10. Climate change and catchment hydrology

Conor Murphy [1]

Climate change is expected to alter catchment hydrology through changes in extremes of flooding and drought. River catchments are complex, dynamic systems and it is important to develop our understanding of how these systems are likely to respond to changes in climate. Work is ongoing in using EC-Earth simulations to further our understanding of how climate change will affect catchment hydrology and flood risk. In Ireland, the importance of this task is emphasised given the widespread socio-economic impacts of recent flood events. This chapter reviews recent Irish research concerning the hydrological impacts of climate change.

Observed trends in river flows

Detection of climate-driven trends from observations of river flows is a challenging task due to the many confounding factors (e.g. urbanisation, land-use change etc.) that can impede the analysis and interpretation of trends. To help detect and attribute trends in river flows more confidently many countries have identified Reference Hydrometric Networks (RHNs) to help limit these factors (Whitfield et al., 2012). In Ireland, Murphy et al. (2013a) have capitalised on the existing Irish hydrometric network to identify the Irish Reference Network (IRN); a subset of 35 gauges from the national hydrometric register that can be used for monitoring and detecting climate change signals. This flow archive, together with eight river flow stations that comprise the UK Benchmark Network (Hannaford and Marsh, 2006) has been analysed for changes in the full range of flow conditions (Murphy et al., 2013a; Murphy et al., 2013b).

Hydrometric Stations

There are 703 active hydrometric stations in the Republic of Ireland operated by various bodies. Continuous water level records are maintained at 680 of these sites.

High Flow indicators are dominated by increasing trends, with these becoming significant since 2000 in many stations.

Indicators of high flows from the IRN are dominated by increasing trends, a large proportion of which are statistically significant (5 percent level). Spatially, increasing trends in high flows are distributed throughout the country with the exception of the northwest and northeast where clusters of decreasing trends are evident.

Annual and seasonal mean flows are subject to large interannual variability making it difficult to detect trends. Trends in summer flows are not in line with projections from climate models.

For winter mean flows, there is some evidence of increasing trends in long records but these are not statistically significant. However, shorter records suggest decreasing trends. Summer mean flows are dominated by increasing trends with the recent spate of wet summers having a large influence on trends even for longer records. However, even when these recent wet summers are removed, increasing trends in summer mean flows remain prevalent. Trends in summer mean flows are heavily influenced by the historical development of the monitoring network with monitoring beginning for many stations around the early 1970s, a period of marked drought conditions, thereby hardwiring an increasing trend.

---

[1] Irish Climate Analysis and Research Unit (ICARUS), Department of Geography, National University of Ireland, Maynooth.

It is difficult at this stage to attribute observed trends in observations of Irish river flows to anthropogenic climate change.

While there is considerable evidence of variability and change in the hydrological indicators derived from the flow records in the IRN, it is difficult at this stage to attribute changes to greenhouse-gas induced climate change. High flows show the greatest number of significant and persistent trends and are strongly correlated with the North Atlantic Oscillation (NAO), particularly in western areas. However, how the NAO itself will respond to anthropogenic climate change remains an open question (Osborn, 2004; Stephenson et al. 2006; Dong et al., 2011). More complete research on attributing changes in the IRN to drivers beyond the NAO should be a priority for future work.

Projected changes in catchment hydrology

Future projections of climate change impacts at the catchment scale are subject to large uncertainties.

Uncertainties in future impacts need to be quantified to ensure that the best quality information is available for decision making processes.

Seasonal flows

A broad signal of wetter winters and drier summers is evident from a number of independent studies.

Murphy and Charlton (2008) used statistically downscaled output from three Global Climate Models (GCMs) forced by the SRES A2 and B2 emissions scenarios (described in Chapter 1) to assess the impacts for nine Irish catchments. Results indicated increases in winter flow and decreases in summer. Murphy and Charlton also highlighted the importance of catchment properties in modulating the response to anthropogenic climate change. McGrath et al. (2008) and Steele-Dunne et al. (2008) used dynamically downscaled scenarios from the Rossby Centre Atmosphere Model (RCA3), forced using the European Centre Hamburg Model Version 5 (ECHAM5) to assess catchment scale impacts using the HBV hydrological model. Their results suggest an amplification of the seasonal cycle of runoff across the country driven by increased winter precipitation and decreased summer precipitation.

A small number of Irish studies have attempted to produce probabilistic climate change scenarios, built from a wider sample of GCM output (Fealy, 2010; Bastola et al., 2012). Bastola et al. (2012) derived probabilistic scenarios for the IPCC's AR4 CMIP3 climate model set. This dataset comprises 17 global climate models used in the IPCC's Fourth Assessment Report. Each of the 17 GCMs was run with the A1B, A2 and B1 SRES emissions scenarios and comprised 51 future scenarios (17 GCMs X 3 SRES scenarios). Figure 1 shows the probability density functions (PDFs) representing percentage changes in seasonal mean flows relative to present conditions for the Blackwater, Boyne, Moy and Suck catchments for the period 2070-2099 as simulated for the CMIP3 probabilistic scenarios produced by Bastola et al. (2012). The density is calculated on the basis of the proportion of daily future stream flow lying within the specified interval. Results are presented relative to natural variability in the period 1971-1990. In winter and spring PDFs are shifted to the right relative to estimates of climate variability, indicating increases in flows for these seasons. Summer and autumn flows on the other hand show a shift to the left relative to climate variability indicating a decrease in flows. However, uncertainties in response are large.

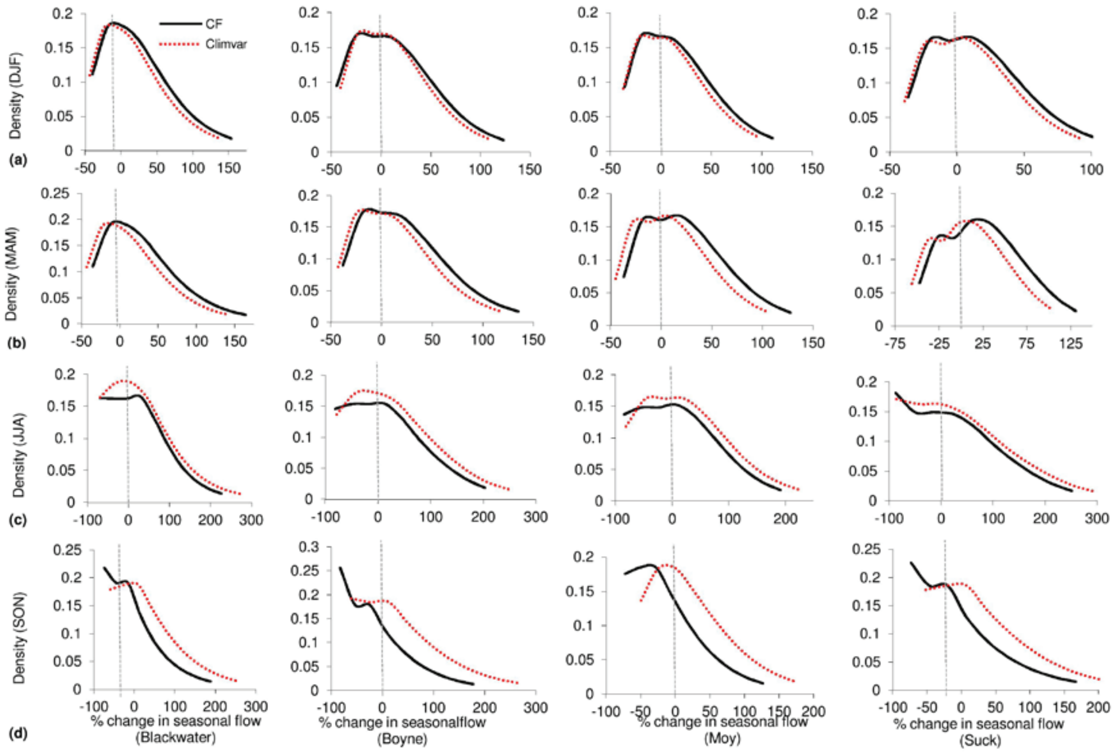

Figure 1. Probability distribution of seasonal mean flows as simulated using 17 CMIP3 global climate models relative to estimates of climate variability for (a) winter, (b) spring, (c) summer and (d) autumn for the Blackwater, Boyne, Moy and Suck catchments.

High flows

> *Increases in winter flows, coupled with likely increases in extreme precipitation events, are likely to lead to an elevated risk of flooding.*
>
> *Uncertainties in future simulations are greater for low frequency (rarer) flood events than for high frequency (common) events.*
>
> *Catchment response is critical in determining the changing nature of extremes.*
>
> *Catchments with a fast response time show increases in flood risk for all return periods*

Steele-Dunne et al. (2008) showed that increases in winter flows, coupled with likely increases in extreme precipitation events led to an elevated risk of flooding. Their work also showed that catchment response is critical in determining the changing nature of extremes; catchments with a fast response time show increases in flood risk for all return periods, while for other catchments little change or marginal decreases in flood risk were found. Increased risk is significantly marked in the southwest of the country for those catchments with fast response times. For example, in the Munster Blackwater the flow associated with a 40-year return period in the past is expected to have a return period of ~9.8 years in the period 2021–2060. The risk of extremely high winter flows is expected to almost double in the Feale and Suir, and is also likely to increase in the Boyne.

Return period

Refers to a flood of a magnitude that is expected to occur on average once in a specified number of years. For example, a flood with a one hundred year return period is expected to occur once on average every one hundred years. Therefore it has a probability of 0.01 of occurring in any one year.

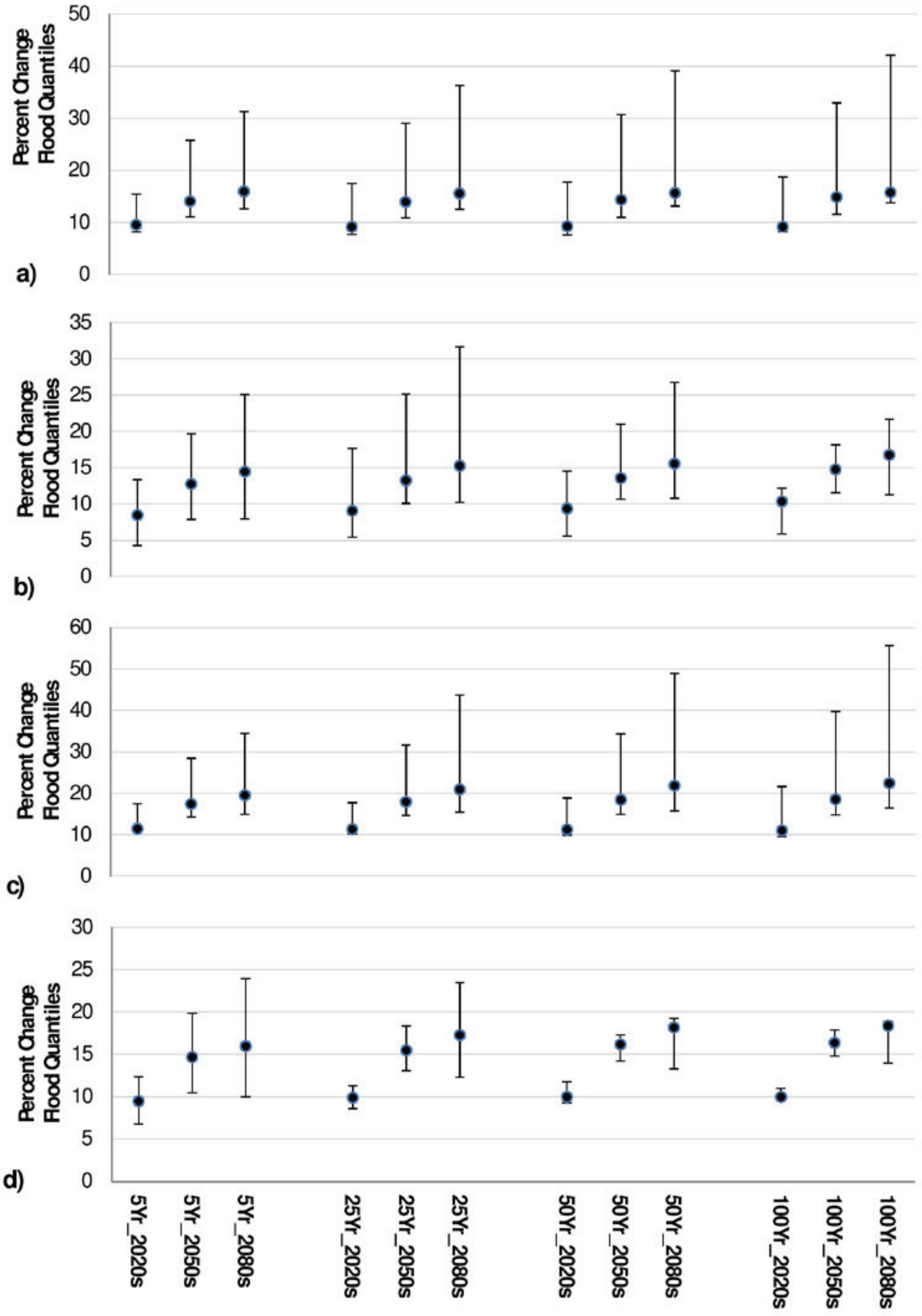

Figure 2. Simulation results showing percentage change in peak flows associated with current 5, 25, 50 and 100-year return period events for three future time periods. Catchments are a) Munster Blackwater b) Boyne c) Moy d) Suck. The black dot represents the median of simulations while the upper and lower error bars mark the 5th and 95th percentiles of future changes respectively.

Bastola et al. (2011) examined changes in flood risk using 17 global climate models that took part in the CMIP3 study and reported in the IPCC Fourth Assessment Report. Each of these models was forced with three SRES emissions scenarios (A1F1, A2, B1) resulting in 51 scenarios of future climate. Changes in flood risk were assessed for three future periods – the 2020s (2011-2040), the 2050s (2041-2070) and the 2080s (2071-2100). The scenarios were used to force structurally different hydrological models resulting in 20,000 simulations of future flood risk for four catchments – the Munster Blackwater, the Boyne, the Moy and the Suck.

Figure 2 shows the results simulated for each catchment in terms of the percentage change in each flood quantile analysed by Bastola et al. (2011). The impact of climate change is not as

great for flood peaks with smaller return periods. Consequently, for low frequency (very heavy precipitation) events, the risk of exceeding design allowances is greater with considerable implications for critical infrastructure. For individual catchments the uncertainties in future flood risk were greatest for the Moy and Blackwater and smallest for the Boyne and Suck. A progressive increase in the peak flow associated with the 5-, 25-, 50- and 100-year return periods was found when moving from the 2020s to the 2080s for all catchments. However, the magnitude of change varies between catchments.

Adapting to an uncertain future

Approaches to developing effective adaptation strategies must take uncertainty into account.

The application of a process-oriented "vulnerability thinking" instead of an "impacts thinking" approach in adaptation planning is promoted.

Rather than basing adaptation decisions on wide ranges of uncertainty, climate scenarios can be used to stress-test decisions to the range of possible future impacts.

Adaptation must be approached as context specific; a successful set of adaptation options may work well in one region but may not be applicable in another.

Adaptation is necessary to position Ireland to be better able to cope with the impacts of climate change (See Chapter 15). However, uncertainties surrounding future impacts are large and approaches to developing effective adaptation strategies must take this uncertainty into account. In the scenarios presented above, only climatic uncertainties are incorporated. Non-climatic factors such as changes in human behaviour, economic uncertainty and change in population dynamics should also be factored. Internationally, such uncertainties have precipitated a move away from traditional "predict and provide" approaches in adapting to climate change, where impacts derived from selected climate change scenarios are used to provide a narrow projection of future conditions on which to base adaptation decisions.

Recently this has been replaced with a bottom-up approach where broad ranges of climate scenarios that sample representative uncertainties are used to stress-test adaptation options which are identified by engagement with stakeholders. In such approaches emphasis is placed on identifying adaptation options that are robust to the inherent and irreducible uncertainties associated with future impacts (e.g. Wilby and Dessai, 2010). Where investment in new infrastructure is required, it is recommended that such infrastructure be subjected to a sensitivity analysis of performance under the full range of uncertainty associated with climate change. In Ireland a number of studies have begun to move in this direction and offer a starting point from which such approaches to adaptation can be developed.

Hall and Murphy (2011, 2012) conducted a vulnerability analysis of future public water supply for selected catchments over the coming decades by accounting for current and future pressures within the water supply system. Potential adaptation options were screened for robustness using exploratory modelling to assess the effectiveness and robustness of different adaptation options. In many cases simple options such as leakage and demand reduction were sufficient to avoid shortfalls in water provision under the range of impacts considered. However, in other systems, particularly those operating close to the maximum of capacity under current conditions, such adaptation options were found not to be sufficient in avoiding problems with water supply.

In the context of flooding, Bastola et al. (2011) use a large ensemble of climate scenarios to stress-test policy decisions in adapting to increases

in flood risk. Taking the example of providing additional safety margins on the design of flood defences, the study tests the effectiveness of such allowances given the uncertainties in future flood risk. Using risk response surfaces, the study shows that an allowance of 20% increases in peak discharges in designing flood defences to cater for future climate change may not be sufficient in some catchments.

Such work highlights the importance of considering uncertainties in developing adaptation plans, particularly the utility of using climate scenarios to stress-test current policies or preferred options. They also raise fundamental questions as to the acceptable levels of risk for instances where the economic cost of protecting against the full range of future impacts are not practical. Such studies also suggest that adaptation must be approached as context specific; different risks and different sensitivities of catchments to change mean that a set of adaptation options may work well in one catchment but may not be successful in another.

Future research needs

- It is crucial that the next generation of climate change scenarios are run for Irish hydrological conditions to help refine understanding of future impacts and our understanding of uncertainty ranges. Research is ongoing between Met Éireann and NUI Maynooth in assessing the hydrological impacts of the new EC-Earth scenarios for Irish catchments.
- Further research is required to better understand the links between large-scale atmospheric variables and flood risk in Ireland. While trends in high flows are correlated with changes in the North Atlantic Oscillation, this is a crude index. Additionally, there is large disagreement among climate models as to how the NAO will respond to increases in greenhouse gases. It is therefore crucial that future research better understands the hydro-climatic drivers of change in flood risk.
- Given the wide range of uncertainties that are inherent to local-scale impacts, new approaches to using climate change scenarios for stress-testing and appraisal of adaptation options are emerging in the international literature. Further development of such approaches for Ireland offers real direction in helping water managers and decision makers to incorporate climate change considerations into operational activities (see, for example, Brown and Wilby, 2012).
- Most studies to date only incorporate climatic changes into future impacts assessment. In the real world, climate change will take place in the context of other non-climatic drivers of change in catchment hydrology such as land-use change, population growth, changes in policy, etc. It is important that future work takes more account of the co-evolution of climate change with internal catchment changes.

References

Bastola, S., Murphy, C. and Fealy, R. (2012) Generating probabilistic estimates of hydrological response for Irish catchments using a weather generator and probabilistic climate change scenarios. *Hydrological Processes,* 26(15), 2307–2321.

Bastola, S., Murphy, C. and Sweeney, J. (2011) The sensitivity of fluvial flood risk in Irish catchments to the range of IPCC AR4 climate change scenarios. *Science of the Total Environment,* 409(24), 5403–5415.

Brown, C., Wilby, R.L. (2012) An alternate approach to assessing climate risks. *Eos,* 93(41), 401-402.

Dong, B., Sutton, R.T, Wollings, T. (2011) Changes of interannual NAO variability in response to greenhouse gas forcing. *Climate Dynamics,* 37, 1621–41.

Fealy, R. (2010) *An assessment of uncertainties in climate modelling at the regional scale: the development of probabilistic based climate scenarios for Ireland.* STRIVE Report Series No. 48, Wexford: Environmental Protection Agency.

Hall, J. and Murphy, C. (2011) Robust adaptation assessment—climate change and the water supply. *International Journal of Climate Change Strategies and Management,* 3(3), 302–319.

Hall, J., Murphy, C. and Sweeney, J. (2012) *Robust adaptation in the water sector in co-ordination, communication and adaptation for climate change in Ireland: an integrated approach.* EPA Climate Change Research Programme 2007–2013. Wexford: Environmental Protection Agency, Ireland.

McGrath, R., Lynch, P., Dunne, S., Hanafin, J., Nishimura, E., Nolan, P., Venkata Ratnam, J., Semmler, T., Sweeney, C., and Wang, S. (2008) *Ireland in a Warmer World. Scientific Predictions of the Irish Climate in the Twenty-First Century. Final Report of Community Climate Change Consortium for Ireland (C4I),* Dublin: Met Éireann

Murphy, C., Harrigan, S., Hall, J., Wilby, R.L. (2013a) *HydroDetect: the identification and assessment of climate change indicators for an Irish reference network of river flow stations.* Wexford: Environmental Protection Agency (In Press).

Murphy, C., Harrigan, S., Hall, J. and Wilby, R.L. (2013b) Climate-driven trends in mean and high flows from a network of reference stations in Ireland. *Hydrological Sciences Journal,* 58(4), 755-772.

Murphy, C. and Charlton, R. (2008) Climate Change and Water Resources. In Sweeney, J. ed. *Climate Change: Refining the Impacts,* Wexford: Environmental Protection Agency. 39-72.

Osborn, T.J., (2004). Simulating the winter North Atlantic Oscillation: the roles of internal variability and greenhouse gas forcing. *Climate Dynamics,* 22, 605–623.

Steele-Dunne, S., et al., (2008). The impacts of climate change on hydrology in Ireland. *Journal of Hydrology,* 356, 28–45.

Stephenson, D.B., et al., (2006). North Atlantic Oscillation response to transient greenhouse gas forcing and the impact on European winter climate: a CMIP2 multi-model assessment. *Climate Dynamics,* 27, 401–420.

Whitfield, P.H., et al., (2012). Hydrologic Reference Networks I. The status and potential future directions of national reference hydrologic networks for detecting trends. *Hydrological Sciences Journal*, 57(8), 1562–1579.

Wilby, R.L. and Dessai, S. (2010) Robust adaptation to climate change. *Weather,* 65, 180–5.