Pathways to Assess Future Drought Risk in Yorkshire using the Latest UK Climate Change Projections

Grimwith in drought 1995
Credit: Stephen Craven (CC)

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Date of Issue:

01.03.18

Version:

1.0

Please cite this document as follows:

Rabb, B., Norman, J. and Dessai, S. (2018). Pathways to Assess Future Drought Risk in Yorkshire using the Latest UK Climate Change Projections. Yorkshire Integrated Catchment Solutions Programme, iCASP report.

iCASP is funded under NERC Grant: NE/P011160/1

Partners:

Contents

1 Introduction

The upcoming UK Climate Projections 2018 – UKCP18[1] will build upon the current set of projections (UKCP09) to provide the most up-to date assessment of how the climate of the UK may change over the 21st century. The aim of this short report is to explore how UKCP18 can be used in Yorkshire to better plan for drought and water scarcity in the region. Example pathways have been mapped to show how users will be able to interact with the forthcoming UKCP18 data products to access and create salient information relevant to their decision-making context and levels of expertise. One example pathway has been further developed into a practical 'step by step' guide to illustrate how UKCP18 can be used for drought planning and also be compared with previous findings from UKCP09.

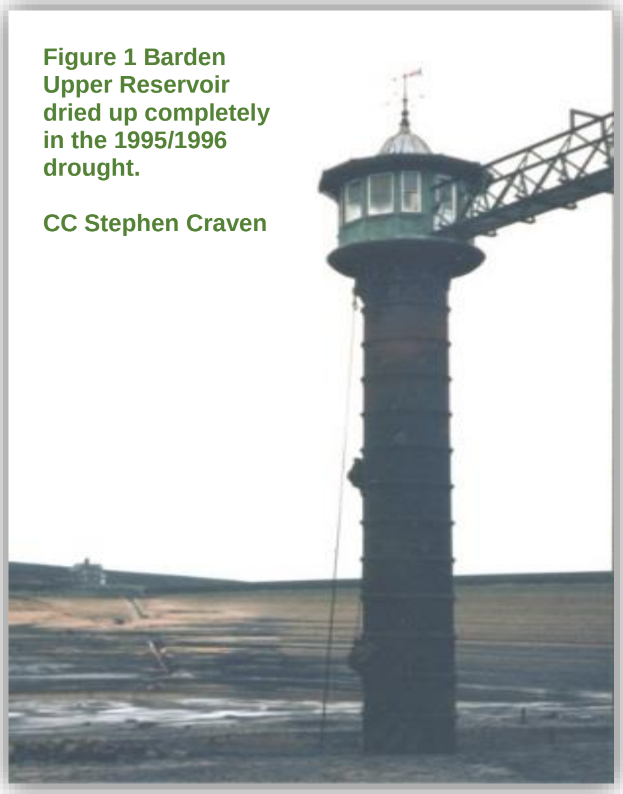

Figure 1 Barden Upper Reservoir dried up completely in the 1995/1996 drought.

CC Stephen Craven

Drought is a relatively infrequent hazard in Yorkshire but the consequences can be costly. The infamous drought of 1995/1996 (see Figure 1) lasted an unprecedented 20 months, led to Yorkshire Water having to use 700 lorries to transport water and resulted in considerable investment and improvements in water resource management in the region. Following the drought, a major transmission pipe was installed that could move water from the rivers Derwent and Ouse in the east into the water supply systems of West Yorkshire. The event was followed by improvements in computerised water resource modelling. Leakage targets were introduced, assumptions around headroom were challenged and a more robust and conservative approach to the risk of future water supply and drought preparedness was taken. The result has been that dry springs in 2010, 2011 and 2017 were managed successfully without significant impact or disruption.

The National Farmers' Union (NFU), Environment Agency (EA) and Yorkshire Water have all previously, in their own way, used climate information derived from UKCP09 to communicate and assess future risks of drought in the region. Broadly speaking, the EA develops water resource planning guidelines for Yorkshire Water, Yorkshire Water implements these and NFU makes use of higher level messages from third parties (including both the EA and Yorkshire Water amongst others). The following sections describe in more detail how these partners have (or have not) previously used climate projections with a view to laying the foundations of how they could make use of UKCP18 following its release.

[1] UK Met Office, Defra, BEIS, EA (2017). UK Climate Projections: A Project Overview: https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/uk-climate/uk-cp/ukcp18-project-overview-final.pdf [Accessed 20.12.17]

1.1 Yorkshire Water

UKCP09 has been used by Yorkshire Water for four significant assessments:

1. Duration Modelling: Impact of multi-year drought events on resources and assets (2012)
2. Company-wide Climate Change Risk Assessment (2013)
3. 25 year water resource management plan (2014)
4. Climate Change Adaptation report (2015)

Yorkshire Water has a statutory duty to publish 25 year water resource management plans (WRMPs) which "take a risk averse approach to managing public water supply, ensuring that there is always enough water to meet demand, including in years of drought" (Yorkshire Water, 2017). River, reservoir and groundwater resources are actively managed to meet the following Level of Service to customers:

- Introduction of temporary use bans: 1 in 25 years
- Drought permits/orders: 1 in 80
- Rota cuts/standpipe: 1 in >500 (note: this is an estimate of an exceptionally rare event)

The planning horizons of the WRMPs have dictated that climate change projections (most recently UKCP09) have made a fundamental contribution to these plans. The basis for how climate change is considered by Yorkshire Water (and other UK water companies) is guided by the EA's report, *Climate change approaches in water resources planning – overview of new methods (2013).*[2] The latest WRMP was released in 2014, in which consultants were commissioned by Yorkshire Water to use UKCP09 to calculate the effect of climate change on river flows and reservoir inflows in Yorkshire catchments.[3] In doing so, 20 representative realisations of modelled future climate were chosen from the pool of 10,000 in UKCP09 and were applied to a Water Resource Allocation Plan Simulation (WRAPSim) model to estimate deployable output between 2012 and 2040 (see Figure 2).[4] A similar approach is being considered for the next WRMP19, currently being prepared for release in 2019.

UKCP09 information has also been used by Yorkshire Water to conduct a company-wide Climate Change Risk Assessment (CCRA), which fed into their second adaptation report, published in 2015.[5] The CCRA was based in part on expert interpretation of summary statistics from UKCP09 e.g. the change in the number of periods of >20 days without precipitation, which was treated as an indicator of change in drought risk (see

[2] EA (2013). Climate Change Approaches in Water Resources Planning – Overview of New Methods. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291598/LIT_7764_ea1e43.pdf [Accessed 20.12.17]
[3] Yorkshire Water (2014). Water Resources Management Plan. https://www.yorkshirewater.com/sites/default/files/Water%20Resources%20Management%20Plan%20-%20Introduction%20and%20supply_0.pdf [Accessed 20.12.17]
[4] HR Wallingford (2012) UKCP09 Climate Change Scenarios in Water Resource Planning: Developing an approach for Yorkshire Water- Summary of Approach.
[5] Yorkshire Water (2015). Adapting to Changing Climate – Yorkshire Water's Adaptation Report. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/474358/climate-adrep-yorkshire-water.pdf [Accessed 20.12.17]

Table 1).[6] Risks were identified across the following areas:

1. Water quality
2. Water availability
3. Sewer flooding and pollution
4. Improving and protecting the environment
5. Customer service
6. Affordability

By the 2080s, flooding of assets, and changing land use affecting water quality were highlighted as the most significant risks. The risk of “demand exceeding supply” is rated high by the 2050s – a combination of both a reduction in the availability of resources coupled with increased demand from residents and visitors (as a result of population growth).

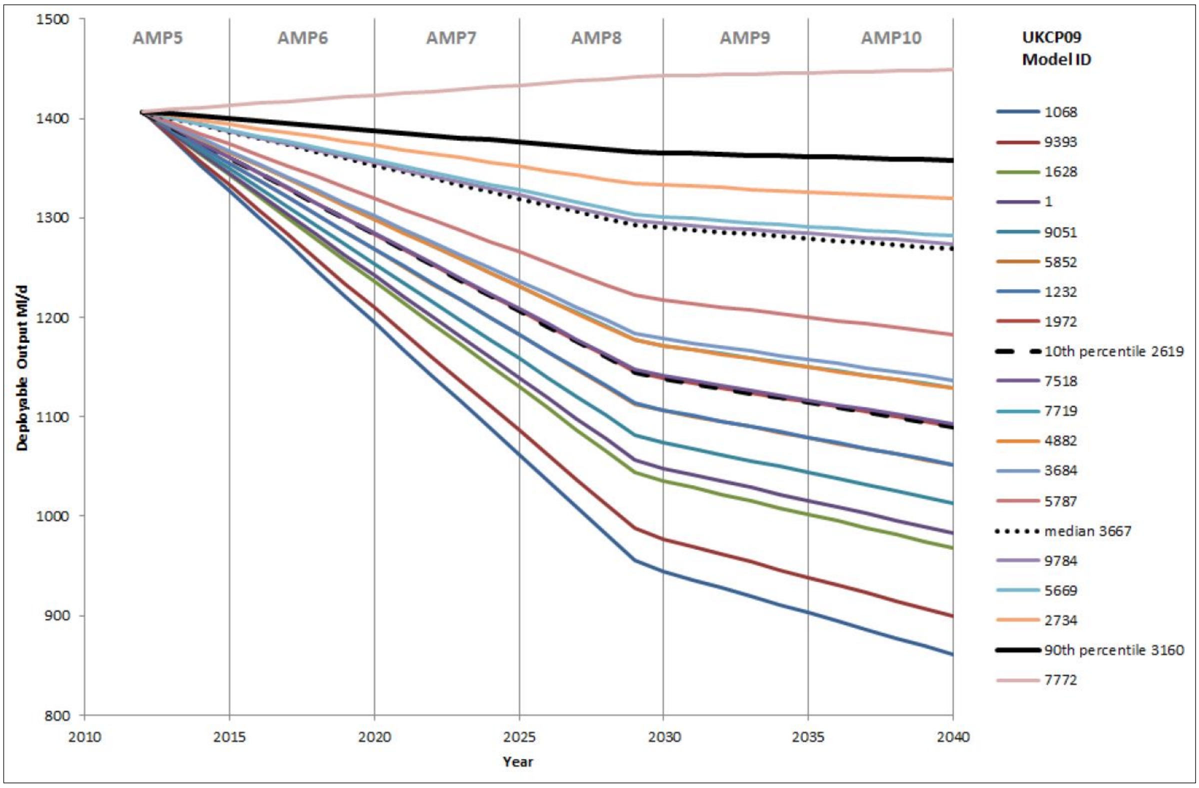

Figure 2 Projected deployable output for Yorkshire Water’s Grid Surface Water Zone (SWZ) between 2012 and 2040 – which accounts for over 99% of the supply area - across 20 UKCP09 projections (under a medium greenhouse gas emissions scenario – A1B).

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[6] Yorkshire Water (2015). Adapting to Changing Climate – Yorkshire Water’s Adaptation Report. Appendix. https://www.yorkshirewater.com/sites/default/files/downloads/YW%20Climate%20Change%20July%202012%20Appendix.pdf [Accessed 20.12.17]

Table 1 Example summary statistics for indicators used as the basis for the Yorkshire Water's CCRA (from UKCP09)

Parameter	Metric	Baseline (1961-1990 average)	Future decade	Medium emissions scenario 50%ile	High emissions scenario 90%ile (10% for cold)
Annual number of dry spells (5+ days with no precipitation)					
Leeds 5km grid square	Average number days	12	**2030s**	13	16
			2050s	15	19
			2080s	18	24
UK average	Average number days	11	**2030s**	12	15
			2050s	15	17
			2080s	16	21

Parameter	Metric	Baseline (1961-1990 average)	Future decade	Medium emissions scenario 50%ile	High emissions scenario 90%ile (10% for cold)
Annual number of 'heavy rain' days (Precipitation greater than 25mm per day)					
Leeds 5km grid square	Average number days	2	**2030s**	6	11
			2050s	7	15
			2080s	9	18
UK average	Average number days	3	**2030s**	8	13
			2050s	10	18
			2080s	10	20

Rare but potentially high impact multi-year droughts (such as 1995-96) have been the focus of a specific study by Yorkshire Water. In 2012, the company commissioned consultants to use UKCP09 data to see if the likelihood of such events might change under a changing climate.[7] The methodology provides an accessible example of how UKCP18 can be used to add to the information already gleaned from UKCP09. More detail of the original method can be seen in Box 1.

Box 1 Study into multi-year drought risk in Yorkshire using UKCP09

The 2012 Yorkshire Water commissioned study into multi-year drought applied a relatively simple hydrological drought index (DSI6 > 20%[8]) to observed precipitation records from a selection of rain gauge stations across Yorkshire.[9] A weather generator was used to supplement the observational record by providing an ensemble of 200 time series for the same baseline period at each location. Finally, UKCP09 change factors (10th and 50th percentiles) from Cumulative Distribution Functions (CDFs) of precipitation projections were applied to the baseline time series - resulting in drought duration / frequency plots for the current and future climates for the region (see Figure 3). A change factor is a term used to describe the difference in average precipitation conditions between current and future time periods.

[7] WRc and Yorkshire Water (2012). Duration Modelling - impact of multi-year drought events on resources and assets.
[8] DSI6 stands for Drought Severity Index 6 – where, if a monthly precipitation anomaly is below a 30 year average for 6 consecutive months a drought begins. It continues (and grows) until the month is wetter than the previous 6 months' average. A DSI of >20% means that the cumulative rainfall deficit is > 20% of the total rainfall that falls, on average, at that location.
[9] WRc and Yorkshire Water (2012). Duration Modelling - impact of multi-year drought events on resources and assets.

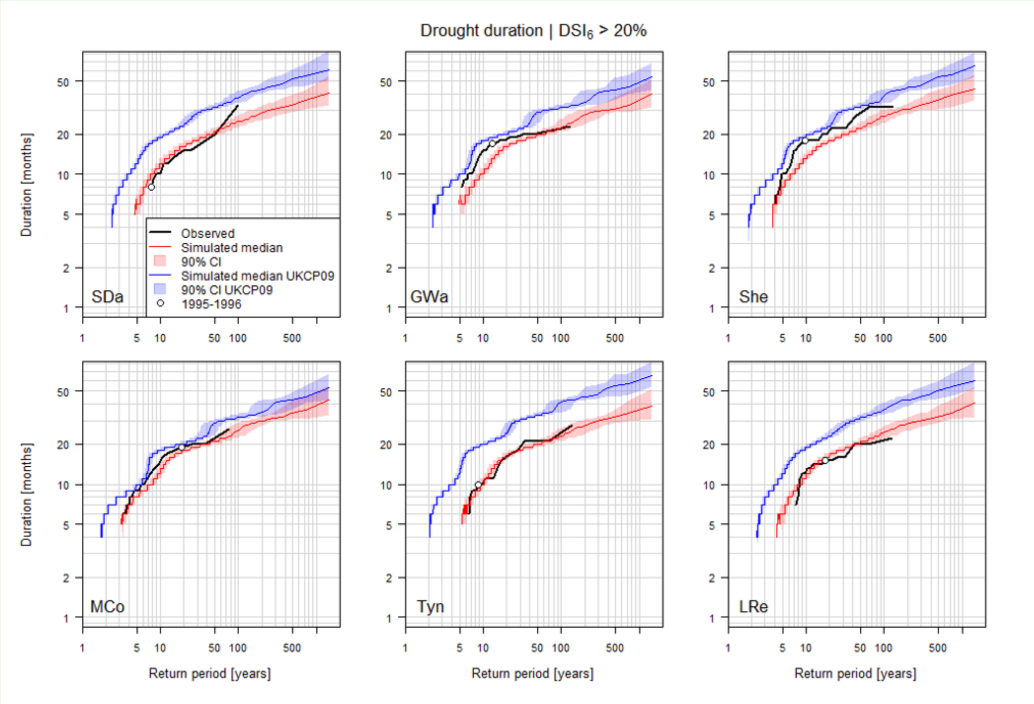
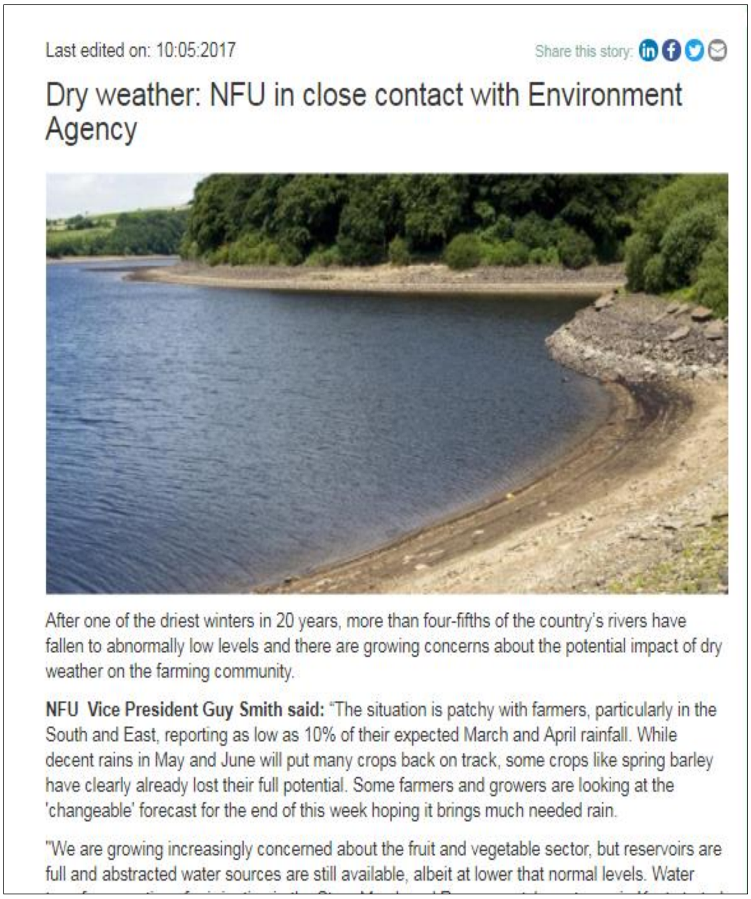


Figure 3 Comparison of drought return period under simulated current precipitation (red) and 10th percentile of projected precipitation, 2050s (blue) and observations (black line). The blue and red shaded areas represent the 5-95% rage of the model spread (i.e. confidence interval) around the median (blue and red lines). The relative duration/ frequency of the 1995-96 event is shown as a circle on each plot. Locations: South Dalton (SDa) in the southern Yorkshire Wolds, Great Walden (GWa) in the south-western region of the Yorkshire Pennines, Sheffield (She) in South Yorkshire to the lee of the Pennine chain, Moorland Cottage (MCo) in the north-western Yorkshire Dales to the west of Hawes, and Lockwood Beck Reservoir (LRe) in the North York Moors.

The study concludes that by applying the 10th percentile of precipitation projections there is an increased risk of drought by the 2050s. However, the study suggests that the persistence of 'blocking' anticyclonic weather conditions is relatively poorly modelled in UKCP09 (as is convective precipitation). These conditions are important in the UK as they govern the intensity and extent (or lack) of late spring and summer precipitation as well as the length of droughts in winter – both processes being of importance to Yorkshire's water resource availability. Box 2 describes how UKCP18 data can be used to supplement this method.

1.2 National Farmers' Union

Weather conditions and water availability are key concerns of farmers. The NFU works closely with the EA, water companies, the Department for Environment, Food & Rural Affairs (Defra) and the Met Office to report on current and seasonal ground conditions as well as providing advice on actions farmers can take to alleviate impacts. For example, the NFU has an incident response plan that includes 'prolonged adverse weather conditions' and which arose from involvement in the UK National Drought Group – convened by the EA in response to the 2010/12 drought.[10]



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Dry weather: NFU in close contact with Environment Agency

After one of the driest winters in 20 years, more than four-fifths of the country's rivers have fallen to abnormally low levels and there are growing concerns about the potential impact of dry weather on the farming community.

NFU Vice President Guy Smith said: "The situation is patchy with farmers, particularly in the South and East, reporting as low as 10% of their expected March and April rainfall. While decent rains in May and June will put many crops back on track, some crops like spring barley have clearly already lost their full potential. Some farmers and growers are looking at the 'changeable' forecast for the end of this week hoping it brings much needed rain.

"We are growing increasingly concerned about the fruit and vegetable sector, but reservoirs are full and abstracted water sources are still available, albeit at lower that normal levels. Water

Figure 2 NFU reporting on potential drought conditions and response during early 2017

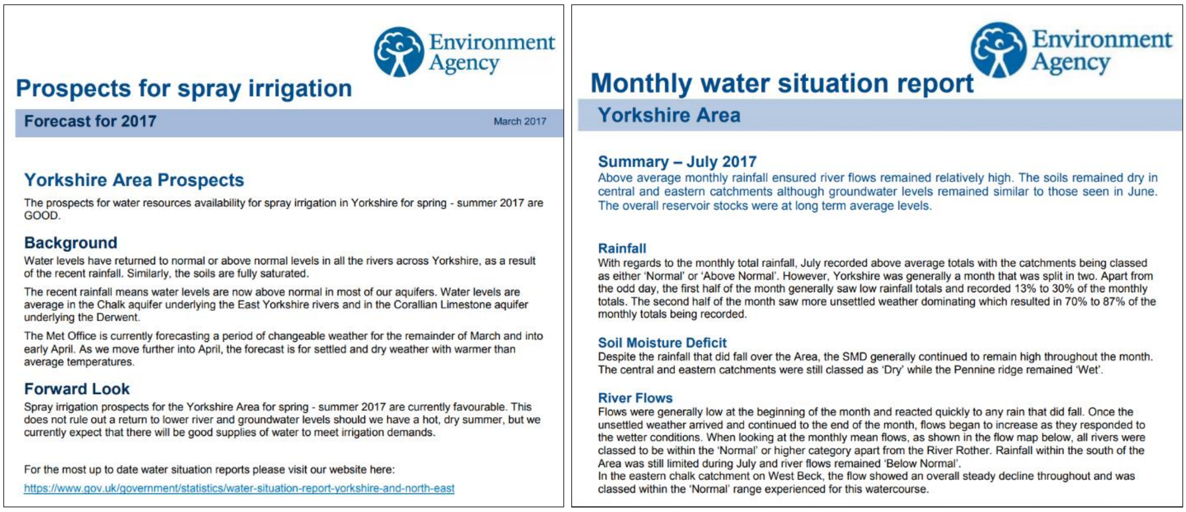
The NFU publishes information that can directly influence and 'speak to' farmers' decision making through their extensive online network (Figure 4). This information includes EA regional water situation (monthly) and prospects for spray irrigation (annual) reports. The water situation reports provide a detailed assessment of precipitation, groundwater levels, river flows, reservoir levels and soil moisture in the region. The prospects for spray irrigation reports are based on these assessments from the preceeding 12 months and include a section on 'ensuring your business is reslient to drought' Figure 5.

The NFU is mindful that climate change will continue to have an impact on British farming over the coming years and regularly reports on studies providing evidence of this.[11] However, as an industry, agriculture is fundamentally reactive, responding to relatively short term external drivers of which the weather is just one of many. It is unusual for farmers to ask for or make explicit decisions based on medium to long-term climate information. Farmers appear more interested in near-term forecasts of up to 2 years ahead. Exceptions exist where high value, long-term business decisions need to be made and projections are considered to be robust, e.g. planting vineyards or olive groves in the UK as a reulst of rising temperatures.

The use of information from UKCP09 by the NFU was limited to summary reports, headline messages and maps used to populate the NFU webpages and reports. UKCP18 is seen by the organisation as an evolution rather than a 'rewrite' of UKCP09. New details and forms of information provided in UKCP18 are unlikely to change the strategic approach or key messaging undertaken by the NFU. Any information on climate change impacts derived from UKCP09 (or elsewhere) invariably indicates that existing risks will be amplified or experienced sooner (albeit with varying degree of uncertainty), rather than the emergence of

[10] NFU (2016). How Prepared are we for the Next Drought? https://www.nfuonline.com/news/latest-news/how-prepared-are-we-for-the-next-drought/ [Accessed 20.12.17]
[11] NFU (2017). Climate Change. https://www.nfuonline.com/cross-sector/environment/climate-change/ [Accessed 20.12.17]

entirely new risks (this is the case with Yorkshire Water and others too). There is demand from farmers for guidance which relates to ‘climate change’ - however, this is not framed or referred to as ‘climate change’. Weather variability, water availability, risk and opportunity in the near term are the concepts that farmers deal with, respond to and seek guidance on.



Environment Agency

Prospects for spray irrigation

Forecast for 2017 — March 2017

Yorkshire Area Prospects

The prospects for water resources availability for spray irrigation in Yorkshire for spring - summer 2017 are GOOD.

Background

Water levels have returned to normal or above normal levels in all the rivers across Yorkshire, as a result of the recent rainfall. Similarly, the soils are fully saturated.

The recent rainfall means water levels are now above normal in most of our aquifers. Water levels are average in the Chalk aquifer underlying the East Yorkshire rivers and in the Corallian Limestone aquifer underlying the Derwent.

The Met Office is currently forecasting a period of changeable weather for the remainder of March and into early April. As we move further into April, the forecast is for settled and dry weather with warmer than average temperatures.

Forward Look

Spray irrigation prospects for the Yorkshire Area for spring - summer 2017 are currently favourable. This does not rule out a return to lower river and groundwater levels should we have a hot, dry summer, but we currently expect that there will be good supplies of water to meet irrigation demands.

For the most up to date water situation reports please visit our website here:
https://www.gov.uk/government/statistics/water-situation-report-yorkshire-and-north-east

Environment Agency

Monthly water situation report

Yorkshire Area

Summary – July 2017

Above average monthly rainfall ensured river flows remained relatively high. The soils remained dry in central and eastern catchments although groundwater levels remained similar to those seen in June. The overall reservoir stocks were at long term average levels.

Rainfall

With regards to the monthly total rainfall, July recorded above average totals with the catchments being classed as either ‘Normal’ or ‘Above Normal’. However, Yorkshire was generally a month that was split in two. Apart from the odd day, the first half of the month generally saw low rainfall totals and recorded 13% to 30% of the monthly totals. The second half of the month saw more unsettled weather dominating which resulted in 70% to 87% of the monthly totals being recorded.

Soil Moisture Deficit

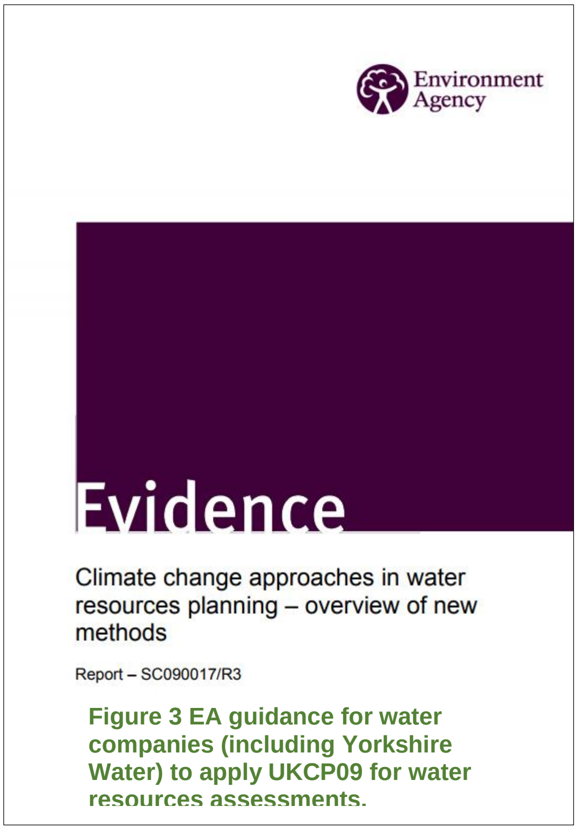
Despite the rainfall that did fall over the Area, the SMD generally continued to remain high throughout the month. The central and eastern catchments were still classed as ‘Dry’ while the Pennine ridge remained ‘Wet’.

River Flows

Flows were generally low at the beginning of the month and reacted quickly to any rain that did fall. Once the unsettled weather arrived and continued to the end of the month, flows began to increase as they responded to the wetter conditions. When looking at the monthly mean flows, as shown in the flow map below, all rivers were classed to be within the ‘Normal’ or higher category apart from the River Rother. Rainfall within the south of the Area was still limited during July and river flows remained ‘Below Normal’.
In the eastern chalk catchment on West Beck, the flow showed an overall steady decline throughout and was classed within the ‘Normal’ range experienced for this watercourse.

Figure 5 EA prospects for spray irrigation (left, 2017) and monthly water situation report (right, July 2017) for Yorkshire

1.3 Environment Agency



Environment Agency

Evidence

Climate change approaches in water resources planning – overview of new methods

Report – SC090017/R3

Figure 3 EA guidance for water companies (including Yorkshire Water) to apply UKCP09 for water resources assessments.

At the national level, the EA have been pivotal in the planning and production of UKCP18. At the regional scale, the EA plays a role in managing the environmental impact of drought in Yorkshire (e.g. re-locating stressed fish stocks during periods of low flow). The EA in Yorkshire is one of 14 regional level offices in England. The role of these offices is largely operational whilst policy planning and strategy is almost exclusively conducted at a national level e.g. issuing guidelines such as *Climate change approaches in water resources planning – overview of new methods (2013)* (Figure 6).[12] Conducting ad-hoc assessments beyond the scope of such guidelines is rare. However, it is likely that such guidelines and methods will be updated in light of the release of UKCP18 and there could be scope for case study applications in Yorkshire to inform this process. Capacity building of EA staff in the region will also help with understanding and applying the new climate information when available.

[12] EA (2013). Climate Change Approaches in Water Resources Planning – Overview of New Methods. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291598/LIT_7764_ea1e43.pdf [Accessed 20.12.17]

The EA could be a conduit for UKCP18 to reach stakeholders such as the NFU, Yorkshire Water and others. The organisation works closely with many partners to plan and manage drought in Yorkshire. For example, they issue regional water situation (monthly) and regional prospects for spray irrigation (annual) reports (Figure 5) which are both re-published by the NFU. UKCP18 information could be tailored to complement these operational reports (see example ‘type 2’ activity in Table 2).

Alongside Defra, the EA manages the region’s abstraction licences - the implications of UKCP18 could be that water abstraction policies are modified in the coming years, or funding will be made available for on-farm drought mitigation schemes e.g. reservoir construction.

2 Pathways for uptake of climate projections for drought risk management in Yorkshire

The ways Yorkshire Water, NFU and the EA may use UKCP18 to assess changing drought risk and make decisions over the coming years are likely to be wide-ranging. Table 2 summarises some ideas for initiatives all three could conduct, contribute to or monitor. They are divided by:

1. **Type 1 activities (short-medium term):** *Useful applications that could be conducted by the organisation soon after release, using the tools (e.g. the online data platform - ’Climate Explorer’) provided by UKCP18*
2. **Type 2 activities (medium term):** *Useful applications that experts (e.g. university academics and/or specialist consultants) could carry out on behalf of and under the direction of the organisation.*
3. **Type 3 activities (longer term):** *Useful applications that would require co-ordinated, longer term investment e.g. from research councils or central government.*

Table 2 Activities for uptake of UKCP18 for drought planning in Yorkshire.

Activity Type	Yorkshire Water	Environment Agency	NFU
1	Update multi-year drought assessment (using basic hydrological drought index) for Yorkshire **(*see below for more detail*)**	Liaise with Yorkshire Water and other early adopters to assess how water resources guidance may need to be modified and communicate possible implications more widely.	Liaise with Yorkshire Water and EA to understand if there is any 'high level' update in drought risk in Yorkshire and the implications (if any) for the farming community.
	Construct projections of potential evaporation (PET) in Yorkshire using basic temperature methods.	Liaise with national EA evidence group to compare their initial findings re drought and UKCP18	
	Develop draft methodology for applying UKCP18 in the Water Resource Allocation Plan Simulation (WRAPSim) model.		
2	Apply updated UKCP18 to the Water Resource Allocation Plan Simulation (WRAPSim) model.	Use Yorkshire Water's initial experience of using UKCP18 to inform the update of national guidance on applying projections for water utilities.	Commission studies to translate UKCP18 projections into useable information for farmers e.g.: - long-term "prospects for spray irrigation" - Long-term "water situation reports" - Yorkshire agriculture Climate Change Risk and Opportunities Assessment (CCROA) e.g. seasonal shifts in planting, harvesting and demand.
	Review CCRA using output from UKCP18 (particularly with reference to new high resolution information and extremes)		
3	Future flows 2.0 e.g. updates to UK-wide daily river flow and monthly groundwater levels time series projections (currently available from 1951 to 2098)		
	Online data portal for other derived variables (e.g. PET, soil moisture) via online interactive map		
	Drought risk maps in shapefile/ GIS format		
	Other regional impact/ risk maps e.g. for wildfire		

3 Updating Yorkshire Water's Multi-year drought assessment using UKCP18

Box 2 outlines the steps that would be needed to update the assessment briefly described in Box 1, with output from UKCP18. The following procedure could be used to estimate the return frequency of drought (both now and in the future) in Yorkshire.

Box 2 Example study into multi-year drought risk in Yorkshire using UKCP18

The following steps represent an example UKCP18 workflow to estimate the return frequency of meteorological drought (both now and in the future) for a single location in Yorkshire.

STEP 1: Navigate to the UKCP18 online Climate Explorer and select location (URL TBC).

STEP 2: Download baseline monthly (or daily and subsequently aggregate to monthly) precipitation totals for the location from the following UKCP18 products:

a. Observational record
b. Global models ~ 20 global HadGEM models and an additional ~ 10 CMIP5 models (*available from* 1900 – present day)
c. High resolution models ~ 15 models at 12km (*available from* 1981-present day)
d. High resolution models ~ 10 models at 2km (*available from* 1981- 2000)

This should be done for a consistent baseline time period e.g. 1981 -2000 (the 2km model output is likely to be restricted to this pre-defined 20 year baseline period)

For a single location this would result in a total of ~ 55 x 20 year time series of monthly precipitation values (plus one observational record). The data will be in a standard text format e.g. csv, which is easily imported in common analysis software such as Microsoft Excel.

STEP 3: The DSI6 index[13] should be calculated (e.g. in Microsoft Excel) for all selected (baseline) time series and observational record– resulting in an ensemble plot similar to that in Figure 7. Given the 20 year time period for the 2km High resolution model projections it may not be possible to reliably characterise events > 1:20 years.

[13] DSI6 stands for Drought Severity Index 6 – where, if a monthly precipitation anomaly is below a 30 year average for 6 consecutive months a drought begins. It continues (and grows) until the month is wetter than the previous 6 months' average.

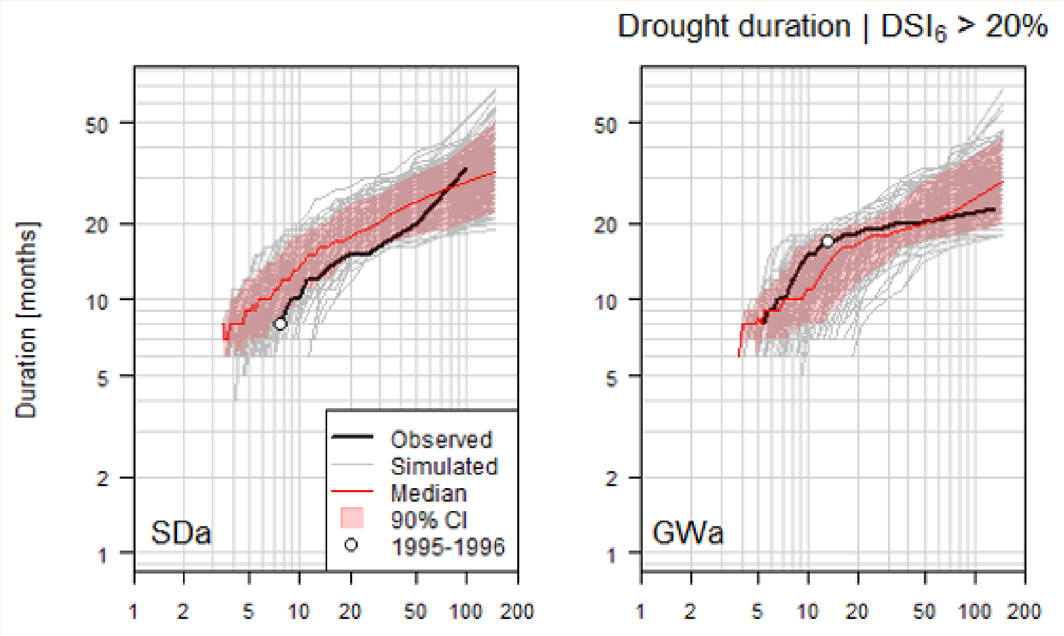


Figure 7 Drought return period under simulated current precipitation (in comparison to overserved records) at two locations in Yorkshire.[14]

STEP 4: Re-do step 2 (download data) but for a future time period e.g. 2021 – 2040 (2030s)
STEP 5: Re-do step 3 (calculate DSI6) but for a future time period e.g. 2021 – 2040 (2030s)

Only Representative Concentration Pathway (RCP) 8.5 will be available with the exception of the ~20 global Hadley Centre models, where an alternative 'lower' greenhouse gas emissions scenario will be available. The resulting (future projections) analysis will therefore include the following time series:

- ~ 20 (x2 RCPs) – Met Office model *(available from present day -2100)*
- ~ 10 (1 RCP) – CMIP5 *(available from present day - 2100)*
- ~ 15 (1 RCP) – 12 km model *(available from present day -2080)*
- ~ 10 (1 RCP) – 2km model (*available for 2021-2040, 2061-2080)*

OUTPUT:

This example is for a single location with the output resembling a plot similar to that in Figure 7.
If conducting this analysis for single locations, users should also look at surrounding points and comment on the degree of spatial coherence.
A spatial analysis e.g. for a (sub) catchment or region could be done by downloading the requisite netCDF / csv for that area (some regions and larger catchments will be pre-defined for data aggregation in UKCP18).

[14] WRc, 2012, Duration Modelling - impact of multi-year drought events on resources and asset

3.1 Sense checking UKCP18 output

The Met Office are undertaking a rigorous process of model development, selection and testing. Prudent users should also undertake their own Quality Assurance relevant to their particular context and use case. **It remains unclear how much the Met Office/ Defra will provide resources to support these 'sense checking' procedures**. It is likely that the onus will fall on the user community. This means the procedures described below could be the focus of Type 2 and Type 3 projects (See Table 2).

Sense-checking UKCP18 outputs will involve (at least) three steps:

1. ***Evaluate projections against observations*** – how well do the models recreate the observed climate?

No example maps, figures or charts demonstrating model performance currently exist, but these will likely form part of UKCP18 documentation. However, it is not clear at exactly what scale model evaluation will be carried out (possibly model grid-scale).

2. ***Bias correction*** – models may do an appropriate job of representing weather patterns and changes over time but 'absolute' levels of various parameters may be inaccurate. It is common for statistical 'corrections' to be applied to 'fix' these systematic biases.

Bias correction should be performed before post processing and derivation of other metrics – i.e. before calculating DSI6 in Box 2. The most appropriate bias correction methodology is context specific and the impact of using various methods on the end results should be assessed. If there is only interest in the change in the risk of drought, bias correction is less important.

3. ***Check model projections represent the "full range of future climate uncertainty" as sampled by PDFs -*** UKCP18 provides Probability Density Functions (PDFs) for 25 km grid cells across the UK and selected river basins. These show a 'range of known uncertainty' from models and emissions scenarios at each location.

PDFs are based on an up-to-date collection of Met Office climate simulations and the latest IPCC-assessed simulations to account for model uncertainties. They also incorporate the latest observations and estimates of carbon cycle feedbacks.

The modelled time series described in Box 2 should be within the spread of the PDFs. It is possible to plot summaries of these time series against PDFs to see how they perform. An individual modelled time series is represented by a blue dot in Figure 8. As well as checking that the models encompass the range of uncertainty, this step could enable the selection of a few 'marker scenarios' that represent a decision-maker's or organisation's attitude to risk. In the context of precipitation and drought, this check should be performed using seasonal PDFs.

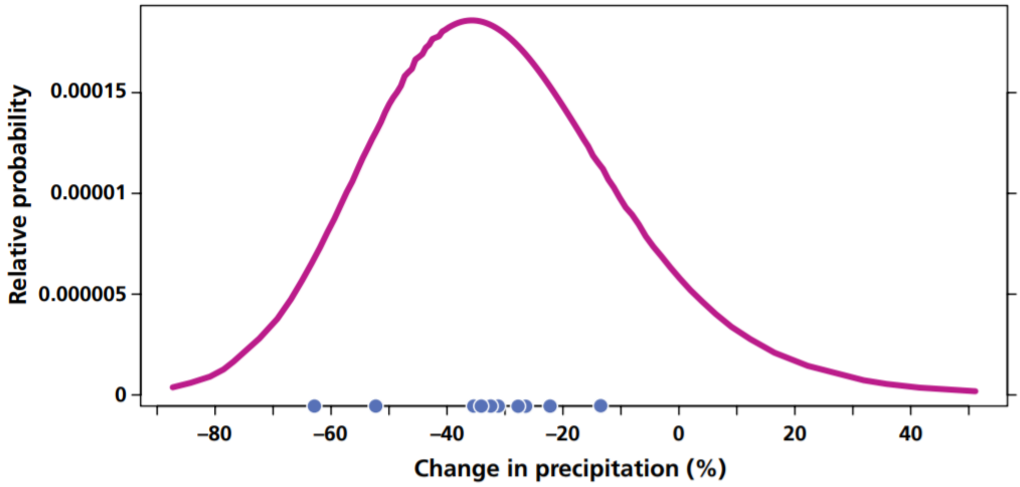


Figure 8 Checking GCM/ RCM time series summary model outputs (blue dots) against probability density function (red line). Adapted from UKCP09 briefing report [15]

3.2 Benefits of using UKCP18 projections in updated drought risk assessments

UKCP18 builds on the previous set of projections (UKCP09) and will represent the most up-to-date assessment of how the climate of the UK may change over the 21st century. Importantly, the products provide a large range of spatially (and temporally) coherent time series at fine temporal and spatial scale. In addition, new probabilistic projections will indicate the range of uncertainty in our knowledge of the climate system and natural variability through the 21st century, using PDFs to provide information on how climate varies from month to month. These PDFs provide an important context in which to assess the other UCKP18 products.

Previously, the 'weather generator' was used to bridge the gap between relatively few, coarse (spatially coherent) models and the finer scale information typically required by impact assessments. However, this approach was limited in its ability to account for spatial coherency in weather events (e.g. if it is raining in Leeds, it is relatively likely to be raining in Bradford too). This technique was reliant on maintaining observed, historic statistical relationships between weather variables into the future. 30 year 'change factors' applied to weather generator time series are likely to have missed the nuances in physical changes (for example that drive drought persistence) as they evolve in the region.

This time around, the user can directly access this fine-scale information without the need to conduct spatial and/or temporal downscaling – the UKCP18 GCMs and RCMs are likely to better represent physical changes in the UK climate e.g. the persistence of 'blocking' anticyclonic conditions which can lead to drought.

Global and local, finer scale weather and climate processes that influence long-term drought conditions in the UK can be accounted for by looking at both the global GCM and high-resolution RCM projections in UKCP18. The methodology outlined in Section 3 aims to reproduce a previous analysis using UKCP09 – therefore allowing direct comparison of the results. Table 2 also shows how this initial assessment could be taken further in conjunction with other organisations e.g. in the computation of derived indices such as PET.

[15] Jenkins, G. J., Murphy, J. M., Sexton, D. M. H., Lowe, J. A., Jones, P. and Kilsby,C. G. (2009). UK Climate Projections: Briefing report. Met Office Hadley Centre, Exeter, UK. http://www.ukcip.org.uk/wordpress/wp-content/PDFs/UKCP09_Briefing.pdf [Accessed 20.12.17]

The availability of a 'lower' greenhouse gas emissions scenario in the Hadley Centre global model projections should help capture some of the range of plausible climate scenarios that account for different socio-economic pathways. However, care should be taken if assessments are made using other products (e.g. 2km model) beyond 2040, when RCP forcing has an increasingly divergent influence. Additional steps in Section 3.1 will help ensure model outputs are checked against the 'full range" of RCP uncertainty as these pdfs include information from RCPs 2.6, 4.5, 6.0 and 8.5 (in addition to SRES A1B).

4 Summary and conclusions

Climate change projections based on atmospheric models continue to inform risk and opportunity assessments in Yorkshire and the UK. Advances in climate science have motivated the development of a new set of national climate projections due for public release in 2018. The projections, referred to as UKCP18, will update the UKCP09 projections over UK land areas, giving greater regional detail and provide more information on potential climate extremes. Importantly, several novel features of UKCP18 could provide insights on certain aspects of climate risk which were unfeasible with UKCP09 projections. This brief has outlined how the forthcoming UKCP18 products could be used to quantify the risk of drought in Yorkshire. In doing so, it has highlighted some of the key technical and practical implications for a variety of users in the region.

Although climate models are constantly being improved, they are not designed to predict future climate conditions with a degree of confidence allowing precise adaptation decisions to be made. Outputs from climate models often differ (as shown by the UKCP18 PDFs), presenting users with a range of possible climate futures to consider. Given these uncertainties, the focus should often be on identifying and implementing adaptation actions which perform well both under current and a range of possible future climatic conditions. [16] Climate information like UKCP18 can be used to establish upper and lower bounds for testing the effectiveness of adaptation options under an uncertain future climate.

5 Acknowledgments

This brief report is part of a project funded under the Yorkshire Integrated Catchment Solutions Programme (iCASP). The project involved a group of six iCASP stakeholders, representing local government, major infrastructure owners and technical specialists. With thanks to:

- Amanda Crossfield, Lead Advisor for Climate Change Adaptation, Yorkshire Water
- Gail Hammond, Project Manager, Environment Programme, Environment Agency
- Robert Curtis, Sustainable Energy & Climate Change Team, Leeds City Council
- Dr Robert Lamb, Chief Scientist at JBA Group and Director of the JBA Trust
- Dr Tim Thom, Northern Regional Manager, Yorkshire Wildlife Trust
- James Copeland, Land Use Adviser, National Farmers' Union

The project also benefitted from the expertise offered by the following colleagues at the UK Met Office and University of Leeds:

- Jason Lowe, Chair of the Priestly International Centre for Climate & Met Office

[16] Wilby, R. L. and Dessai, S. (2010). Robust adaptation to climate change. Weather, 65(7), pp. 180-185. http://onlinelibrary.wiley.com/doi/10.1002/wea.543/full [Accessed 20.12.17]

- Piers Forster, Professor of Physical Climate Change and Director of the Priestley International Centre for Climate, School of Earth and Environment, University of Leeds
- Amanda Maycock, NERC Independent Research Fellow and Associate Professor in Climate Dynamics, Institute for Climate and Atmospheric Science (ICAS), University of Leeds
- Mark Trigg, Academic Fellow, Department of Civil Engineering, University of Leeds