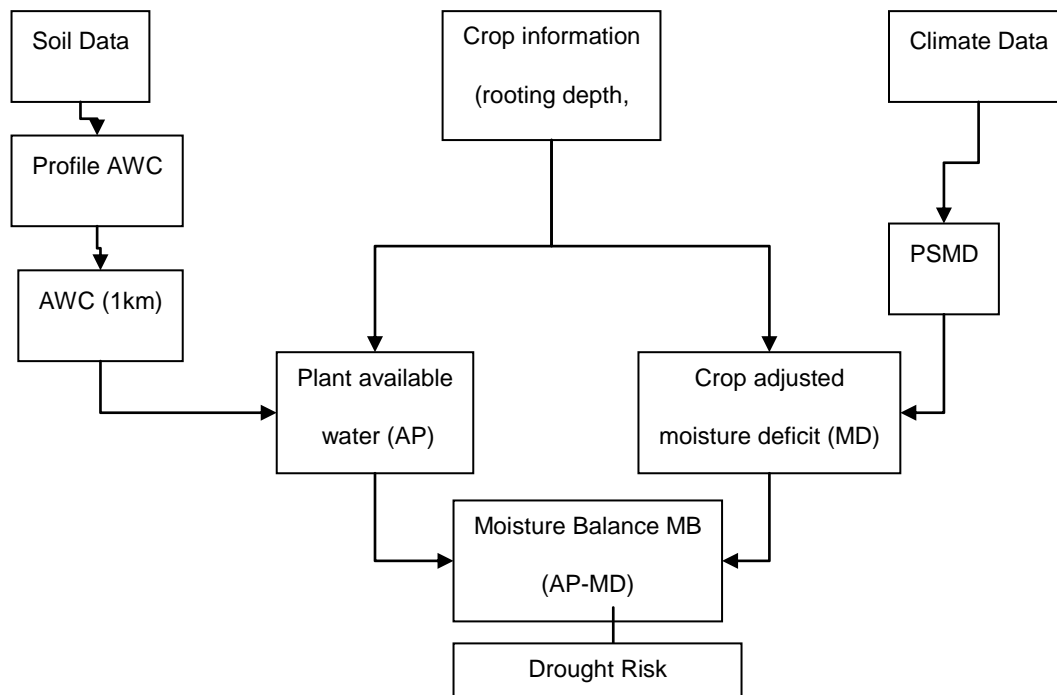


Figure 1. Procedure used to estimate water demand for the indicator crops.

Future changes were based upon modifying the climate variables, and hence PSMD, using data from climate change projections downscaled to a 5km resolution. As with the supply-side estimates (see section 2.1), the HadRM3 regional climate model PPE were used as the basis for the future projections.

Irrigation values are derived using the simple regression-based method developed by Knox et al. (2007) to predict irrigation need based upon maximum PSMD values and a classification of AWC soil types (suitable soils are interpreted to be in the 'medium' AWC class: 100-175mm). This is used to provide an estimate of potential changes for the indicator crop (i.e. potatoes). By multiplying the irrigation need (mm) for the indicator crop with the distribution of crops that are classified with those characteristics (i.e. those currently irrigated) then a volumetric irrigation demand can be calculated. This has been implemented on a 1km² grid using the proportion of the indicator crop within that grid cell to derive the spatial information (Figure 2).

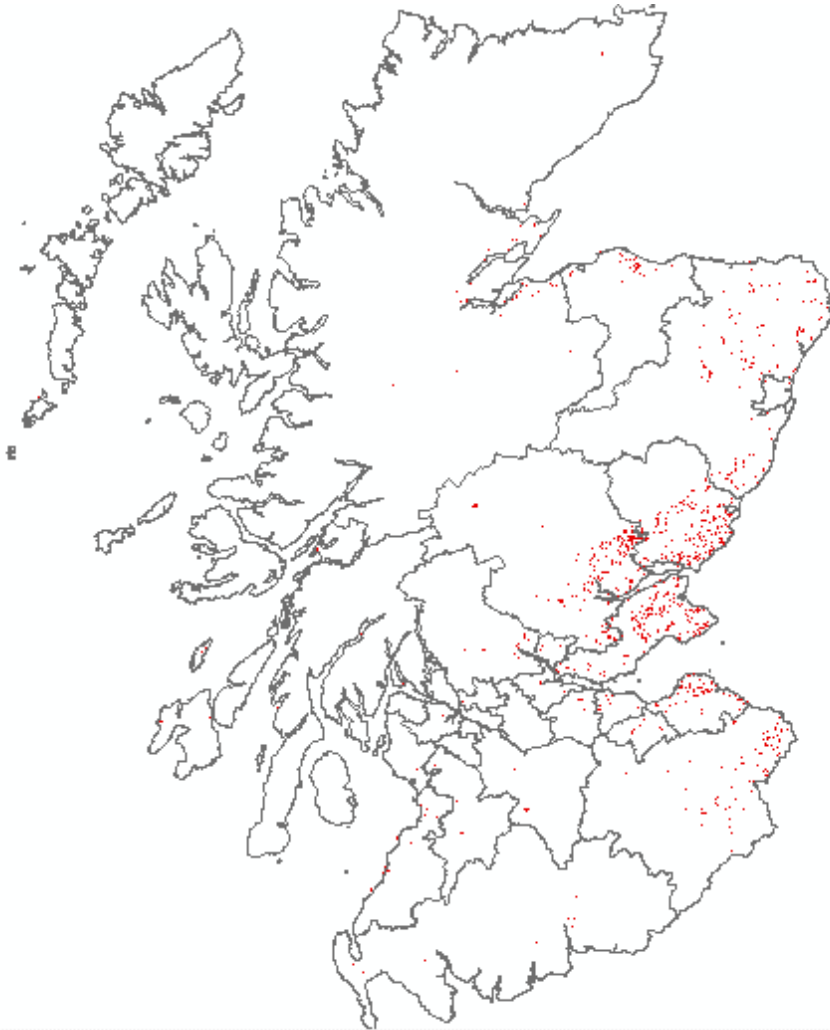


Figure 2 Distribution of potatoes and other fruit and vegetable crops that are normally irrigated based upon the baseline year of 2010 (Local authority areas for reference). Not present in Orkney and Shetland.

3.0 RESULTS

For the future projections, two of the climate model PPE members (Q3 and Q16) were used to explore the uncertainty in the climate change projections based upon the 2050s period. These simulations are consistent with the broader UKCP09 projections in demonstrating that the most likely shift in 2050s climate is towards warmer and drier summers (Murphy et al., 2009). Changes in supply (runoff) are shown in Figure 3 and Figure 4, highlighting that large areas of Scotland, particularly in East Scotland, could see a decline in summer runoff with consequent reductions in river and stream flows.

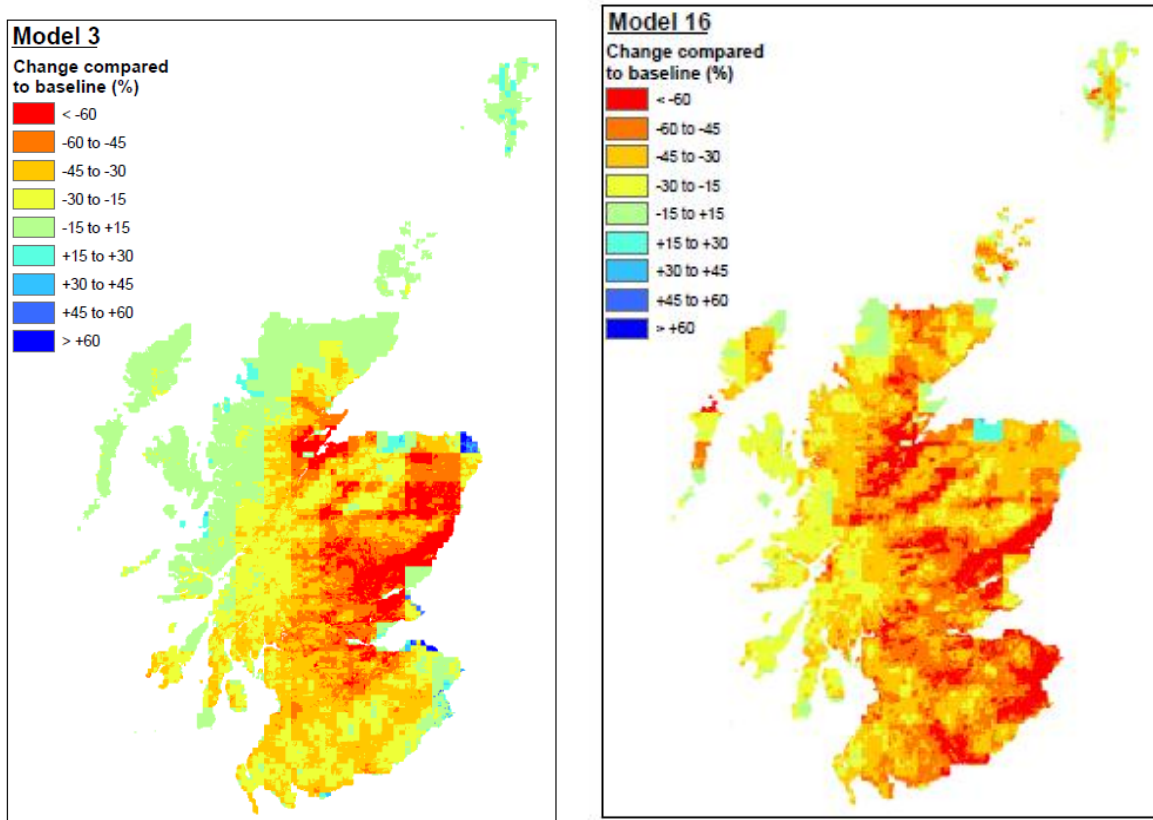


Figure 3. 2050s change in Summer runoff for the Q3 and Q16 climate model PPE members

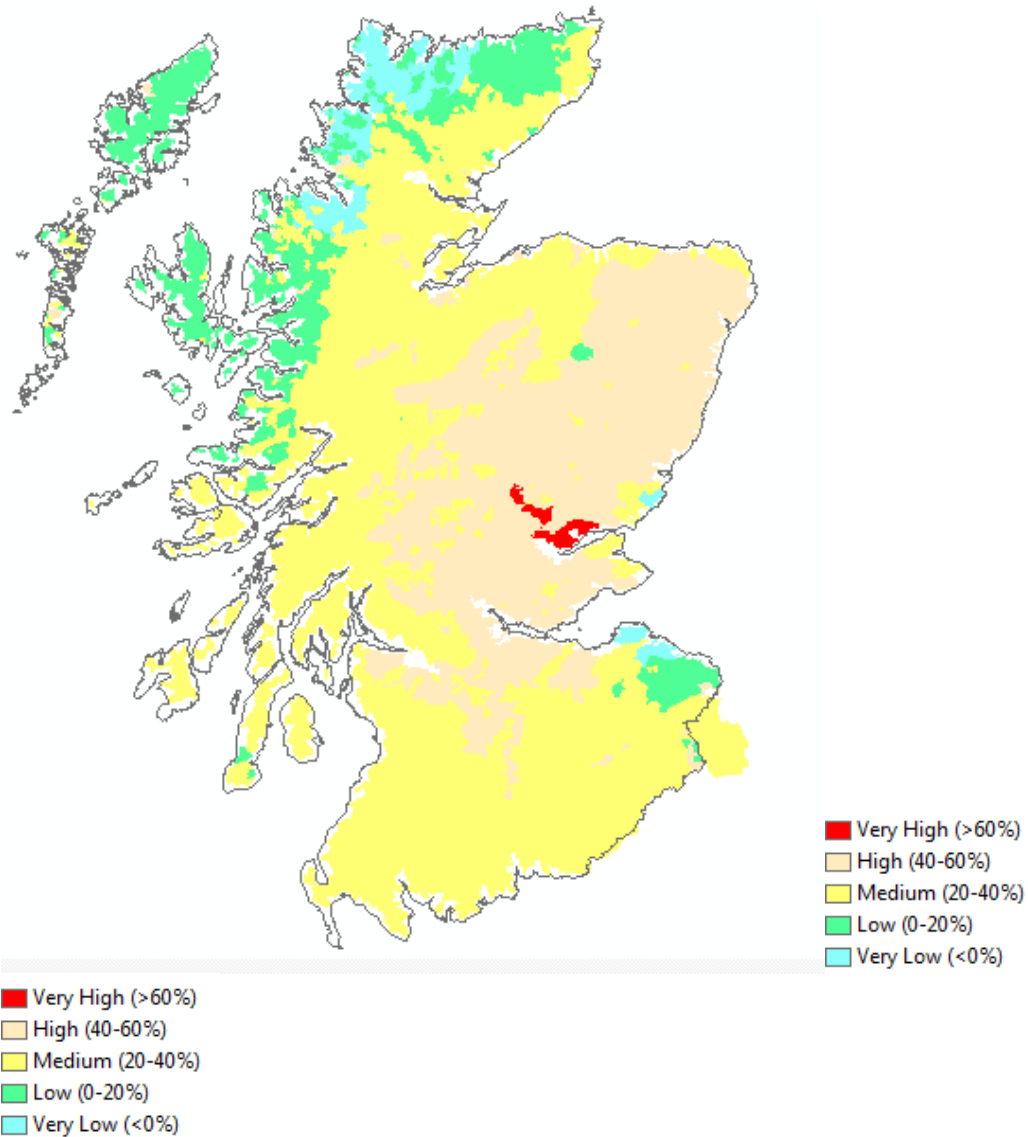


Figure 4 Change in summer runoff for the SEPA intercatchments (Q3 ensemble scenario)

Similarly, many of the same areas are also projected to experience an increase in irrigation demand for those locations that have potatoes or horticulture (Figure 5). The average additional irrigation demand for potatoes would be ca. 50mm.

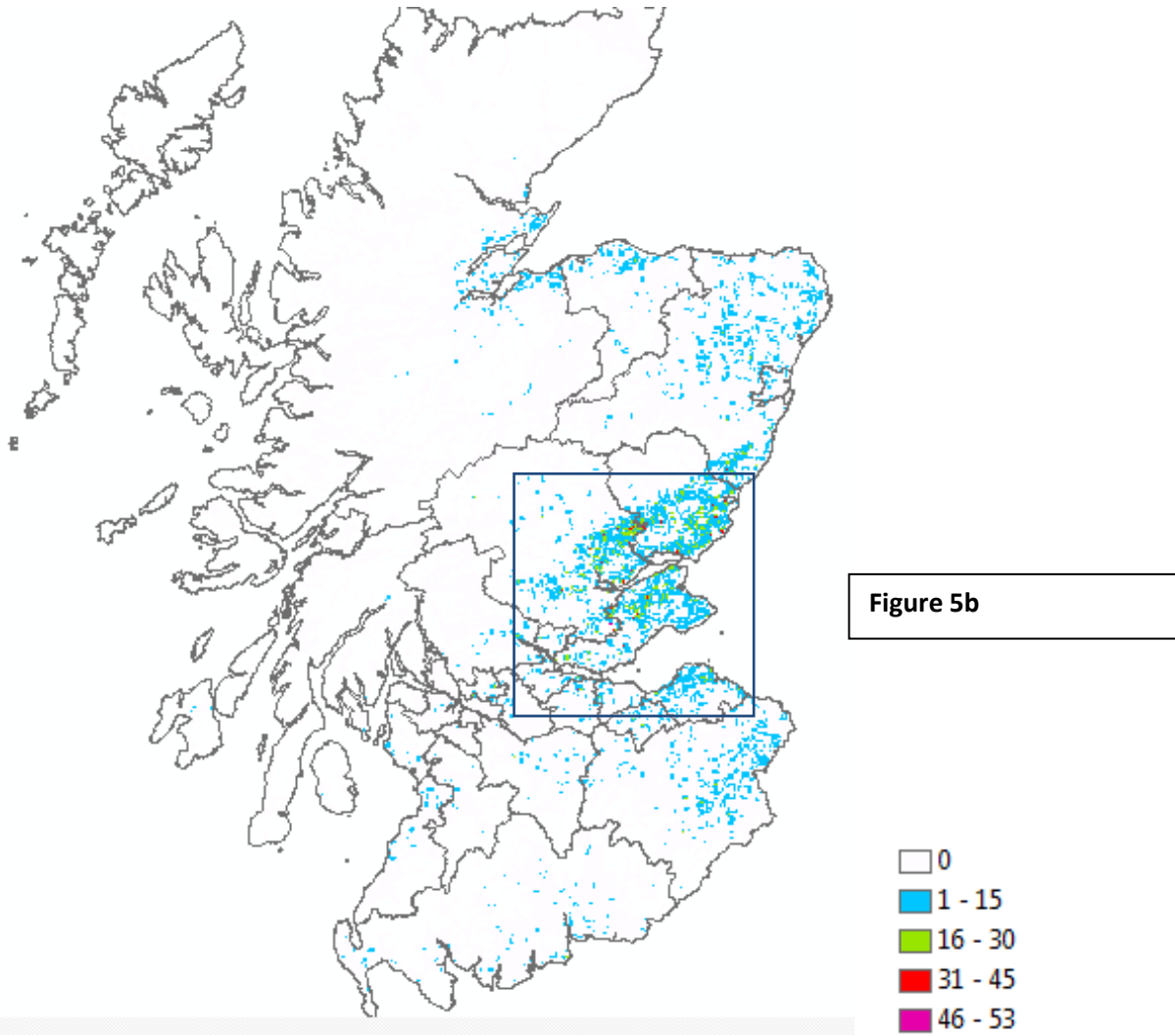


Figure 5a 2050s change in Irrigation Demand (ML/km²) for the Q3 climate PPE member

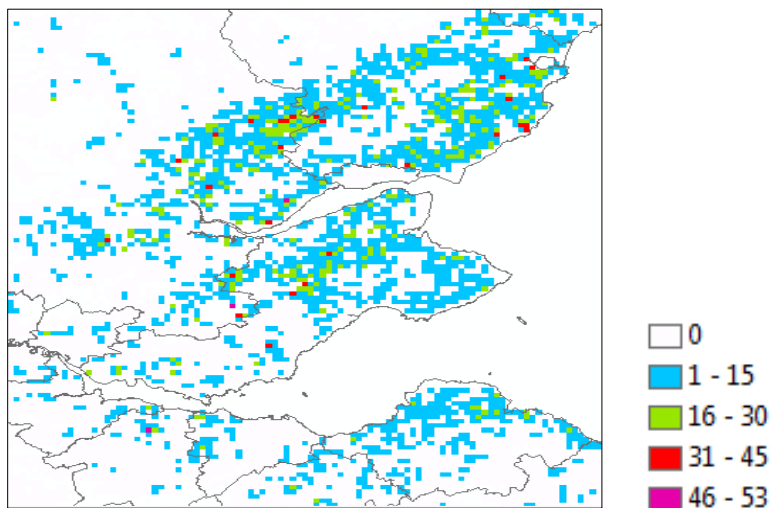


Figure 5b Further detail of Figure 4a for Angus, Tayside, Fife and the Lothians.

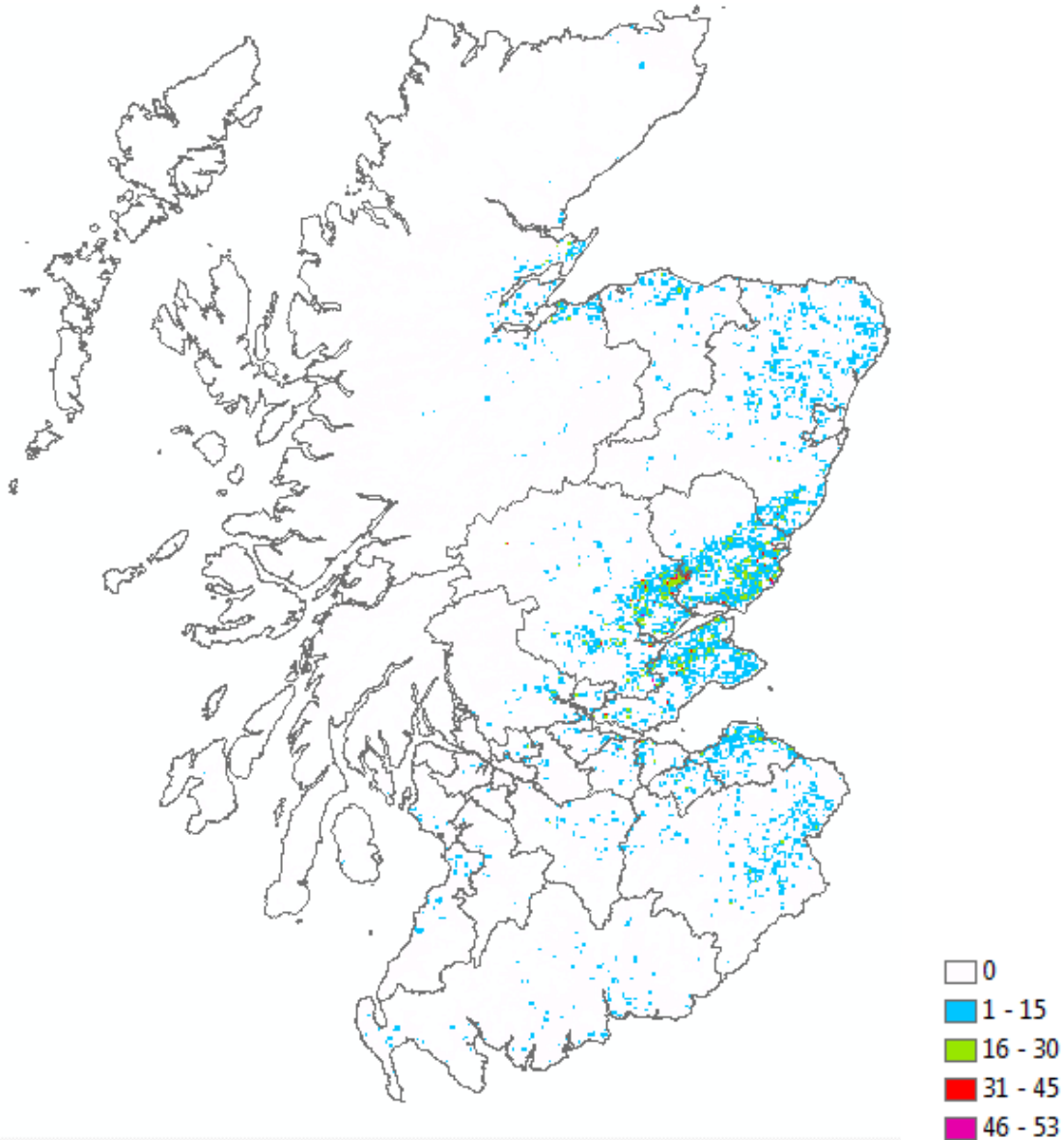


Figure 5c 2050s change in Irrigation Demand (ML/km²) for the Q16 climate PPE member

In terms of volumetric irrigation demand, based upon the current defined area of the main irrigated crops in 2010, the method used in the present study has estimated total demand for all of Scotland at 43000ML. This compares with previous estimates based upon the ‘main’ irrigated areas of 9225 ML year-1 by Knox et al (2007) and of 8265 ML year-1 by Crabtree et al. (2002). Assuming that land use patterns remain the same as present and the defined area of irrigated crops stays the same, the methodology used in this project suggests an increase in irrigation volumes by the 2050s with climate change of ca.30% with important spatial variations (Figure 6).

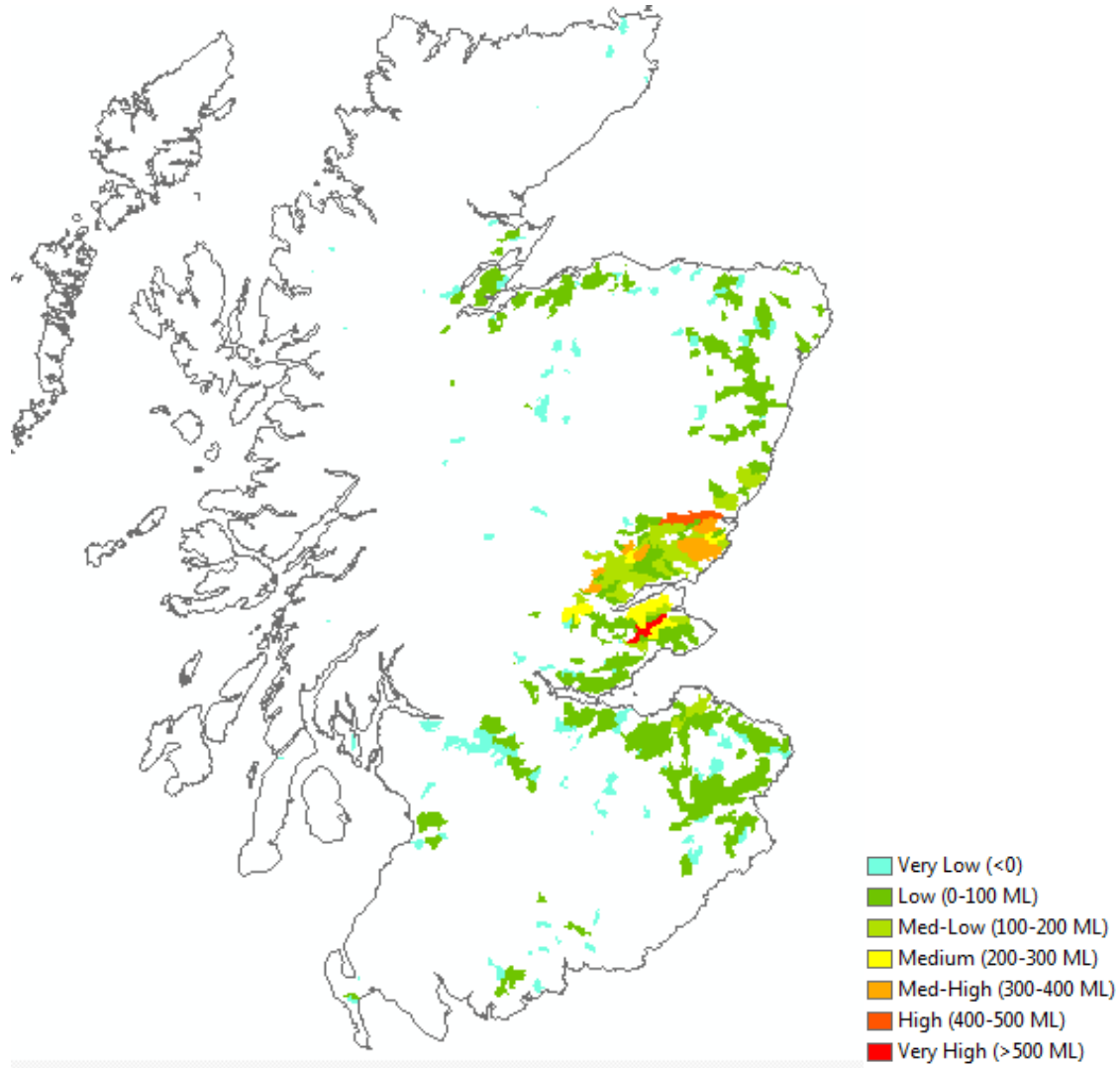


Figure 6a Change in 2050s irrigation demand for SEPA inter-catchments (Q3 ensemble scenario)

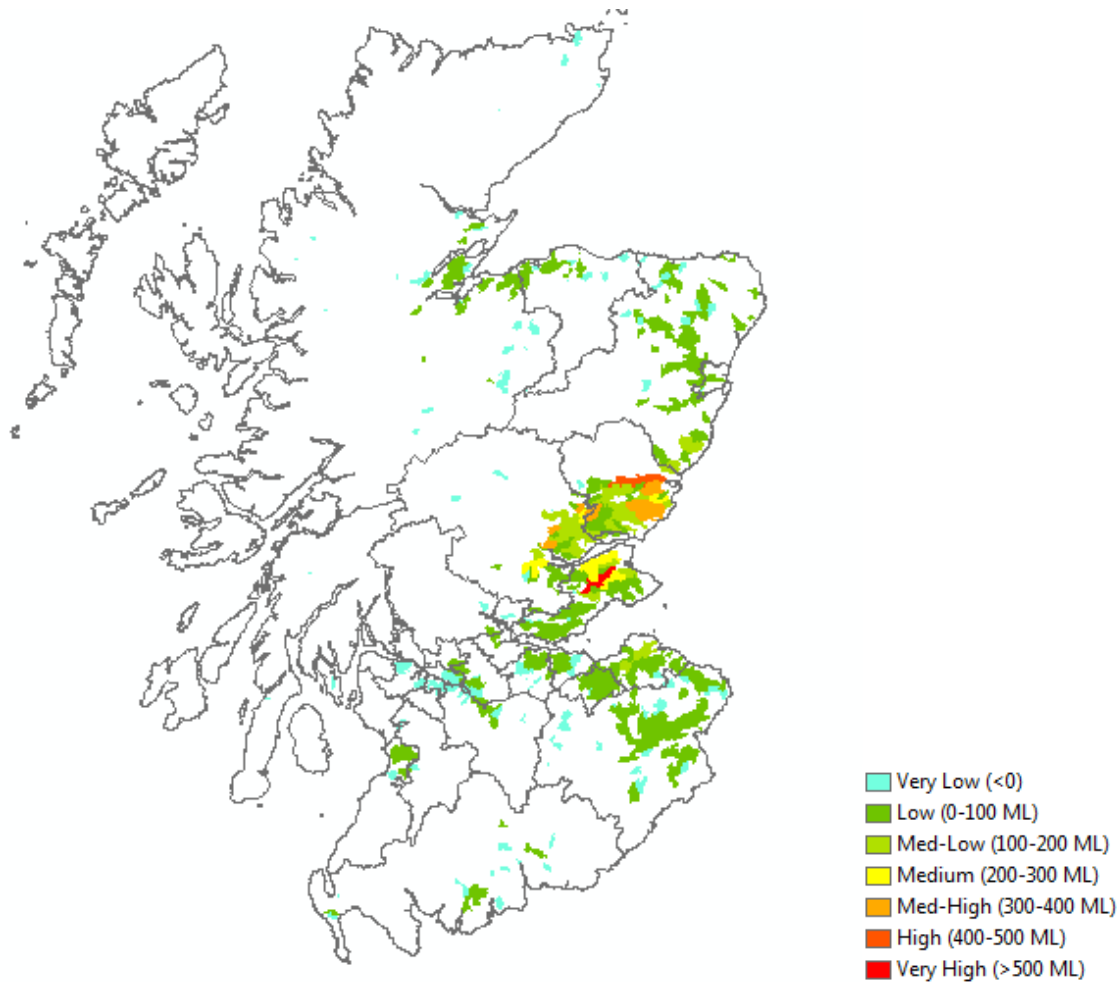


Figure 6b Change in 2050s irrigation demand for SEPA inter-catchments (Q16 ensemble scenario)

In the absence of adaptation measures, the additional irrigation requirements projected for the future would need to be met by transfer of water from rivers or lakes. By using the summer runoff data and maps, an assessment can be made of the potential availability of additional water to compensate for increases in demand. In Figure 6, this has been categorised as qualitative risk assessment with the areas of highest risk defined as those catchments with both an increase in demand and a reduction in supply. Areas defined as lower risk may also have issues regarding the sustainability of future resources depending on the relative balances of changes in supply and demand. The implication for those areas where demand exceeds supply is that continued abstraction to meet demands is likely to reduce flows below environmental limits. Alternatively, restrictions on abstraction to maintain environmental flows may restrict crop yields and food (or energy) production.

4.0 SUMMARY

This preliminary assessment highlights that, in the absence of strategic adaptation measures, climate change is likely to bring a 'double whammy' of impacts on the supply/demand balance through direct and indirect effects. Many areas that experience a reduction in supply also contain high-value crops that are likely to require additional irrigation water, unless alternative measures are put in place. This does not include the further additional water demands from crops that are currently not irrigated, notably cereals, which may expand the currently irrigated area. Combined supply-demand deficits are particularly pronounced in the smaller catchments of East Scotland that are not supplied with large rivers that have their source in the wetter west. In the absence of inter-basin water transfers, these smaller catchments are highlighted as particularly vulnerable. However, even the larger catchments may experience increased problems, particular in drier years (which have not been evaluated in this study) and declining river flows may require regulatory intervention in order to maintain environmental flow conditions.

The changing supply-demand balance has implications for several policy areas, notably the EU Water Framework Directive (WFD) and Habitat Directive, both of which have no explicit inclusion of climate change. With regard to the WFD, baseline reference conditions, against which water body status is assessed, are very likely to be altered, posing difficult questions about how future reference conditions should be defined. Important interactions also exist with other national-level policy agendas such as development of actions in the national Climate Change Adaptation Programme, the Land Use Strategy, and the implementation of new water-related measures during reform of the Common Agricultural Policy.

Further work is required to confirm this preliminary assessment. Only one climate model (HadRM3) was used for the climate change projections and a more robust assessment would use a range of models. In particular, it should be noted that a comparison with the observed baseline suggested that some of the coastal catchments in SE Scotland may contain climate model errors that cause the projections of reduction in summer runoff and irrigation demand to be underestimated.

5.0 RECOMMENDATIONS

- The present study has evaluated changes only in average conditions but the climate of Scotland exhibits considerable variability from year to year (Figure 7).

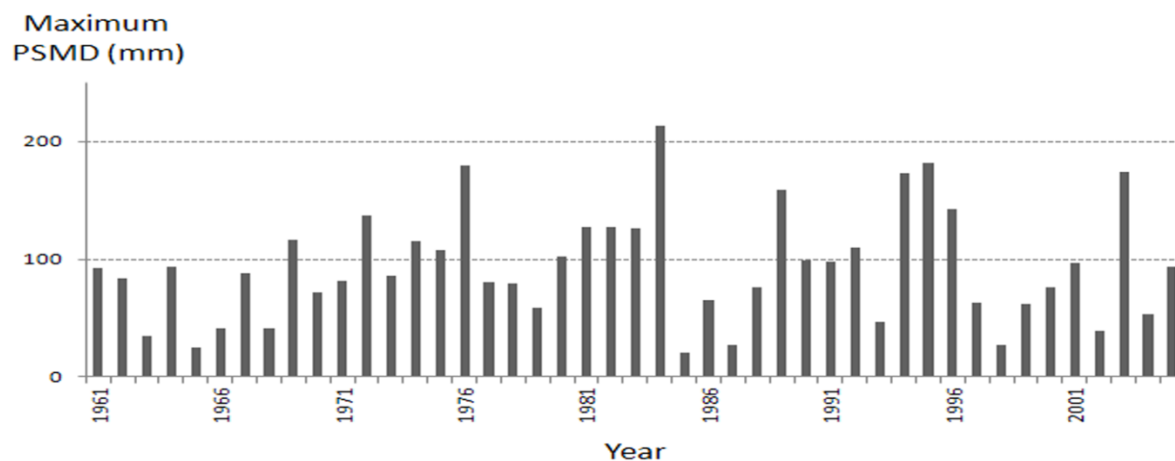


Figure 7. Annual changes in maximum potential soil moisture deficit (PSMD), averaged for the main cropping areas of Scotland. PSMD is a measure of the water balance with higher values indicating drier years.

It could be particularly useful to consider changes in extreme years, investigating the particular challenges that need to be addressed during drought conditions. In this context, reference to a design 'dry year' (e.g. 2003) would provide a meaningful baseline against which to compare future changes. Significant conflicts regarding water resources and ecosystem damage can occur in drought years. Without additional adaptation measures such damage may become irreversible (Brown et al, 2012).

- Increased temporal and spatial variability in irrigation demand is likely to cause problems in allocating (licensing) water resources for agriculture in a fair and rational manner. These problems could be better anticipated by a detailed analysis of current abstraction licenses to understand these spatial and temporal patterns, including where possible differences between amounts of water applied for, granted, and actually used.
- The present study has only considered surface water resources and not groundwater reserves which remain a source of considerable uncertainty despite some preliminary work (e.g. Clews et al., 2005; Herrera-Pantoja and Hiscock, 2008).
- The analytical procedures applied in the present study are also only applicable to field-scale agricultural and horticultural crops. Further work to refine the analysis for protected crops (e.g. in glasshouses or polytunnels, which in theory should be more efficient) or for other irrigation requirements, such as landscape and amenity uses (e.g. golf courses) is suggested.
- It would also be beneficial to develop a more robust analysis across a wider range of future climate projections, including climate models other than HadRM3, in order to assess sensitivity to the key uncertainties inherent in these climate models. At present, only 'medium confidence' exists for future projections of drier summers although it is almost certain that they will be warmer on average.

- A more comprehensive assessment for the land use sector would also include changes in water use by livestock.
- Further research is required on the efficacy of demand-side measures as an adaptation to climate change, particularly considering that climate, soil and market constraints may limit the savings that can be made by some agronomic changes to promote water efficiency. Product quality and profitability are highly dependent on the timing and volume of water applied. For example, it has been suggested that a 10% increase in efficiency could be sought by improving overhead irrigation methods (e.g. booms) and a further 10% by better scheduling. Scheduled trickle irrigation³ might increase efficiency by 20 to 30% in total (Weatherhead et al., 1997). Previous research suggests that a major water-saving opportunity exists with a shift to trickle irrigation for potatoes. Improved water efficiency could also be achieved through developing potato cultivars with increased drought resistance, common scab resistance, and deeper rooting systems (Warwick HRI and ADAS, 2006). Water-use efficiency can be improved by an array of management practices including inter-cropping, multicropping and relay cropping (Olesen and Bindi, 2002), or simply by improved farmer co-operation and co-ordination of resources. Avoiding soil compaction and good soil management have also been recognised as important.
- More research on the efficacy of supply-side measures in adapting to climate change would also be beneficial. It has been highlighted that despite the adoption of the twin-track supply-demand approach, supply-side measures (reservoirs, connectivity) are traditionally considered more reliable, more certain and more effective in addressing imbalances in the supply–demand balance (Charlton and Arnell, 2011) . Supply-side alternatives can include: (i) moving water from areas where there are fewer requirements to areas with higher demand (ii) better use of excess winter rainfall and flood water through capture and storage, especially through on-farm storage (iii) water re-use, although what is feasible and acceptable to the consumer needs to be established.
- The economics of water supply and demand are likely to change. Currently, water conservation measures typically cannot compete with the present low cost of direct summer abstraction. A more flexible licensing system could help promote effective use of water and water conservation, such as encouraging an emphasis on high-value goods or by favouring a shift in production to areas where water is more readily available
- Additional scenario-based work could explore the strengthening policy interactions between water, food and energy security in a changing climate. For example, the present study has not considered potential expansion in energy crops, some of which have a significant water demand, or new agricultural crops (e.g. maize). Important links also exist in an international context with the import/export of commodities and the concept of ‘embedded water’ in these commodities.
- Further work should consider changes in attitudes and behaviours that could have significant impacts on the volumes of water abstracted for irrigation. For example, these may include changes in dietary preferences due to climate change (e.g. switching to a greater dependence on salads and pasta) and/or changes in consumer attitudes to the quality of produce (skin blemishes, shape, size)

³ With trickle (drip) irrigation only a proportion of the total field area is wetted depending on the crop type whereas most overhead systems (such as sprinkler) wet the entire field. Trickle systems can therefore satisfy the crop water requirements without an unnecessary amount of water being applied to bare ground.

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