Plausible worst-case storylines for current and future UK droughts

Hydrological droughts, prolonged period of low river flows, disrupt water supplies, reduce habitat for freshwater ecosystems and lead to a soil moisture deficits impacting agricultural productivity. Warming temperatures and changes to rainfall patterns are expected to increase the frequency and severity of UK droughts.[1-4] While future warming is certain, there is less confidence in rainfall changes due to uncertainty in how atmospheric patterns would respond to climate change. There is a need to better understand low-likelihood, high-impact events to enhance climate resilience.[5,6] In the following, we present findings from a novel storyline approach to enhance

Ladybower Reservoir, Derbyshire during the 2022 drought

Key summary:

- **A "reasonable worst-case" drought relates to water supply implications for South/ East England should three consecutive dry winters occur** according to the latest UK Government National Risk Register. Current guidance encourages UK water companies to plan against an extreme drought with a 1:500-year return period.[7,8] It is unclear how such an extreme drought might unfold in the present/future climate and how this reasonable worst-case scenario relates to historical observations and past observed events.

- **Novel use of climate storylines to explore downward counterfactuals (i.e. what if a past event turned out worse; see Box).**[9] Downward counterfactuals of the 2010-12 UK drought explore the hydrological implications should the NRR reasonable worst-case scenario be realised. Persistent high pressure dominated winter 2010/11 and 2011/12, bringing settled and dry weather across southern England. Although the drought rapidly terminated in spring 2012, a logical downward counterfactual would be what if the drought was succeeded by continued dry conditions and a third dry winter.

What is a downward counterfactual?

Downward counterfactuals asks what if an observed event turned out worse.[10,11] This type of analysis recognizes that the observed past is only one out of many other alternative realisations that could have occurred from plausible changes to the event's drivers. Downward counterfactuals explore "near misses" that can be used to stress test adaptation options.

- **The 2010-12 drought can be considered a near miss.** Continued dry conditions and a third dry winter would lead to an increase in the drought severity by 50% at some river catchments in southeast England.[10] This could mean catchments approaching, but not exceeding the conditions seen in the benchmark 1989-93 drought for this region. However, should this storyline occur in a warmer world, conditions could exceed the benchmark drought.

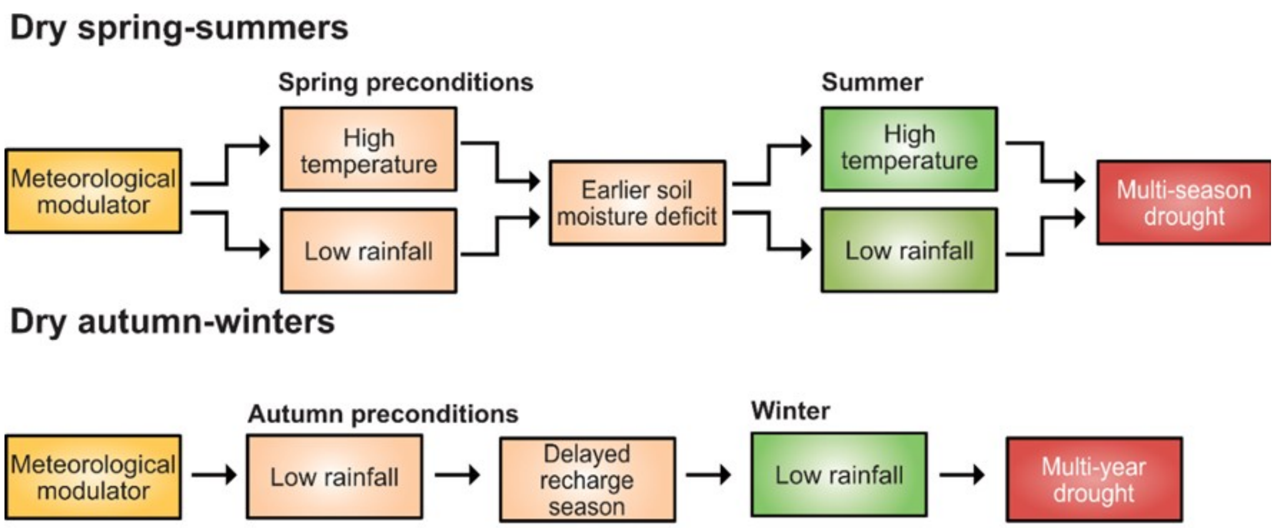
- **Application of the UNprecedented Simulation of Extremes with ENsembles (UNSEEN) technique highlights the increasing risk of extremely hot and dry summers .** UNSEEN is a new way to understand unprecedented extremes by searching through many thousand years of climate model output for events not seen in the observations.[11] Application of this technique estimated that for southeast England, the chance of extremely warm summer months in a given year increases from 6% in the present day to 58% in a 3°C warmer climate and the chance of an unprecedented dry summer month increases from 9% in the present day to 18%.[12] Despite projections of wetter winters in general, the risk of dry winters is not eliminated and the chance of the driest winter occurring may not change significantly and could be up to 50% drier than the driest observed winter.[12]

- **The risk of severe compound drought events is under-estimated using traditional methodologies.** Compound events refer to the coincident occurrence of multiple extremes (e.g. hot and dry) or the concurrent combinations of different extremes occurring in succession.[13] For example, past severe droughts were characterised by conditions such as dry spring followed by dry summer (e.g. 1976 and 2022) or dry autumn followed by dry winter (e.g. 1921) (Figure 1). A robust sampling of these conditions can be achieved by employing large ensemble climate model simulations.[14] Sampling for these "storylines" in an existing large ensemble showed that dry spring-summers become drier as summers are more likely to be hot with high evaporation. Further, dry conditions may be prolonged even with moderate autumn–winter precipitation deficit given the higher likelihood of being followed by a hot and dry summer .[12,14]

- **A reasonable worst-case drought may vary for different regions of the UK and for different sectors.** An extreme drought may also plausibly arise from the some or all of the conditions outlined in previous bullet points, leading to novel conditions that may not have been observed in the past.

Summary

Hydrological droughts incur significant impacts in different sectors. Storyline-based analysis enables a better understanding of present-day risk by looking at alternative unfolding of past droughts. New climate model simulations provide opportunities to more robustly sample for future drought storylines, including the novel combination of drivers that may not have occurred in the past. The CANARI project aims to further create storylines of plausible worst case droughts through the production of large ensemble climate model simulations using the latest Met Office global climate model.



References

1. Met Office. UKCP18 Science Overview Executive Summary. (2019).

2. Reyniers, N., Osborn, T. J., Addor, N. & Darch, G. Projected changes in droughts and extreme droughts in Great Britain strongly influenced by the choice of drought index. *Hydrology and Earth System Sciences* **27**, 1151–1171 (2023).

3. Tanguy, M. *et al.* How will climate change affect the spatial coherence of streamflow and groundwater droughts in Great Britain? *Environ. Res. Lett.* **18**, 064048 (2023).

4. Parry, S. *et al.* Divergent future drought projections in UK river flows and groundwater levels. *Hydrology and Earth System Sciences Discussions* 1–36 (2023) doi:10.5194/hess-2023-59.

5. Sutton, R. T. Climate Science Needs to Take Risk Assessment Much More Seriously. *Bull. Amer. Meteor. Soc.* **100**, 1637–1642 (2019).

6. Sillmann, J. *et al.* Event-Based Storylines to Address Climate Risk. *Earth's Future* **9**, e2020EF001783 (2021).

7. Ofwat. PR24 and beyond: Future challenges and opportunities for the water sector. (2020).

8. DEFRA. Policy Paper: Plan for Water: our integrated plan for delivering clean and plentiful water. (2023).

9. Shepherd, T. G. *et al.* Storylines: an alternative approach to representing uncertainty in physical aspects of climate change. *Climatic Change* **151**, 555–571 (2018).

10. Chan, W. C. H., Shepherd, T. G., Facer-Childs, K., Darch, G. & Arnell, N. W. Storylines of UK drought based on the 2010–2012 event. *Hydrology and Earth System Sciences* **26**, 1755–1777 (2022).

11. Thompson, V. *et al.* High risk of unprecedented UK rainfall in the current climate. *Nature Communications* **8**, 107 (2017).

12. Chan, W. C. H. *et al.* Current and future risk of unprecedented hydrological droughts in Great Britain. *Journal of Hydrology* 130074 (2023) doi:10.1016/j.jhydrol.2023.130074.

13. Zscheischler, J. *et al.* A typology of compound weather and climate events. *Nat Rev Earth Environ* **1**, 333–347 (2020).

14. UK Climate Risk Independent Assessment (CCRA3) Technical Report Chapter 3: Natural Environment and Assets.

Contact us

Wilson Chan
email: wilcha@ceh.ac.uk
www.canari.ac.uk