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Regional hydrological impacts of climate and socio-economic change in North West England, UK

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Abstract An integrated approach to assessing the regional hydrological impacts of climate and socio-economic change is described for North West England, UK for the 2050s. A series of models were linked to investigate the effects of future climate and socio-economic change on the sectors driving landscape change. Many factors will affect future catchment behaviour including changed precipitation and temperature regimes, flooding, urbanization, woodland establishment, and changes in cropping and rotations. The results show that to focus on the direct impacts of climate change is to neglect the potentially important role of policy, societal values and economic processes in shaping the landscape of our catchments, and thus hydrological processes.

Key words climate change; numerical modelling; socio-economic aspects; water management; water resources

INTRODUCTION

There is acceptance that the climate is changing, due to human emissions of greenhouse gases (IPCC, 2001), which will affect all of society. Climate change impacts have been reported on water resources (e.g. Arnell, 1998), groundwater (e.g. Keating *et al*., 2003) and water quality (e.g. Gomez *et al*., 2003), but have generally applied impact models to scenarios of climate change, to understand the sensitivity to variations in climate. Other possible (non-climate) changes have often not been considered, even though it is recognized that significant socio-economic and political changes will continue to occur (Nakicenovic & Swart, 2000).

This paper describes hydrological results from the first regional Integrated Assessment study in the UK, which considered both climate and non-climate (socio-economic) changes. The **Reg**ional Climate Change **I**mpact and Response **S**tudies in East Anglia and North West England (RegIS) (Holman *et al*., 2005a, b) developed a methodology for stakeholder-led assessment that explicitly evaluated local and regional scale impacts and adaptation options, and cross-sectoral interactions between the major "sectors" (agriculture, biodiversity, coasts and flood plains, and water resources) driving landscape change.

METHODOLOGY

Regions and input scenarios

Although two contrasting regions (East Anglia and the North West of England) were studied (see Holman *et al*., 2005b), only results from the latter, with its wet climate

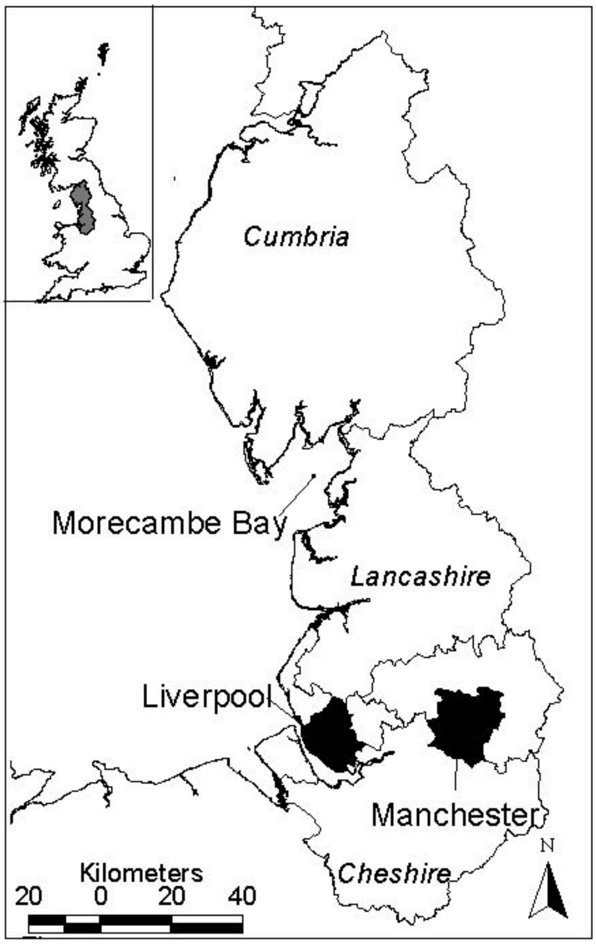

Fig. 1 The North West of England RegIS area.

(average annual rainfall: 650–3200 mm), uplands dominated by extensive grazing and urbanized lowlands (Fig. 1), are described.

A low and a high climate change scenario for the period 2040–2069, termed the 2050s Low and 2050s High scenarios, from the UK Climate Impacts Programme (UKCIP) scenarios (Hulme & Jenkins, 1998) were used to characterize the lower and upper ends of the expected temperature changes. As the future world will change even without climate change, regional socio-economic scenarios were derived (Shackley & Deanwood, 2003), which contained a range of quantified spatial (urban development, see Fig. 2, and protected areas, nitrate vulnerable zones, etc) and non-spatial (crop prices, yields, etc.) model parameters. The two climate change scenarios were modelled with baseline (current) socio-economic scenarios. Internally consistent futures were then modelled, in which the assumptions underpinning all of the scenarios (socio-economic, CO_2 emission and climate change) are consistent, to assess the relative importance of climate change and socio-economic change:

(a) Regional Enterprise (equivalent to the IPCC A2 emissions scenario) socio-economic scenario linked with the 2050s High climate change scenario, provides an extreme case of a society that does not respond to climate change;

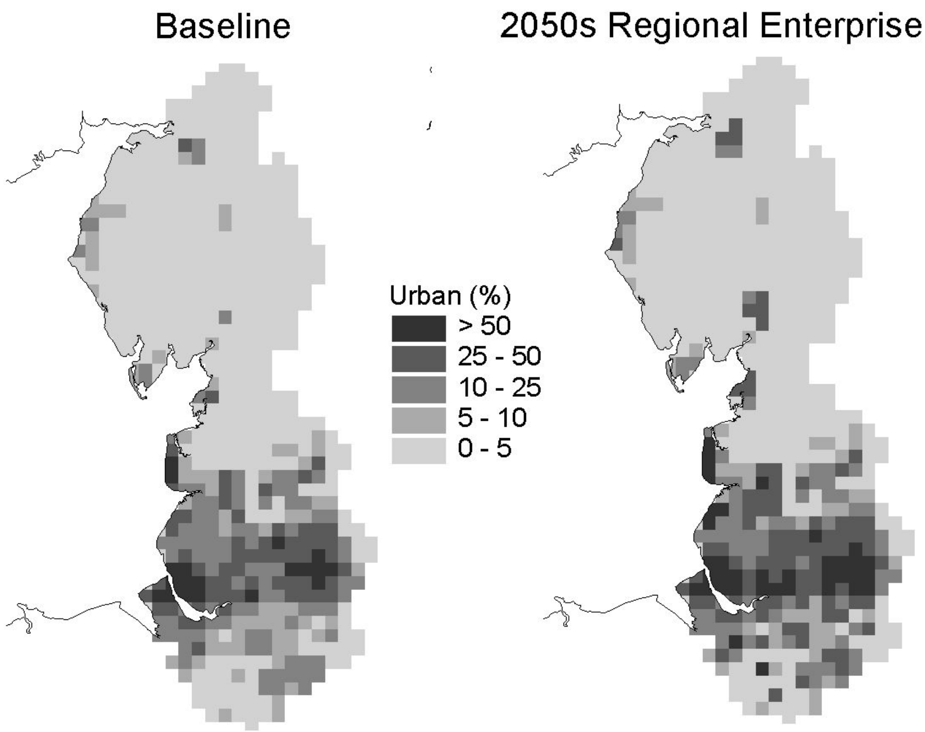

Fig. 2 Baseline and 2050s Regional Enterprise patterns of urbanization, expressed as percentage coverage of grid square.

(b) Global Sustainability (equivalent to IPCC B1 emissions scenario) socio-economic scenario linked with the 2050s Low climate change scenario, represents a "better case" analysis with respect to pressures upon environmental systems.

Impact models

A range of validated impact models (Holman *et al*., 2005a) were linked (Fig. 3) within the "Drivers–Pressure–State–Impact–Response" (DPSIR) approach (European Environment Agency, 1998), which are briefly described below. A coastal and river flooding model assessed the impact of increased flood frequency on the agricultural sector. Flood plains with a future standard of defence (i.e. risk of flooding) of less than 1 in 10 years were assumed to be unsuitable for arable farming, while those with less than a 1 in 1 year standard were assumed to be unsuitable for both arable and pastoral farming.

The agricultural land-use modelling integrated a crop growth model with an optimization approach to farm level cropping decisions. Simulated long-term farm cropping plans were optimized by maximizing farm profit, in response to changes in the profitability/feasibility of enterprises, soil workability and simulated yields brought about by changes in climate and/or socio-economic conditions.

The semi-distributed SWANCATCH (Surface WAter Nitrate CATCHment) model was used to simulate naturalized surface water flows in all catchments/sub-catchments. Hydrologically effective rainfall (that proportion of the rainfall which is able to runoff

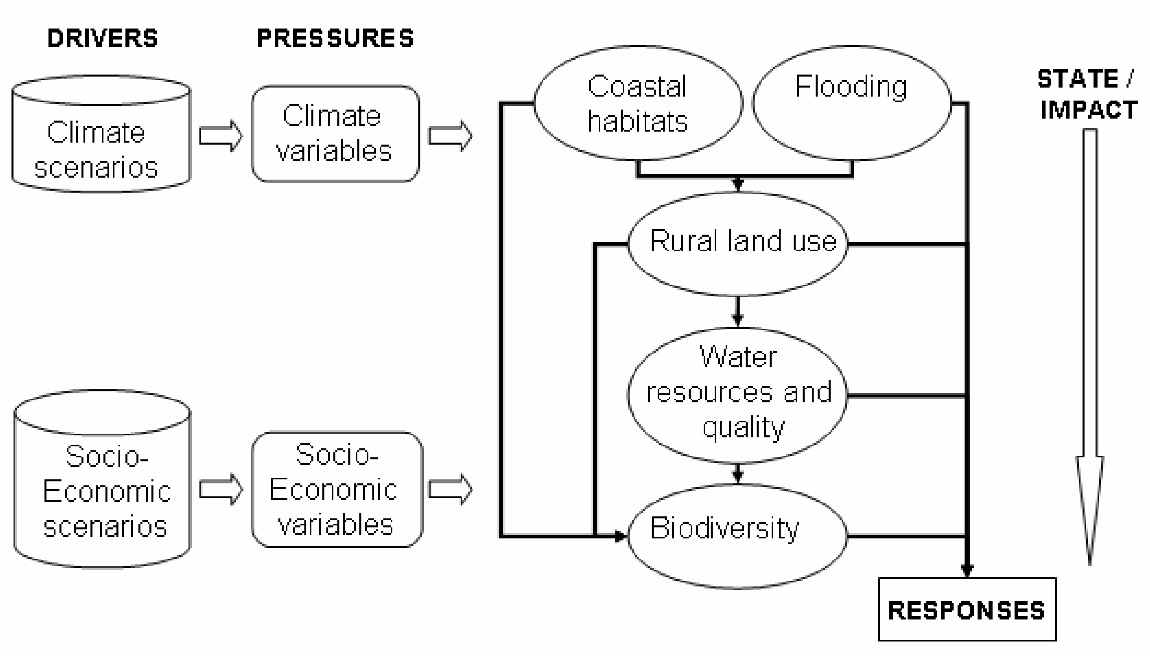

Fig. 3 Overview of the RegIS Integrated Assessment methodology.

or recharge), as given by the land-use modelling, is routed through each soil type directly to surface water or via a groundwater store, according to the Hydrology Of Soil Types (HOST) system (Boorman *et al.*, 1995). The paucity of naturalized river flow data makes the validation of such regional studies difficult. SWANCATCH was regionally calibrated against long-term observed average annual river discharge for 12 catchments (r^2 = 0.99); and validated against observed 95th percentile and 5th percentile exceedence river flows (r^2 = 0.80 and 0.98, respectively).

CASE STUDY RESULTS FROM NORTH WEST ENGLAND

Hydrologically effective rainfall

Considering climate change only, the increased winter rainfall generally outweighs the temperature effects of a lengthened growing season and higher winter evapotranspiration, leading to increased average annual hydrologically effective rainfall (AAHER). Only with the 2050s High scenario do parts of the region start to experience reduced AAHER (Fig. 4).

However, the socio-economic scenarios exert a significant influence on the simulated AAHER. Urbanization decreases evapotranspiration due to increased areas of hard surfaces and consequently leads to increased HER. Both socio-economic scenarios cause regional changes in land use, in particular an increase in the arable area at the expense of intensively farmed grassland, which causes a small regional decreases in AAHER.

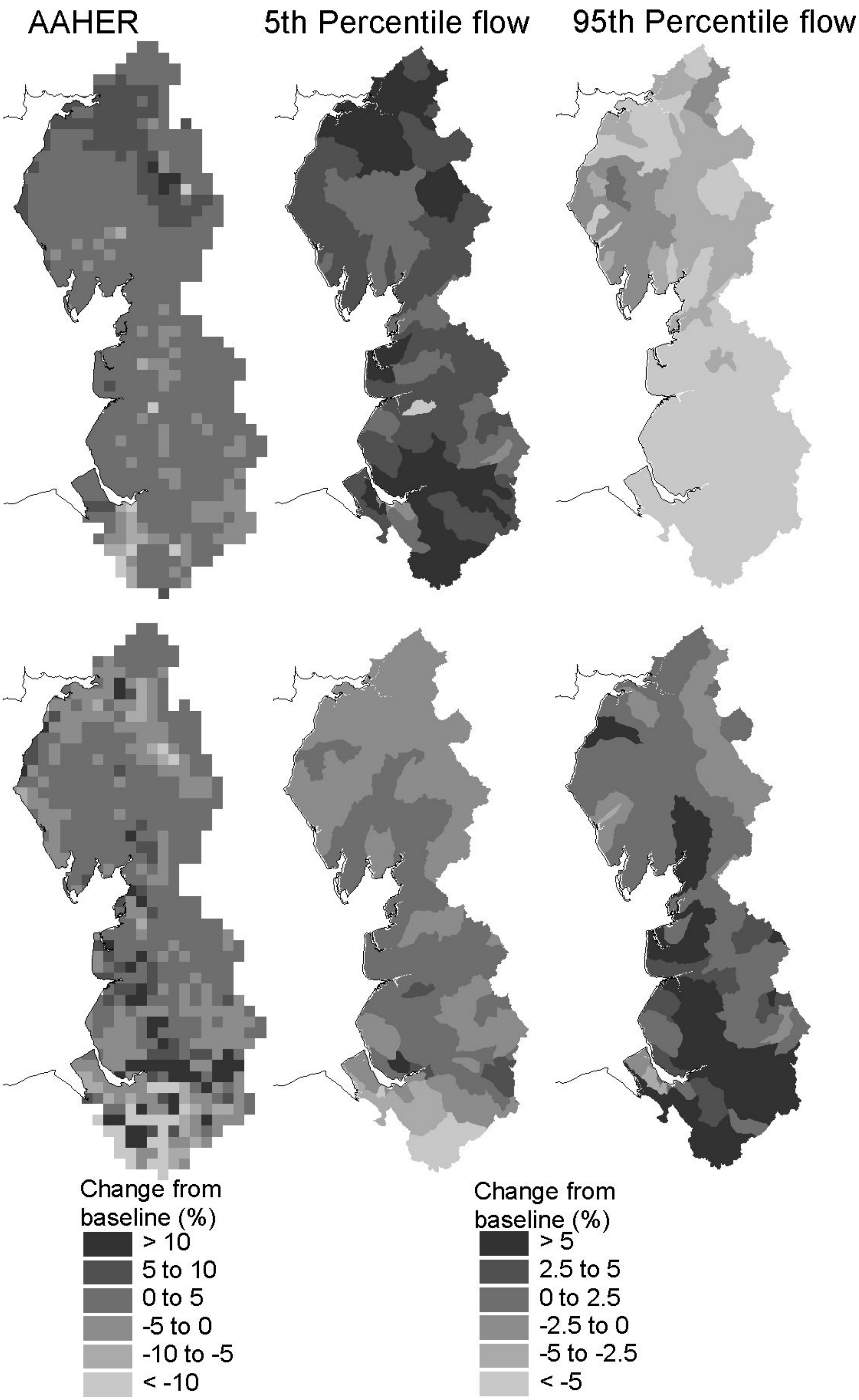

Fig. 4 Separating out the effects of the (Upper) 2050s High climate change scenario and the (Lower) Regional Enterprise socio-economic scenario on Average Annual Hydrologically Effective Rainfall, 5th and 95th percentile river flows.

River flows

High river flows, as given by the weekly average flow exceeded 5% of the time, generally increase with climate change (Fig. 4). Although the socio-economic scenarios lead to a small reduction in high flows, the overall effect is an increase for most catchments. It is probable that daily peak flows will also increase leading to greater fluvial flood risk, although snow accumulation/melt was not included in the models.

The pattern is different with low flows (the weekly average flow exceeded 95% of the time). The 2050s Low climate scenario leads to small increases in low flows in most catchments, which are partially or completely offset by a small decrease arising from the Global Sustainability scenario. The 2050s High scenario causes a significant regional decrease in low flows, despite the increase in average annual HER. This is only partially offset by the effects of the Regional Enterprise scenario (Fig. 4), so that there may be an increased risk of saline incursion in the lower reaches of coastal rivers, which may have implications for water supply intakes located close to the current tidal limit.

Surface water quality

Decreases in predicted mean nitrate-N concentration arise from both the climate and socio-economic scenarios in almost all catchments, despite significant increases in arable cropping at the expense of grassland. This is due to a combination of increased activity of in-river processes, shifts towards less leaching-prone land uses (such as sugar beet and housing) and increased dilution which outweigh the effects of more leaching-prone land uses (such as potatoes, peas and oilseed rape) and, in some catchments, less dilution.

Although nitrate-N water quality may improve, this will not be the case for all water quality indicators. Increased air temperatures will lead to (lower) increases in water temperature which, with changes in low flows, may lead to increased risks of low dissolved oxygen contents. Increased runoff associated with the higher winter rainfall (and possible increased rainfall intensity) may increase the risk of pathogens being “washed-off” into rivers.

DISCUSSION

An integrated assessment has allowed the impacts of future change on the water environment to be explored. In particular, the successful integration of socio-economic scenarios into the modelling of spatial land use enables the indirect impacts, resulting from changing patterns of urbanization, flooding and cropping, to be assessed and quantified.

The direct impacts of the climate scenarios are generally regionally more important than those arising from the socio-economic scenarios. However, the socio-economic scenarios do cause regional changes in HER and locally their impacts can be highly significant, especially where there are major land-use changes. The changing patterns of urbanization are dependent upon the scenarios of population change, housing density and household size. Because the simulated land use is based on maximizing farm profit, the results are sensitive to the elements of the socio-economic scenarios which directly (e.g. subsidies, prices, etc.) or indirectly (labour, input prices, etc.) affect the profitability of individual crops.

Clearly, even though they are developed within the constraints of the scenario future, all of these parameters are uncertain. For example, although the area of Nitrate Vulnerable Zones (as designated under the EC Nitrate Directive) was increased within the Global Sustainability scenario (compared to the baseline), the increases were actually significantly less than those subsequently designated by the UK Government in 2002! Although scenario development is an imperfect "science" (Parson & Granger Morgan, 2001), few alternatives exist for exploring the consequences of unknown futures. Scenarios are therefore an integral part of climate impact assessment (Leemans, 1999). They will continue to be widely used, as addressing policy questions regarding the impact of climate change requires an holistic assessment of the effects of our changing future, including the effects of all change factors, the interactions between sectors and an evaluation of adaptation options (Cash & Moser, 2000).

This is because the actual impacts of climate change, locally or regionally, will be the product of multiple interacting systems, which leads to two important limitations of such regional integrated assessments. Firstly, there is the difficulty of incorporating feedbacks across scale boundaries within the scenarios, such as the effect of changing land use areas on agricultural prices: increasing the *local* supply of an individual crop may result in lower prices but is dependent upon *market* demand and supply. Secondly, as the complexity of the representation of the systems and interactions increases, it becomes more difficult to identify a link between cause and effect, as several interacting processes may have contributed.

In exploring these aspects of impacts and adaptation at the local and regional scale, there is a clear conflict between the detailed spatial resolution (of the order 1 km × 1 km) desired by stakeholders and the resolution of the climate scenarios (10 km × 10 km). RegIS used a compromise resolution of 5 km × 5 km to present stakeholders with information that was of sufficient detail for use in regional decision support, whilst limiting over-interpretation of model results at very local scales. Nevertheless, there was significant demand for finer resolution local information from stakeholders, many of whom are operating (or have responsibility for implementation) at the local level (Shackley & Deanwood, 2003).

CONCLUSIONS

An integrated approach to assessing the direct and indirect impacts of climate and socio-economic change on catchments in the North West of England has been described. Many factors will affect future catchment behaviour including changed precipitation and temperature regimes, flooding, urbanization, woodland creation, and cropping changes. The direct impacts of the climate scenarios are generally regionally more important than those of the socio-economic scenarios. However, the socio-economic scenarios do cause regional changes and locally, the impacts of the socio-economic scenarios can be highly significant, especially where they lead to major land-use changes. Despite the many uncertainties involved in the use of socio-economic scenarios, to solely focus on the direct impacts of climate change (arising from temperature and precipitation changes) is to neglect the potentially important role of societal values and economic processes in shaping catchments.

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