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CLIMATE CHANGE AND WATER RESOURCES IN IRELAND: INITIAL INVESTIGATIONS USING DOWNSCALED GCMS AND HYDROLOGICAL MODELLING TECHNIQUES

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ABSTRACT: Predictions are made of changes in effective runoff at a high spatial resolution for the island of Ireland under different climate change scenarios. Although previous studies have examined the response of selected Irish catchments to future climate scenarios this is the first time that the whole area of the island has been considered. This paper discusses the initial investigation that has been carried out and outlines research currently in progress.

Polynomial regression techniques are used to derive a baseline climatology for Ireland. Downscaled precipitation and evaporation data from the United Kingdom Climate Program (UKCIP) for the Medium-low 2080 scenario is used together with the baseline data for the initial investigation. The precipitation and potential evaporation (PE) data are converted to a suitable form for input to HYSIM. Two sets of simulations are carried out for 825 10 x 10 km grid squares covering the land area of the island of Ireland for the baseline period and the 2080 scenario. The hydrological parameters for each of these squares are considered to be identical for this initial investigation. The results of this investigation are presented.

Future work is considered, focusing on the parameterisation of HYSIM for individual grid cells. The initial investigation demonstrates that the representation of storage is of particular importance. Parameter values are derived for each square using data from the Soil Survey of Ireland, the CORINE land use database and information on major aquifers provided by the Geological Survey of Ireland. The flexible data requirements of HYSIM allow some representation of the diverse hydrological conditions found within Ireland. For example, approximately 40% of Ireland is underlain by limestones, many of which are karstified. These karst aquifers are an important water resource and can respond very rapidly to precipitation inputs. There are also extensive areas of lakes and wetlands. The land area is divided into broad hydrological zones to provide some representation of this variability.

RESUMEN: En este trabajo se predicen con alta resolución espacial los cambios en escorrentía para la isla de Irlanda bajo diferentes escenarios de cambio climático. Aunque estudios anteriores han examinado la respuesta de cuencas irlandesas frente al cambio climático, ésta es la primera vez que se considera la totalidad de la isla.

Se han utilizado técnicas de regresión polinomial parta obtener una base climática de Irlanda. Los datos de precipitación y evaporación se han simulado a partir del Programa Climático del Reino Unido para un escenario del año 2080. La precipitación y la evaporación potencial se han adaptado para incorporar al modelo HYSIM. Dos conjuntos de simulaciones se han llevado a cabo para 825 cuadrículas de 10 x 10 km.

La investigación realizada demuestra que la representación del almacenamiento de agua en el suelo y en el sustrato es de capital importancia. Los valores se han derivado del mapa de suelos de Irlanda, la base de datos de uso del suelo de CORINE e información sobre los principales acuíferos, proporcionada por el Servicio Geológico de Irlanda. La flexibilidad del modelo HYSIM permite la representación de las diversas condicionbes hidrológicas de Irlanda. Por ejemplo, aproximadamente el 40% de Irlanda está formado por calizas, muchas de ellas karstificadas. Estos acuíferos kársticos son un importante recurso hídrico y pueden responder muy rápidamente a los inputs de precipitación. También hay extensas áreas ocupadas por lagos y humedales. La superficie de la isla se ha dividido en amplias zonas hidrológicas con el fin de representar esta variabilidad.

Key-words: Climate change, Runoff changes, Water resources evaluation, Hydrological modelling, Ireland.

Palabras clave: Cambio climático, Cambio hidrológico, Evaluación de recursos hídricos, Modelización hidrológica, Irlanda.

1. Introduction

Instrumental records indicate a rise of 0.3-0.6ºC since 1860 with an acceleration of global warming during the 20th century. These observations could be due to natural variability and/or human influences. Changes in the amount and in the spatial and temporal distribution of precipitation have been associated with this climate signal. In Ireland changes in the synoptic pattern of Irish precipitation have been investigated by Houghton and O'Cinneide (1976), Sweeney (1985) and Sweeney and O'Hare (1992). Kiely (1999) tested observations of precipitation and runoff for climatic and hydrological change and found that an increase in annual precipitation had occurred at 8 precipitation stations after 1975 and that this effect was most noticeable on the west of the island. Streamflow records for 4 rivers were found to show the same trends. Kiely associated the change that occurred in the North Atlantic Oscillation around 1975 with an increased westerly airflow circulation in the northeast Atlantic which is correlated with wetter climate in Ireland. Future changes in climate are likely to have major impacts on regional and local runoff patterns. This may influence the annual and seasonal availability of water resources with significant implications for water resource use, water quality management and strategies, as well as flood/drought hazard indices in Ireland.

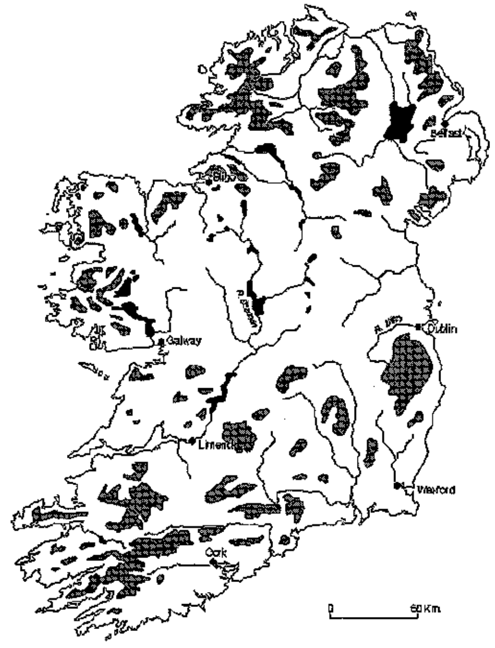

Figure 1: Map of Ireland showing the main rivers and lakes. Upland areas are shaded in grey.

Compared with much of Europe Ireland is relatively well endowed with water, although the rapid expansion of urban areas such as Dublin, Cork and Limerick (Figure 1) associated with present economic conditions, is putting an increasing strain on the water supply infrastructure. Low flows are more frequent as a result and this in turn reduces the availability of water to dilute effluent discharged into rivers, with obvious implications for water quality. The increased demand for water comes mainly from the industrial and domestic sectors with domestic demand increasing both as a result of increased population and per capita consumption increases. Most of the water supplied in Ireland is surface water with between 20% and 25% supplied from groundwater. In some counties the groundwater proportion is much greater and in many rural areas with no access to a public or group supply scheme groundwater from wells provides the only source of water (Daly and Warren, 1998). As well as being an important source of water, groundwater is also very important in maintaining base flow. Changes in groundwater storage or in any of the other stores including lakes, peatlands, riparian areas and soil moisture would have a considerable impact on low flows and water availability for crops.

Although a number of studies have investigated the impact of predicted future climate scenarios on water resources for Britain (Arnell, 1996; Arnell and Reynard, 1993, 1996; Pilling and Jones, 1999) very little work has so far been carried out for Ireland. Cunnane and Regan (1991) investigated the effect of 4 climate scenarios produced by modifying the precipitation and PE on the runoff from the catchment of the River Brosna, a tributary of the Shannon. To date there has not been any attempt to model effective runoff for the whole land area of Ireland under under future climatic scenarios although Ireland's water budget for the period 1961-1990 has been modelled at a 5 x 5 km resolution by Mills (2000). The main aim of the research outlined here is to model effective runoff for the whole island of Ireland at a high spatial resolution in order to identify changes in seasonal and annual effective runoff.

2. Methodology

This section will concentrate mainly on the application of the downscaled data to predict changes in effective runoff. The downscaling techniques used will only be briefly outlined here but further information may be obtained from Sweeney and Fealy (2001). The aim of the initial investigation was to provide some insight into possible future changes in runoff at the 10 km^2 spatial resolution for the island of Ireland.

2.1. Baseline climate data

Monthly climate data for both the Republic of Ireland and Northern Ireland for the period 1961-90 were obtained from Met Éireann and from the British Atmospheric Data Centre of the UK Meteorological Office. In total this consisted of 560 precipitation stations, 65 for temperature, 14 for PE and 14 for radiation. Polynomial regression techniques were used to derive a baseline climatology for Ireland at a scale of 1 km^2 (this spatial resolution was selected because the climate data is also being used to drive agricultural and ecological models as part of a larger project). Monthly climate variables were related to position and elevation on a digital elevation model and these were found to provide good predictors for precipitation, maximum and minimum temperature and sunshine hours. Baseline maps for mean monthly radiation receipt and potential evapotranspiration were also derived at 1 km^2 scales.

2.2. Hydrological model

The hydrological model selected is the process-based conceptual model HYSIM (Manley, 1978, 1993). This has previously been used in a number of applications, including those examining the effects of climate change on hydrological water resources (Pilling and Jones, 1999). The approach taken to model the effective runoff is based on that of Pilling and Jones who examined the implications of climate change scenarios on runoff in Britain at a 10 x 10 km spatial resolution. HYSIM has a number of advantages for this type of application, being flexible in its data requirements and providing a range of output data which includes simulated streamflow, simulated storage in each conceptual reservoir (e.g. upper and lower soil moisture, groundwater) and simulated transfers between these reservoirs.

2.3. Initial investigation

Two sets of HYSIM simulations were carried out, one for the baseline period and the second for a future climate scenario in order to gain an initial impression of changes in runoff and storage. For these first pass simulations the land area of Ireland was assumed to be hydrologically homogenous with identical hydrological parameter values assigned to each grid square. The ongoing work of parameterising the model for each of the 825 grid squares covering Ireland is described in the next section. Since the future climate scenario downscaled data was not yet complete, precipitation and PE data from the UK Climate Impacts Programme (UKCIP) were used instead (Hulme and Jenkins, 1998). This data has been downscaled from the HadCM2 GCM to a 10 x 10 km spatial resolution over the land area of Britain and Ireland using a delta change technique. The UKCIP Medium-low scenario for 2080 was used for this study.

The precipitation and PE data were converted to input files in HYSIM format for each of the grid squares. The mean monthly precipitation was divided by the number of days for each month to provide a daily precipitation input for HYSIM. The HYSIM input files contained two identical years of precipitation and PE data in order to allow one year as a run in period for the model. Standard values for the hydrological parameters representing 'average' hydrological characteristics for Ireland were used (Manning 1993) with the same parameter file used for each grid square. Once these model simulations had been carried out, annual and seasonal predictions of effective runoff were calculated from the HYSIM output data files for each square and the percentage change between these was calculated and analysed using ArcView.

3. Initial Results

The predicted annual and seasonal changes in runoff patterns are shown in Figures 2-5. These results should be examined with some degree of caution since the statistical downscaling technique used for the baseline data differs from that used for the UKCIP scenario. This may mean that some of the apparent changes are due to this. It is also important to remember that the HYSIM simulations were carried out for a hydrologically homogenous Ireland, meaning that patterns of precipitation and potential evaporation will have a much greater influence on the predicted runoff patterns than they would otherwise. As a result the predicted runoff patterns broadly reflect the changes observed in patterns of precipitation and potential evaporation between the baseline period and UKCIP 2080 Medium-low scenario. In terms of the annual effective runoff (Figure 2), a decrease is observed for almost 80% of the land area. This is most marked in the south-west, parts of the Midlands and also in the north-east. Increases in runoff are observed for some areas, and are consistent with changes in precipitation patterns. These areas include the mountains of Donegal (north-west), the Wicklow Mountains to the south of Dublin and the Mourne Mountains on the east coast between Dublin and Belfast. It is possible that this effect may have been brought about or exaggerated by differences in the areal averaging techniques used in downscaling the precipitation data since the areal averaging technique used for the baseline data tended to under represent precipitation for some upland areas. This is currently being investigated further.

Runoff patterns for the winter months (December, January and February) are shown in Figure 3. There is a reduction in effective runoff for approximately 60% of the land

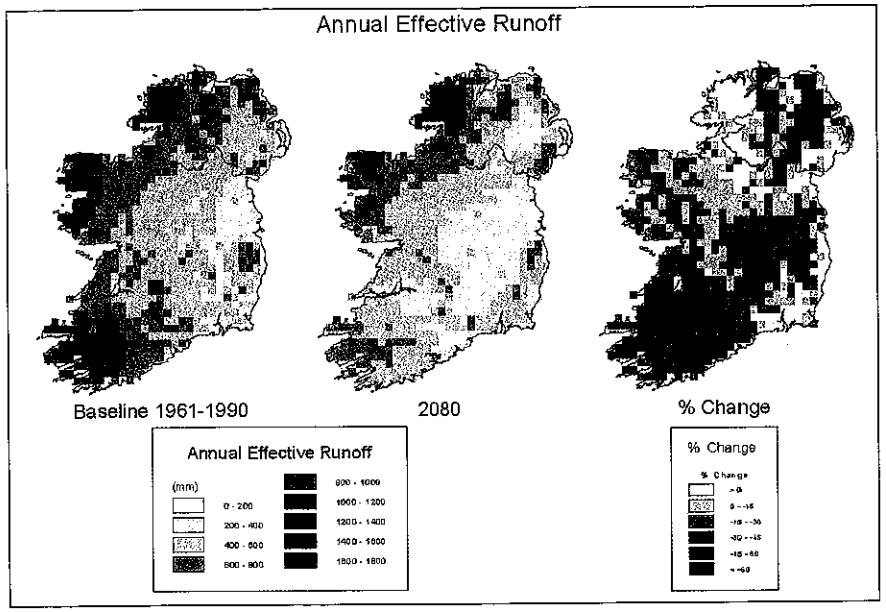

Figure 2: Baseline and 2080 patterns of annual runoff and percentage decrease. Squares for which an increase occurs are unshaded.

area which occurs despite increases in precipitation for some of these squares. Changes in storage predicted by HYSIM by examining output files for selected squares for groundwater storage and water stored in the upper and lower soil horizons. In general these stores were found to be lower at the end of summer for the 2080 scenario than under baseline conditions. This would mean that a greater percentage of the winter precipitation excess would be required for recharge which could account for the lower effective runoff observed for these months. An increase in winter runoff is observed for approximately 35% of the island. Figure 4 shows these areas (squares with a decrease in runoff are unshaded for this particular map) which include a significant proportion of the upper Shannon basin. This river has a long history of seasonal flooding and has a very low gradient for much of its course so an increase in winter effective runoff could have major implications. An increase in runoff is also observed for the east coast, including the Wicklow mountains south of Dublin from which rivers with steep mountainous headwaters subsequently flow through the urban areas of Greater Dublin. Since this study considers annual and seasonal changes it is not possible to speculate on possible changes in the magnitude and frequency of floods although it may be possible to comment on the seasonal flooding which affects parts of the low-lying Irish Midlands.

During the summer months (June, July and August) a decrease in effective runoff is predicted for most areas and is especially marked in the south-west as well as parts of the Midlands, west coast and north-east (Figure 5). Changes in ground and soil water storage were examined for selected squares on a month by month basis. For squares in the north-west, where changes were relatively small, differences in groundwater storage

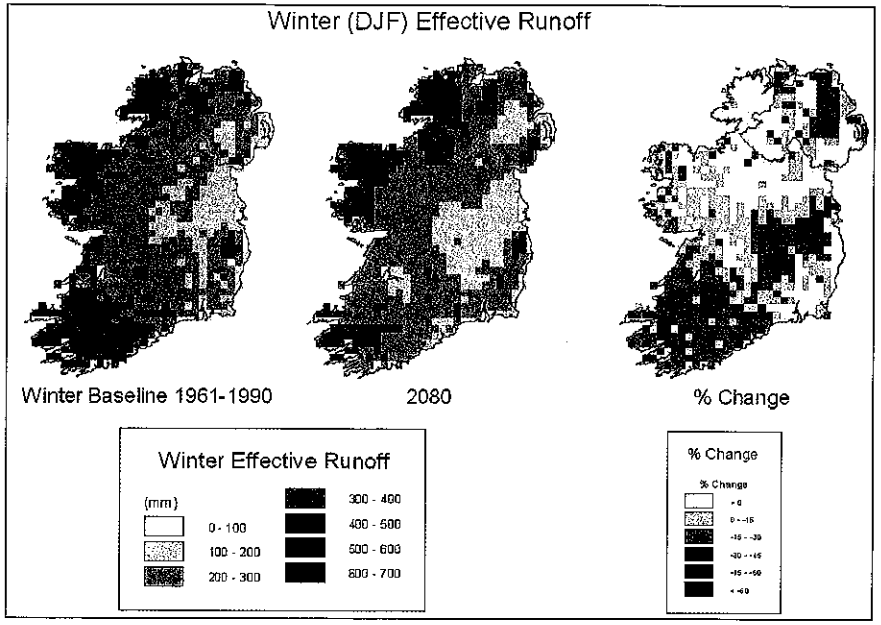

Figure 3: Baseline and 2080 patterns of winter (December, January, February) runoff and percentage decrease.

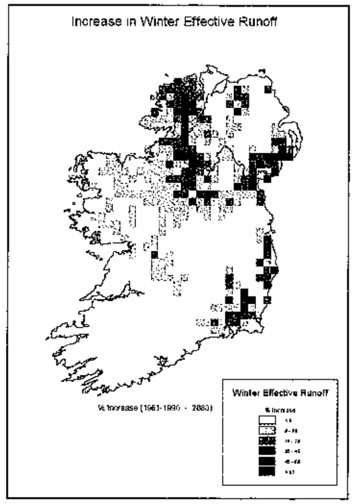

Figure 4: Percentage increase in winter (December, January, February) runoff. stores and how these affect flows.

were greatest during the spring and summer months. A delay of approximately two weeks was observed for the onset of groundwater recharge in the autumn. These effects are much greater for squares in the south-west where the duration of the winter recharge period is reduced by one month at the end of winter, ceasing in early February. Recharge does not start until October, which is significantly later than for the baseline period when

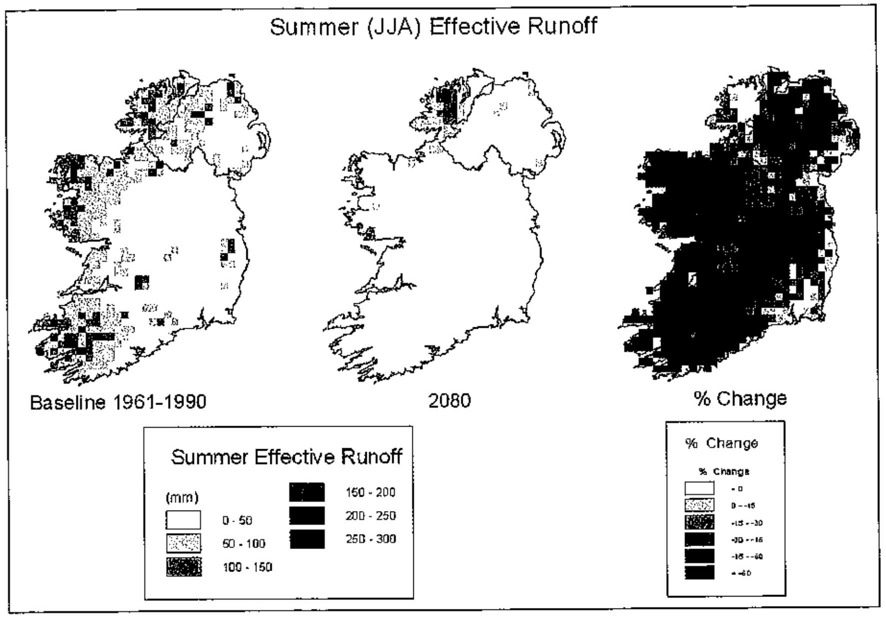

Figure 5: Baseline and 2080 patterns of summer (June, July, August) runoff and percentage decrease.

recharge starts in July to August. The difference in groundwater levels is greatest in September and, for the 2080 simulation, there is very little percolation to groundwater between May and late September. A deficit in soil moisture storage starts to develop in February and, for both the upper and lower soil layers, is very marked by May onwards with the greatest change is in the upper soil layer.

4. HYSIM Parameterisation

The next stage will be to create parameter files to define the hydrological characteristics for each of the 825 grid squares. Due to the simplifying assumptions made for the initial investigation the results of the initial investigation are of limited use in assessing patterns of runoff. However, the observations made during this study have relevance to parameterisation of HYSIM, especially with regard to the representation of storage.

Model parameters include; soil hydrological properties, land use and vegetation cover, groundwater extent and recession characteristics, lakes and reservoirs. Standard values can be assigned to certain parameters. For example, since effective runoff is being simulated at annual and seasonal temporal scales, channel hydraulics will not be simulated and the time-to-peak parameter used for minor channels will be given an 'average' value to be representative for Ireland. This parameter is derived from a Flood Studies Report equation on the basis of slope (NERC, 1975). Values for soil parameters will be assigned through the use of standard values on the basis of soil texture (Manley, 1993). These parameters include the pore size distribution index, bubbling pressure, permeability, porosity and residual saturation. Using the digital 1:575,000 soils map produced by

the Soil Survey of Ireland (Gardiner and Radford, 1980), the 44 soil associations in Ireland have been assigned to one of 11 soil textural classes. This was carried out by examining field analyses of soil texture reported by Gardiner (1980). Hydrologic characteristics for the extensive areas of blanket peat and lowland basin peat in Ireland will be derived separately on the basis of field observations made by Galvin (1976). The CORINE land use database (O'Sullivan, 1994) will be used to provide values for a number of parameters. For example values for interception storage, the interception factor (a weighting factor to account for the faster rate of evaporation from interception storage) and soil rooting depth can be derived from vegetation type. The impermeable proportion will also be determined for each square to take account of natural areas of rock as well as urban areas, roads and car parks. It is proposed to include a representation of the extent and recession characteristics of the major aquifers using information obtained from the Groundwater Section of the Geological Survey of Ireland. Groundwater in Ireland occurs mostly in shallow aquifers dominated by fissure permeability, many of which show some degree of karstification (Daly and Warren, 1998). As a result these aquifers may be almost as vulnerable as surface water to an increased frequency of low flows with implications for groundwater contributions to base flow during these periods. HYSIM has been successfully applied to model a karst aquifer (Manley, 1993) and this was one of the main reasons why the model was felt to be suitable for modelling Irish runoff.

HYSIM simulations will be carried out using the baseline climate data as the input and validation will be carried out using catchment data converted to effective runoff for the baseline period (1961-90). Catchments will be selected according to available length of records and quality of data and the effective runoff from the grid squares falling within these catchments compared with the observed runoff. NCEP/NCAR Reanalysis data will be related to the baseline climatology and relationships between upper air variables and surface climate established. Using these relationships the climate differences between a HadCM3 run for the 1961-90 period and two future periods; 2041-70 and 2051-80 will be established. These differences will then be applied to the baseline climate data to provide future climate scenarios for Ireland for these periods at the 10 x 10 km resolution. Further HYSIM simulations will be carried out using this downscaled data.

5. Conclusions

The initial investigation indicates an overall decrease in annual effective runoff. Localised increases reflect precipitation patterns shown by UKCIPS data. Winter runoff is predicted to increase for approximately 40% of the land area and includes flood-prone areas such as the upper Shannon basin. Summer runoff is predicted to decrease, with changes particularly marked in the west and north-east. These results should be treated with caution. These predictions have been based on a number of assumptions and will be refined by the use of statistically downscaled climate data and hydrological parameters representative of each grid square. The initial investigation has indicated that the accurate parameterisation of storage parameters is of particular significance.

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