Climate Change Impact on Surface and Groundwater Resources: Example from: The UK

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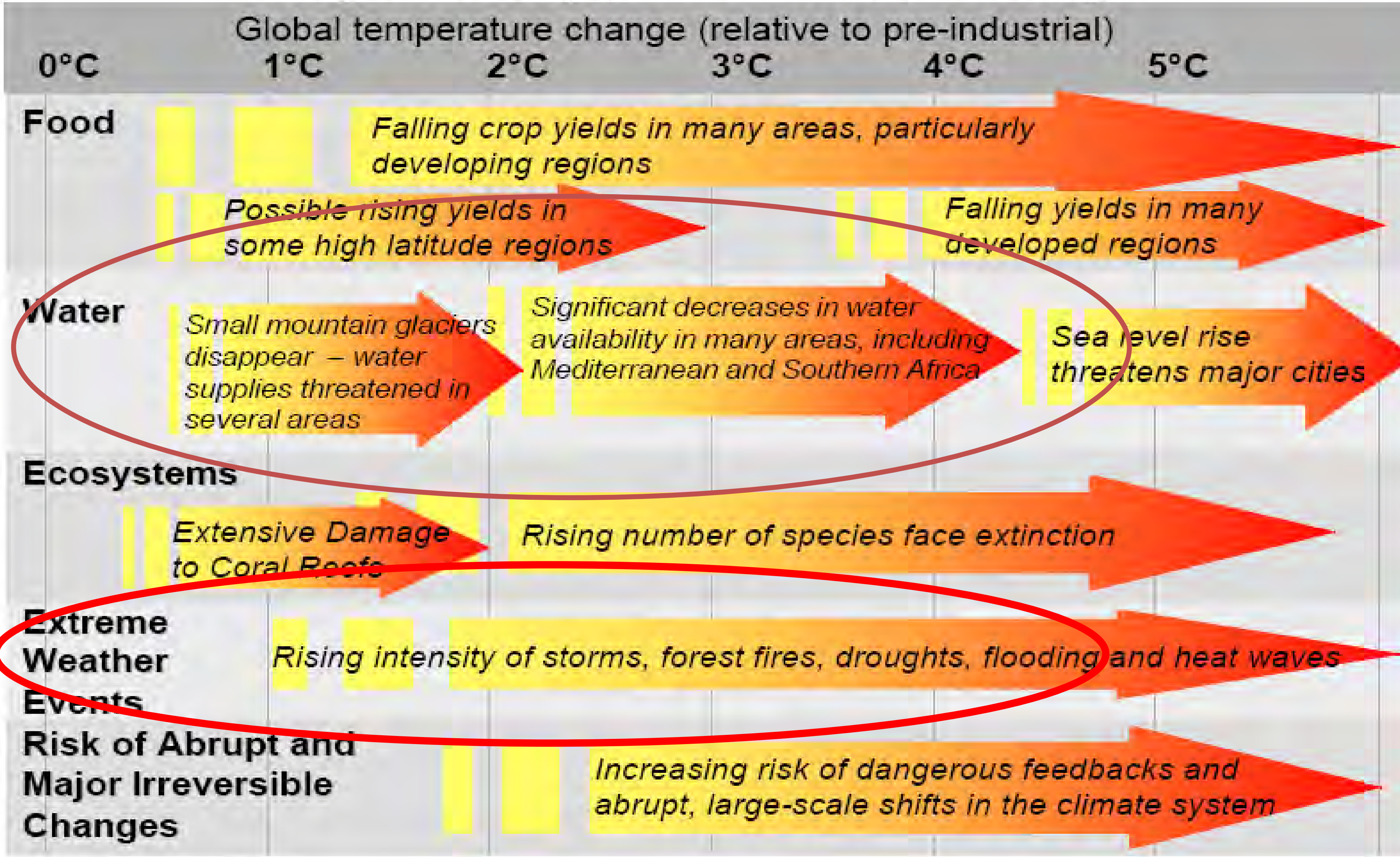
UK Centre for Ecology & Hydrology

ICID•CIID

Projected Impacts of Climate Change



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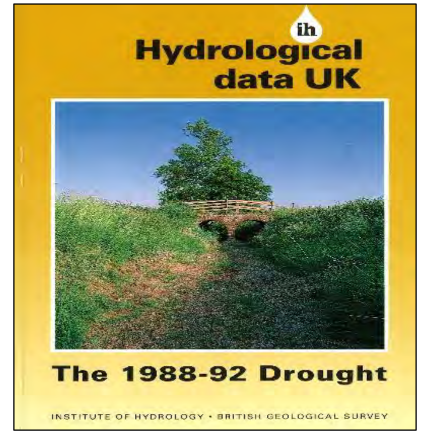
Stern Review (2006)

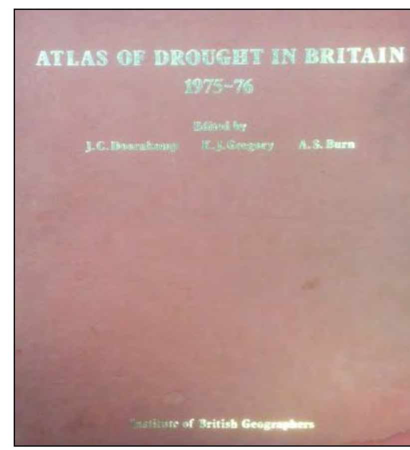
Historic droughts in the UK

Major Water Resources Droughts
in E & W

(Marsh et al. 2007)

- 2018
- 2010 - 12
- 2003 – 6
- 1995-97
- 1990-92
- 1975-76
- 1959
- 1933-34
- 1921
- 1890-1909
- 1887-88
- 1854-60
- 1798-1808





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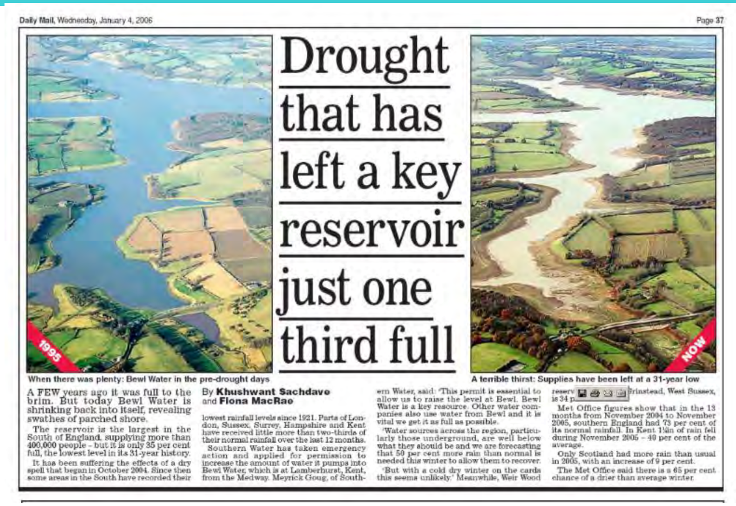
THE 2006 DROUGHT


Daily Mail, Wednesday, January 4, 2006 Page 37

Drought that has left a key reservoir just one third full

When there was plenty: Bewl Water in the pre-drought days

A terrible thirst: Supplies have been left at a 31-year low

By **Khushwant Sachdave** and **Fiona MacRae**

A FEW years ago it was full to the brim. But today Bewl Water is shrinking back into itself, revealing swathes of parched shore.

The reservoir is the largest in the South of England, supplying more than 400,000 people – but it is only 35 per cent full, the lowest level in its 31-year history.

It has been suffering the effects of a dry spell that began in October 2004. Since then some areas in the South have recorded their lowest rainfall levels since 1921. Parts of London, Sussex, Surrey, Hampshire and Kent have received little more than two-thirds of their normal rainfall over the last 12 months.

Southern Water has taken emergency action and applied for permission to increase the amount of water it pumps into Bewl Water, which is at Lamberhurst, Kent, from the Medway. Meyrick Goug, of Southern Water, said: 'This permit is essential to allow us to raise the level at Bewl. Bewl Water is a key resource. Other water companies also use water from Bewl and it is vital we get it as full as possible.

'Water sources across the region, particularly those underground, are well below what they should be and we are forecasting that 50 per cent more rain than normal is needed this winter to allow them to recover.

'But with a cold dry winter on the cards this seems unlikely.' Meanwhile, Weir Wood reserv[...] Forest Row, near East Grinstead, West Sussex, is 34 p[...]

Met Office figures show that in the 13 months from November 2004 to November 2005, southern England had 73 per cent of its normal rainfall. In Kent 1¼in of rain fell during November 2005 – 40 per cent of the average.

Only Scotland had more rain than usual in 2005, with an increase of 9 per cent.

The Met Office said there is a 65 per cent chance of a drier than average winter.

Daily Mail 04-01-2006


DAILY EXPRESS

The World's Greatest Newspaper

BRITAIN DEFIANT

WEDNESDAY JANUARY 4, 2006 40p

Unbelievable: Now we face a drought

HIGH AND DRY: This man should be 12ft under water, but because of the lack of rain this huge reservoir contains only a third of what it should do at this time of year

SNOW AND SUB-ZERO TEMPERATURES ARE ON THE WAY AGAIN BUT WHAT WE NEED IS RAIN PAGE SEVEN

Daily Express 04-01-2006


Daily Express Wednesday January 4 2006 7

CRISIS: Bewl Bridge reservoir full in 1995.Right, water manager Meyrick Gough, who also appears in our Page One picture, shows how dry it is today

Snow is coming, but pray for rain

By **John Ingham**
Environment Editor

WINTER is set to sweep back across Britain with a vengeance tomorrow, but what is really needed is rain to end the worst drought in 85 years.

The Met Office predicts plunging temperatures and snow flurries in the South and East, with snow and ice from Siberia.

[...] pointing to to a cold winter in the UK – warm seas off Iceland, cold off the US eastern seaboard and in the Caribbean, and warm off west Africa. The Met Office has stood by the forecast ever since.

And yesterday a spokesman said: "The NAO forecast predicted that there would be a lack of westerly winds across Europe generally and Britain in particular, with cold temperatures instead coming from the east.

"This is what happened in December and and what we are moving to again.

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Drought Project - NERC Grant

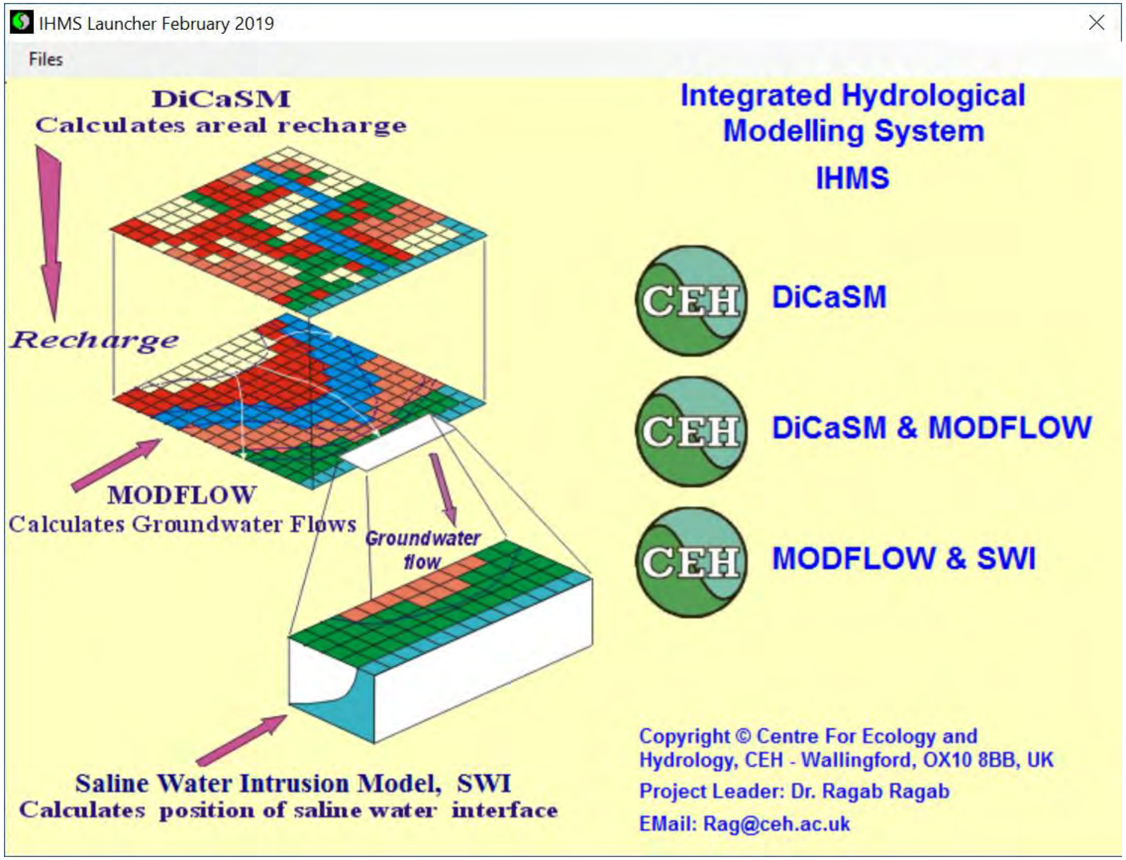

Table 1. Average annual rainfall (1961-90) in the case study catchments

South - North		West –East	
Fowey	1436 mm	Fowey	1436 mm
Ebbw	1456 mm	Frome	792 mm
Don	1009 mm	Pang	695 mm
Eden	799 mm	Bevills Leam	630 mm

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Acknowledgement

This Research was funded by the UK Natural Environment Research Council, NERC

Grant reference NE/L010292/1 and carried out by the CEH Modelling Team of the DRY Project.

Project leader and contact person: Dr Ragab Ragab, UKCEH, E mail: rag@ceh.ac.uk

& ragab@icid.org

Stakeholder Group

- Group involved to date as partners in the project include:
- Canal and River Trust
- Chartered Institution of Building
- Climate Outreach and Information Network
- Emergency Planning Society
- Environment Agency
- Federation of Small Businesses (Regional Office of S&E Yorkshire)
- Natural England
- Natural Resources Wales
- Public Health England
- Scottish Environmental Protection Agency (SEPA)
- Scottish Natural Heritage
- Scottish Water
- The Eden Project
- The Wildlife Trust BCN/ Great Fen Project
- UK Water Industry Research
- Farmers Union
- Allotment society

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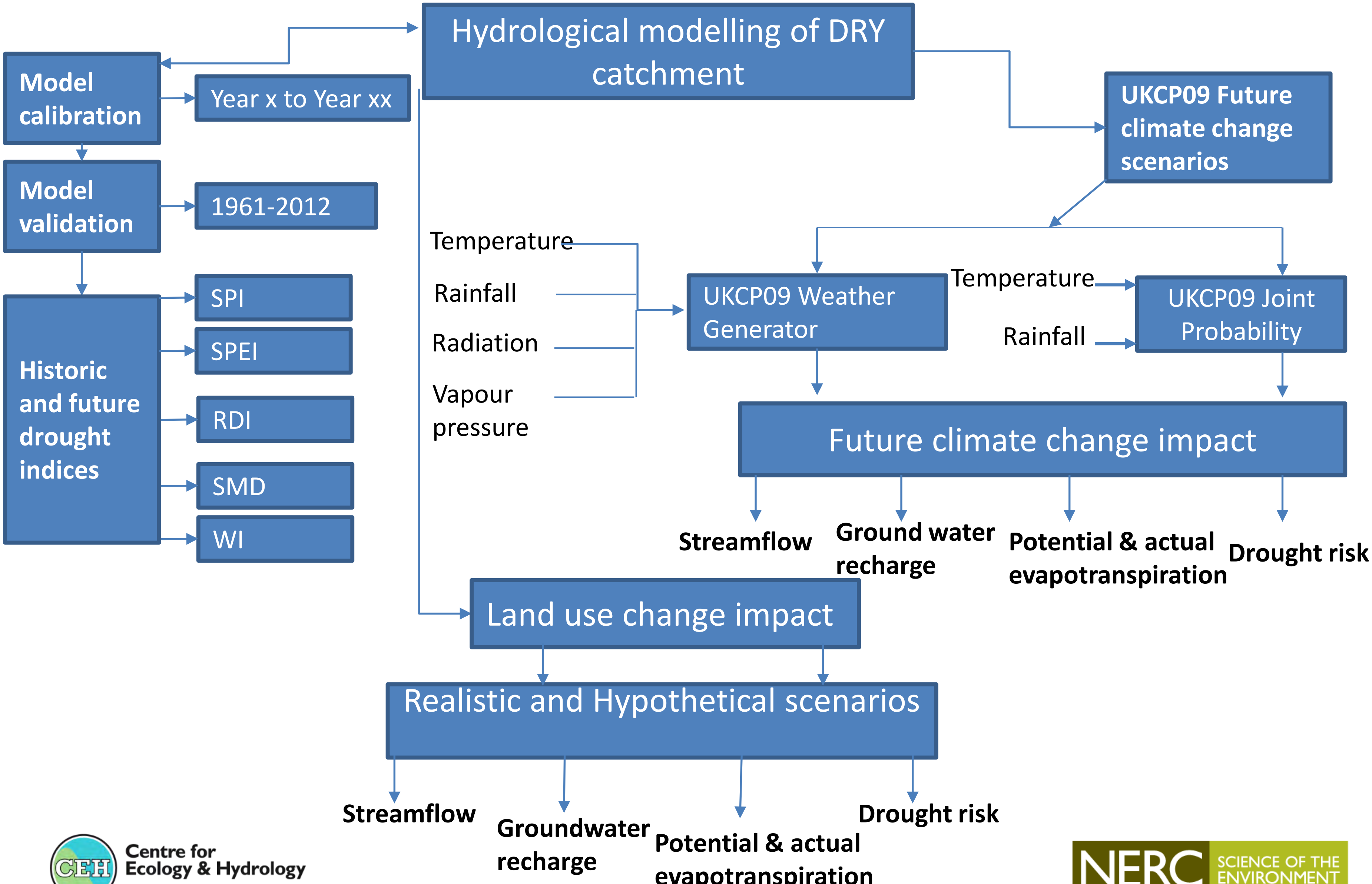
Modelling of the DRY project catchments



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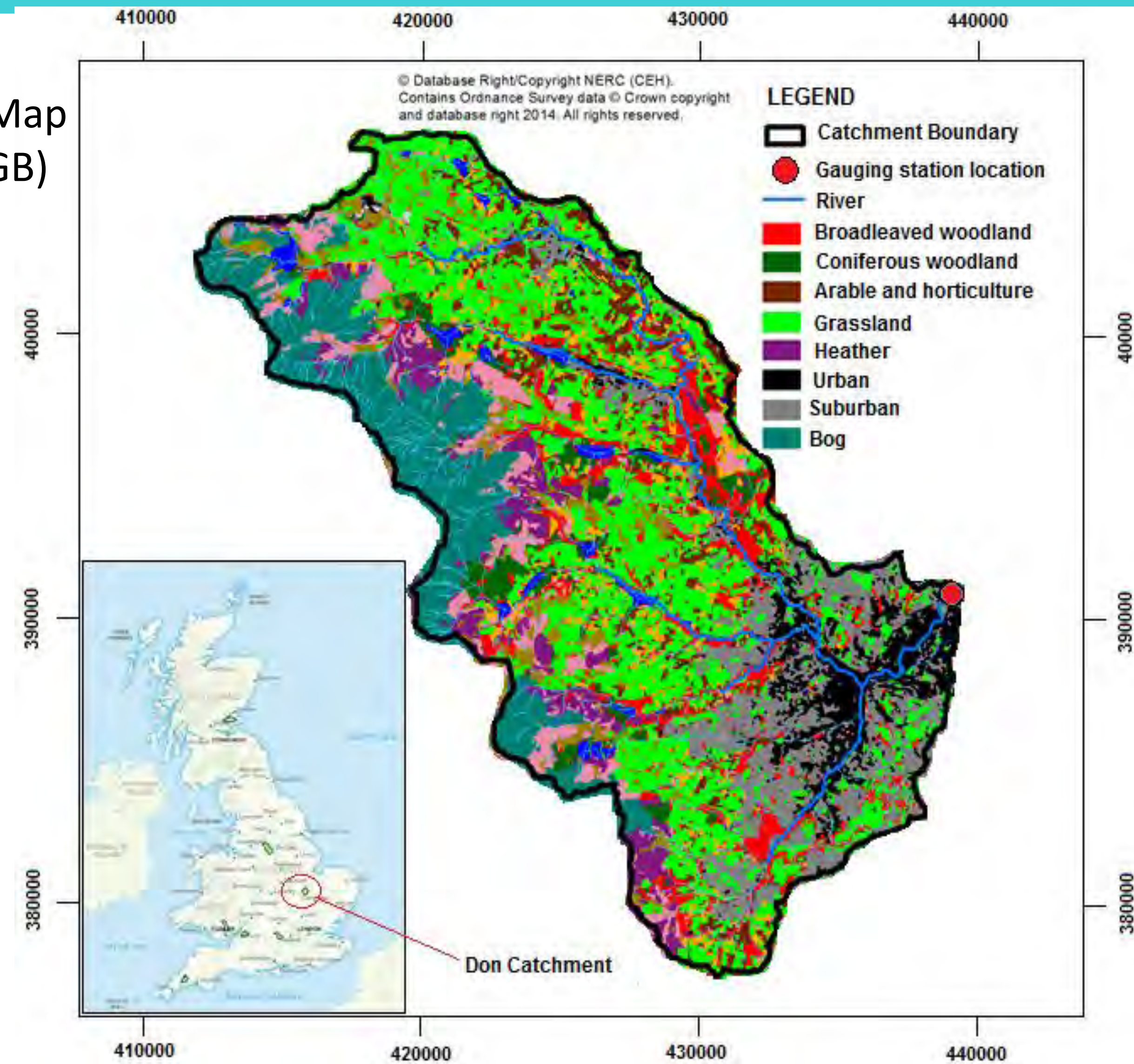
DiCaSM Model data requirement

- Rainfall & climate data (Distributed or lumped)
- Land cover % for each grid square
- Soil Series % for each grid square
- Elevation (DTM) for each grid square
- Land cover properties (e.g. plant height, LAI, canopy conductance, sowing-harvest dates)
- Soil Series Properties
- Data on abstraction, irrigation, wastewater discharge to river, water bodies, etc.

Don catchment main land use

(Land Cover Map 25 m raster, GB)



catchment area 373 km²

23 reservoirs

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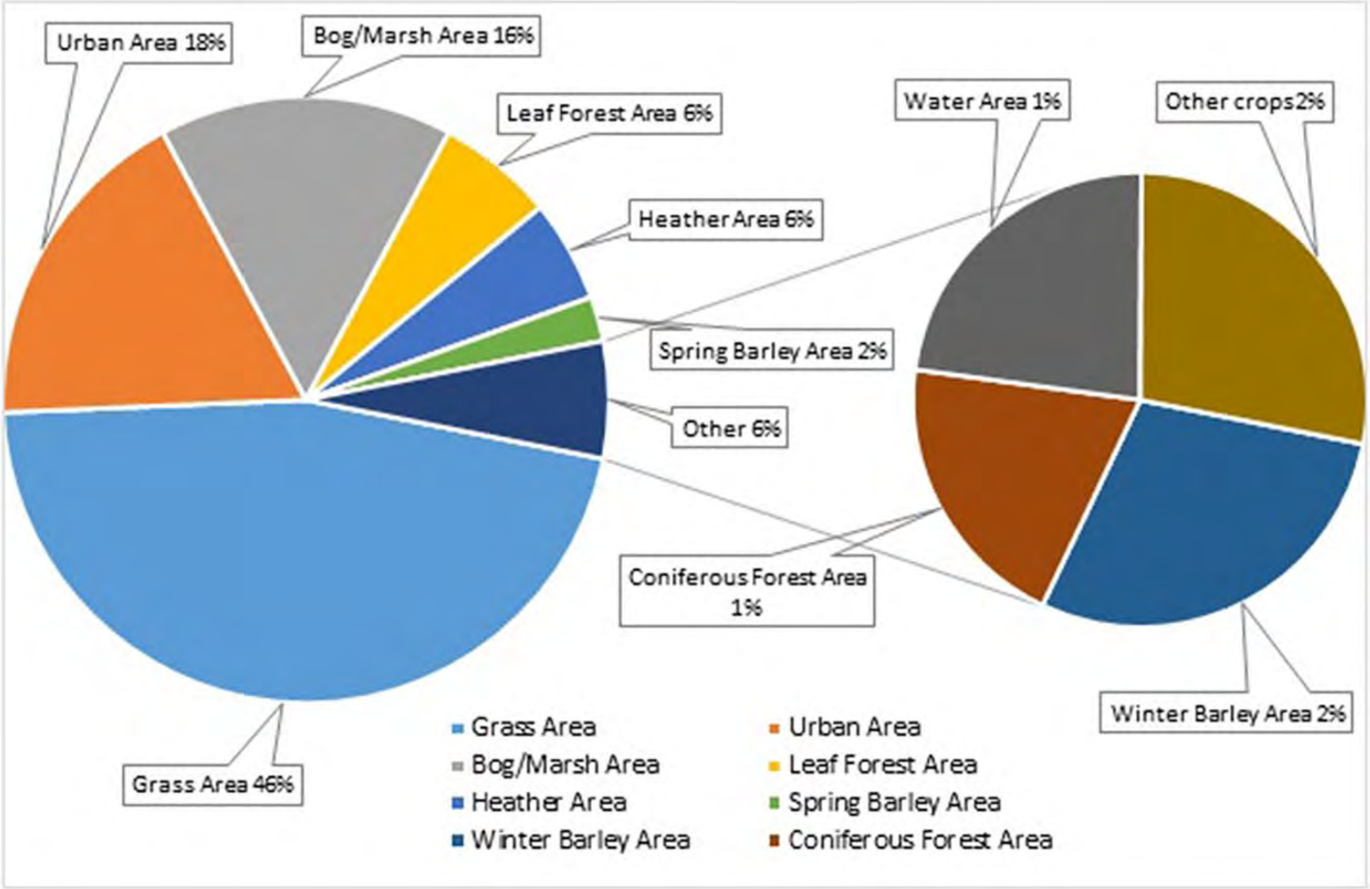
Don Land Use



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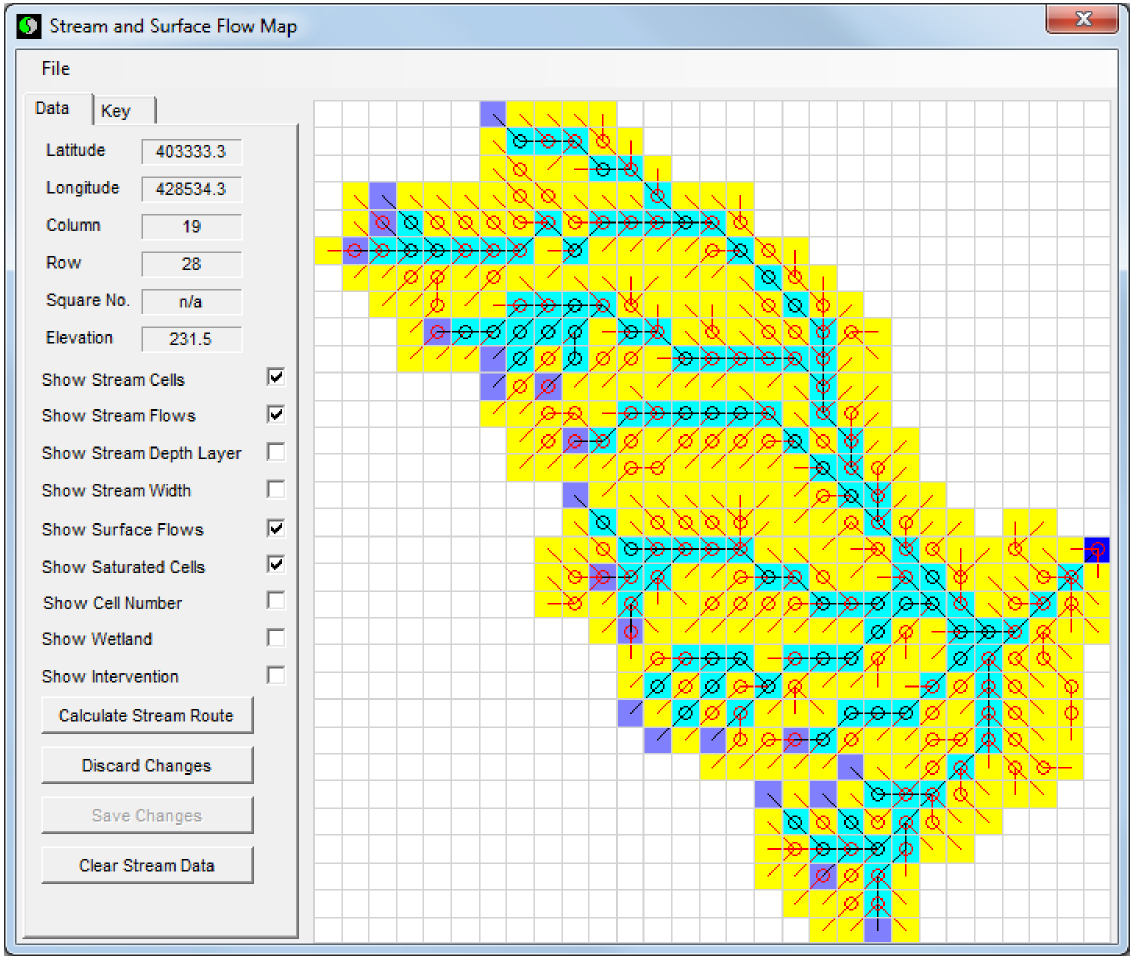
Modelling the Don catchment

Model grid square size is optional, default is 1km by 1km grid square.

Daily time step.

435 grid squares



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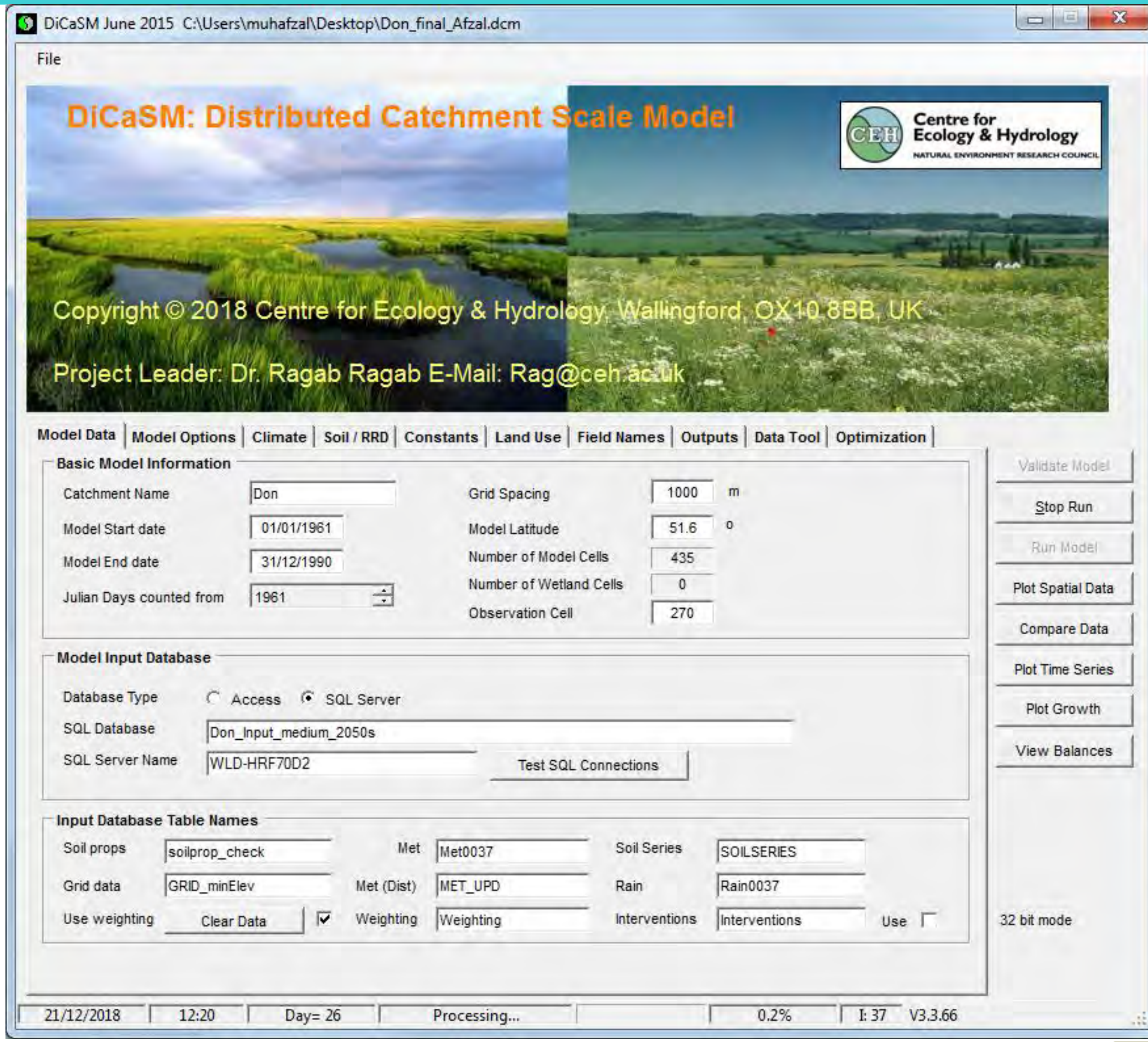
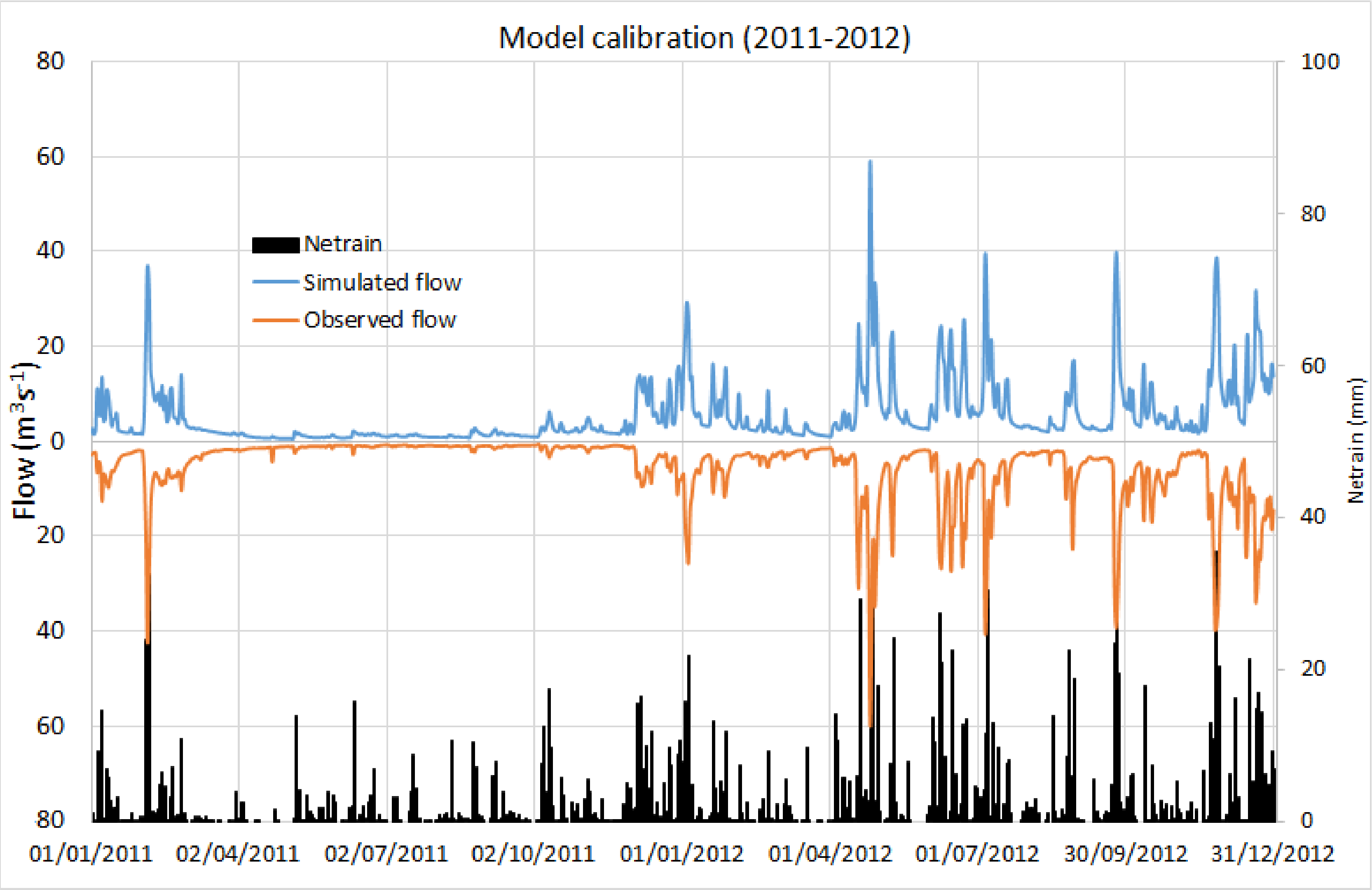
Modelling the Don catchment



Don catchment calibration: stream flow



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Nash-Sutcliffe Efficiency (*NSE = 91.5%)*

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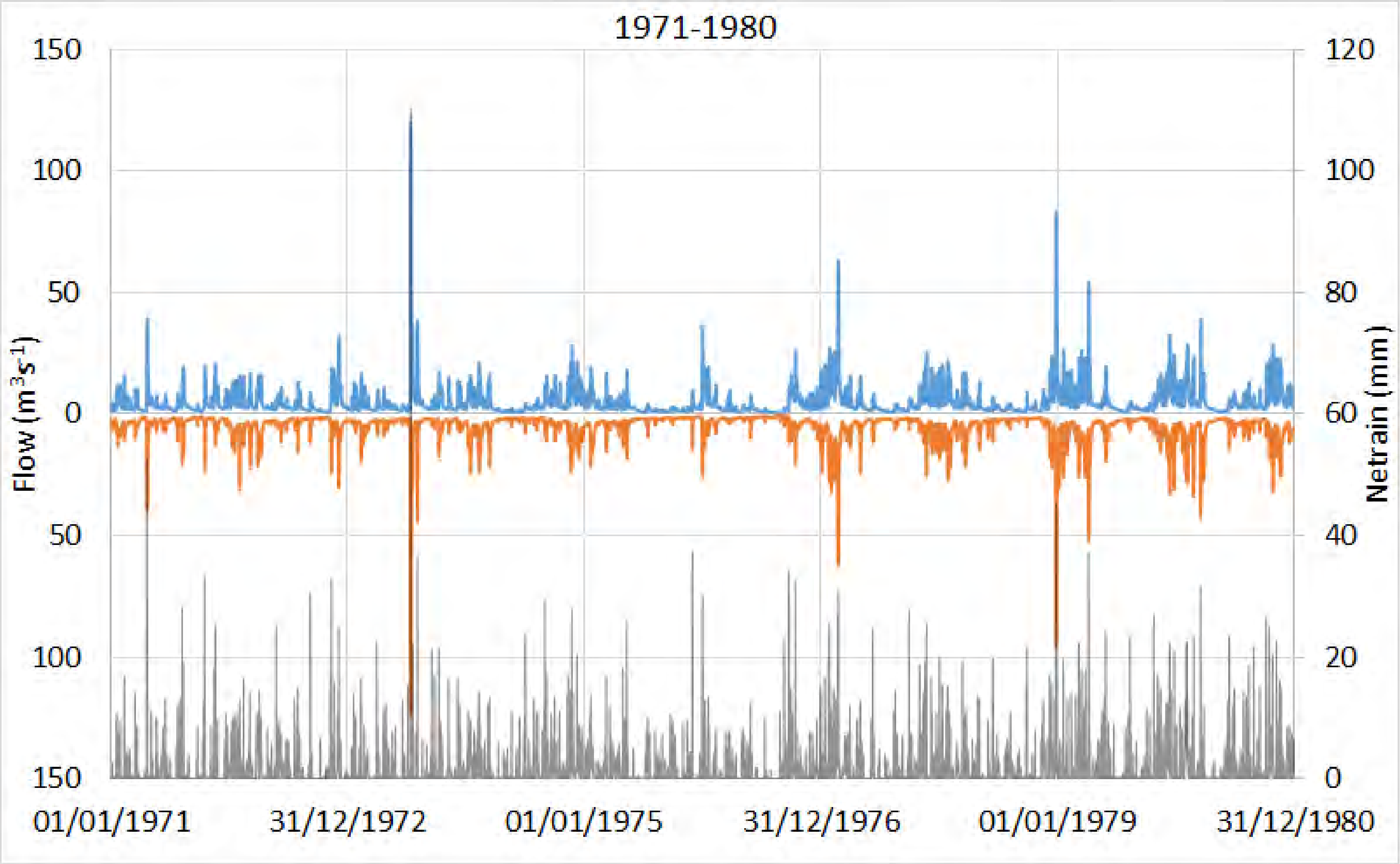
Don validation (1971-1980): stream flow



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Nash-Sutcliffe Efficiency (*NSE*=82.2%)

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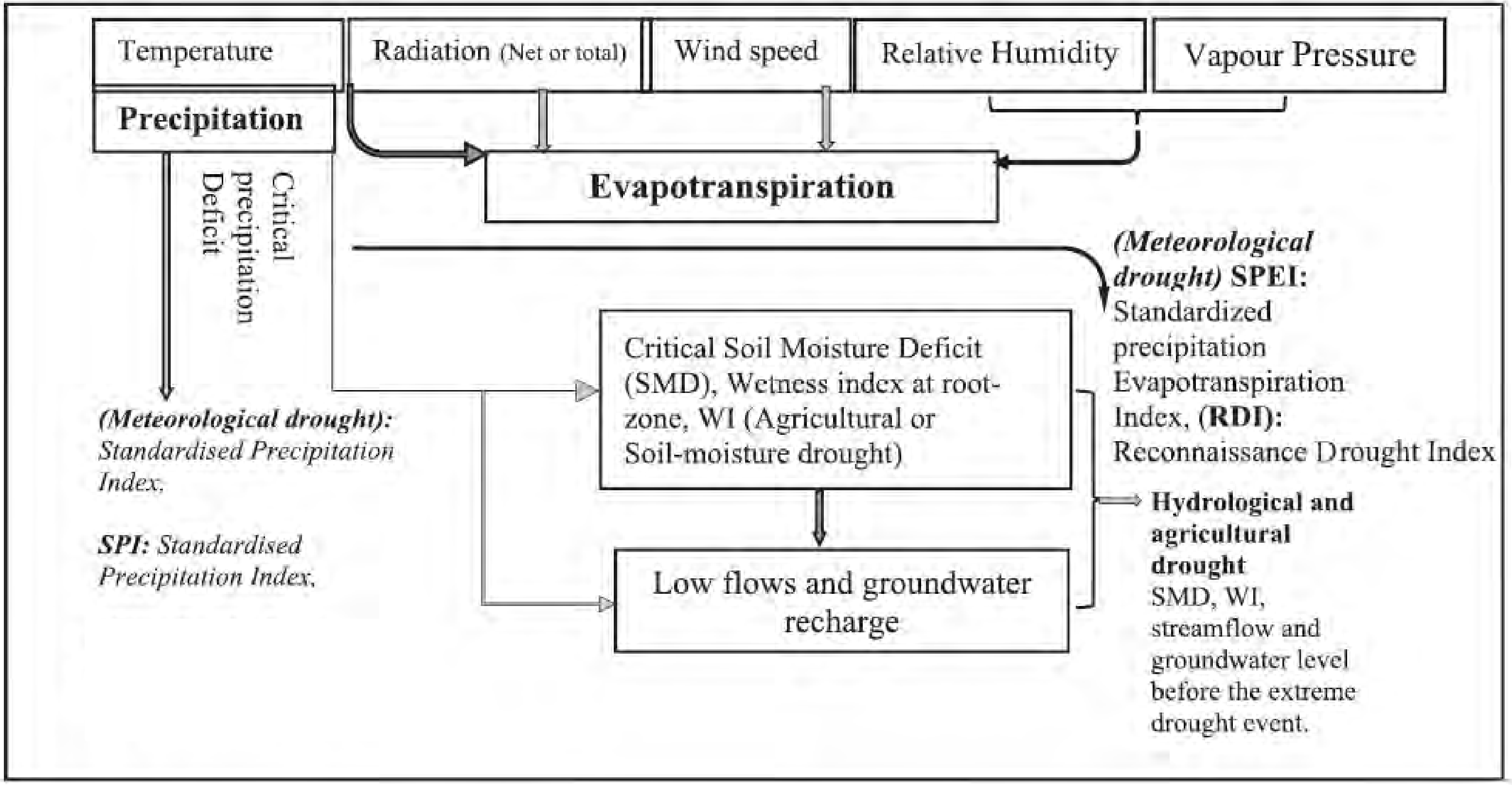
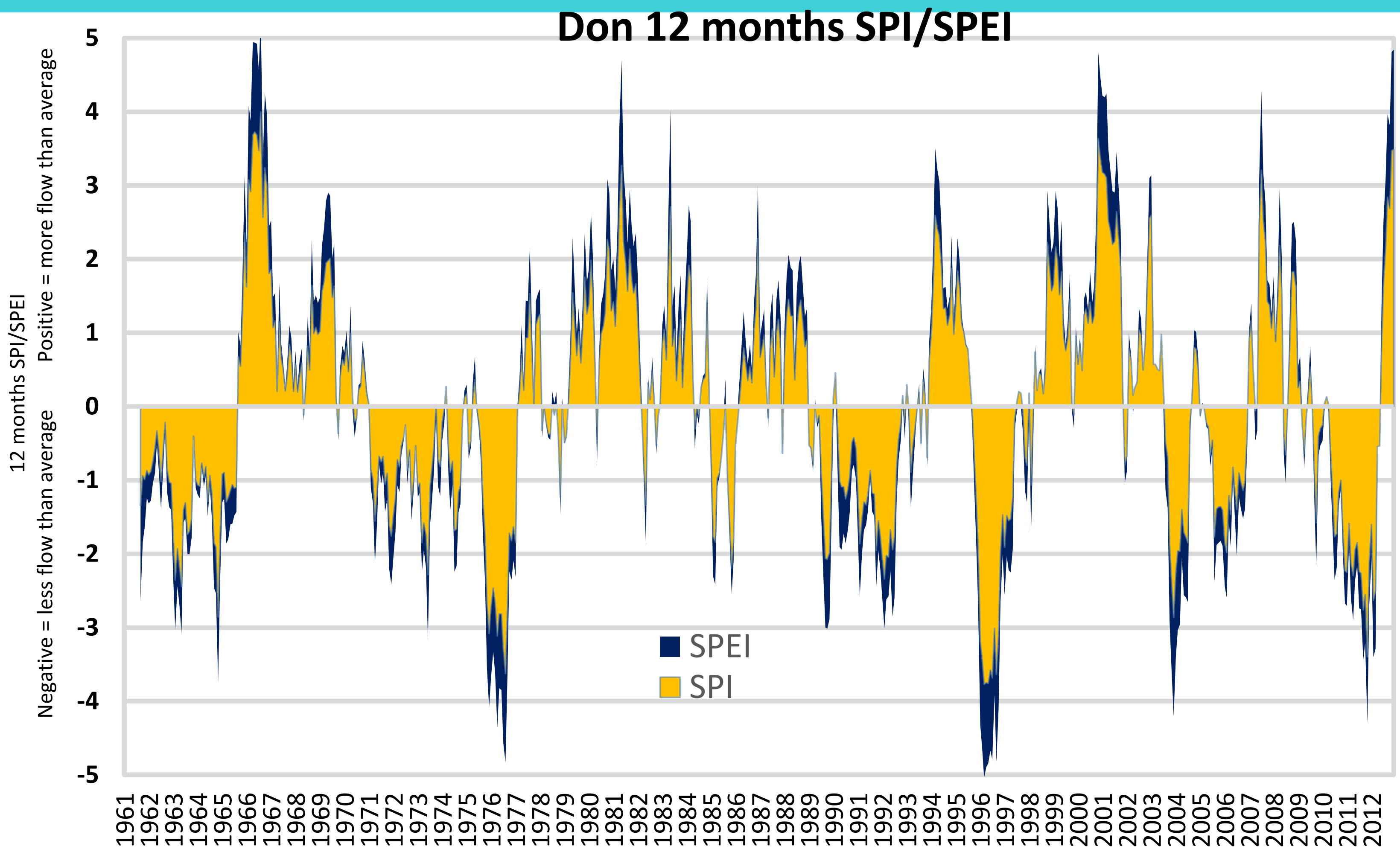
The Drought Indices



Key drought drivers of meteorological, agricultural and hydrological droughts

Drought in Don catchment: Standardized Precipitation Index, SPI



The SPI represents the deviation of precipitation from the long-term average. The SPI index represents the deviation of precipitation from the long term average; negative values indicate below average 'dry periods' and positive values indicate above average precipitation, 'wet periods'. SPEI=P -PET

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The reconnaissance Drought Index (RDI)

The above drought index was adapted from (Tsakiris et al. 2007) following these equations:

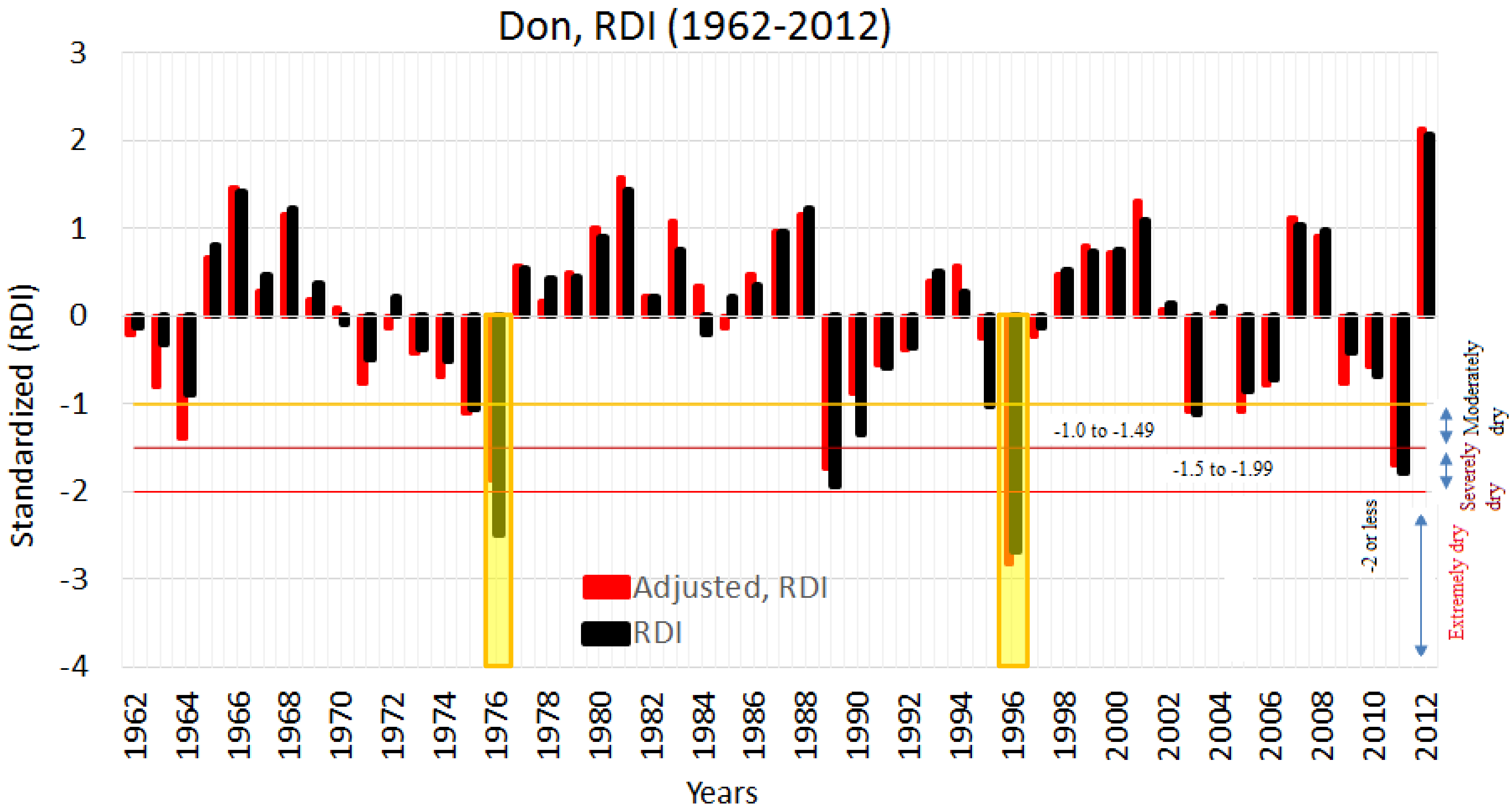
$$a_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad (1)$$

$$RDI_n^i = \frac{a_0^{(i)}}{\overline{a_0}} - 1 \quad (2)$$

$$RDI_{st\ (k)}^i = \frac{y_k^{(i)} - \overline{y_k}}{\hat{\sigma}} \quad (3)$$

Tsakiris et al 2007, Water Resources Management 21: 821-833, Regional Drought Assessment Based on the Reconnaissance Drought Index

Don: Reconnaissance Drought Index RDI



Standard RDI is the ratio of sum of rainfall to sum of potential evapotranspiration.
Adjusted RDI is the ratio of sum of Net rainfall to the sum of actual evapotranspiration

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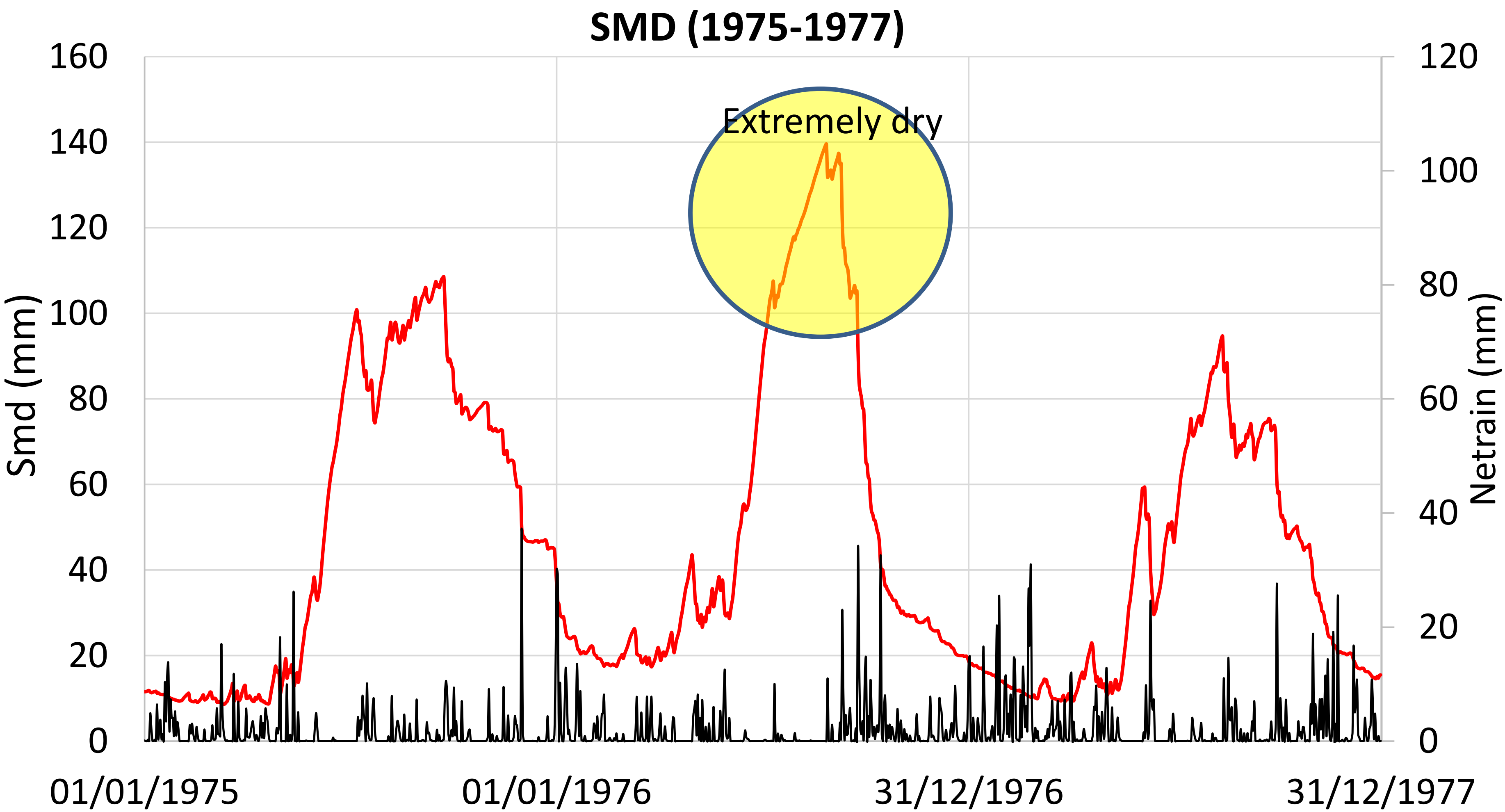
Don: Soil moisture deficit, SMD (1975-1977)



SMD is the difference between current soil moisture and the maximum water holding capacity of the soil known as “Field Capacity”.

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The WI reduces the spatial variability between different locations (network of Neutron probes or model grid squares. On a certain day WI can be calculated as:

$$WI = \frac{\sum \ [(SMz) - (SMz)\min]}{\sum \ [(SMz)\max - (SMz)\min]}$$

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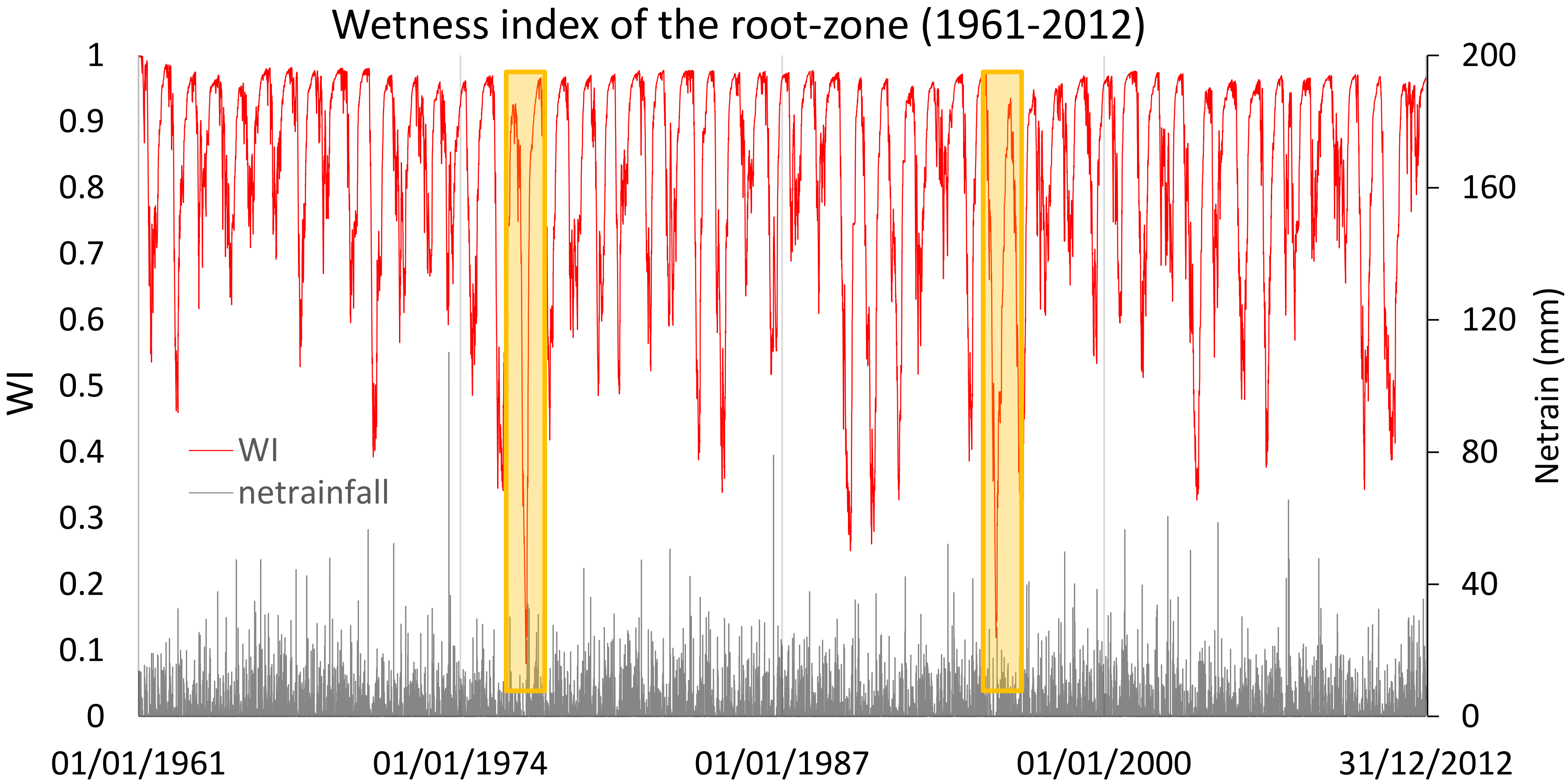
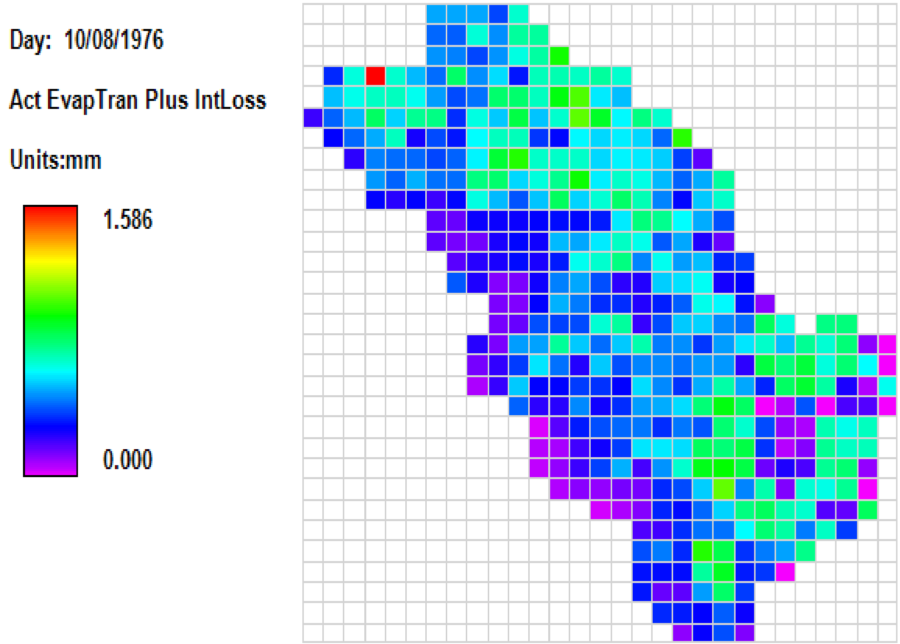
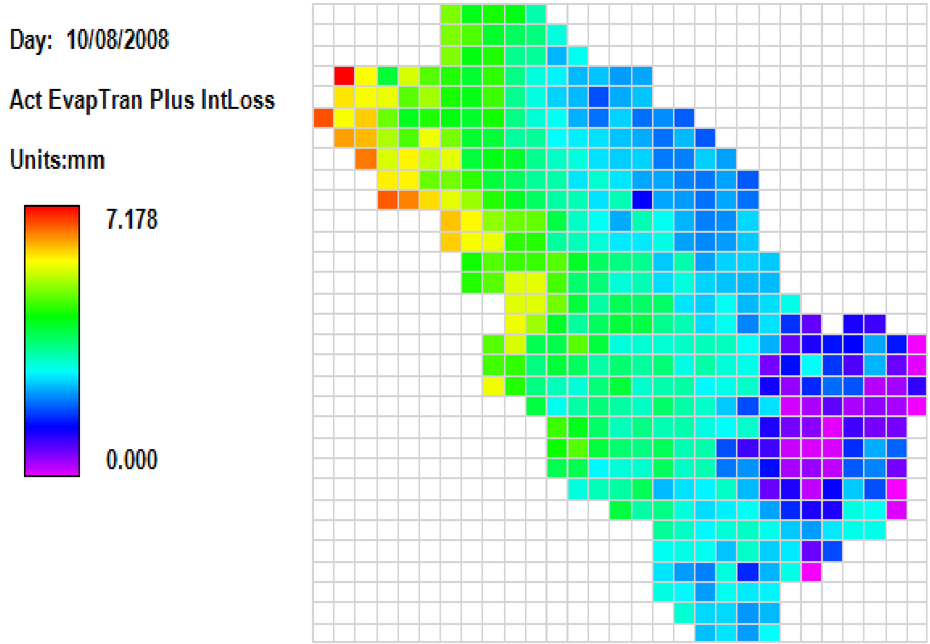
Don: Wetness index of the root-zone, WI



WI is the scaled soil moisture: 1 means, soil water content at maximum value, 0: means the soil water content at its minimum value. The WI accounts for the spatial variability of soil types, elevation , vegetation cover, etc. across the catchment.

Actual Evapotranspiration – Don dry vs average year





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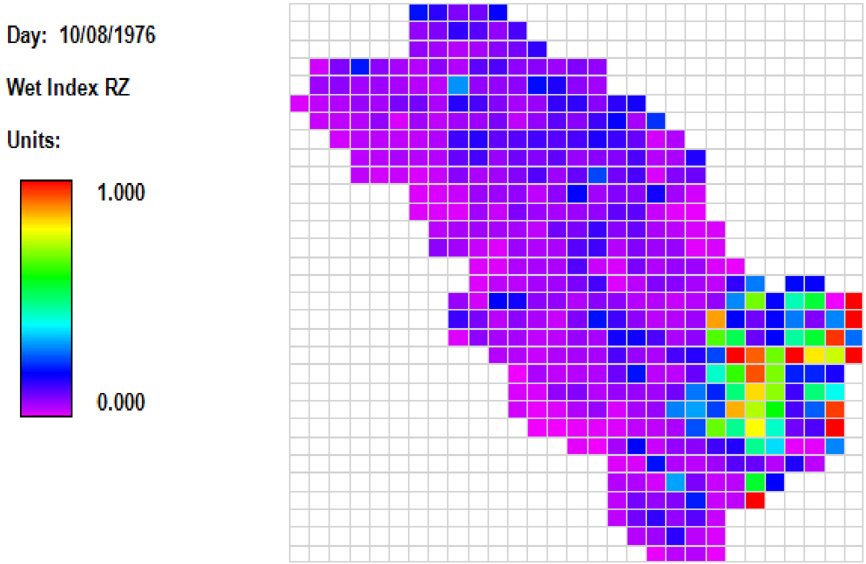
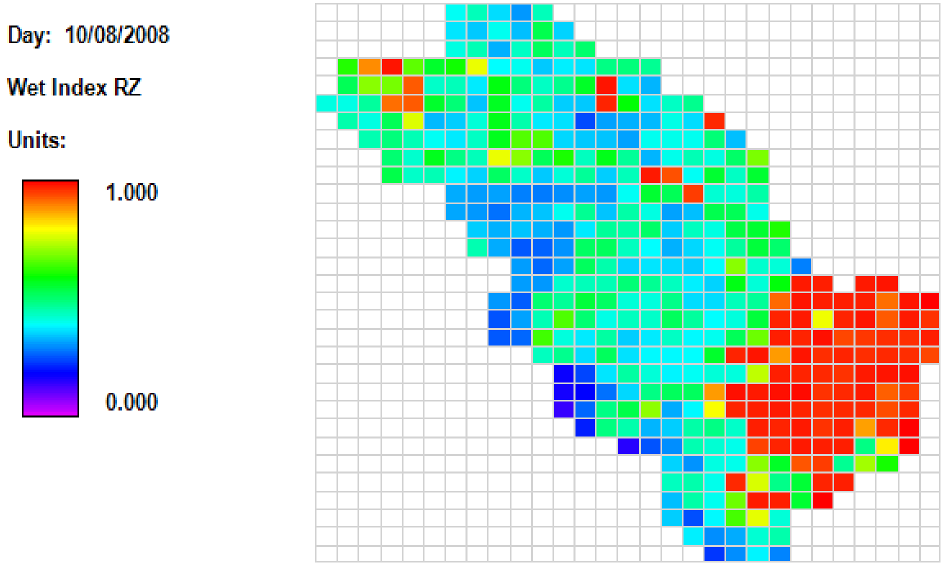
Wetness Index – Don. Dry vs Average year





CLIMATE CHANGE SCENARIOS

- Joint Probability plot: provides % change in future precipitation and ± change in temperature. Seasonal and Monthly changes.

- Weather Generator: Provides daily prediction of precipitation, temperature, sunshine hours and relative humidity.

Scenarios Modelling

Climate change

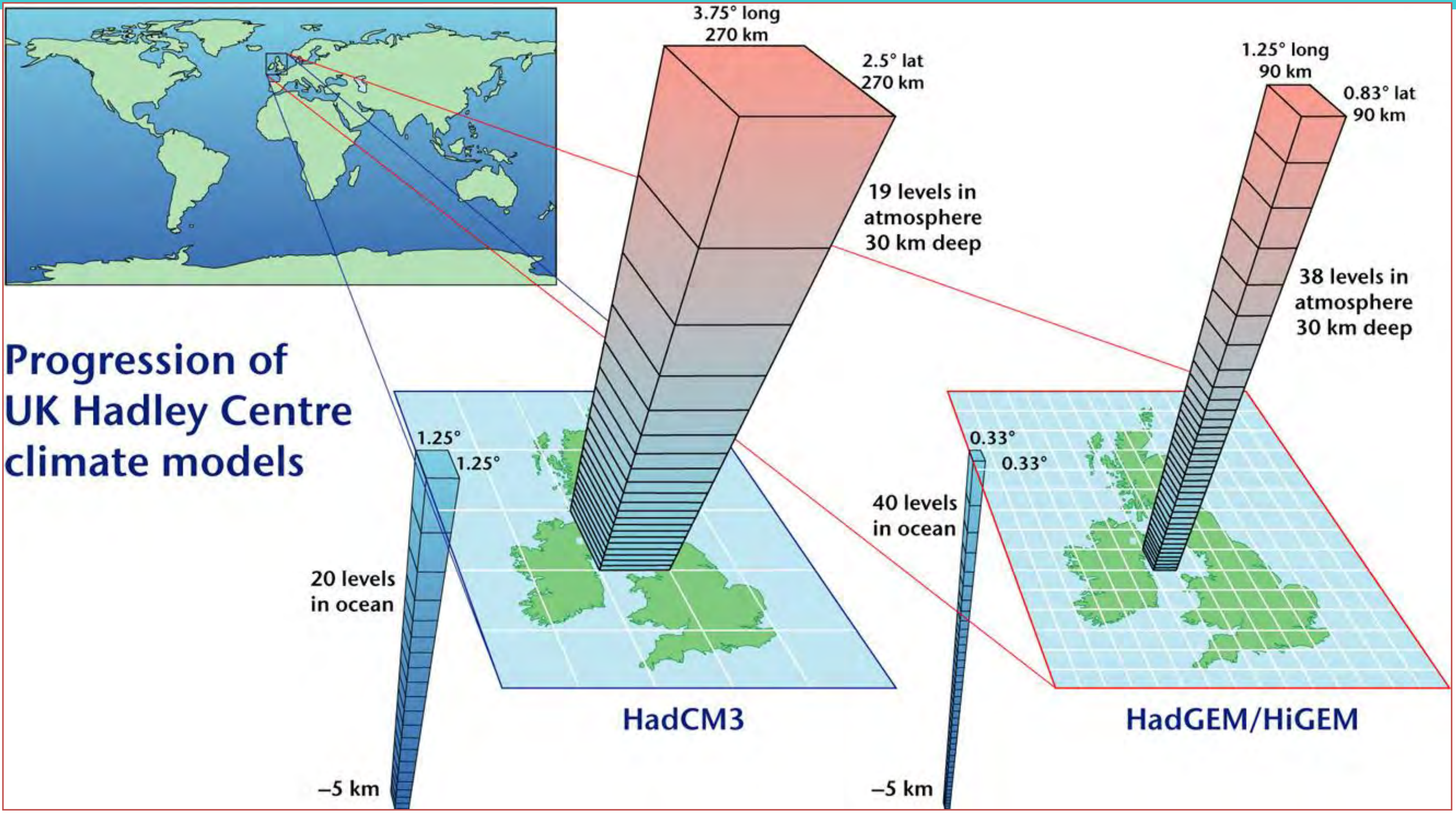
Simple initial approach: change factors (UKCP09)

- Change in precipitation and temperature (Seasonally)
- UKCP09 joint probability plots
- 1961 – 1990 ‘baseline’ climate

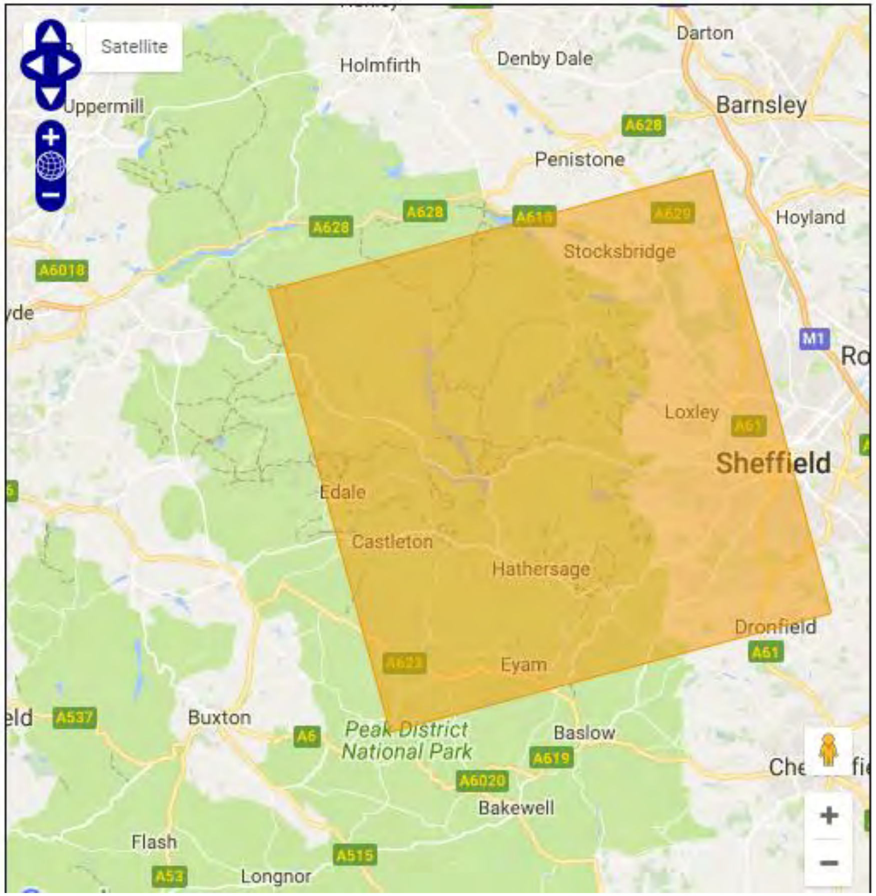
Future time period and three emissions scenarios (High, Medium and low):

- 2020s (2010 – 2039)
- 2050s (2040 – 2069)
- 2080s (2070 – 2099)

Progression of UK Hadley Centre climate models

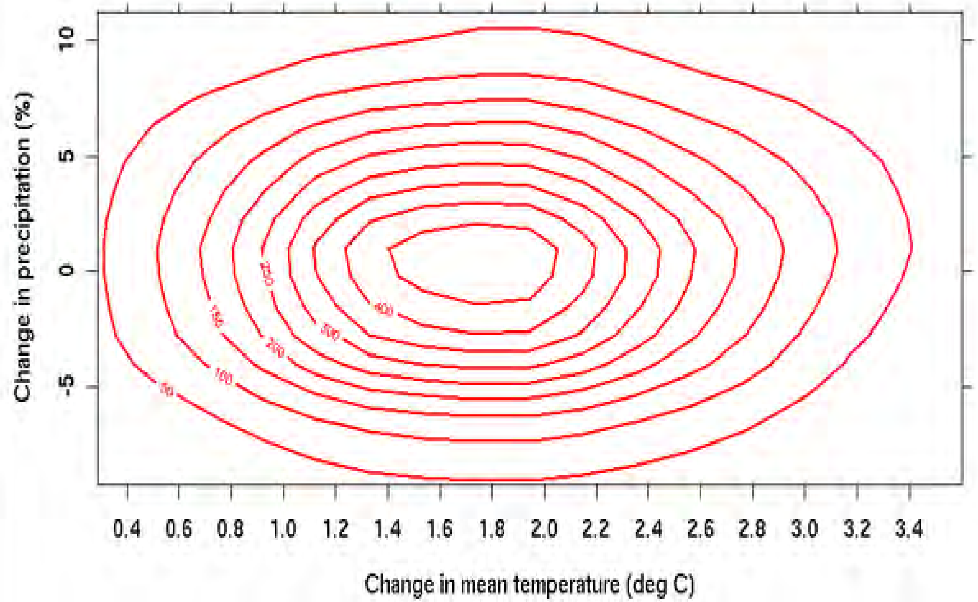


UKCP09 Grid Area



UK CLIMATE PROJECTIONS

UKCP09
joint probability plot



The UKCP09 provides monthly, seasonal and annual probabilistic change factors at 25 by 25 km grid square resolution for precipitation and temperature

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Weather Generator data bias Correction

- For the detailed weather generator simulations, 100 realizations of the daily time series data were generated in order to account for the uncertainty associated with the scenarios.
- Since the climate predictions were associated with the UK baseline data (1960–1990), which is different from the catchment baseline data, these data were subjected to bias correction using the ‘qmap’ package in the R statistical tool using the 1961–1990 observation data as a reference period.

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Don : future climate change scenarios – Joint Probability

		Low emissions				Medium emissions				High emissions			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Change in temperature (°C)	2020s	1.3	1.3	1.5	1.6	1.4	1.3	1.4	1.5	1.4	1.3	1.4	1.6
	2050s	2.0	1.7	2.2	2.3	2.1	1.9	2.0	2.6	2.6	2.3	2.4	2.7
	2080s	2.4	2.2	2.1	2.7	2.7	2.8	3.0	3.3	3.5	3.5	3.8	4.3
Change in precipitation (%)	2020s	4.7	2.2	-6.8	3.2	4.1	1.6	-6.5	2.2	4.8	1.3	-7.3	2.4
	2050s	8.0	1.2	-16.3	1.9	8.5	0.6	-14.8	4.1	9.8	0.7	-16.5	5.0
	2080s	9.6	1.3	-13.4	3.5	11.8	1.5	-20.1	4.6	16.8	1.5	-28.2	5.0

Time period

increased greenhouse gas emissions

- Climate modelling 'central estimates' (UKCP09) compared to 1961-1990 'baseline' period (average annual rainfall 1456 mm; average temperature 8.4°C)
- Temperatures increase with emissions scenario and time, particularly in summer and autumn
- Precipitation (rainfall) decreases in summer but increases in winter

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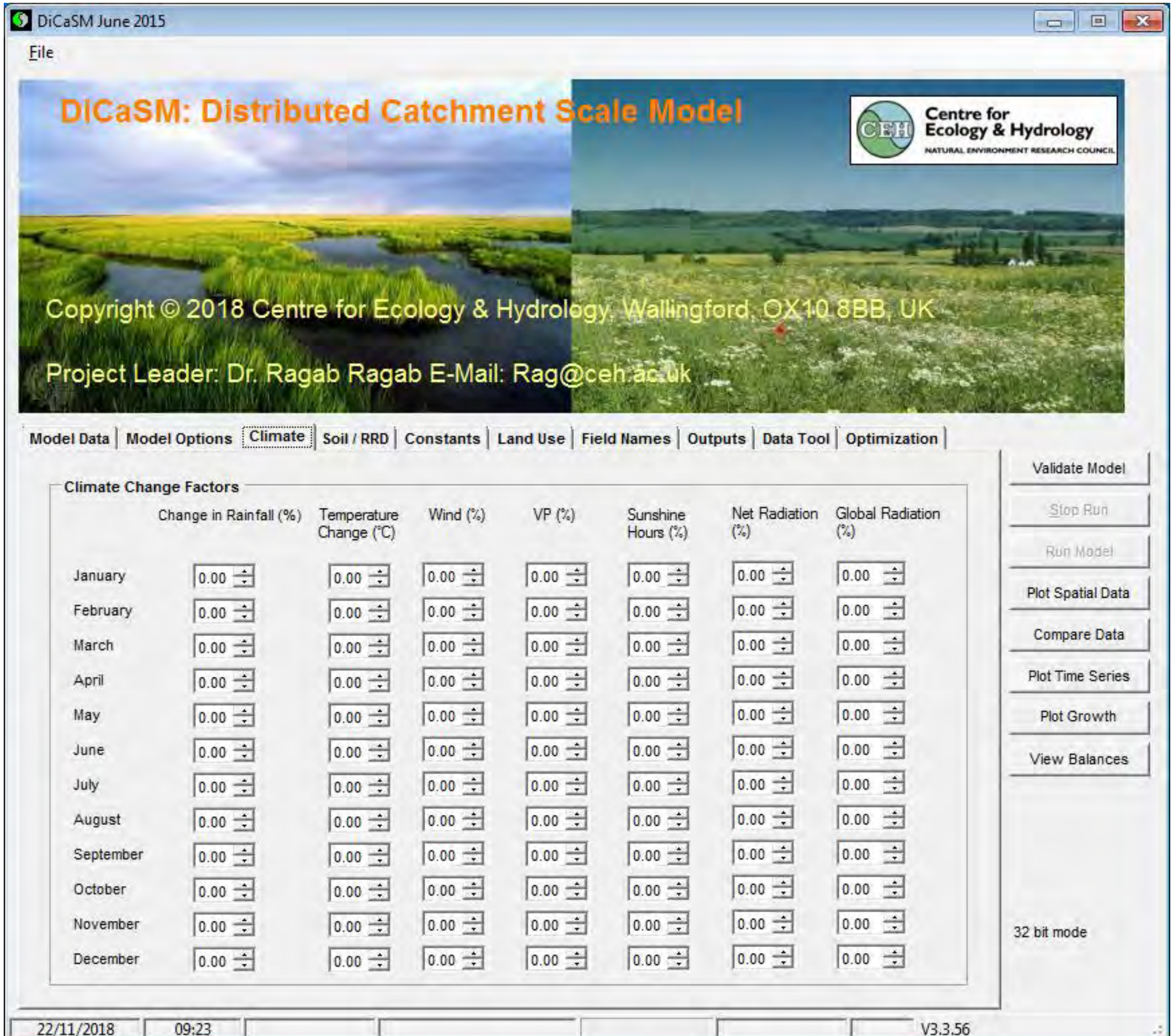
Monthly changes in climate variables



UKCP09 Scenarios applied:
Three, 30 years periods:
2020's (2010-2039),
2050's (2040-2069),
2080's (2070-2099) and
three greenhouse gas emission scenarios:
high, medium & low

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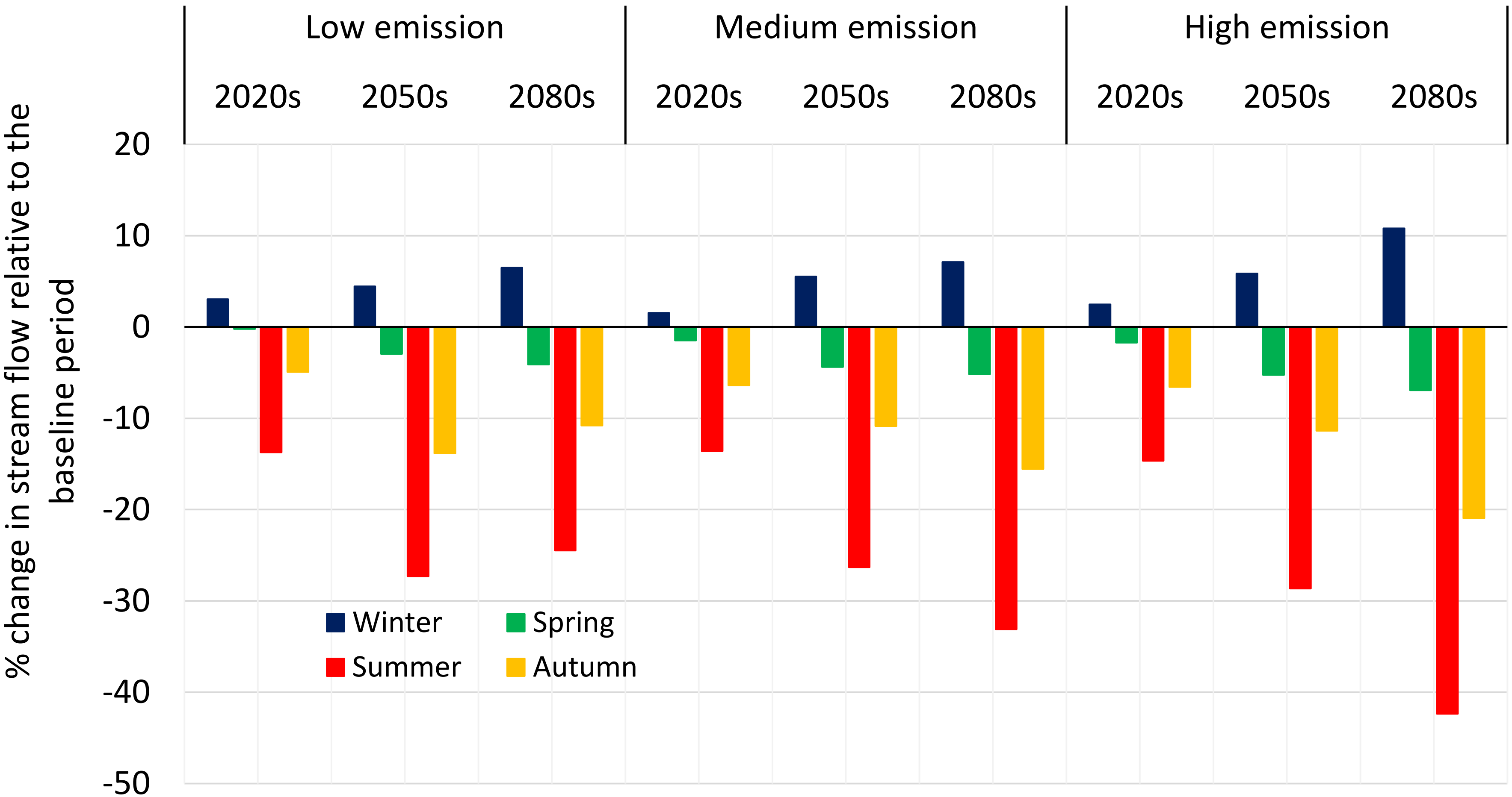
DON: STREAM FLOW USING JOINT PROBABILITY DATA



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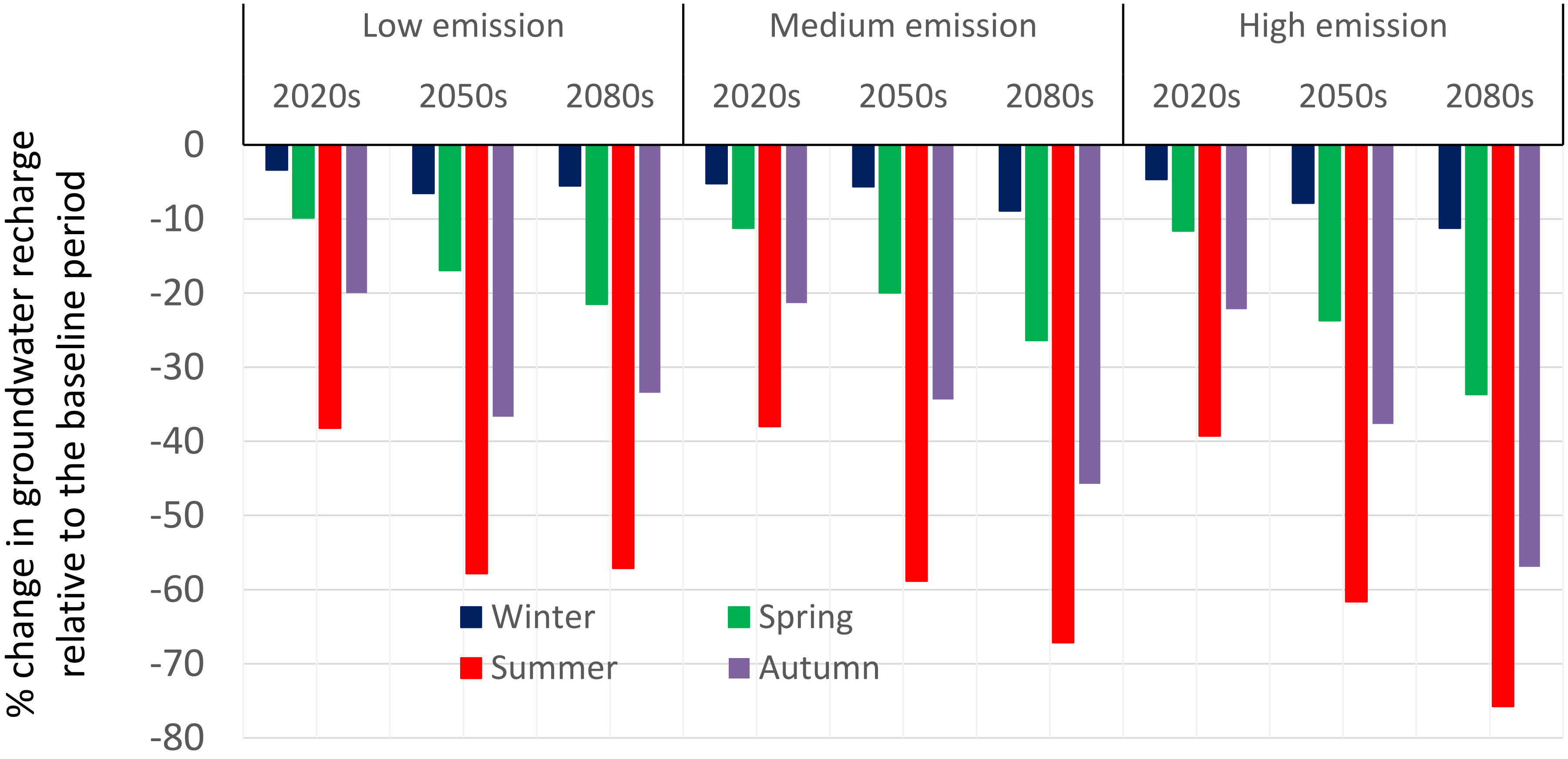
DON: GROUNDWATER RECHARGE USING JOINT PROBABILITY DATA



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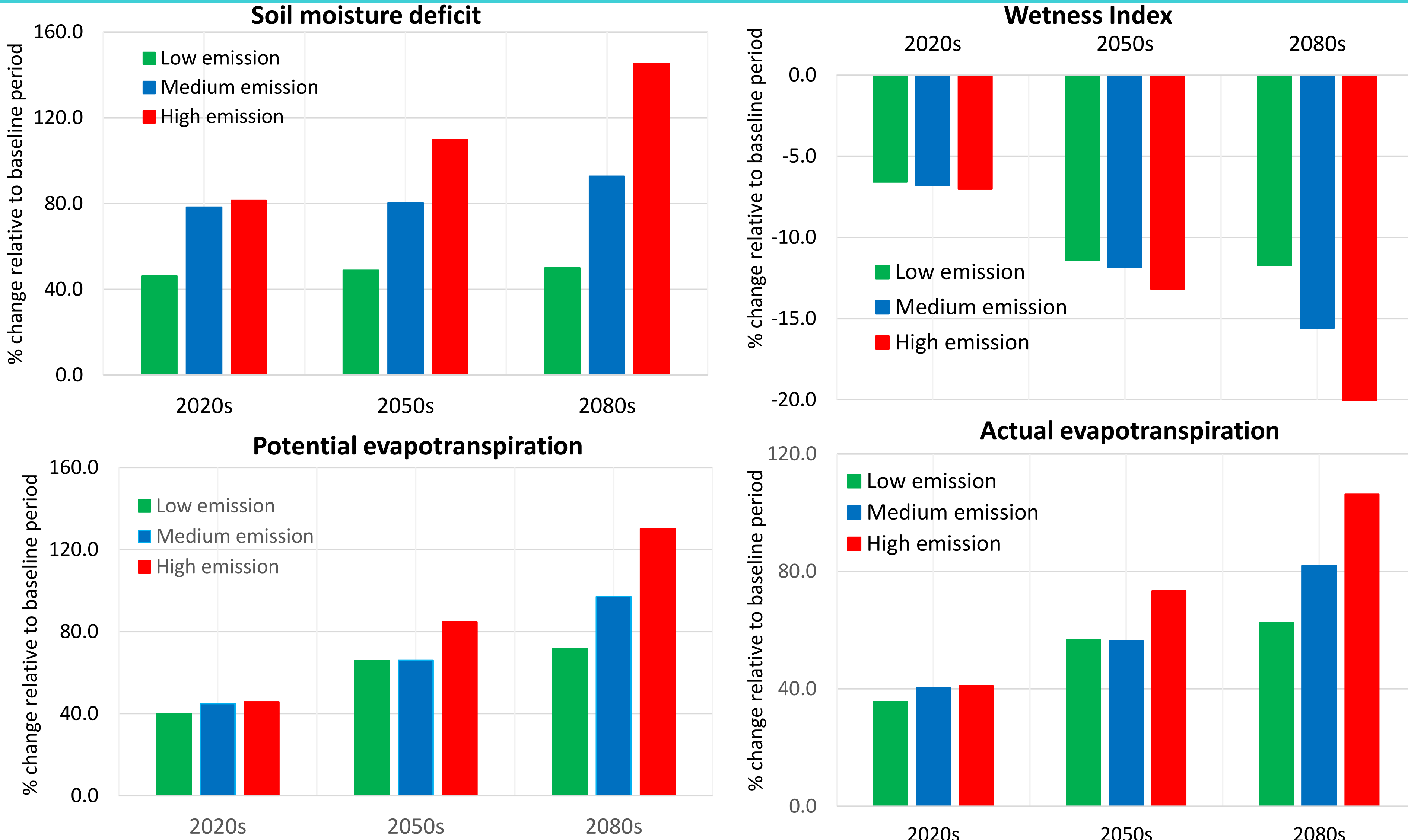
Don: % change in other hydrological variables using Joint Probability



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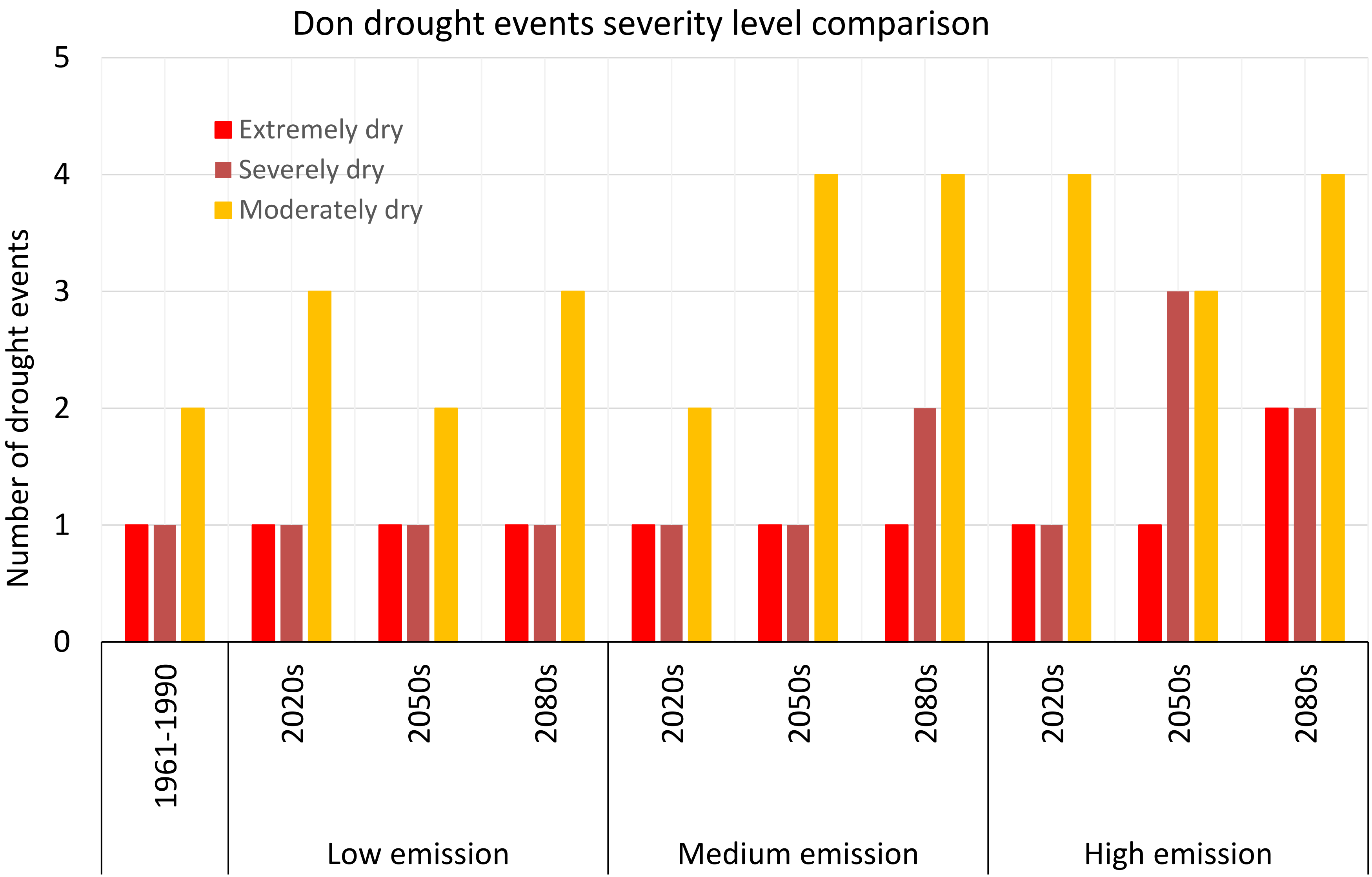
Don: Reconnaissance Drought Index, RDI (using Weather Generator data)



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Extremely dry RDI ≤ -2 , Severely dry RDI -1.5 to -1.99, Moderately dry RDI -1 to -1.49

Don: Climate Change scenario comparison

Hydrological variable		Joint Probability method			Weather generator method		
		Low	medium	High	Low	medium	High
River flow (Summer)	2020s	−	− −	− −	−	−	−
	2050s	− − −	− − −	− − −	− −	− −	− −
	2080s	− − −	− − − −	− − − −	− −	− −	− −
Actual evapotranspiration (annual)	2020s	+	+	+ +	+	+	+ +
	2050s	+ +	+ +	+ +	+ +	+ +	+ +
	2080s	+ +	+ +	+ + +	+ +	+ + +	+ + +
Soil moisture deficit (summer)	2020s	+ +	+ +	+ +	+ +	+ +	+ +
	2050s	+ +	+ +	+ + +	+ +	+ +	+ + +
	2080s	+ +	+ + +	+ + + +	+ +	+ + +	+ + + +
Groundwater recharge (Winter)	2020s	−	−	−	+	+	+
	2050s	−	−	−		−	
	2080s	−	−	− −	−	−	−

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− Magnitude of decrease (up to 10%)

+ Magnitude of increase (up to 10%)

Drought Risk and You

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Climate Change Impact on water resources

- UKCP09 projected more rain in winter and reduced rain in summer.
- However, the increase in winter rain did not produce a similar increase in the stream flow or ground water recharge.
- Modelling results indicated a decrease in summer river flows, groundwater recharge with time and with increasing emission levels.

The Drought Indicators

- The severity and frequency of the drought events will significantly increase with time and the emission level in all catchments.
- All the applied drought indices (*SMD*, *WI*, and *RDI*) identified an increase in the severity of the drought with time and with increasing the emission level.

Impact of Land use change on water resources

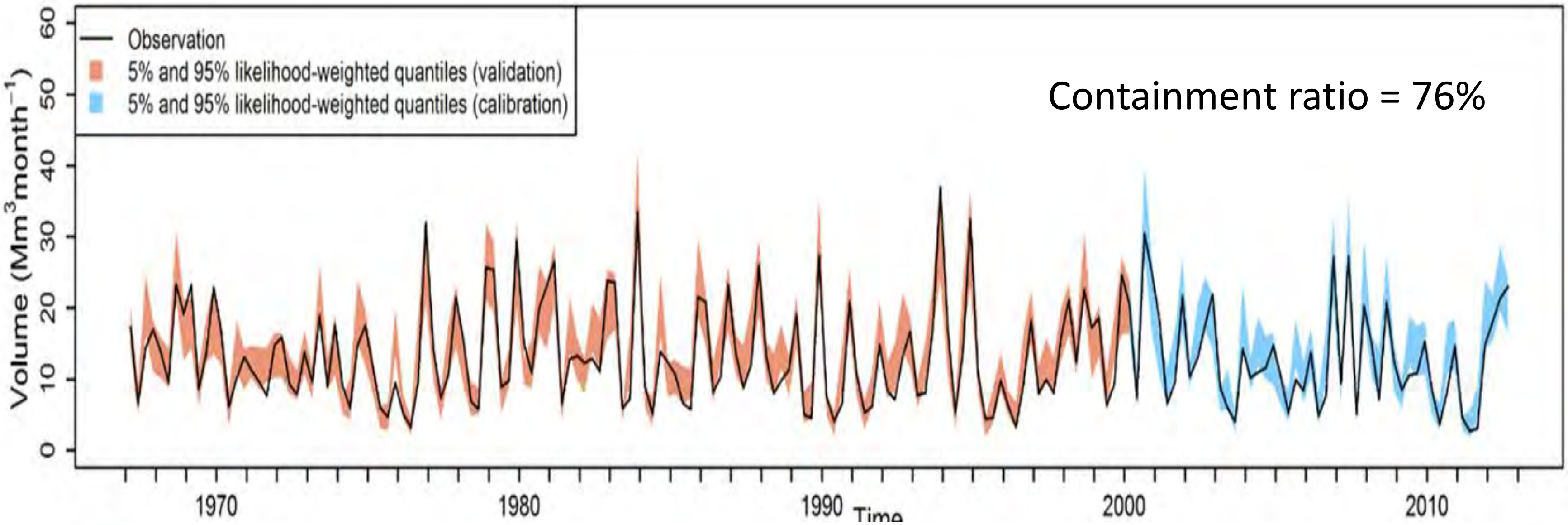
- Increasing broadleaf woodland area reduces river flows and groundwater recharge but increases evapotranspiration
- Increasing heather or grass or crops areas by replacing trees would increase river flows, groundwater recharge and reduce evapotranspiration.
- The impact of climate change was greater than the impact of land use change on water resources. This is not a general conclusion as this dependant on the catchment and % of land use change + type of change (from what to what).

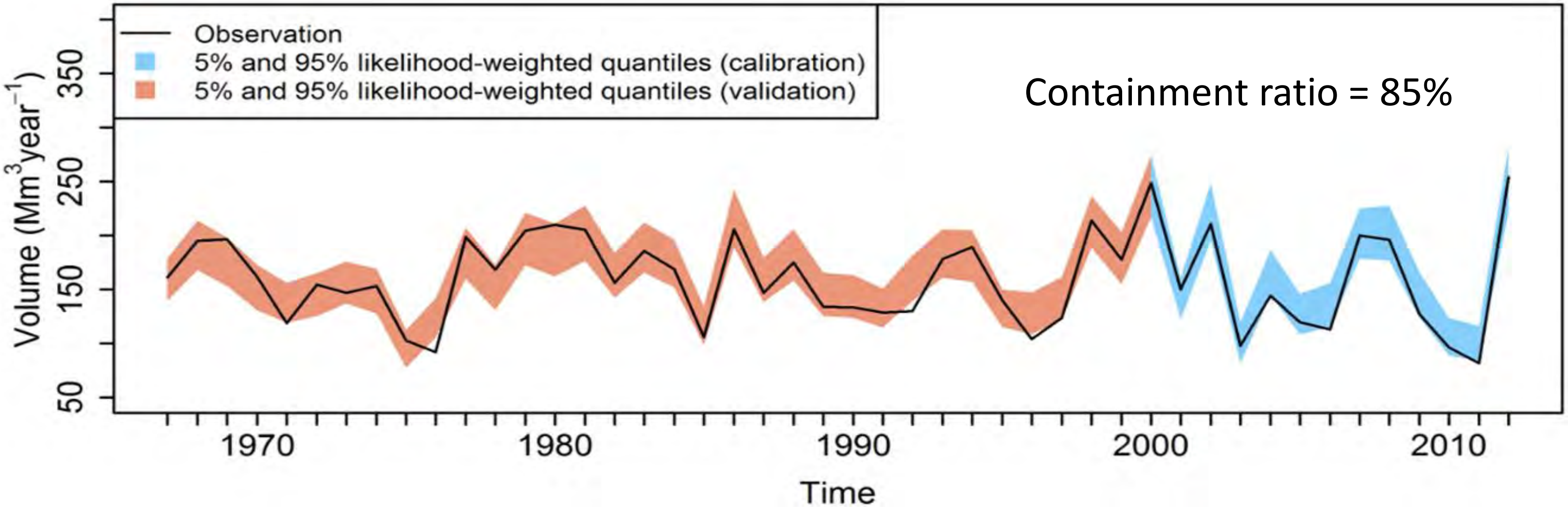
The Uncertainty analysis of river flow prediction

- Generalized Likelihood Uncertainty Estimation, GLUE indicated that the model captures above 70% of the observed river flow (Containment ratio CR) i.e. more than 70% observed values are included in the 5%-95% likelihood-weighted quantiles envelope.

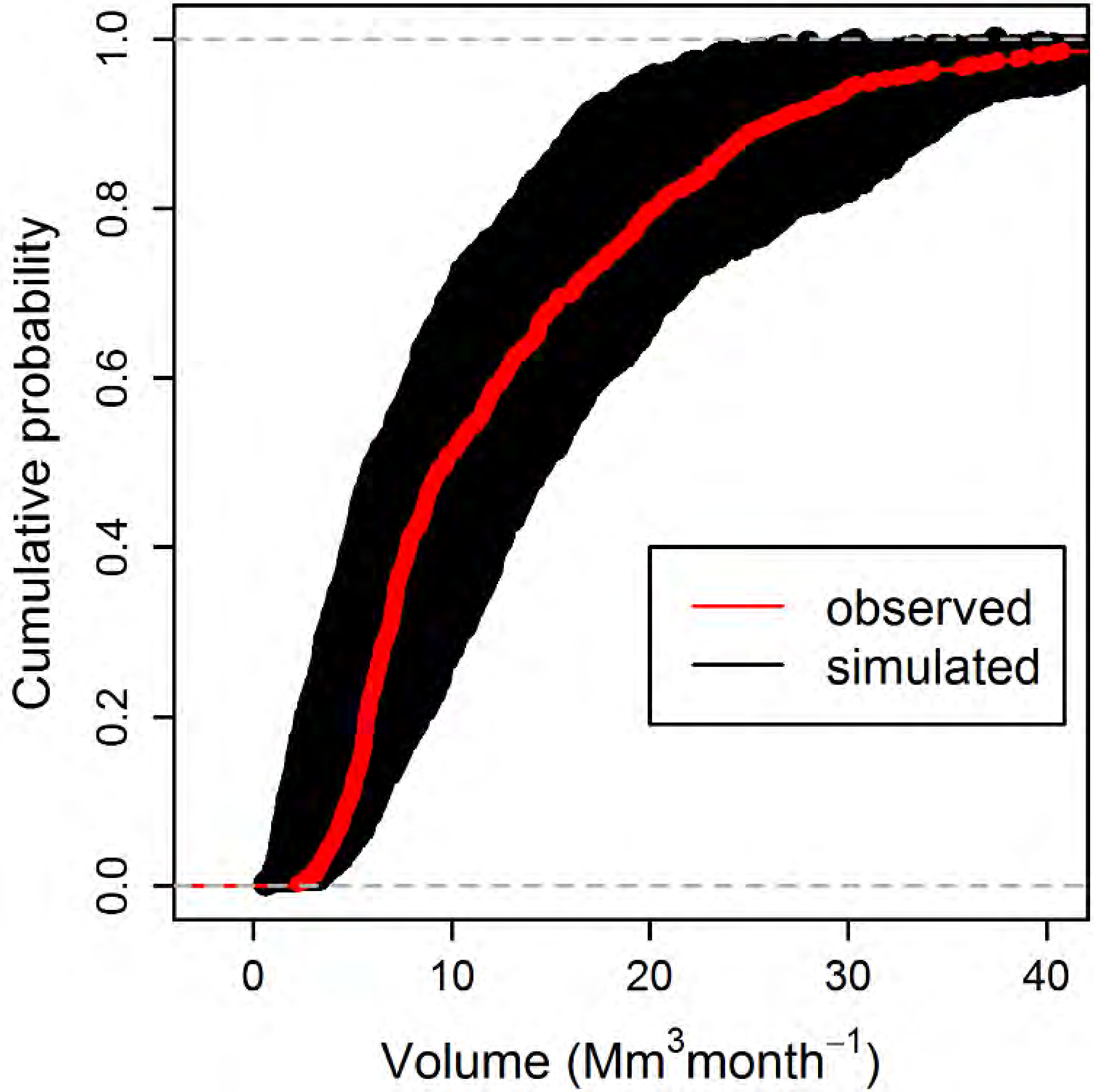
- This gives confidence in model stream flow prediction.

Don: Model uncertainty plots - stream flow





Don: Model uncertainty monthly plots - stream flow



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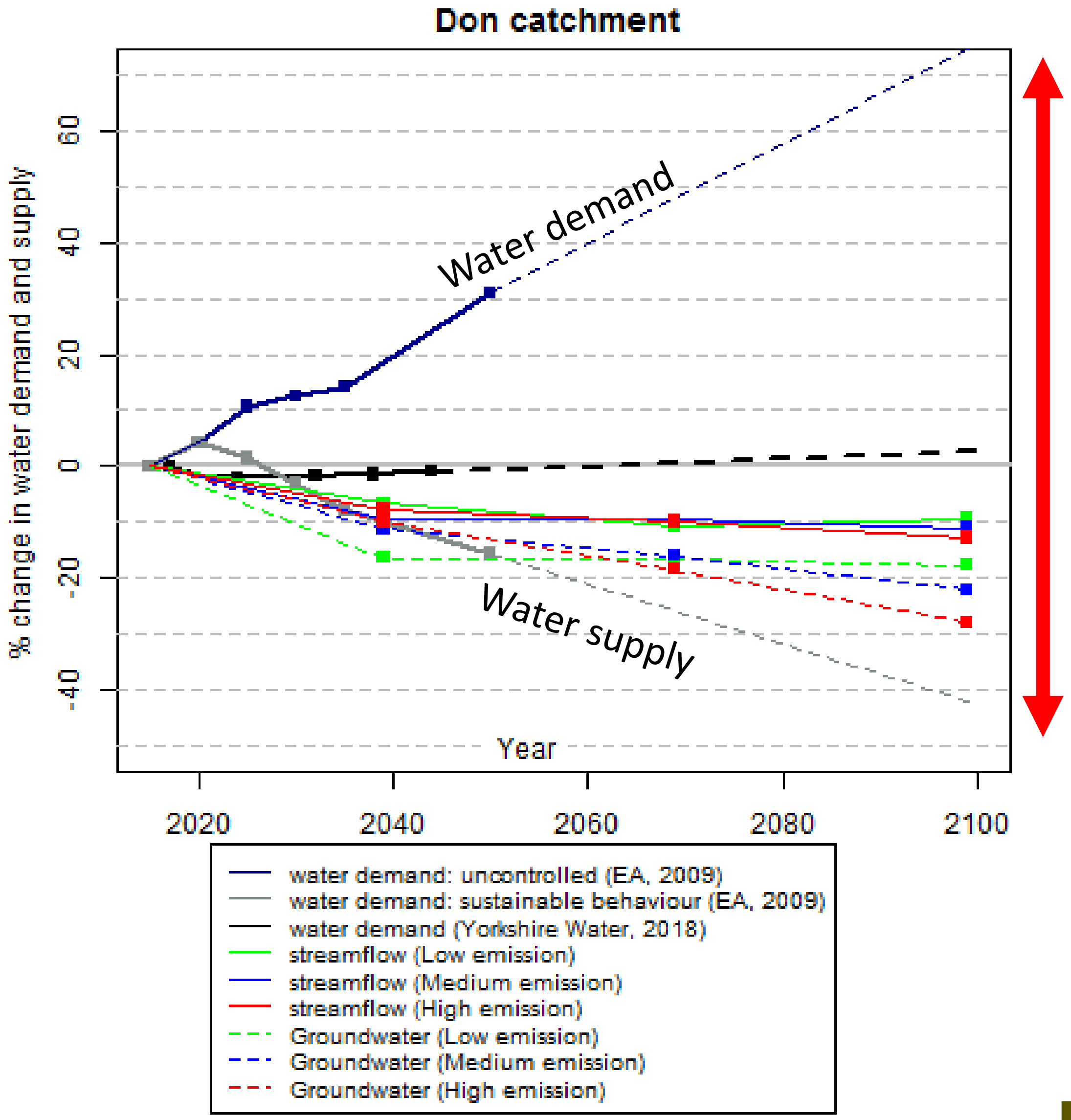
Don future supply vs demand under climate change



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The gap between future water demand and future water supply

- In all 7 catchments apart from Eden in Scotland, there will be a gap between future water supply and future water demand and that gap is widening over time up to 2099 if water demand is not sustainably managed and controlled.

UNCERTAINTIES IN CLIMATE CHANGE PREDICTIONS

The uncertainties in climate predictions arise from our imperfect knowledge of:

- **Future rates of human-made emissions & how these will change the atmospheric concentrations of greenhouse gases.**

- **The responses of climate to these changed conditions.**

UNCERTAINTY IN HYDROLOGICAL MODELLING

Uncertainty in results could be attributed to:

- **Model assumptions, processes descriptions, mechanisms, mathematical formulation & the numerical scheme.**
- **In nature all processes operate simultaneously while in model they don't (they follow order of execution based on flow chart). If evaporation comes after infiltration, expect recharge, soil moisture to be different from the other way around.**
- **Linearity exists in model processes but not in nature where nothing is linear.**
- **Measurements (e.g., stream flow, soil moisture, groundwater levels, etc.) and parameters values (hydraulic conductivity, soil physical and plant parameters, etc.)**
- **The mismatch between the scale of model application (e.g. 1km^2 and the scale of observation, e.g. Point Scale).**
- **Assumptions in climate change scenarios and predictions.**

No one trusts a model except the man who wrote it; everyone trusts an observation except the man who made it.

Harlow Shapley

In modelling a complex system:
It is better to be approximately right than precisely wrong!!

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