Changes in water footprints, availability and scarcity in the Anglian River Basin District through to the 2050s

by

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Abstract

This study assesses water consumption, availability and scarcity at a catchment scale across the Anglian River Basin District for the present, the 2020s and the 2050s. The model ‘Cropwat’ was used to calculate the green and blue water footprint of agriculture for each catchment. The blue water footprint was combined with the blue water footprint of the domestic (household) sector to estimate the catchment water footprint. Current surface water and groundwater availability was estimated from mean river flow and annual recharge volumes respectively, taking the environment’s requirement of water into account. Future assessments took climate change (for agricultural water footprints and water availability) and socio-economic change (for domestic water footprints) into account. Blue water scarcity was calculated as the ratio of the catchment water footprint to the catchment’s water availability. The study found that the Combined Essex and East Suffolk catchments are currently consuming more water than is available on an annual basis. For future years all but two catchments are found to consume more water than is available annually. Groundwater scarcity is generally higher than surface water scarcity, and summer months are higher than winter months. Different management techniques may need to be prioritised in each catchment as the relative contributions of different factors to scarcity levels varies. Both a reduction in water consumption and an increase in availability should be aimed for.
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1. Acknowledgements

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2. Introduction

Water is vital to all life. Effective management of water resources is therefore essential to ensure that both humans and the environment have sufficient supplies. Management is becoming more complex as water resources are being put under increasing pressure from growing populations and climate change (EA, 2011).

This study investigates current water supply and demand in the Anglian River Basin District (RBD), eastern England, and projections for the 2020s and 2050s at a management catchment scale. Agricultural and domestic sector consumption is compared to surface water and groundwater availability in order to estimate water scarcity in each catchment. The implications of these findings for current and future management will be discussed.

2.1. The Anglian River Basin District

The Anglian RBD is one of ten river basin districts in England and Wales (and part of Scotland) used to implement the EU Water Framework Directive (2000) (Figure 1). The region is generally very dry, meaning that low river flows and groundwater levels are common (EA, 2009a). Despite this, it contains many water-dependent and internationally important natural environments and is one of the world’s most productive agricultural areas (EA, 2009b). In addition, its population is rapidly increasing (EA, 2009a). This conflict between high water demand and relatively low water supply makes it an interesting region to study and necessitates a twin-track approach to management and to this research, whereby water availability and consumption and their interrelationship are investigated (Defra, 2008). It also highlights the need to examine the water requirements of the environment as well as the agricultural and domestic sectors.

The Anglian RBD is divided into 11 management catchments; these units are used by the Environment Agency to manage water abstraction (Defra, 2013). Catchment-scale water resource management allows local issues to be identified and targeted solutions to be created through community collaboration, ultimately increasing its effectiveness (Defra, 2013). Management catchments (hereafter referred to as ‘catchments’) were therefore chosen as the scale for this study in order to provide an in-depth, policy-relevant analysis.
2.2. Literature review

2.2.1. Water use and availability

In the UK, water is used by households (the domestic sector), for electricity generation, other industry, and by the agricultural sector (EA, 2011). Public water supply (for the domestic sector and part of the agricultural and industrial sectors) and agriculture are the two biggest water abstractors in the Anglian RBD (EA, 2009c). Spray irrigation accounts for the majority of agricultural water consumption and is used intensively in the river basin (Kowalski et al., 2011; Defra, 2014). Irrigation puts great pressure on the environment as it mainly occurs in summer when river and groundwater levels are lowest (EA, 2009c). Agricultural water consumption is also significant for water scarcity studies because it is consumptive and thus removes water from the environment for a longer time period than domestic and industrial consumption (Hess et al., 2011). Irrigation in the Anglian Region (a geographical unit similar to the Anglian RBD, used by the Environment Agency until 2009) is mainly for potato and sugar beet, as these are high value crops and the improved yield and quality resulting from irrigation can therefore increase revenues substantially (Knox, 2000). The assessment of agricultural water use in this study will focus only on crops (omitting horticulture and livestock farming), as they are the principal form of agriculture in the river basin (EA, 2009b).

The relative proportions of groundwater and surface water used by the domestic and agricultural sectors varies spatially, depending on resource availability. Eastern England relies on groundwater more than other areas of England and Wales due to the existence of a highly productive chalk aquifer (EA, 2011; NERC, 2015). In addition, the Anglian RBD contains a highly productive Jurassic limestone aquifer (Figure 2). The region also contains many rivers (Figure 1). However, river flows and groundwater levels vary greatly throughout the year as dry periods and floods are common (EA, 2009b).

When estimating the volume of water in a catchment available for human use, the requirements of the environment need to be taken into account. The Environment Agency attempts to protect the environment by identifying the ecological sensitivity of each water body and assigning allowable abstraction volumes as percentages of different flow levels (EA, 2013). This helps to

Figure 2: Map of the UK showing major aquifers. The Chalk and Jurassic Limestone aquifers are present in the Anglian RBD. Source: Rivett et al. (2007).
maintain healthy ecosystems and ensure that the resources are being used sustainably. Groundwater abstraction can be regulated by setting a sustainable yield (Ponce, 2007). This can prevent over-abstraction which would lead to a depletion of groundwater reservoirs and reduced base flows in rivers.

2.2.2. Water footprints and water scarcity

Water use can be thought of in terms of a product, process, consumer group, business or geographical area’s ‘water footprint’. A water footprint is the volume of water consumed, and can relate to blue, green or grey water (Zhang et al., 2013). The blue water footprint accounts for fresh surface water and groundwater consumption, the green water footprint accounts for rainwater consumption and the grey water footprint accounts for the volume of freshwater required to dilute a pollutant load to ambient water quality standards, with reference to natural background concentrations (Hoekstra et al., 2011). Grey water footprint calculations are complicated and volumes are likely to be less than green and blue footprints; grey water is therefore not included in this study. The water footprint approach differs from more traditional methods of assessing water use as it takes return flows into account (water that is not consumed and is returned to the catchment within a short time-period) rather than focussing solely on abstractions (Hoekstra et al., 2011). This makes it more a more useful indicator.

Water footprints, or indeed any measure of water use, are only useful to decision-makers if they are compared to water availability; otherwise no environmental impact can be measured (Hess et al., 2011). This comparison can highlight areas where water is being over-consumed or where more water is available for consumption. Hoekstra et al. (2011) recommend water availability to be calculated as the natural runoff minus the environmental flow requirement (for groundwater, surface water or both combined).

Water scarcity in a catchment can be calculated as the ratio of the catchment’s water footprint to the water available in the catchment (Hoekstra et al., 2011). This can be done for blue or green water; however, it is difficult to assess green water scarcity accurately due to the complexity of calculating green water availability (Hoekstra et al., 2011). In addition, blue water scarcity has more direct relevance to water resources management. For these reasons, only blue water scarcity is assessed in this study.

The Environment Agency successfully used the water footprint and water scarcity methodologies to assess the current and future (2060) situation in the Hertfordshire and North London area (Zhang et al., 2014). They examined the blue and green water footprints of crops, the blue water footprint of the domestic sector and blue water scarcity on a monthly timescale at sub-catchment level. Blue water footprints and scarcity were divided into groundwater and
surface water in order to give a more detailed picture. This study aims to conduct a similar assessment for the Anglian RBD as no such assessment has yet taken place for this area.

2.2.3. Current and future challenges to managing water resources

Water resources in the Anglian RBD are already under great pressure. In 2009, 59% of catchments in the Anglian Region were over-abstracted or over-licensed at low flows, meaning that no more water was available for additional abstractions (EA, 2009a). Over-abstraction has caused 70 conservation sites in the region to be damaged or at risk of becoming so (Ibid.). These problems will become more acute in the future.

There is great uncertainty surrounding the effect of climate change on future water availability (EA, 2011). The UK Climate Projections 2009 (UKCP09) central estimate of 2050s annual mean precipitation for a medium emissions scenario is a 0% change from the present (1961-1990 baseline period), but the estimate of winter precipitation change is 14% and that of summer is -16% (EA, 2009c). Thus drier summers and wetter winters could occur, but the ranges in projections over all probability levels are large. Using the 11-member regional climate model (RCM) ensemble used by the UKCP09 studies, Sanderson et al. (2012) predict that future runoff (of surface water and groundwater combined) may decrease in autumn (-15 to 5% change) and increase in winter (5 to 15% change) by the 2050s for the medium emissions scenario. Summer changes are -5 to 5% and spring changes are 5 to 15%. Changes in summer flows do not therefore match the central estimate of precipitation change; many factors are involved and uncertainty is high. However, the degree of climate change will depend on the volume of greenhouse gasses that are released, which itself will depend on whether society continues along ‘business as usual’ path or acts to become more sustainable.

Future water demand will also depend on future climate and socio-economic factors. For example, irrigation demand may increase as increased temperatures and reduced rainfall necessitate an expansion of irrigated crop areas and increased volumes per hectare to maintain high yields (Downing et al., 2003; Knox et al., 2013). However, socio-economic factors such as technological advances in high yield varieties may mean that the demand increase is smaller than would be predicted from the current situation (Knox et al., 2013).

Studies investigating water demand and availability under future socio-economic scenarios suggest that a society that prioritises the economy and is not concerned about the environment might set higher abstraction limits in order to maximise water use and boost the economy, whereas a society with a greater sense of environmental responsibility would use less water (Henriques et al., 2008; EA, 2008). It is therefore important when assessing future water scarcity that a range of futures are tested.
2.2.4. Water scarcity in the Anglian River Basin District

Although no studies have assessed water scarcity using the water footprint methodology for the Anglian RBD, several studies use other methods and cover the area in country-wide investigations of water stress. Knox et al. (2013) identified current ‘irrigation hotspots’ across England and Wales based on 2010 land use where high irrigation demand conflicts with over-abstracted and/or over-licensed resources. They classified much of the Anglian RBD as a hotspot, including ‘very high’ pressures identified in North Essex and ‘high’ pressures in the North Norfolk, Cam and Ely Ouse and East Suffolk catchments.

The Environment Agency and Natural Resources Wales (EA NRW) (2013) also identified high levels of water stress in the Anglian RBD in their classification of water resources in England and Wales, particularly in the Witham, Combined Essex and Cam and Ely Ouse catchments (Figure 23). This study calculated water stress for each water body using the modified water exploitation index (WEI+) developed by the European Environment Agency. The WEI+ is the net abstraction as a percentage of the total resource available:

\[
\frac{\text{Abstraction} - \text{Discharge}}{\text{Natural water resource} - \text{change in artificial storage}}
\]

Once calculated, the WEI+ is then classified into levels of water stress using environmental requirements as thresholds for different flow levels. These requirements are based on Environmental Flow Indicator (EFI) thresholds and vary according to flow level and ecological sensitivity (EA, 2013). The EFI approach will also be used in this study; overall this method is similar to the water scarcity assessment used in this study.

The EA NRW (2013) water stress classifications for water bodies were aggregated to identify stress levels for each water company. Water company water stress was then classified for four future socio-economic scenarios for the 2050s. All water companies serving the Anglian RBD were classified as having ‘moderate’ or ‘serious’ water stress for both current and future time periods.

Overall, there has been considerable research into current and future water consumption (especially for irrigation) and availability. However, comprehensive studies that spatially link the two phenomena are rare. Two studies currently provide an indication of water stress/scarcity in the Anglian RBD. However, Knox et al. (2013) focus only on scarcity for current irrigation and both studies are on a country-wide scale and assess the annual rather than monthly stress/scarcity levels. This study will provide an in-depth analysis of current and future water scarcity in the Anglian RBD on a monthly timescale, including the water consumption of both agriculture and the domestic sectors to build a detailed picture of water resource issues in the region.
2.3. Aims and research questions

The overall aim of this study is to examine current and future water consumption, availability and scarcity in the Anglian RBD. This will allow the identification of catchments or issues that need to be prioritised in terms of water resources management. In order to achieve this aim, three research questions have been formulated along with specific objectives for each one:

1. What are the current levels of water consumption, availability and scarcity in the Anglian RBD?
   Objectives:
   - To estimate the current water footprints of the agricultural and domestic sectors
   - To estimate current water availability
   - To estimate current blue water scarcity

2. What will future water consumption, availability and scarcity levels in the Anglian RBD be under climate change and different socio-economic scenarios?
   Objectives:
   - To estimate the future water footprints of the agricultural and domestic sectors for the 2020s and 2050s
   - To estimate future water availability for the 2020s and 2050s
   - To estimate future blue water scarcity for the 2020s and 2050s

3. What are the implications of these findings for current and future water resources management?
   Objective:
   - To assess which catchments or aspects of consumption and availability need to be prioritised
   - To compare these suggestions to existing plans for current and future management

3. Methods

3.1 Water footprints

3.1.1 Current blue and green water footprints of agriculture

The blue and green water footprints of agriculture were estimated by assessing the water consumption of the six main crops grown in eastern England: wheat, barley, maize, sugar beet, potatoes and oilseed rape. Crop water consumption was calculated using the Cropwat model created by the FAO. Monthly climate and rainfall data (averaged over 2007-2013) from six weather stations across the Anglian RBD were input into the model, along with
crop data for each crop (including planting and harvesting dates, rooting depth and crop height) (Table 1). Crop characteristics of certain species depend on the planting date and on whether they are rainfed or irrigated so separate entries were created for these variations. Soil characteristics were also required to calculate irrigation (blue water) requirements; these included total available soil moisture and maximum rain infiltration rate. 11 soil types were used.

Table 1: Input variables for the Cropwat model.

<table>
<thead>
<tr>
<th>Weather stations (catchments covered)</th>
<th>Crops</th>
<th>Soil types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedford (Upper and Bedford Ouse)</td>
<td>Spring wheat (rain)</td>
<td>Sand</td>
</tr>
<tr>
<td>Cavendish (Combined Essex)</td>
<td>Winter wheat (irrigated)</td>
<td>Loamy sand</td>
</tr>
<tr>
<td>Denver (Broadland Rivers, Cam and Ely Ouse, North Norfolk, North West Norfolk and Old Bedford and Middle Level)</td>
<td>Winter wheat (rain)</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Waddington (Witham)</td>
<td>Spring barley (rain)</td>
<td>Loam</td>
</tr>
<tr>
<td>Wattisham (East Suffolk)</td>
<td>Winter barley (irrigated)</td>
<td>Silt loam</td>
</tr>
<tr>
<td>Wittering (Welland and Nene)</td>
<td>Winter barley (rain)</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td></td>
<td>Maize (rain)</td>
<td>Sandy clay</td>
</tr>
<tr>
<td></td>
<td>Potatoes (irrigated)</td>
<td>Clay loam</td>
</tr>
<tr>
<td></td>
<td>Potatoes (rain)</td>
<td>Silty clay loam</td>
</tr>
<tr>
<td></td>
<td>Sugar beet (irrigated)</td>
<td>Silty clay</td>
</tr>
<tr>
<td></td>
<td>Sugar beet (rain)</td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td>Oilseed rape (rain)</td>
<td>Peat</td>
</tr>
</tbody>
</table>

A ‘daily soil moisture balance’ was computed under the ‘crop irrigation schedule’ for every combination of weather station, crop and soil type. This calculated the actual and potential water use of the crop and the net irrigation required where applicable. For irrigated crops, irrigation was set to occur at critical depletion and to refill soil moisture content to 100% field capacity. For rainfed crops, the ‘no irrigation’ option was selected. Monthly blue and green water footprints (mm) were recorded as follows (following the method of Hoekstra et al. (2011):

\[
\text{Monthly blue WF} = \text{total monthly net irrigation}
\]

\[
\text{Monthly green WF} = \text{total monthly } ET_a - \text{total monthly net irrigation}
\]

Where \( ET_a \) is equivalent to the actual crop water use. Annual volumes were then calculated as the sum of all monthly water footprints for each water type. The total crop water footprint was calculated as the sum of the blue and green water footprints.
Land use maps from the UK National Ecosystem Assessment Follow-On Phase (UK NEAFO) (Bateman et al., 2014) were used as the principal crop area data for the study area. However, maps were only available for oilseed rape and the broader categories of cereals and root crops; Agcensus data was therefore used to calculate the relative percentages of each crop contained in these categories (i.e. the relative percentages of wheat, barley and maize for cereals) for each catchment. Firstly, a ‘union’ of the UK NEAFO dataset to a shapefile of the Anglian RBD was conducted using ArcMap 10.2.2. A second ‘union’ was then conducted to join this data to a soil map from the British Geological Society (BGS). The BGS soil textures were grouped together into the types shown in Table 1 using the BGS soil group classifications as a guide. The area of each broad crop category on each soil type was then calculated for each catchment.

For the Agcensus data, relative percentages of each crop were calculated by using the ‘extract select’ tool to separate each catchment, then displaying X Y data for the Agcensus datasets and clipping these datasets to each catchment’s extent, using the ‘geoprocessing clip’ tool. Agcensus did not separate winter and spring wheat areas so relative percentages were taken to be 95% and 5% respectively (Impey, 2012). Neither source of land use data separated irrigated from rainfed crop areas. It was therefore assumed that the need for irrigation depends on soil type. On soil types with the lowest Total Available Water (TAW) (sand, loamy sand, sandy clay and sandy loam) 80% of the crop area was assumed to be irrigated; on soil types with medium TAW (clay loam, loam, silt loam and silty clay loam) 50% of the crop area was assumed to be irrigated; and on soil types with the highest TAW (clay, silty clay and peat) 20% was assumed to be irrigated.

In order to calculate the water footprint of a crop for a catchment, the crop’s water consumption was then multiplied by the crop’s area for each soil type in the catchment. The volumes for each soil type were then added together to get the crop WF of the catchment. The agricultural water footprint of a catchment was calculated as the sum of all crop WFs of the catchment. Blue, Green and total (blue and green combined) WFs were calculated.

### 3.1.2 Current domestic blue water footprints

The current domestic water footprint was calculated by multiplying the population of each catchment by the average per capita consumption (pcc) of water. Pcc was averaged over unmeasured and measured households and across Anglian Water’s service zone for the years 2007-2013 (excluding 2012 as no data was available), using values from the company’s June Returns and its Annual Report. This gave an overall average value of 148 litres per person per day, which was converted into m$^3$/month. It was assumed that pcc would be similar across all water company service zones; Anglian Water is the main provider for the Anglian RBD so other companies’ reports were not consulted.
UK Census data from 2011 at the district level (population density per district) was used to estimate the population of each catchment. A table of the population densities of all districts in the Anglian RBD was joined by attributes to the district boundaries. For each catchment, this was clipped (using the ‘geoprocessing clip’) to the catchment’s extent and the area of each district in the catchment was calculated. The population of each district in the catchment was then calculated by multiplying its area (ha) by the population density (people per ha). The population was multiplied by the pcc (m$^3$/month) to get the total water consumption of each district, and these values were summed to get the total water consumption of the catchment. This process was conducted for all catchments and a map of water consumption was produced.

According to Hoekstra et al. (2011), water footprints should account for return flows of water back to the environment via sewage treatment works. However, no data on return flows was available and due to the complexity of return flow pathways, this aspect was omitted from the assessment. Domestic WFs calculated here therefore account for both non-evaporative and evaporative consumption.

3.1.3. Future blue and green water footprints of agriculture

Future agricultural water footprints for the 2020s and 2050s were calculated in the same way as current water footprints, but using projections of future climate and rainfall for both future year ranges and projections of future land use for the 2050s. Crop and soil properties were kept constant, and it was assumed that land use will not have changed by the 2020s. A projection of land use for the 2050s was sourced from the UK NEAFO; this projection is for 2063 but it was assumed that it would also apply to the 2050s. The relative percentages of rain and irrigated crop areas and of individual cereal and root crops remained the same.

UKCP09 projections for the 2020s and 2050s under the medium emissions scenario were used at a 50% probability level to gain a central estimate of future climate. Projections were required for several variables that were spatially coherent with each other and across all weather station sites, but it was not possible to download this precise data. A simpler approach was therefore taken: the ready-made maps on the UKCP09 website were used. These show joint probabilities (linking the two variables) of temperature and precipitation changes – these are available at a UK wide, regional or WFD river basin scale. Only minimum and maximum temperature and precipitation variables were needed as Cropwat can calculate the other variables from temperature and the location of the weather station. Both UK-wide and Anglian RBD data was used, as neither scale had a complete set of the variables required. Variables were used as explained in Table 2.
Table 2: Climate variables used in Cropwat for future time periods.

<table>
<thead>
<tr>
<th>Variable(s) needed</th>
<th>Variable(s) used</th>
<th>Geographical scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter and summer mean minimum and maximum temperatures</td>
<td>Winter and summer mean minimum and maximum temperatures</td>
<td>UK</td>
</tr>
<tr>
<td>Spring and autumn mean minimum and maximum temperatures</td>
<td>Annual mean temperature</td>
<td>Anglian RBD</td>
</tr>
<tr>
<td>Winter and summer mean precipitation</td>
<td>Winter and summer mean precipitation</td>
<td>UK</td>
</tr>
<tr>
<td>Spring and autumn mean precipitation</td>
<td>Annual mean precipitation</td>
<td>UK</td>
</tr>
</tbody>
</table>

It was assumed that UK and Anglian RBD climate projections would be the same, and spring and autumn changes would be equal to annual mean changes. All values were very similar. All months in each season used the same value. The values on the maps are percentage changes from a 1961-1990 baseline; it was therefore necessary to convert them into absolute values. This was done by adding the percentage changes to the 1961-1990 values for the 25km grid squares in which the weather stations are located (baseline data was downloaded from the Met Office. These absolute values could then be used in the Cropwat model.

3.1.4. Future domestic water footprints

Two future socio-economic scenarios were used to provide a possible range of domestic water footprints for the 2020s and 2050s. The Environment Agency has predicted future change in domestic water consumption for four socio-economic scenarios for the 2050s for England and Wales (EA, 2008). Different 2006-based population projections from the Office of National Statistics (ONS) were chosen for each one to match the fertility rate, life expectancy and migration expected. Expert judgement was used to estimate what the pcc would be like in each scenario (for example volumes relating to daily washing routines).

The two most extreme scenarios were chosen; these are ‘Sustainable behaviour’ and ‘Market forces’, with a 15% decrease and a 55% increase in domestic water consumption for England and Wales respectively. The percentage changes were interpolated for the 2020s, assuming a linear trend in water consumption from the present to the 2050s. The 2050s
percentage changes were reduced by 2/3 as the 2020s are roughly 1/3 of the way between 2006 and the 2050s.

3.1.5 Proportions of groundwater and surface water consumption

Proportional consumption of groundwater and surface water on a catchment scale was determined according to the Environment Agency (2013). Proportions were only available for the volumes of water licensed but it was assumed that these proportions also represent actual abstractions. For the domestic sector the public water supply proportions were used and for agricultural consumption the overall proportions were used. For both sectors the median percentage was taken for each catchment (i.e. 81-100 % groundwater was taken as 90.5 %). The relative proportions of each source used was kept the same for future years.

3.2. Blue water availability

3.2.1. Current surface water availability

Current blue surface water availability for each catchment was calculated using the following equation (Hoekstra et al., 2011):

\[ \text{Blue surface water availability} = \text{natural run off} - \text{environmental flow requirement} \]

This was done on both a monthly and annual scale. Actual flow data from the National River Flow Archive (NRFA) was used to estimate natural flow. Actual flows differ from natural flows due to abstractions and effluent returns; natural flows were therefore derived by adding the total catchment water footprint (agriculture and domestic surface water and groundwater footprints combined). The total blue water footprint was used rather than the blue surface water footprint because river flows at most of the stations used are affected by both groundwater and surface water abstractions.

First, the gauging stations furthest downstream in each catchment were selected. In most catchments multiple stations were chosen; some catchments contain rivers that flow out at different locations and some lack downstream main channel stations so tributary stations were used. A total of 52 stations were selected. The whole record for each station was used rather than the baseline years 2007-2013; this was because many stations closed before 2007, including several that represented the flow of a whole catchment. As shorter time periods are more influenced by interannual variability, it would not have been possible to compare water availability in the catchments with only older records to those with the baseline years. In addition, the year ranges of the stations’ records vary greatly. Using the whole record was an attempt to gain a long-term average for each station.

For each station in a catchment, the mean daily flow (m3/s) was averaged over the whole record for each day of the year. The total mean daily flow for the whole catchment for
each day of the year was calculated by adding all station values together. The appropriate monthly total blue water footprint (m3/s) was then added to each value to get the natural mean daily flow for the catchment. This was converted to flow in m3/day, and these daily values were summed for each month (m3/month) and for the whole year (m3/year).

The environmental flow requirement (EFR) is the volume of water required to maintain healthy freshwater and estuarine ecosystems and thus their uses to humans (Hoekstra et al., 2011). Here it is based on the Environmental Flow Indicator (EFI). The EFI is the percentage of natural flow required by the environment and is defined for four flow conditions for each of the three Abstraction Sensitivity Bands (ASBs), which relate to the ecological sensitivity of rivers (EA, 2013). The difference between the natural flow and the EFI is the volume of water available for abstraction (Table 3).


<table>
<thead>
<tr>
<th>Abstraction Sensitivity Band</th>
<th>Q30</th>
<th>Q50</th>
<th>Q70</th>
<th>Q95</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASB3 high sensitivity</td>
<td>24%</td>
<td>20%</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>ASB2 moderate sensitivity</td>
<td>26%</td>
<td>24%</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>ASB1 low sensitivity</td>
<td>30%</td>
<td>26%</td>
<td>24%</td>
<td>20%</td>
</tr>
</tbody>
</table>

EFI values for the Q95 flow were chosen because the Anglian RBD is often very dry and low flows are therefore common (Anglian Water, 2014; following Zhang et al., 2014). An EFI/EFR of 80 % was chosen for Old Bedford and Middle Level, and a value of 85 % was chosen for the other catchments. This was because Old Bedford and Middle Level is mainly classified as ASB1 while the others are mainly ASB2. The surface water availability (m3/month and m3/year) for each catchment was therefore 20 % (for Old Bedford and Middle Level) or 15 % (all other catchments) of the natural flow for that catchment.

3.2.2. Current groundwater availability

Groundwater availability is assumed here to be equal to the sustainable yield. The sustainable yield of an aquifer is the amount of water that can be abstracted without affecting groundwater contribution to river flows (as base flow) and related ecosystems or groundwater quality (Ponce, 2007; Maimone, 2004). In order to assess groundwater availability for each catchment, the sustainable yield of all aquifers in each catchment was estimated and these values were combined. Sustainable yield was be estimated as 10 % of groundwater recharge, as Ponce (2007) suggests that this is a “reasonably conservative” estimate. Groundwater recharge estimations were based on the water-table fluctuation method:
\[ R(t_j) = S_y \times \Delta H(t_j) \]

Where \( R(t_j) \) (m) is recharge occurring between times \( t_o \) and \( t_j \), \( S_y \) (dimensionless) is the specific yield of the aquifer and \( \Delta H(t_j) \) (m) is the peak rise in water level due to the recharge period (USGS, 2014). Estimating \( \Delta H(t_j) \) requires extrapolation of the downwards trend to estimate the difference between the recharge peak and the water level if recharge had not occurred. However, hydrographs were not available for all groundwater wells for the entire time period and so the mean annual range of groundwater level was used for \( \Delta H(t_j) \) instead (Hydrometric Register, 2008). This method assumes that all water level fluctuations are due to infiltration. The Hydrometric Register (2008) presented only the mean annual range of each well over the whole observation period; this was from the 1950s/60s to 2005 for most wells. It was therefore assumed that these values represented long-term fluctuations which could be compared with long-term averaged surface water availability. The specific yields of each aquifer were taken from Allen et al. (1997); it was assumed that these were representative of the location of the well and the whole water column. The mean annual recharge was multiplied by the area of the aquifer in a catchment to get the water available from that aquifer in that catchment. These volumes were then added together to get the total volume of groundwater available in the catchment.

3.2.3. Future water availability

Projections of future water availability for the 2020s and 2050s were taken from Sanderson et al. (2012). This paper reported ranges of percentage changes in total (surface water and groundwater combined) runoff for each season, predicted by the 11-member RCM used in the UKCP09 reports. However, as my estimation of current groundwater availability was only on an annual timescale it was not possible to assess total seasonal water availability. Instead, the values were used to assess monthly surface water availability and annual total water availability. In order to achieve this it was assumed that changes in surface water availability would be equal to changes in total water availability and that annual change in groundwater water availability would be equal to the average change over the seasons. The median of each percentage change range was used in order correspond as closely as possible with the 50% probability level future climate used for the Cropwat model.

3.3. Current and future blue water scarcity

The surface water scarcity of a catchment is the ratio of the total blue surface water footprint to blue surface water availability in the catchment:

\[ \text{Blue water scarcity} = \frac{\text{Blue water footprint}}{\text{Blue water availability}} \]
Scarcity was classified according to Zhang et al. (2014) for both current and future time periods (Table 4):

Table 4: Levels of blue water scarcity (BWS). Adapted from Zhang et al. (2014) to make the categories more explicit.

<table>
<thead>
<tr>
<th>Level of BWS</th>
<th>BWS Score</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.0 - 1.00</td>
<td>Blue WF does not exceed blue water availability</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.01 - 1.50</td>
<td>Blue WF is between 100 and 150 % of blue water availability</td>
</tr>
<tr>
<td>Significant</td>
<td>1.51 - 2.00</td>
<td>Blue WF is between 150 and 200 % of blue water availability</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;2.00</td>
<td>Blue WF is more than 200 % of blue water availability</td>
</tr>
</tbody>
</table>

3.4. Sensitivity analysis

3.4.1. Current EFR and sustainable yield

The lowest and highest EFIs relating to the percentages of allowable abstraction were chosen from Table 4 (70 % and 90 %) as alternative EFRs for surface water. Sustainable yield was tested at 40 % (recommended by Ponce (2007) as an average value) and 5% for groundwater. The effect of these changes on blue water scarcity were tested for East Suffolk for the current period.

3.4.2. 2050s climate data for Cropwat

UKCP09 10% and 90% probability level climate projections for the medium emissions scenario were tested for the 2050s for North West Norfolk. Blue agricultural water footprints and water scarcity were calculated.

3.4.3. 2050s water availability

The lower and upper values from the ranges of percentage changes in 2050s water availability (Sanderson et al., 2012) were tested for North West Norfolk. The effect on blue water scarcity was noted.

3.4.4. 2050s land use change

Current land use was used to calculate blue agricultural water footprints and water scarcity for North West Norfolk and Cam and Ely Ouse.
4. Results

4.1. Cropwat results

4.1.1. Current crops

**Figure 3:** Current blue water consumption (mm) of irrigated crops, averaged over all soil types for each weather station. Volumes are for the whole growing period.

Root crops currently use more blue water than cereals throughout the river basin, and potatoes use by far the most (Figure 3). Cavendish and Denver crops require much more blue water than for all other stations. For the other stations, almost potatoes consume most of the blue water, no blue water is required for winter wheat and only Wittering winter barley requires a small volume of blue water.

**Figure 4:** Current green and blue water consumption of irrigated potatoes in the Denver area. Volumes are for the whole growing period.
Generally, there is a negative correlation between the volume of blue water consumed by a crop and the Total Available Water (TAW) in the soil (which changes with soil type) (Figure 4). Crops grown on sand therefore generally have the highest blue water consumption.

Less than 20 % of all crops are grown on the two soil types with the lowest TAW (Figure 5). Upper and Bedford Ouse has the highest percentage at 18 % for root crops, and North West Norfolk has the lowest for both crop types.

The annual blue agricultural water footprints of five catchments consist entirely or almost entirely of water consumption by potatoes, with any remaining water being consumed by sugar beet (Figure 6). The annual blue agricultural water footprints of all other catchments are dominated by winter wheat, but to a lesser extent so that winter barley contributes between 11 and 28 % and root crops also consume small amounts. Cereals generally consume blue
water in April, May and June and root crops in June, July, August and September. Cereals dominate months where both crop types consume water.

4.1.2 2020s crops

![Figure 7: 2020s blue water consumption of irrigated crops, averaged over all soil types for each weather station area.](image)

Blue water consumption greatly increases for all crops and all weather stations for the 2020s (Figure 7). Volumes are more similar between weather stations than for the present. Root crops are still the largest consumers but all stations now require blue water for winter wheat and winter barley.

![Figure 8: The difference between potential and actual green water consumption of rainfed crops, averaged across all soil types and catchments for the present and for the 2020s.](image)

All rainfed crops have a water deficit (potential minus actual use) in the 2020s, whereas only potatoes, sugar beet and oilseed rape have deficits for the current period (Figure 8). Root crops have the highest deficits.
In the 2020s there is a clear dominance of blue water consumption by winter wheat in all catchments (Figure 9). This is because winter wheat water consumption increases from 0 in the five catchments that are dominated by potato water consumption in the present. Apart from this large increase and the increase in winter barley water consumption in Nene, all other changes are quite small and of similar size across the crops. Most changes are increases but some (for example winter barley in Broadland Rivers) are decreases.

4.1.3. 2050s crops

The crop areas of all irrigated crops increase from the current to the 2050s in all catchments (Figure 10). The area of winter wheat increases the most, followed by winter barley.
4.2. Agricultural water footprints

4.2.1. Current agricultural water footprints

Annual green agricultural water footprints range from 57,943,870 m$^3$ (North Norfolk) to 74,723,087 m$^3$ (Witham) (Figure 11). Welland, Old Bedford and Middle Level and East Suffolk also have large water footprints for their size (m$^3$/ha). Annual blue agricultural water footprints range from 137,394 m$^3$ (Nene) to 43,127,204 m$^3$ (Combined Essex) (Figure 11). Western catchments have smaller water footprints for their size than eastern ones. The total volume of water (green water and blue water combined) consumed annually in catchments for agriculture ranges from 61,168,047 m$^3$ (North Norfolk) to 748,119,379 m$^3$ (Witham) (Figure 12).

All catchments consume more green water than blue water for agriculture annually. Blue water use ranges from 0.04 % (Nene) to 8.89 % (Broadland Rivers) of total water consumption. Agricultural water consumption is highest in the summer months in all catchments. In May and June in some catchments, the percentage of water consumption that is blue water is much higher than the annual percentage. For example in May in Broadland Rivers and Cam and Ely Ouse blue water makes up 35 % and 25 % of total agricultural water consumption respectively. No blue water is consumed between October and March in any catchment.
Annual green and blue agricultural water footprints

Figure 11: Annual green and blue water footprints of agriculture in the Anglian RBD.
4.2.2 2020s agricultural water footprints

Witham has the largest annual green agricultural water footprint for the 2020s (657,688,945 m$^3$), while North Norfolk has the smallest (7,773,872 m$^3$) (Figure 11). Green water footprints decrease in all catchments except North West Norfolk and Old Bedford and Middle Level, with the highest decrease in North Norfolk (87%).

Cam and Ely Ouse has the largest annual blue agricultural water footprint for the 2020s (72,690,372 m$^3$), while North Norfolk has the smallest (9,848,556 m$^3$) (Figure 11). Water footprints increase in all catchments, with highest increases in catchments that have the...
smallest footprints in the present. The lowest increase is for Combined Essex (56 %) and the highest is for Nene (17,646 %).

Witham has the largest total (green and blue combined) annual agricultural water footprint (726,361,304 m$^3$) and North Norfolk has the smallest (17,622,428 m$^3$) (Figure 12). Water footprints increase in six catchments (with the highest increase in North West Norfolk at 19 %) and decrease in five catchments (highest decrease in North Norfolk at -71 %).

Of all total agricultural water consumption, that which is blue water increases in all catchments. The relative proportions of groundwater and surface water consumed by the agricultural and domestic sectors were kept the same for all future assessments.

4.2.3. 2050s agricultural water footprints

Annual green water footprints increase from the present to the 2050s in all catchments by an average of 43 %. Water footprints therefore increase from the 2020s to the 2050s as well. Witham has the largest annual green agricultural water footprint for the 2050s (974,667,385 m$^3$), while North Norfolk has the smallest (92,302,383 m$^3$) (Figure 11).

Annual blue water footprints increase from the present in all catchments by an average of 9464 %; this is much higher than for the 2020s. Cam and Ely Ouse has the largest annual blue agricultural water footprint for the 2050s (155,168,220 m$^3$), while North Norfolk has the smallest (17,759,707 m$^3$) (Figure 11).

Water footprints increase from the present in all catchments by an average of 62 %. Witham has the largest total (green and blue combined) annual agricultural water footprint (1,086,271,635 m$^3$) and North Norfolk has the smallest (110,062,089 m$^3$) for the 2050s (Figure 12). The range in catchment water footprints increases by 42 %. All catchments consume more green water than blue water annually, with blue water consumption ranging from 9 % to 19 % of the total agricultural water footprint for the 2050s.

The proportion of total agricultural water consumption that is blue water consumption increases in all catchments. For all catchments, the month of highest consumption is June for blue water and total water and May or June for green water for the 2050s. Upper and Bedford Ouse has the highest percentage of monthly water consumption that is blue water; this is 45 % in July.

4.3. Blue domestic water footprints

4.3.1. Current blue domestic water footprints

Combined Essex has the largest domestic blue water footprint by far (71,491,248 m$^3$) and North Norfolk has the smallest (2,726,112 m$^3$) (Figure 13). Nene and Upper and Bedford
Ouse also have large water footprints for their size (m3/ha). Monthly domestic consumption only varies due to the number of days in the month, as a fixed value of daily pcc was used.

4.3.2. 2020s blue domestic water footprints
Under the ‘market forces’ socio-economic scenario, all domestic blue water footprints increase by 18.3 %. Combined Essex has the highest domestic blue water footprint (84,589,705 m$^3$) and North Norfolk has the lowest (3,225,584 m$^3$) (Figure 13). Under the ‘sustainable behaviour’ socio-economic scenario, all domestic blue water footprints decrease by 5 %. Combined Essex has the highest blue domestic water footprint (67,910,045 m$^3$) and North Norfolk has the lowest (2,589,553 m$^3$).

4.3.3. 2050s blue domestic water footprints
Under the ‘market forces’ socio-economic scenario, all domestic blue water footprints increase by 55 %. Combined Essex has the highest domestic blue water footprint (110,800,600 m$^3$) and North Norfolk has the lowest (4,225,060 m$^3$) (Figure 13). Under the ‘sustainable behaviour’ socio-economic scenario, all domestic blue water footprints decrease by 15 %. Combined Essex has the highest blue domestic water footprint (60,761,619 m$^3$) and North Norfolk has the lowest (2,316,968 m$^3$).
Annual blue domestic water footprints

Figure 13: Annual blue domestic water footprints in the Anglian RBD.
4.4. Blue catchment blue water footprints

4.4.1. Current blue catchment water footprints

Total annual blue water consumption in the Anglian RBD (domestic and agricultural consumption combined) is highest in Combined Essex (114,618,451 m$^3$) and lowest in North Norfolk (5,950,292 m$^3$) (Figure 17). North Norfolk and Witham rely most on groundwater overall (90.5 % and 89.5 % of total blue water consumption respectively) and Nene, Old Bedford and Middle Level and Welland rely most on surface water (all 89.5 % of total blue water consumption) (Figure 14).

Agricultural consumption is dominant in four catchments (54.2 and 53.6 % of total annual blue water consumption in North Norfolk and North West Norfolk and 52.9 and 53.0 % in Broadland Rivers and Cam and Ely Ouse) (Figure 15). Combined Essex and Old Bedford and Middle Level have a slightly less dominant agricultural sector (37.6 and 41.1 % of total annual blue water consumption respectively). The remaining five catchments are heavily dominated by domestic consumption, accounting for between 95.6 and 99.7 % of annual consumption. The relative contributions of each sector vary throughout the year. For example agriculture accounts for 92.0 % of blue water consumption in Broadland Rivers in May but it consumes no blue water from October to March.

![Relative percentages of groundwater and surface water consumption](image)

*Figure 14: Groundwater and surface water consumption as percentages of the blue catchment WF.*
4.4.2. 2020s blue catchment water footprints

Under the 'market forces' socio-economic scenario, catchment water footprints increase from the present by an average of 110 % and is highest in Combined Essex (151,891,765 m$^3$) and lowest in North Norfolk (13,074,140 m$^3$) (Figure 17). Under the ‘sustainable behaviour’ socio-economic scenario, catchment water footprints increase by an average of 93 % and is highest in Combined Essex (135,212,105 m$^3$) and lowest in North Norfolk (12,438,109 m$^3$).

The percentage of catchment water footprint that is agricultural increases under both scenarios. The highest percentages are under the ‘sustainable behaviour’ scenario, when all catchments except Combined Essex are dominated by agricultural consumption.

Figure 15: Current relative contributions of agriculture and the domestic sector to the blue catchment WF.

Figure 16: 2050s relative contributions of agriculture and the domestic sector to the blue catchment WF.
4.4.3. 2050s blue catchment water footprints

Under the ‘market forces’ socio-economic scenario, catchment water footprints increase by an average of 263 % and is highest in Combined Essex (243,181,345 m$^3$) and lowest in North Norfolk (20,376,740 m$^3$) (Figure 17). Under the ‘sustainable behaviour’ socio-economic scenario, catchment water footprints increase by an average of 212 % and is highest in Combined Essex (193,142,364 m$^3$) and lowest in North Norfolk (18,468,648 m$^3$).

Under the ‘market forces’ scenario, agricultural consumption accounts for more than half of the catchment water footprint in all catchments except Nene (Figure 16). Under the ‘sustainable behaviour’ scenario Nene is also dominated by agricultural consumption and agriculture accounts for more than 90 % of total consumption in June in all catchments.
Figure 17: Annual blue catchment water footprints in the Anglian RBD (blue agricultural and domestic water footprints combined. Shown in m3/ha.)
4.5. Blue water availability

4.5.1. Current blue water availability

North West Norfolk has the most surface water available annually for consumption (136,166,315 m$^3$), while North Norfolk has the least (5,150,165 m$^3$) (Figure 18). December, January, February and March have the highest flows in most catchments, but in Broadland Rivers, Cam and Ely Ouse and North Norfolk highest flows occur in May (in addition to high winter flows). Annual groundwater availability is highest in Broadland Rivers (16,772,765 m$^3$), and lowest in Old Bedford and Middle Level (4,911 m$^3$) (Figure 18). Total annual water availability is highest in North West Norfolk (566,792 m$^3$) and lowest in North Norfolk (10,060,319 m$^3$) (Figure 18). Surface water accounts for more than half of total annual water availability in all catchments, with the highest percentage in Old Bedford and Middle Level (99.99 %) and the lowest in North Norfolk (51.19 %). Surface water availability is generally proportional to catchment area, but North Norfolk has the highest availability for its size despite having one of the lowest total volumes.

4.5.2. 2020s blue water availability

Annual surface water availability increases by between 2.75 % (North Norfolk) and 4.5 % (Old Bedford and Middle Level) by the 2020s. Annual volumes range from 52,92,018 m$^3$ (North Norfolk) to 141,876,212 m$^3$ (North West Norfolk) (Figure 18). Surface water availability in winter months (December, January and February) increases by 10 % and all other months remain the same as present. Highest flows in Broadland Rivers, Cam and Ely Ouse and North Norfolk still occur in May, and in January for all other catchments.

Annual groundwater availability increases by 2.5 % in all catchments by the 2020s. Annual volumes range from 5,033 m$^3$ (Old Bedford and Middle Level) to 17,192,085 m$^3$ (Broadland Rivers) (Figure 18).

Annual total water availability increases by between 2.63 % (North Norfolk) and 4.5 % (Old Bedford and Middle Level) by the 2020s. Annual volumes therefore range from 10,324,926 m$^3$ (North Norfolk) to 142,251,694 m$^3$ (North West Norfolk) (Figure 19).

4.5.3. 2050s blue water availability

Annual surface water availability increases by between 4.25 % (North Norfolk) and 6.09 % (Old Bedford and Middle Level) by the 2050s from the current situation. Annual volumes range from 5,369,011 m$^3$ (North Norfolk) to 143,830,918 m$^3$ (North West Norfolk) (Figure 18). Surface water availability increases by 10 % in winter and spring, decreases by 10 % in autumn and stays the same in summer. Months of highest flows stay the same (May
for Broadland Rivers, Cam and Ely Ouse and North Norfolk, January for all other catchments). Annual groundwater availability is the same as the 2020s.

Annual total water availability increases by between 3.4 % (North Norfolk) and 6.09 % (Old Bedford and Middle Level) by the 2050s from the current situation. Annual volumes range from 10,401,919 m$^3$ (North Norfolk) to 144,411,879 m$^3$ (North West Norfolk) (*Figure 19*).
Figure 18: Annual surface water and groundwater availability in the Anglian RBD. Shown in m3/ha.
Total annual water availability

Figure 19: Total annual water availability in the Anglian RBD (groundwater and surface water combined). Shown in m3/ha.
4.6. Blue water scarcity

4.6.1. Current blue water scarcity

All catchments except Combined Essex have low annual blue surface water scarcity, meaning that blue water consumption is less than blue water availability (Figure 20). Annual blue surface water scarcity is lowest in North West Norfolk (0.02). Combined Essex has significant annual blue surface water scarcity (1.63). Six catchments have at least one month of moderate or higher blue surface water scarcity, all between April and November. Combined Essex has the most months at moderate or higher blue surface water scarcity (8 months), with June being the highest at 3.78 (severe). The only other catchment to reach severe blue surface water scarcity is East Suffolk in July.

Only three catchments have low annual blue groundwater scarcity; these are Welland, Nene and Upper and Bedford Ouse. Old Bedford and Middle Level has the highest annual blue groundwater scarcity by far at 284.83 (severe) (Figure 21). Six other catchments are also classified as severe and North Norfolk is classified as moderate (1.09).

Total annual blue water scarcity is low in nine catchments. Combined Essex is classified as significant (1.7) and East Suffolk is classified as moderate (1.08). North West Norfolk has the lowest annual blue water scarcity (0.08) (Figure 22).

4.6.2. Future blue water scarcity

Total, surface water and groundwater water scarcity increases under both socio-economic scenarios for both the 2020s and 2050s. Old Bedford and Middle level remains the most groundwater-scarce catchment, Combined Essex remains the most surface water-scarce catchment except for the 2050s ‘sustainable behaviour’ scenario, and East Suffolk becomes the catchment with the highest annual total water scarcity. All types of blue water scarcity are lower under the ‘sustainable behaviour’ scenario than the ‘market forces’ scenario, but are still higher than present values.

4.6.2.1. 2020s blue water scarcity

Annual surface water scarcity is ‘moderate’ or higher in five out of 11 catchments under both scenarios (Figure 20). Combined Essex and Welland have the highest scarcity, at 2.05 and 1.56 (respectively) under the ‘market forces’ scenario. Surface water scarcity is highest in June for all catchments under both scenarios.

Under the ‘market forces’ scenario all catchments have ‘moderate’ or higher annual groundwater scarcity and the highest scarcity is in Old Bedford and Middle Level (478.84) (Figure 21). Under the ‘sustainable behaviour’ scenario Nene has low groundwater scarcity but all other catchments are still ‘moderate’ or higher.
Total annual blue water scarcity is ‘moderate’ or higher in nine out of 11 catchments under both scenarios and is highest in East Suffolk and Witham (*Figure 22*). These catchments both have ‘severe’ annual total blue water scarcity under the ‘market forces’ scenario.

### 4.6.2.2. 2050s blue water scarcity

Annual surface water scarcity is ‘moderate’ or higher in six out of 11 catchments under both scenarios, and is higher than in the 2020s for all catchments (*Figure 20*). Surface water scarcity is highest in June for all catchments under both scenarios.

Under the ‘market forces’ scenario annual groundwater scarcity is ‘severe’ in all catchments except Nene, where it is ‘significant’ (*Figure 21*). Under the ‘sustainable behaviour’ scenario Nene has ‘moderate’ groundwater scarcity and Welland has ‘significant’ scarcity; all other catchments remain ‘severe’.

Total annual water scarcity is ‘significant’ or higher in nine out of 11 catchments under both scenarios (*Figure 22*). Only North West Norfolk and Old Bedford and Middle Level have ‘low’ annual total water scarcity.
Annual blue surface water scarcity

Figure 20: Annual blue surface water scarcity in the Anglian RBD.
Figure 21: Annual blue groundwater scarcity in the Anglian RBD.
Figure 22: Total annual blue water scarcity in the Anglian RBD.
4.7. Sensitivity analysis

4.7.1. Current EFR and Sustainable Yield

Using an EFR of 90 % for East Suffolk for the present changes annual blue surface water scarcity from ‘low’ to ‘moderate’ water scarcity and increases the number of months with ‘moderate’ or higher scarcity from six to nine. Five months have ‘severe’ scarcity, compared to one month before. Using an EFR of 70 % lowers annual blue surface water scarcity in East Suffolk and results in just one month of ‘moderate’ water scarcity, with all others being ‘low’.

Using a sustainable yield of 40 % lowers annual blue groundwater scarcity in East Suffolk closer to the boundary between ‘significant’ and ‘severe’ (scarcity is 2.24). Using a sustainable yield of 5 % raises the scarcity level to 17.91 (twice as high as in the main assessment).

When the two higher environmental requirements are combined (90 % EFR and 5 % sustainable yield), total annual blue water scarcity changes from ‘moderate’ to ‘significant’. When the two lower environmental requirements are combined (70 % EFR and 40 % sustainable yield), total annual blue water scarcity changes from ‘moderate’ to ‘low’.

4.7.2. 2050s climate data for Cropwat

Minimal change in total annual blue water scarcity is caused by using 2050s UKCP09 climate projections at the 10 % and 90 % probability levels in the Cropwat model for North West Norfolk (compared to the 50 % probability level used in the main assessment). Both probability levels lead to slightly higher levels of scarcity, but increases are less than 0.1% for the 10% projections and less than 0.8% for the 90% projections.

4.7.3. 2050s water availability

Percentage changes (applied to the present) corresponding to drier 2050s conditions result in a 0.6 % decrease in surface water availability from the main assessment in North West Norfolk. This in turn results in a 0.6 % higher value of annual blue surface water scarcity for both socio-economic scenarios (still a ‘low’ level). Applying the percentage changes corresponding to wetter conditions results in an 8.9 % increase in annual surface water availability from the main assessment and an 8.1 % lower annual blue surface water scarcity level for both scenarios.

Drier percentage changes cause a 5 % decrease in groundwater availability from the main assessment and a corresponding 5.1 % increase in annual blue groundwater scarcity for both scenarios. Wetter percentage changes cause a 5 % increase in groundwater availability from the main assessment. Under the ‘market forces’ scenario, annual blue groundwater...
scarcity decreases by 4.7 %. Under the ‘sustainable behaviour’ scenario, scarcity decreases by 14.3 %.

Drier percentage changes cause a 1 % decrease in total water availability from the main assessment and a 0.6 % increase in annual total blue water scarcity for both scenarios. Wetter percentage changes cause a 125 % increase in total water availability from the main assessment, a 55.6 % decrease in scarcity under the ‘market forces’ scenario and a 59.2 % decrease in scarcity for the ‘sustainable behaviour’ scenario.

4.7.4. 2050s future land use change

When current land use is used to calculate the blue agricultural water footprint of North West Norfolk for the 2050s, the water footprint decreases by 29 % from the main assessment and total annual blue water scarcity decreases by 24 and 26 % for the ‘market forces’ and ‘sustainable behaviour’ scenarios respectively. Similarly, the blue agricultural water footprint of Cam and Ely Ouse is 29 % lower than in the main assessment and results in a 22 and 24 % decrease in total annual blue water scarcity. However in this catchment the scarcity classification is lowered from ‘severe’ to ‘significant’.

5. Discussion

5.1. Current blue water scarcity

All but two catchments in the Anglian RBD have low total annual blue water scarcity (Figure 22). This means that most catchments are consuming less water than is available on an annual basis. However, Combined Essex and East Suffolk have significant and moderate total annual blue water scarcity (respectively). These catchments are consuming more water than is available and may therefore be depleting resources, resulting in environmental damage and creating greater problems for the future.

‘Significant’ total annual water scarcity in Combined Essex is caused by a combination of large water footprints and low water availability. Both agricultural and domestic water consumption are likely to be major contributors to the scarcity, as the water footprints of both sectors are the highest of all catchments in terms of total volume and relative to the catchment’s size. The domination of domestic consumption is due to the large population of the catchment. The large blue agricultural water footprint is likely to be due to several factors. Irrigated winter wheat covers the greatest land area in the catchment out of the four irrigated crops; this is in common with most other catchments. However, unlike many other catchments, winter wheat actually consumes blue water (Figure 3). This raises the agricultural water footprint considerably and helps explain why it is larger than water footprints of other
catchments. In addition, irrigated root crops require much more blue water in Combined Essex than in all other catchments (Figure 3). It seems therefore that the combination of climate, land use and soil types specific to Combined Essex has resulted in a large blue agricultural water footprint.

‘Moderate’ total annual blue water scarcity in East Suffolk is mainly due to low water availability. The combined blue water footprint is quite low for the catchment’s size, but total, surface water and groundwater availability is also low, meaning that the ratio of the two variables still results in ‘moderate’ scarcity. Groundwater availability is low because only a small area of Chalk aquifer is present (Figure 2), while surface water availability is low because all gauging stations in the catchment recorded low mean flows.

Although most catchments are classified as having ‘low’ total annual blue water scarcity, assessing surface water and groundwater sources separately and on a monthly timescale reveals greater variation. Annual blue surface water scarcity is ‘low’ in all catchments except Combined Essex, but monthly blue surface water scarcity is not. Scarcity is generally higher in summer due to higher temperatures and lower rainfall, which lead to increased agricultural blue water consumption and lower river flows. In Combined Essex, ‘moderate’ scarcity in April, October and November is mainly caused by low availability, as crops do not consume any blue water in these months and domestic consumption is very similar to other ‘low’ scarcity months. However, higher water availability in May and June is coincides with very large agricultural water footprints, as both cereals and roots consume blue water in these months. For all other catchments with three or more months of moderate or higher water scarcity, low surface water availability is likely to be the main cause of water scarcity as it is noticeably lower in the summer/autumn and agriculture is not prominent in these catchments so does not affect the catchment water footprint greatly. These examples show how water scarcity can be attributed to fluctuations in different factors at different times and reinforces the importance of examining scarcity on a monthly scale.

Annual groundwater scarcity is ‘moderate’ or higher in all but three catchments (Figure 21). The scarcity value for Old Bedford and Middle Level suggests that the annual blue groundwater footprint is about 28,000 times higher than the annual groundwater recharge in the catchment. This value is extremely high despite the catchment having the lowest total groundwater footprint in the Anglian RBD; this is because there is only a small area of moderately productive Great Oolite (limestone) aquifer in the catchment (Figure 2). Similarly, the annual groundwater scarcity value for North West Norfolk suggests that groundwater consumption is 1,600 times greater than the annual groundwater recharge. Roughly one third of this catchment is underlain by the highly productive Chalk aquifer, but groundwater is heavily relied upon by both agricultural and domestic sectors and the water available is insufficient. The situation suggested by my findings for these catchments could only be
possible in reality if large inter-catchment groundwater-sourced transfers were taking place. Transfers have not been included in this water scarcity assessment due to their complex nature, but they may play an important role in water resource management, especially for domestic water supply by water companies. Transfers could mean that receiving catchments are not as water-scarce as this study suggests, but they could be contributing to water scarcity in the catchments from which water is being removed. Thus, high levels of water scarcity in this study still point towards unsustainable water consumption and highlight the need for further investigation into the effects of transfer flows.

5.2. Future water scarcity

Annual total, surface water and groundwater scarcity increases in all catchments under both socio-economic scenarios. The main reason for this is that annual blue catchment water footprints increase by a large amount while blue water availability increases by a small amount.

Blue water consumption by crops increases because crops generally require more water in total due to changes in climate such as increased temperatures, which increase the rate of evapotranspiration. In addition, lower rainfall leads less green water to be available in some catchments. Specifically, cereals consume blue water in all catchments for the future year ranges; this increases blue agricultural water footprints considerably and makes winter wheat the dominant crop in terms of blue water consumption in all catchments (Figure 9). For the 2050s, land use change may have also caused increases in blue agricultural water footprints as areas of all irrigated crops increased. The 2050s has especially large increases in winter wheat in catchments that already had the largest areas of the crop (Figure 10). This is likely to have contributed to the increased range of blue agricultural water footprints between catchments.

Domestic consumption increases dramatically (by 55% by the 2050s) under the ‘market forces’ scenario due to increased population (by 45% by the 2050s) and increased per capita consumption (by 5% by the 2050s). These increases are based on a future society that is focussed on the economy and consumerism and which takes no action to reduce water demand. The environment is given a lower priority and thus individuals do not see the need to reduce their water consumption.

Domestic consumption decreases (by 15% by the 2050s) under the ‘sustainable behaviour’ scenario. Although population still increases under this scenario it is by a smaller amount (25% by the 2050s) than under the ‘market forces’ scenario, and per capita consumption decreases by 30% by the 2050s. This is because the ‘sustainable behaviour’ society prioritises sustainable development and recognises the need to reduce water
consumption. However, 2020s annual catchment water scarcity under this scenario is still much higher than in the current situation, and scarcity continues to increase up to the 2050s. This is explained by the fact that the increase in agricultural blue water consumption is larger than the decrease in domestic consumption.

In common with the current situation, only two catchments (Welland and Nene) have higher surface water scarcity than groundwater scarcity. The gap between scarcity values for the two sources widens in all catchments from the present to the future; this is mainly because surface water availability increases more than groundwater availability and is greater for the 2050s than the 2020s, whereas groundwater availability increases from the current situation by the same amount for both future year ranges (2.5 %). The highest annual groundwater scarcity value is 804.34 for Old Bedford and Middle Level in the 2050s; this suggests that annual groundwater consumption is roughly 80,000 times higher than annual groundwater recharge in the catchment. Total annual water scarcity is highest in Combined Essex in the 2050s at 3.46, which suggests that annual water consumption is roughly 300 times higher than the total water available annually in the catchment. As mentioned earlier, more water may be available in these catchments in reality due to water transfers made by water companies. However, as most catchments are found to have ‘severe’ total annual scarcity by the 2050s there is likely to be a water shortage across the whole river basin, suggesting the need for immediate and large-scale action to prevent this from occurring.

Overall, summer/autumn months still have the highest water scarcity, as future water availability either stays the same or decreases, and blue agricultural water footprints generally increase.

5.3. Sensitivity analysis – implications for results

The sensitivity analysis aimed to test the robustness of the blue water scarcity classifications and highlight areas requiring further research in order to improve the classifications. The variable that produces the most change in scarcity was the environment’s requirement of surface water and groundwater. Changing the EFR and sustainable yield in East Suffolk for the current situation results in different annual and monthly blue water scarcity classifications. This suggests that the main results may not be robust. Quantifying environmental water requirements is complex; there are many factors to take into account and the abstraction limits set depend on the desired state of the resource and the priorities of different parties (Acreman and Dunbar, 2004). Environmental requirements change throughout the year as ecosystems react to the volume of water available (EA, 2013). For example, they may be more vulnerable in periods of low flow and therefore require a higher percentage of river flow. Equally the sustainable yield of groundwater may need to be lower.
in low flow periods to protect river base flows. The fixed EFR value used in this report is a low flow (Q95) value and the sustainable yield is conservative, but they may still not accurately represent the environment’s needs, as most catchments have water bodies that are classified under more than one Abstraction Sensitivity Band and have different requirements. It is also possible that the environmental requirements will increase as ecosystems are put under pressure from climate change and human activities (EA, 2011).

Future water availability has an important influence on 2050s annual blue water scarcity in North West Norfolk. The wetter percentage changes greatly affect groundwater and total water scarcity, suggesting a high sensitivity. Availability has the largest influence under the ‘sustainable behaviour’ scenario as blue catchment water footprints are lower. Surface water scarcity is not as sensitive and drier percentage changes cause less scarcity change for both water sources. Despite some large changes in scarcity values, the classifications of all catchments do not change. This strengthens the robustness of the results. However, there is great uncertainty surrounding future water availability and this analysis points to the need for further investigation so that water scarcity assessments can be as accurate as possible.

Land use change may affect scarcity classifications in some catchments, as using current land use for the 2050s lowers the total annual blue water scarcity level of Cam and Ely Ouse to ‘significant’. However, although land use changes much more in Cam and Ely Ouse than in North West Norfolk from the present to the 2050s, scarcity in both catchments decreases by the same amount when current land use is used. This may mean that the recorded change in scarcity is the maximum change that could occur from testing these two land use datasets.

2050s blue water scarcity is not sensitive to the probability level used for climate projections for the Cropwat model. This may be partly because the large values of domestic consumption reduce the influence that changes in these variables have on total blue water footprints. The low sensitivity suggests that the scarcity classifications are robust for the medium emissions scenario.

Overall, environmental water requirements are found to have the greatest influence on water scarcity. Although this sensitivity test was only done for the current period, it is likely that future scarcity is also sensitive to the variable. Future water availability and land use change are also important influencing factors and should be investigated further. Central estimates and recommended values were used for all these variables in the main scarcity assessment. However, the results of this analysis will be taken into account when discussing management and policy options.
5.4. Assumptions made and their impact on results

Table 5 shows the main assumptions made in this report and the impact they may have had on blue water scarcity classifications. Current agricultural and domestic water footprints are likely to be reasonably good estimates as over-/underestimations roughly cancel each other out. Assumptions relating to future agricultural water footprints may have resulted in an underestimation of water scarcity but those relating to future domestic water footprints may overestimate it. Overall, future catchment water footprints may produce an overestimate of scarcity due to the dominance of domestic consumption in most catchments. The impact of assumptions relating to water availability is less clear. Current surface water availability may produce an overestimate of scarcity, but this depends on the accuracy of the catchment water footprint. Assumptions relating to current groundwater availability may be causing an overestimation of water scarcity in catchments such as Broadland Rivers and East Suffolk where aquifers other than those accounted for are being used for abstraction. Assumptions linked to future water availability could be either under- or overestimating scarcity. Overall, the current surface water scarcity classification is thought to be a reasonably central estimate, but groundwater scarcity may be overestimated in catchments where minor aquifers are used for abstraction. Future water scarcity may be a slight overestimate due to over-estimated domestic consumption.

Table 5: Assumptions made and their impact on results - whether they are likely to have produced an overestimation or underestimation of blue water scarcity.

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current agricultural WFs</td>
<td></td>
</tr>
<tr>
<td>Whether crops are either rainfed or irrigated relates to soil type only</td>
<td></td>
</tr>
<tr>
<td>Irrigation occurs at critical depletion and replenish soil to 100% moisture capacity</td>
<td></td>
</tr>
<tr>
<td>No soil water depletion at start of growing period</td>
<td></td>
</tr>
<tr>
<td>Crop data is accurate for the Anglian RBD</td>
<td></td>
</tr>
<tr>
<td>Current domestic WFs</td>
<td></td>
</tr>
<tr>
<td>The proportion of rainfed and irrigated crop areas and proportions of different cereals and roots would stay the same for future years</td>
<td></td>
</tr>
<tr>
<td>Planting and harvesting dates will stay the same for future years</td>
<td></td>
</tr>
<tr>
<td>UK and Anglian climate change is equal to climate change at each weather station</td>
<td></td>
</tr>
<tr>
<td>Future domestic WFs</td>
<td></td>
</tr>
<tr>
<td>2006-based population projections are accurate</td>
<td></td>
</tr>
<tr>
<td>General future WFs</td>
<td></td>
</tr>
</tbody>
</table>

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5.5. Comparison of results with other studies

It is difficult to compare the results of this study with other reports on water scarcity because all studies examine different aspects of the topic and use different methods or geographical scales to do so. However, a few useful observations can be made on relative scarcities between catchments. North Essex (part of Combined Essex) is identified by Knox et al. (2000) as the only Anglian catchment to be a ‘very high’ irrigation hotspot; this agrees with the results of this study that find Combined Essex has the highest current blue agricultural water footprint and blue water scarcity. The EA NRW (2013) report classifies the greatest number of water bodies as being under ‘serious’ or ‘moderate’ stress in Witham, Combined Essex and Cam and Ely Ouse (Figure 23); these catchments have also some of the higher water scarcity levels in this study. However, the report also classifies all water companies in the Anglian RBD as being under ‘moderate’ or ‘serious’ stress for the present and the 2050s. These findings do not match the results of this study as current water scarcity is ‘low’ in most catchments. This difference in results may be explained by the methods used to aggregate water body-scale stress classifications to water company-scale ones.

<table>
<thead>
<tr>
<th>Current surface water availability</th>
<th>Overestimation - some channels were not accounted for so water availability is likely to be higher than estimated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term flow records represent the current mean flow and can be compared to current blue water consumption.</td>
<td>Overestimation - flows in several years in the 2007-2013 period were higher than long-term flows in some catchments. Scarcity may therefore be lower.</td>
</tr>
<tr>
<td>Adding the total blue water footprint from actual flow is a good estimation of natural flow.</td>
<td>Either - depends whether the total blue water footprint accurately accounts for all abstractions and the effects of groundwater abstraction on flows.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Current groundwater availability</th>
<th>Overestimation - in Broadland Rivers and East Suffolk groundwater is also abstracted from the Crag aquifer (Jones et al., 2000).</th>
</tr>
</thead>
<tbody>
<tr>
<td>All water level fluctuations are due to infiltration. Specific yields are constant throughout the water column, for the exact location of the wells and over time. Groundwater is only abstracted from principal aquifers.</td>
<td>Either - peaks or troughs could occur for other reasons such as groundwater pumping.</td>
</tr>
<tr>
<td>Either - many factors influence specific yield.</td>
<td>Overestimation -- in Broadland Rivers and East Suffolk groundwater is also abstracted from the Crag aquifer (Jones et al., 2000).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Future water availability</th>
<th>Overestimation - availability percentage changes were based on the UKCP09 medium emissions scenario so should be quite similar.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage changes in water availability are consistent with the climate change percentage changes used for Cropwat.</td>
<td>Either - this was the best estimate possible.</td>
</tr>
<tr>
<td>Seasonal surface water availability change is equal to seasonal total water availability change, and annual change is equal to the average of all seasonal change.</td>
<td>Overestimation - availability percentage changes were based on the UKCP09 medium emissions scenario so should be quite similar.</td>
</tr>
</tbody>
</table>

**Figure 23: Water stress classification of water bodies in the UK. Source: EA NRW (2013).**
5.6. What do these findings suggest for management?

On an annual scale, there is currently enough water for agricultural and domestic consumption in nine out of 11 catchments when considering total (surface water and groundwater combined) water availability. However, some of these catchments are nearing ‘moderate’ total annual water scarcity and six catchments have ‘moderate’ or higher surface water scarcity for at least one month of the year. In addition, annual groundwater scarcity is ‘moderate’ or higher in all but three catchments. There is no catchment in which all types of blue water scarcity are consistently low for all time periods. It is therefore clear that action must be taken now and across the whole river basin to reduce current scarcity levels and prevent higher levels from being reached in years to come.

Although groundwater scarcity seems to be more acute than surface water scarcity, it may not be advisable simply to switch to consuming more surface water as this would have a negative impact on surface water ecosystems and increase surface water scarcity. Instead, a holistic view of the water balance of each catchment should be taken. Water scarcity can be reduced by reducing consumption or increasing availability. The relative importance of these aspects depends on what the main contributors to the water scarcity are. This and other study’s findings suggest that Combined Essex, Witham and East Suffolk should be the main focus of urgent attempts to reduce scarcity. However, as all catchments are classified as ‘severe’ in future years, change is needed across the river basin.

5.6.1. Reducing domestic consumption

Action can be taken by regulators or by individuals. Individuals can reduce their domestic consumption by installing water-saving devices such as low-flush toilets and watering the garden using rainfed water butts (Waterwise, 2015). Anglian Water have launched a campaign to encourage efficient water use in the home and aim to increase the number of metered households as this has been shown to reduce consumption (EA, 2009b). If they were taken up by the population, these changes could help reduce water consumption to more sustainable levels in Combined Essex and East Suffolk where scarcity levels are currently highest.

Educating people now on the importance of saving water may help to steer society toward a ‘sustainable behaviour’ scenario rather than ‘market forces’ one. Water companies are already teaching about sustainable water use in schools and organisations such as Waterwise East are informing their partners on how to increase water efficiency in new housing developments (EA, 2009b). However, reaching ‘sustainable behaviour’ levels of consumption will still require significant voluntary lifestyle changes and as many other societal factors affect the way people choose to live these changes may not occur (EA, 2008). Either
way, additional action will need to be taken to minimise water scarcity as ‘severe’ water scarcity is shown to occur across the river basin even under the ‘sustainable behaviour’ scenario.

5.6.2 Reducing agricultural blue water consumption

Future catchment water footprints are dominated by agriculture in all catchments under both socio-economic scenarios (Figure 16). As the large increase in water deficit for rainfed crops shows (Figure 8), other crops are likely to require irrigation in the future too. This study therefore recommends that a reduction in agricultural blue water consumption begins now to avoid high levels of water scarcity and potential reductions in crop yields and quality if blue water availability becomes too low.

Blue agricultural water footprints can be reduced by adopting better irrigation scheduling and using more efficient equipment. Weatherhead (2007) found that on 40% of the irrigated area of England and Wales irrigation is scheduled using operator judgement only. By basing scheduling on in-field soil moisture measurements and weather forecasts, these operators could avoid over-irrigation and reduce blue water consumption by making the most of rainfall (Hess et al., 2011).

The findings of this report also suggest that changing the location of specific crops could help reduce water consumption. For example in Upper Bedford and Ouse 18% of all root crops are currently grown on sand or loamy sand (Figure 5); these crops are therefore much more likely to need irrigation. If they were grown on another soil type within the catchment, or cereal crops (which require less irrigation) were grown in these areas instead, the blue agricultural water footprint of the catchment would decrease. Another way to reduce the blue water consumption of crops would be to move higher consuming root crops to catchments in which they require less water. For example, potatoes require much more irrigation in Combined Essex than any other catchment yet 11% of all potatoes grown in the Anglian RBD are grown here. If instead these potatoes were grown in Witham, their blue water requirements would decrease. However, these changes are very unlikely to occur, at least at present. This is because some farmers may only own land with freely-draining soil types or in Combined Essex and would still prefer to grow high value crops such as potatoes even if they require more irrigation. Equally, land with other soil types or in other catchments may not be available and shifting root crop production to another catchment could increase blue water scarcity in that catchment if water resource pressures were already high. This type of action would need strong collaboration between farmers, agri-environmentalists and regulators such as the Environment Agency, but may have to be considered more seriously in the future as scarcity levels increase.
Agricultural blue water consumption in the Anglian RBD could also be reduced by lowering abstraction allowances. The Environment Agency has set environmental flow-related limits for newer licenses, but older ones do not have these (Hess et al., 2011). Regulatory action can cause conflicts as license holders are generally reluctant to have their licensed volumes reduced. However, Water Abstractor Groups have been set up and may help communication between the two sides as well as encourage more efficient water use between members (Knox et al., 2009).

5.6.3. Increasing water availability

The findings of this report support the government’s recommendation of a twin-track approach, aiming to reduce water consumption and increase water availability (Defra, 2008). The mismatch in the timing of water availability and water consumption over the year, which causes surface water scarcity in summer months, suggests the need for winter storage reservoirs on farms. These can capture water from high winter flows when more water can be abstracted without harming the environment, in order to use it in periods of lower flows. Although this practice does not reduce water consumption, it does reduce the impact on the environment and alleviates water scarcity in low flow months. An additional advantage for is that the price of abstraction in winter is lower than in summer (Hess et al., 2011). Abstraction licenses for spray irrigation are either for direct use or for storage; Weatherhead et al. (2014) report that the volume of water abstracted for storage is highest in the Anglian RBD out of all of England and Wales, with abstraction concentrated in Combined Essex, East Suffolk, Witham and Cam and Ely Ouse. This suggests that winter storage reservoirs may already be well established in the areas found by this study to have the highest levels of water scarcity. However, volumes are still very low compared to the blue agricultural water footprints calculated in this study so abstractors still need to be encouraged to invest.

Anglian Water recognises that future water resources management may be concerned principally with increasing supply rather than reducing demand (Anglian Water, 2015). This will include inter-catchment transfers, aquifer storage and recovery, trading between water companies, leakage reduction and water reuse schemes (Ibid.). As future water availability is uncertain and sensitivity analysis shows that scarcity levels can be greatly affected by it (especially for groundwater), plans need to be adaptable (EA, 2009b). In addition, they must take into account the fact that environmental requirements of water may increase (EA, 2011) and thus more supply-side measures may need to be implemented to compensate.

Overall, collaboration between water companies, regulators such as the Environment Agency and individuals will be needed if current and future water scarcity is to be minimised (EA, 2009b). Trade-offs between the environment, agricultural and domestic sectors may have
to be made but an integrated approach to management should be taken, for each catchment and for the river basin as a whole.

5.7. Recommendations for further research

The main limitations of this research are based on the assumptions and simplifications that had to be made in order achieve the aims within the time available. Recommendations for further research therefore focus on gaining more detailed data and investigating variables identified by the sensitivity analysis as having an important influence on water scarcity. Research into the quantification of the environment’s requirement of water should be prioritised, along with the projection of future river flows and groundwater recharge. Livestock and horticulture could be included in the agricultural water footprint assessment and the industrial sector could also be taken into account. Finally, more accurate calculations of current water availability could be gained by using abstraction data from water companies and the Environment Agency.

6. Conclusion

The Anglian RBD has many pressures on water resources; it has a large population, important agricultural sector and is the driest region in the country. This report finds that two catchments (Combined Essex and East Suffolk) are currently consuming more water than is available on an annual basis, five others consume surface water unsustainably for at least one month of the year and all but three catchments consume more groundwater than is available annually. Results suggest that future blue water scarcity will be much higher; in the 2020s and 2050s total annual blue water scarcity is calculated to be ‘moderate’ or higher in all but two catchments. If this situation occurs water resources will be depleted quickly and ecosystems will suffer greatly.

Although current groundwater scarcity and future scarcity classifications may be slight overestimations, results generally agree with a similar study (EA NRW, 2013) and it is still clear that action must be taken to make water resource use more sustainable. This action needs to be targeted to each catchment to ensure effectiveness, as the relative contributions of different factors to scarcity levels vary across the basin. The situation requires both a reduction in blue water consumption and an increase in water availability where possible. Increasing availability may become the main focus in future years as population increases and other socio-economic factors may make it difficult to reduce consumption beyond a certain level. Uncertainty surrounding the effect of climate change on environmental requirements and water availability increases the complexity of the challenge, but plans should be adaptable so that water scarcity can continue to be minimised as our understanding deepens.
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