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# Climate Change Scenarios and Challenges for the Water Environment

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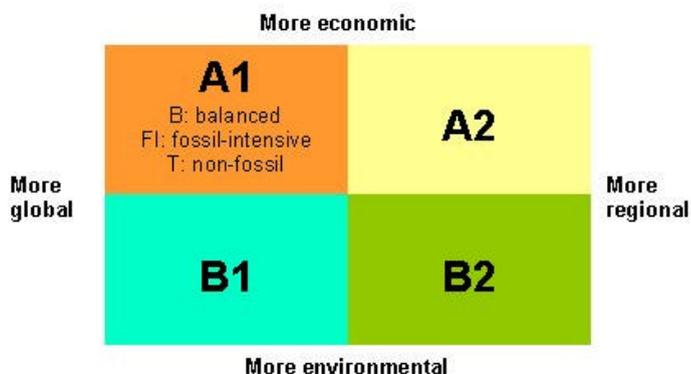
## Introduction

The provision of downscaled global circulation output is the first stage in assessing the implications of climate change for the water environment. Using only one global climate model Sweeney and Fealy, 2003 concluded that projected changes in climate will have potentially large effects on the water environment in Ireland, particularly on flood and drought frequencies. Increased winter runoff in western parts as a result of wetter winters and decreased summer runoff, especially in eastern Ireland as a result of substantial reductions in summer rainfall are projected. Considerable uncertainties however exist from such projections since they are based on only one GCM. These uncertainties limit the reliability of such climate scenarios for future water resource management since different GCMs tend to show different results for areas such as Ireland. This arises from inherent weaknesses they possess due to problems of scale and feedback. One way of addressing these uncertainties and providing more reliable inputs to hydrological models is to use multi-model downscaling, and this approach is presented here.

## Tackling Uncertainty

### **Model Uncertainty: The SRES Emission Scenarios**

Future estimates of greenhouse gas and aerosol loadings in the atmosphere cannot be forecast with a high degree of confidence for decades ahead. Ultimately these are dependent on population, economic growth and energy relationships, none of which can be projected with absolute confidence more than a few years ahead. To address this major uncertainty the Intergovernmental Panel on Climate Change employ a range of plausible future socioeconomic scenarios based mainly on UN projections which are then equated to greenhouse gas concentrations and aerosols Nakicenovic *et al* (2000). A range of 'storylines' is used of which four 'marker' scenarios are normally used to drive GCMs.



**Figure 1: SRES Scenarios**

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The A2 and B2 scenarios were selected for this study of future Irish climate scenarios. The A2 emissions scenario envisages a strengthening of regional and local with large disparities in wealth and well-being. Global population reaches 15 billion by 2100 with modest economic growth. Per capita income grows only slowly and less emphasis on environmental protection is apparent. Relatively high emissions are suggested by the A2 scenario. The B2 scenario sees population reaching about 10 Billion by the end of this century with global per capita income growing to about US\$12,000 by mid century. Income divergence between rich and poor nations diminishes with a gradual transition to renewables with a gradual decoupling of energy production and greenhouse gas emissions.

### **Downscaling Global Climate Models - Principles**

Despite major advances in computing in recent years the computing power needed to solve the equations of mass, energy and motion at thousands of grid points means that the horizontal resolution of Global Climate Models (GCMs) remains quite coarse. For most, grid sizes are approximately 300km, meaning that for many GCMs, Ireland is represented by only one grid square. This is not helpful for water engineers since many hydrological phenomena such as: convective rainfall, cloud, local winds etc., typically occur on finer scales. As a result, many hydrometeorological processes are often simplified for inclusion into a GCM. Clouds are particularly problematic since they occur at sub grid scale sizes and have complex feedback effects on global temperature changes

Discerning changes over space and time is also hindered by large grid sizes. This is problematical for Ireland since regional changes in precipitation will be the most important component of climate change and have significant effects on water availability at different seasons. There is therefore a scale discrepancy between what policy makers and environmental managers need and what GCMs can provide and a need exists to downscale GCM output in order to enable local scale impact analysis to be undertaken.

This study employs empirical statistical downscaling (SD) which has become increasingly used where high spatial and temporal resolution climate scenarios are required. Unlike Regional Climate Models which require large computing resources, statistical downscaling requires very modest computational resources and produces results that are comparable to RCMs. SD is based on the development of mathematical transfer functions between observed large-scale atmospheric variables and the local surface climatic variable of interest. The transfer functions are usually regression-based and are derived between a set of atmospheric grid scale predictors, output from both reanalysis projects and GCMs, and a single predictand.

SD requires a number of assumptions, the most important one being that the relationships between the observed predictor and predictand remain constant over time (Yarnal, 2001). It also assumes that the large-scale predictor variables are satisfactorily modelled by the GCM. Busuioc *et al.* (1998) found that GCMs were reliable at the regional scale with respect to precipitation and that the assumptions of validity of predictor-predictand relationship were reasonably robust for future conditions. Von Storch *et al.* (1993) suggested that the relationship between predictor and predictand should explain a large part of the observed variability and that the expected future changes in the mean climate should lie within the range of its already observed natural variability. This is generally valid for temperature though for precipitation the effect of 'local' factors can often be considerable. As a result the

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relationship between the large-scale predictors and local outputs is often weaker, especially in topographically diverse areas such as Ireland.

### **Downscaling Global Climate Models-Data**

Daily data for precipitation, temperature and sunshine hours from 14 synoptic stations were obtained for 1961-2000. Potential evapotranspiration, based on the Penman-Montieth formula, was obtained for the 1971-2000. Radiation was only available from a few of the synoptic stations. Large-scale surface and atmospheric data were obtained from the NCEP/NCAR Reanalysis project, regridded to conform to the output resolution of the various GCMs employed. Standardised reanalysis variables were then used as candidate predictor variables to calibrate the transfer functions, linking the large-scale surface and atmospheric variables to the daily precipitation series for each of the 14 synoptic stations.

GCM data for three models was obtained from the Hadley Centre (HadCM3), Canadian Centre for Climate Modelling and Analysis (CCCma) (CGCM2), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO Mark 2). For each GCM data runs with both the A2 and B2 emissions scenarios were obtained for the grid box representing Ireland.

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## **Downscaling Global Climate Models – Results for Ireland**

### **Calibration and verification**

Temperature varies much less than precipitation over space. For calibration and verification, daily maximum and minimum temperature data for the 1961-2000 periods were split into two periods. Acceptable results were obtained for the calibration and verification periods (Tables 1 & 2).

<b>Maximum Temp.</b>	<b>DJF</b>		<b>MAM</b>		<b>JJA</b>		<b>SON</b>	
<b>Stations</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>
<b>Valentia Observatory</b>	0.88	0.87	0.89	0.90	0.83	0.84	0.88	0.86
<b>Shannon Airport</b>	0.89	0.88	0.89	0.91	0.82	0.84	0.88	0.87
<b>Dublin Airport</b>	0.82	0.81	0.87	0.89	0.80	0.82	0.87	0.87
<b>Malin Head</b>	0.83	0.86	0.83	0.86	0.78	0.78	0.85	0.84
<b>Roche's Point</b>	0.89	0.88	0.85	0.87	0.76	0.80	0.86	0.87
<b>Belmullet</b>	0.85	0.86	0.85	0.87	0.79	0.79	0.86	0.85
<b>Clones</b>	0.86	0.85	0.87	0.90	0.81	0.82	0.87	0.86
<b>Rosslare</b>	0.90	0.90	0.86	0.86	0.74	0.79	0.87	0.87
<b>Claremorris</b>	0.87	0.86	0.87	0.90	0.79	0.82	0.86	0.86
<b>Mullingar</b>	0.88	0.88	0.87	0.91	0.80	0.85	0.87	0.87
<b>Kilkenny</b>	0.90	0.89	0.89	0.91	0.83	0.85	0.87	0.87
<b>Casement Aerodrome</b>	0.90	0.89	0.88	0.90	0.81	0.84	0.87	0.87
<b>Cork Airport</b>	0.90	0.89	0.87	0.89	0.80	0.84	0.87	0.87
<b>Birr</b>	0.89	0.88	0.89	0.92	0.83	0.85	0.87	0.87

**Table 1: Pearson's R values for the seasonal calibration and verification periods for maximum temperatures.**

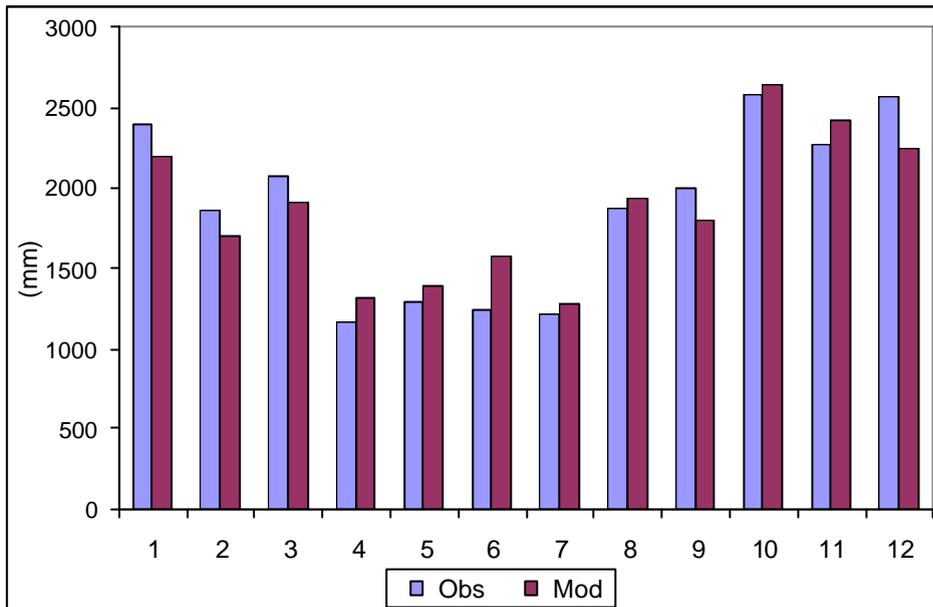
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<b>Minimum Temp.</b>	<b>DJF</b>		<b>MAM</b>		<b>JJA</b>		<b>SON</b>	
<b>Stations</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>	<b>Cal.</b>	<b>Ver.</b>
<b>Valentia Observatory</b>	0.83	0.81	0.82	0.81	0.73	0.74	0.84	0.85
<b>Shannon Airport</b>	0.84	0.83	0.84	0.86	0.77	0.80	0.88	0.89
<b>Dublin Airport</b>	0.79	0.81	0.83	0.85	0.75	0.81	0.88	0.89
<b>Malin Head</b>	0.77	0.80	0.80	0.82	0.72	0.74	0.84	0.83
<b>Roche's Point</b>	0.85	0.84	0.88	0.89	0.82	0.85	0.90	0.90
<b>Belmullet</b>	0.81	0.80	0.81	0.82	0.70	0.72	0.81	0.81
<b>Clones</b>	0.78	0.79	0.82	0.83	0.74	0.77	0.86	0.86
<b>Rosslare</b>	0.81	0.82	0.86	0.88	0.81	0.84	0.89	0.89
<b>Claremorris</b>	0.81	0.80	0.82	0.83	0.73	0.75	0.85	0.86
<b>Mullingar</b>	0.79	0.78	0.83	0.82	0.75	0.76	0.87	0.87
<b>Kilkenny</b>	0.78	0.77	0.79	0.79	0.71	0.73	0.83	0.85
<b>Casement Aerodrome</b>	0.80	0.80	0.82	0.82	0.75	0.77	0.87	0.88
<b>Cork Airport</b>	0.85	0.85	0.87	0.88	0.83	0.84	0.91	0.91
<b>Birr</b>	0.82	0.82	0.84	0.82	0.74	0.77	0.87	0.88

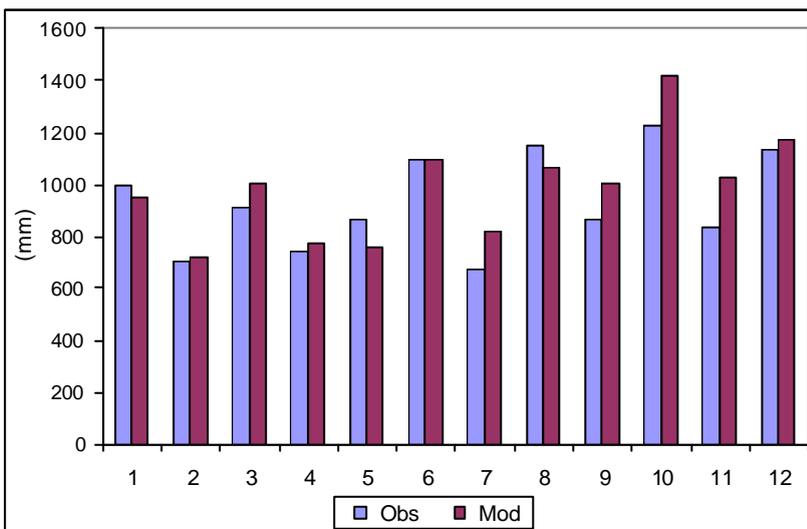
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**Table 2: Pearson's R values for the seasonal calibration and verification periods for minimum temperatures.**

A Generalised Linear Model (GLM) was used to model precipitation amounts. GLMs are useful for modelling rainfall series, as they do not require the dependent variable to be normally distributed. A log link function,  $g(\mu)$ , and gamma distribution were employed for the purposes of modelling precipitation amounts. This has been found to be an extremely good fit to precipitation amounts in a number of regions. Acceptable results were obtained for both east and west coast regions (Figures 2 & 3)



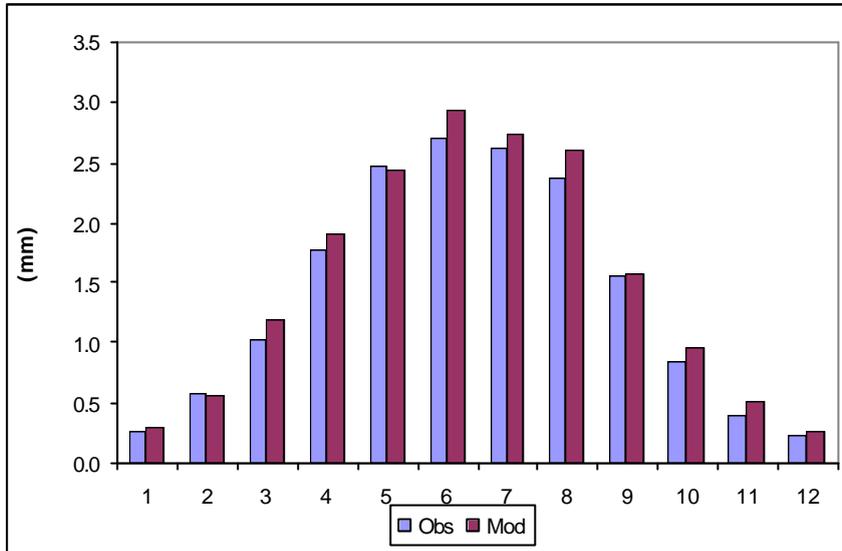
**Figure 2: Comparison of observed and modelled precipitation from Valentia, a west coast station with high annual receipts, for the independent verification period 1979-1993.**



**Figure 3: Comparison of observed and modelled precipitation from Dublin Airport, an east coast station with low annual receipts, for the independent verification period 1979-1993.**

Since global solar radiation is only measured at a limited number of stations, the Angstrom formula was used to convert sun hours to radiation (Angstrom, 1924; Brock, 1981). Radiation, precipitation occurrence and precipitation amounts were then used to calculate potential evapotranspiration (Figure 4). While wind plays an important role in potential evapotranspiration, it has a seasonal dependence, being more influential during the winter months and diminishing during the spring, summer and autumn months. As potential evapotranspiration values are at a minimum during the winter months, the exclusion of this

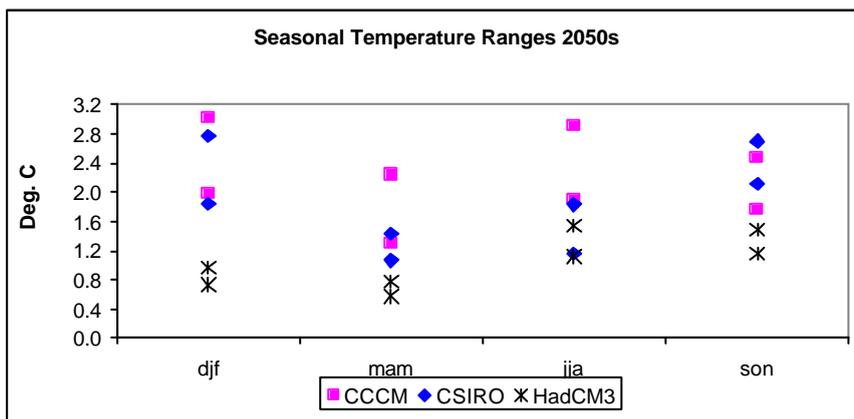
variable was considered unlikely to alter significantly the predicted values of potential evapotranspiration.



**Figure 4: Comparison of observed mean daily potential evapotranspiration from Kilkenny and modelled potential evapotranspiration for an independent verification period of 1991-2000.**

### Scenario Results

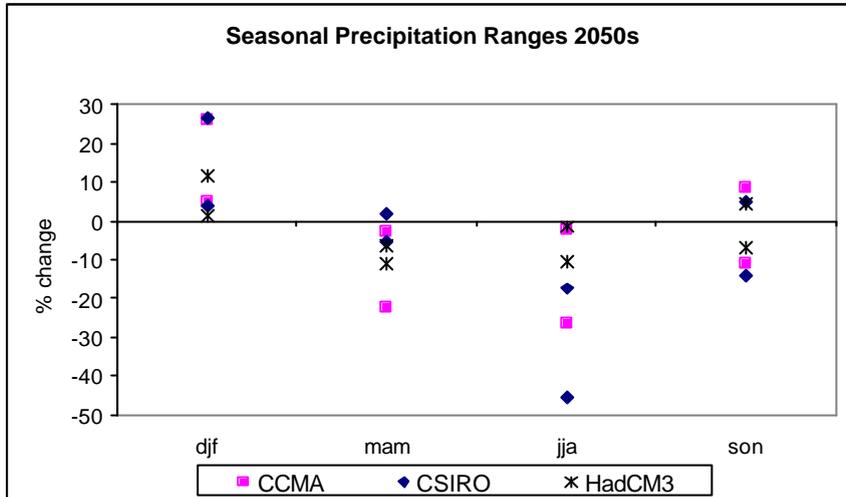
For the A2 emissions scenario for the 2050s the locations showing the largest change and the smallest change in temperature for the different GCMs are illustrated in Figure 5. In general, the CCCM GCM shows the largest amount of seasonal change. The differences shown largely arise due to different GCM model climate sensitivities or equilibrium temperatures under a doubling of the pre-1990 atmospheric CO<sub>2</sub> concentrations.



**Figure 5: Seasonal temperature ranges for stations showing the smallest and greatest changes for the A2 emissions scenario**

For precipitation, the stations showing the largest and smallest percent change for the different GCMs are shown in Figure 6 for the A2 emissions scenario. All models suggest an increase in winter and a decrease in summer rain with the largest increases in winter

demonstrated by the CCMA GCM. These differences demonstrate the importance of using a number of GCMs when conducting impacts analysis due to the various uncertainties that cannot be accounted for when employing just one GCM.

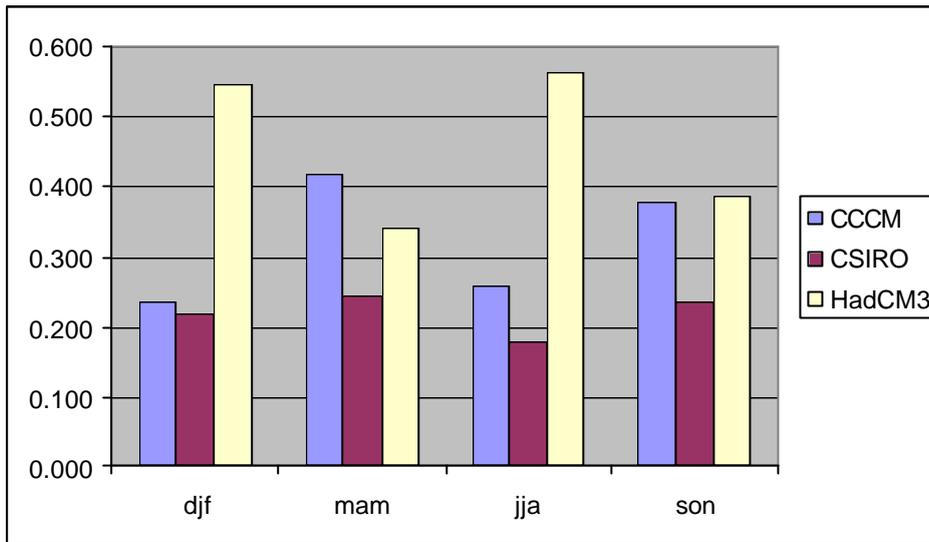


**Figure 6: Seasonal precipitation ranges for stations showing the smallest and greatest changes for the A2 emissions scenario**

### *Ensembles*

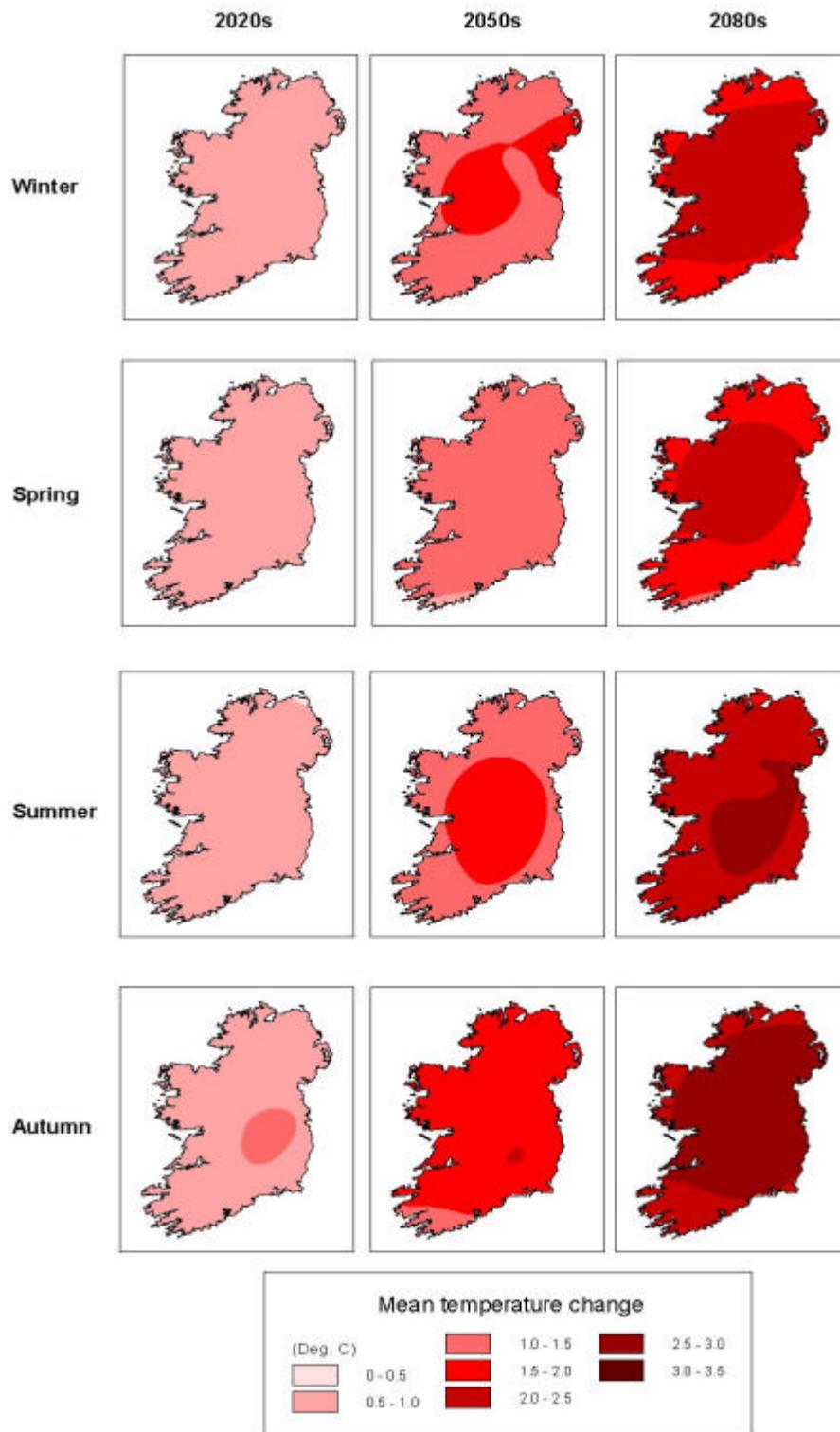
The fact that different GCMs produce different regional climate responses even when run with the same emissions data has long been recognised. Despite this, until recently many impact studies employed only one climate change scenario, based on only one emissions scenario and a single GCM. This could be considered unsound (Hulme and Carter, 1999). An alternative approach incorporating ensembles or weighting of the downscaled results was used in this study. Weighting was based on the particular GCMs ability to reproduce the properties of the observed climate, derived from the root-mean-square difference between modelled and observed climatological means, calculated over the baseline period (Wilby and Harris, 2006).

Mean ensembles, produced from the weighted averaging described above, implies that by the 2020s, average temperatures across Ireland will have increased by 0.75-1.0°C (Figure 8). By the 2050s, Irish temperatures will have increased by 1.4-1.8°C, with most warming occurring during the autumn. An enhanced ‘continental’ effect is seen to occur during all seasons, especially during the 2080s when the mean temperature in all seasons is suggested to increase by 2°C or more. Summer increases in the order of 2.5-3.0°C are indicated from the ensemble mean.

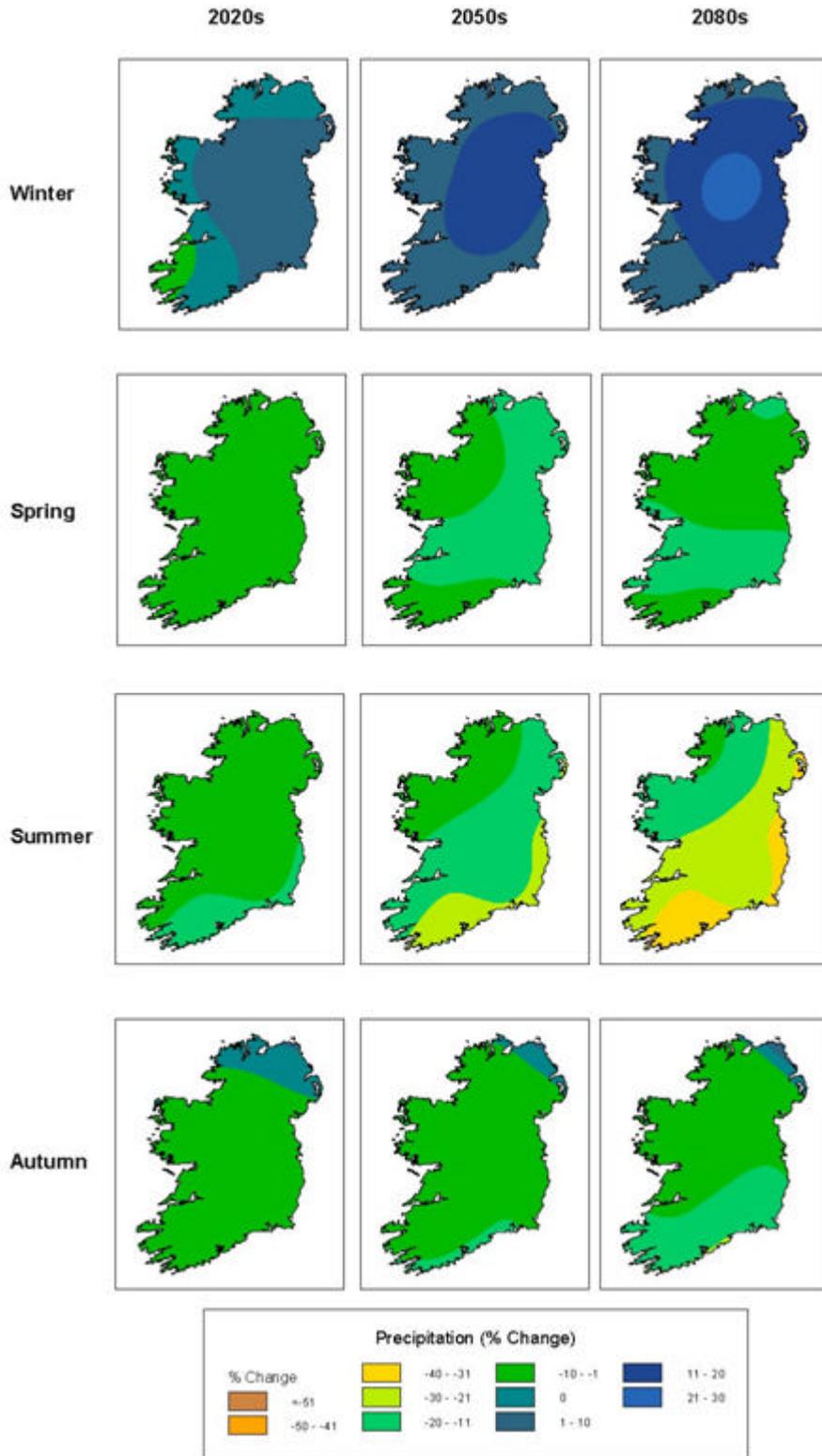


**Figure 7: Seasonal weights derived from the CPI score for each of the GCMs to produce the weighted ensemble mean.**

Winter precipitation is likely to increase slightly by the 2020s, by between 0.7-3.7% (Figure 9). The greatest seasonal changes are suggested for summer, with a reduction of 8.5% for the ensemble mean. However, reductions of between 10-16% are suggested for regions along the southern and eastern coasts. By the 2050s, changes range from a 10% increase in winter to reductions of between 12-17% in summer. While increases are experienced along the east coast and midlands during winter, reductions of between 20-28% are projected to occur along the southern and eastern coast during the summer season. If realised, these changes are likely to have a large impact on hydrology in Ireland. These seasonal and spatial changes in precipitation are further enhanced by the 2080s, with winter increases of 11-17% and summer reductions of between 14-25%.



**Figure 8: Mean temperature increases for each season and time period**



**Figure 9: Percentage Changes in precipitation for each season and time period**

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The largest percentage increases in winter precipitation are projected to occur in the midlands, of up to 20%, while the largest reductions during the summer months are again projected to occur along the southern and eastern coast, which are likely to experience decreases of between 30-40% during these months.

### **Key future impacts for water management in Ireland**

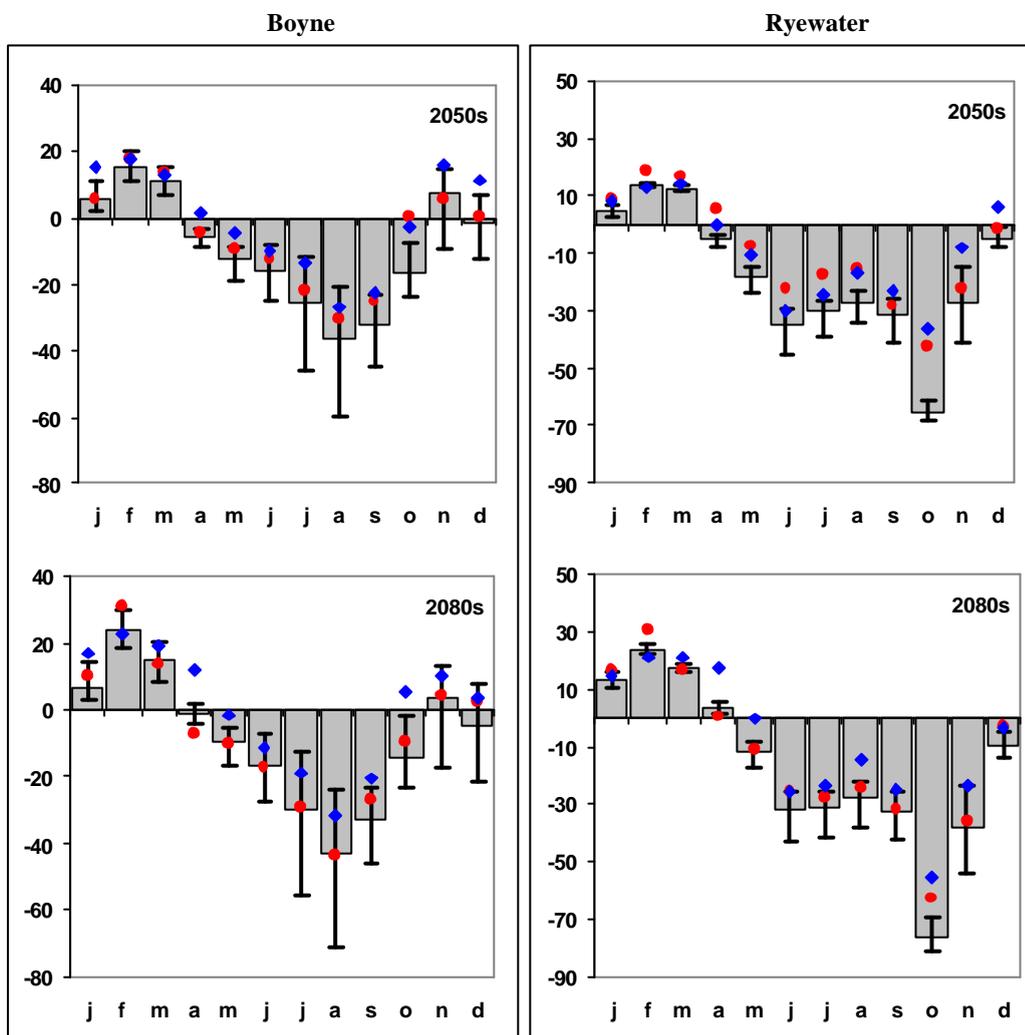
Changes in climatological variables of the magnitude highlighted above would have serious implications for catchment hydrology and water resource management. In order to assess these impacts the climate scenarios and ensembles generated were used as input to a conceptual rainfall-runoff model, which was calibrated and validated for nine catchments throughout the country. So as to continue the cascade of uncertainty in climate impact assessment uncertainty derived from the parameterisation of the rainfall-runoff model was also captured. Changes in soil moisture and groundwater storage, monthly streamflow and extreme events were derived for each catchment. While full consideration of these impacts is beyond the scope of this paper, this section will highlight the most salient findings of this research. Further insight into the likely impacts of climate change on aspects of water management will also be considered in other papers in this workshop.

In terms of groundwater storage, lower levels of recharge and thus lower groundwater levels are likely to result in a shift in the nature of groundwater-surface water dynamics for entire rivers (Scibek and Allen 2005). For each of the catchments elevated water levels persist into the early summer months. However, from late summer to the end of the year, water levels are generally lower than at present. Given the magnitude of changes for many of the catchments analysed, the possibility exists for low-lying streams to become perched above the water table during times of low groundwater storage and thus lose water to groundwater. Under current conditions the late autumn and winter recharge period is critical to sustaining groundwater levels throughout the year. By mid to late century, significant reductions in storage during this time of the year will increase the risk of severe drought, as the failure of winter or spring precipitation may result in prolonged drought periods where the groundwater system is unable to recover from previous dry spells. Such impacts would be greatest in catchments where groundwater attenuation is greatest, (E.g. the Suir, Blackwater and Barrow). Changes in the characteristics of winter precipitation may also have significant implications for groundwater recharge. Prolonged rainfall is more effective at recharging groundwater levels, however, climate change is likely to result in shorter, more intense periods of precipitation becoming more frequent, thus decreasing the amount of water that is infiltrated to storage (Arnell and Reynard, 1996). Reductions in groundwater of the magnitude simulated may have significant implications for groundwater supplies. Unfortunately, it is the areas where reliance on groundwater supplies is greatest that the most significant reductions in groundwater storage are suggested.

In terms of surface water, simulations indicate that all catchments will experience decreases in streamflow, with greatest decreases in the majority of catchments likely to occur in the late summer and autumn months, when water provision is already problematic in many areas. Two broad responses between catchments were recognised. For runoff dominated catchments such as the Boyne the most extreme reductions in monthly streamflow were shown for the summer and autumn months. On the other hand, for catchments with large groundwater storage capacity (e.g. the Suir, the Blackwater and the Barrow) reductions in flow during

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summer months were offset by contributions from storage, however, in these catchments substantial reductions were also found for autumn months. The most extreme reductions in surface water are simulated for the Ryewater and Boyne (Figure 10). Unfortunately, these catchments are the most heavily populated in the analysis and comprise a substantial proportion of the Greater Dublin Area (GDA). Added to this is the fact that non-climatic drivers of water demand in the past will be supplemented by climate change. Herrington (1996) in studying the impact of climate change on water consumption in the UK suggests that a rise in temperature of about 1.1°C would lead to an increase in average domestic per capita demands of approximately 5%. Peak demands are likely to increase by a greater magnitude, while the frequency of occurrence of current peak demand is also likely to increase (Zhou *et al.*, 2001). From the simulations conducted, it is during times of the year that demand is greatest (summer and autumn), that the greatest reductions in surface water resources are likely.



**Figure 10** Changes in monthly streamflow for the Boyne and Ryewater by the middle and end of century for the A2 (red), B2 (blue) and mean (columns) ensembles. Error bars represent uncertainty for the mean ensemble

Furthermore, increases in evaporation are likely to result in increased losses from storage reservoirs. It is also important to note that it is not just the domestic sector from which pressures are likely to increase, with agricultural demand being particularly sensitive to climate change. Reductions in soil storage of the extent suggested in many catchments may require the implementation of irrigation practices for particular crops.

One of the most high-profile impacts of climate change is on flood frequency and risk with major areas of concern relating to the integrity of flood defences, planning and development control, urban storm drainage and the implications for the insurance industry. In order to assess the impact of climate change on future flood events two flood indicators were examined; the *severity* of flood events; described by the change in magnitude of flood events of a fixed return period and the *frequency* of flood events; described by the change in the

return period of a flood of a given magnitude. Changes in the frequency of selected flood events for each of the catchments studied for HadCM3 for each scenario and time period are shown in Table 1. Substantial increases in frequency are shown for many catchment, for example, in the Boyne catchment the current 25 year event is suggested to become almost a 3 year event by the 2080s under the A2 scenario.

		Barrow	B'water	Boyne	Brosna	Inny	Moy	R'water	Suck	Suir	
T2	20s	1.8	1.8	1.9	2.1	2.5	1.6	1.6	1.5	1.8	
	A <sub>2</sub>	50s	1.6	1.5	1.4	1.5	1.4	1.5	1.4	1.4	1.7
		80s	1.3	1.4	1.2	1.3	1.2	1.3	1.5	1.2	1.5
		20s	1.8	1.5	1.4	1.8	1.6	1.4	1.4	1.4	1.8
	B <sub>2</sub>	50s	1.6	1.5	1.4	1.4	1.3	1.4	1.7	1.4	1.8
		80s	1.5	1.5	1.3	1.3	1.3	1.4	1.6	1.4	1.6
T10		20s	4.8	3.6	7.1	13.9	12.7	4.2	3.4	4.4	4.4
	A <sub>2</sub>	50s	4.8	4.2	3.4	3.4	4.5	4.4	3.3	4.5	6.9
		80s	3.4	3.4	1.8	2.0	2.0	2.2	4.1	2.1	3.2
B <sub>2</sub>		20s	3.7	2.6	2.3	4.0	4.1	2.2	3.5	2.4	4.1
	50s	4.0	2.6	3.5	3.0	3.5	4.6	5.5	5.5	4.1	
	80s	2.9	3.8	2.2	2.1	2.3	3.9	5.4	4.6	2.8	
T25	20s	8.3	5.1	15.1	39.3	26.4	7.7	5.3	8.8	6.5	
	A <sub>2</sub>	50s	10.1	7.3	5.6	4.9	7.5	8.5	5.5	9.7	16.9
		80s	6.7	5.3	2.3	2.8	2.7	3.1	6.9	3.0	4.7
		B <sub>2</sub>	20s	5.5	3.2	3.0	5.6	6.6	3.0	6.4	3.5
	50s		7.7	3.4	6.9	4.5	6.1	10.3	11.0	14.2	5.8
	80s		4.6	6.6	3.2	2.6	3.2	8.2	12.8	13.8	3.7
T50	20s	12.6	6.5	26.8	85.1	26.4	12.3	7.6	8.8	8.4	
	A <sub>2</sub>	50s	18.3	11.1	8.2	6.4	10.6	13.9	8.1	17.8	34.4
		80s	11.5	7.3	2.9	3.8	3.3	4.0	10.2	4.0	6.2
		B <sub>2</sub>	20s	7.4	3.8	3.7	7.2	9.4	3.9	10.2	5.2
	50s		13.2	4.1	12.0	6.1	9.1	19.6	18.5	29.7	7.2
	80s		6.8	10.1	4.2	3.1	4.1	15.0	25.5	35.9	4.5

**Table 3 New return periods derived for the flow associated with the 2, 10, 25 and 50 year floods under the control period for the HadCM3 A2 and B2 climate scenarios**

Figure 11 shows the changes in severity of flood events for the Boyne and the Suir catchment. Confidence limits were calculated to assess whether changes in flood magnitude were significant outside of the range of natural variability shown for the control period. Two distinct responses were derived from the catchments analysed. Significantly the largest increases in the severity of flood events were derived for runoff dominated catchments such as the Boyne, while changes for each future time period were not as great for groundwater dominated catchments. As an example of the latter Figure 11 shows changes in the magnitude of flood events for the Suir where, for all future time periods and both scenarios changes are within the bounds of natural variability.

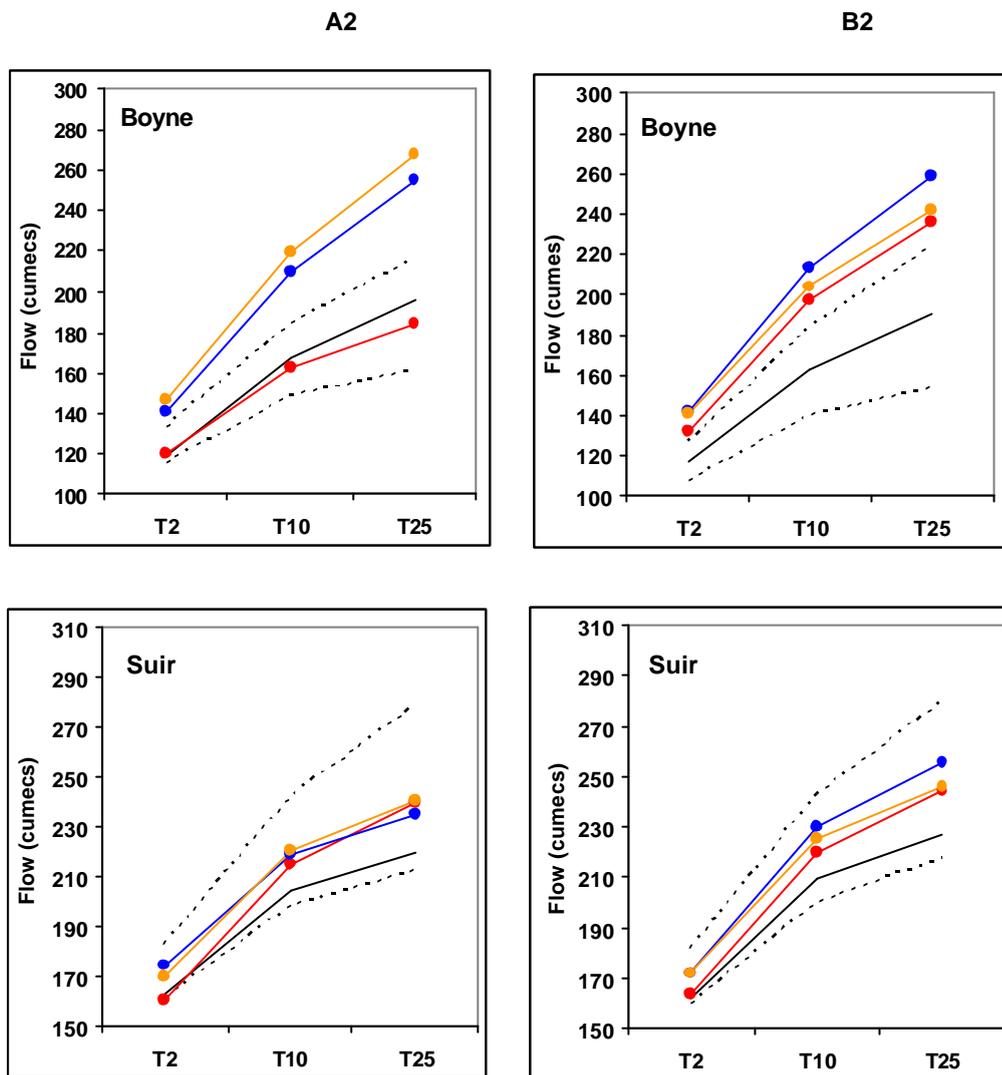


Figure 11 Changes in the severity (magnitude) of selected flood events for the 2020s (red), 2050s (blue) and 2080s (orange). Each point represents the average value for that return period from each future run. Error bars represent natural variability for the control period 1961-1990.

### Adapting to future change

Modern approaches to water management have been founded on the ability to react and adapt to changing pressures and demands with adaptation historically based on reactive measures that are triggered by past or current events, or anticipatory measures where decisions are based on assessment of future conditions (Adger *et al.*, 2005). While such decision-making practices are unlikely to change in the future, increasing importance must be placed on the anticipation of impacts. Traditionally such anticipatory measures have been built on the premise that the past is the key to the future. Changing trends in many important hydrological time series such as rainfall intensity and maximum flood peaks have introduced non-stationarity, with the result that past events can no longer be relied upon in driving future decision-making. Added to this is that fact that climate change impact assessment is

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necessarily uncertain, thus adding to complexities in decision making. Therefore adaptation to climate change presents new challenges to water resources management, requiring innovative approaches to complex environmental and social problems.

The wide range of potential impacts derived from uncertainty in modelling climate change has major implications for deciding on successful adaptation options (see uncertainty ranges for monthly streamflow in Figure 10). In light of these uncertainties it is bad practice to base adaptation options on output from a single GCM or scenario. In such cases there is a significant risk of over or underestimating impacts, with substantial societal, environmental and economic consequences. Rather, we need to use multi-model ensembles that provide representative uncertainty ranges for impacts. Furthermore, there is a requirement to establish a set of industry standard climate scenarios, which need to be continually updated as more refined scenarios come on line, which can be used in advising policy implementation throughout the water sector. While it is important to bring on board emerging decision support tools and uncertainty frameworks in generating climate change scenarios, uncertainty will always be an important challenge to adaptation. Therefore we need to begin the task of identifying potentially successful adaptation options that are robust to uncertainty, while striving to minimize uncertainty in climate change impact assessments.

Historically, water management has been largely concentrated on the physical control of water and economic cost benefit analysis, where the allocation of economic worth to many natural resources has been underestimated. Internationally, the recent shift towards the integrated assessment of water resources has resulted in a less narrowly focused and disjointed approach to management and the movement away from small scale site specific hard engineering approaches, to dealing with water management issues holistically at the catchment scale. This shift reflects developments at the European level through the Water Framework Directive. Integrated management offers considerable potential to decision-making in adapting to climate change. Characteristic of such an approach is the consideration of multiple pressures (not just climate change) and multiple stakeholders, the ability to further understand the interaction between nature and society, as well as the ability to model the impact of critical decisions over a range of scales. Indeed through its objective of integrated assessment at the catchment scale and the coherent management framework adopted; from the European through to local levels, the Water Framework Directive offers huge potential as a legislative and management tool in adapting to climate change. Furthermore, the Water Framework Directive allows for the economic appraisal of measures, covers a range of impacts from water quantity to quality and establishes catchment management plans involving local partnerships which are subject to revision as understanding increases and uncertainty decreases.

The role of technology has been essential in water resources management and is likely to remain so into the future. The emphasis placed on technology in adaptation is largely dependant on economic conditions, policy initiatives and future scientific breakthroughs, with perhaps the greatest potential in water supply management. At present, options such as improved water treatment and reuse, deep well pumping, the transfer of resources between catchments and desalinisation are becoming ever more accessible. However, it is of prime importance that the employment of technology in adapting to climate change be environmentally sustainable (some adaptation options may hold intensive energy

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requirements, where this energy is fossil fuel based these options may counter mitigation strategies) with equity fairly distributed between all resource stakeholders.

### **Conclusion**

While climate change globally is predominantly associated with increases in temperature, the largest impacts in Ireland will be felt due to changes in precipitation regimes. With increases in the amount and intensity of rainfall during the wetter months coupled with reductions in rainfall and increases in evaporation during the summer and autumn, the ability to adapt our water management systems will be critical to ensuring the wellbeing of future generations in Ireland. While many challenges are faced, early action to reduce impacts through adaptation measures will avoid damages and the need for increased expenditure at a later date. From a societal, institutional and operational perspective we need anticipatory action now. We cannot suddenly start adapting to climate change in 30 years time. The successful management of future water resources and the capacity to adapt to a changing climate will be dependent on our ability to incorporate both technological and scientific advances into decision-making processes in an integrated and environmentally sustainable fashion. With this in mind, adaptation should be focused on reducing the sensitivity, increasing the resilience and altering the exposure, through preparedness, of both society and our water management systems to the effects of climate change. Therefore decisions we make today need to ensure that we are on the right adaptation, technological and policy development pathways.

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