National-scale sediment delivery to watercourses across England and Wales under recent (1970–2004) land-use change

A. L. COLLINS, D. DUETHMANN & P. TAYLOR
Environment Group, ADAS, Woodthorne, Wergs Road, Wolverhampton WV6 8TQ, UK
adrian.collins@adas.co.uk

Abstract Land-use change has been widely reported as a key driver of temporal trends in soil erosion and sediment delivery. As a means of generating strategic information on sediment pressures, the process-based PSYCHIC (Phosphorus and Sediment Yield CHaracterisation In Catchments) model was used to simulate sediment delivery from agricultural land, excluding channel banks, to all rivers across England and Wales. Evaluation of PSYCHIC using available field-scale monitoring data is ongoing (r^2 = 70%). Scenario analyses employed a national land-use database assembled for the years 1970, 1980, 1995, 2000 and 2004. The total sediment loading delivered to all rivers for these reference years was estimated at 2774 kt, 2890 kt, 2720 kt, 2659 kt and 2518 kt, respectively. On the basis of the hindcasting, PSYCHIC therefore predicted that total sediment delivery to watercourses from agricultural sources peaked in 1980 and decreased by 9% between 1970 and 2004.

Key words land-use change; sediment delivery; modelling; River Basin Districts

INTRODUCTION

Although suspended sediment yields across England and Wales are relatively low compared to the rest of the world, local sediment pressures are nevertheless responsible for a number of important environmental problems in receiving freshwaters. Fine sediment governs the transfer and fate of harmful nutrients and contaminants (Rees *et al.*, 1999; Collins *et al.*, 2005) and can degrade fish spawning gravels (Greig *et al.*, 2005) or reduce macroinverterbrate biodiversity (Wood & Armitage, 1999). Sediment mobilisation and delivery to rivers therefore plays an important role in the wider diffuse pollution issues reported across England and Wales.

Numerous studies have examined the impact of land-use change on sediment pressures (e.g. Slaymaker, 2000), focusing in particular, upon the effects of European colonisation in various parts of the world, including North America (Phillips, 1993) and Australia (Olley & Wasson, 2003). In the case of England and Wales, palaeolimnological reconstructions have been used to explore the impact of a range of disturbances on lake sediment systems over the past approx. 100 years (Foster, 2006). But, although such field-based studies have provided important insight into the interactions between land-use change and sediment yields, it remains difficult to extrapolate the findings to strategic scale for policy support purposes. Appreciable changes in land use and agricultural intensity have been observed in England and Wales over the past 40 years in response to political, economic and social drivers. At present, further change is underway due to the de-coupling of farm subsidies from agricultural production, and greater emphasis upon environmental objectives. It is therefore useful for policymakers to understand the impact of recent land-use change on sediment pressures so that future land-use–sediment dynamics might be better understood. Given that longer-term (>5 years) suspended sediment flux records for England and Wales are sparse, an alternative approach is to model sediment pressures as a function of land-use change.

METHODOLOGY

In order to assess the impact of recent (1970–2004) land-use change on sediment pressures at strategic scale across England and Wales, the process-based PSYCHIC (Phosphorus and Sediment Yield CHaracterisation In Catchments) model (Davison *et al.*, 2008) was deployed using the ADAS national land-use database as input. PSYCHIC conceptualises land-to-water diffuse pollution transfers in terms of source-mobilisation-delivery and uses as input, statistical data (1 km^2

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resolution or finer) on climate, drainage density, slope and soil types and characteristics, in addition to land-use input on crop types and livestock numbers. Sediment mobilisation is calculated at plot scale using a modified version of the Morgan-Morgan-Finney model (Morgan, 2001) and a parameterisation of rainfall erosivity (Davison *et al.*, 2005). Resulting inputs to neighbouring watercourses are calculated by attenuating mobilisation using a source–channel connectivity function and a particle size selectivity factor. Critically, PSYCHIC includes representation of assisted drainage, since approx. 40% of agricultural land across England and Wales is underdrained. Sediment transfers to rivers via artificial drainage are estimated by attenuating mobilisation using a fixed connectivity coefficient of 0.9 and an alternative grain size selectivity factor based on field data. The presence of drains is assumed using the Hydrology of Soil Types (HOST) classification scheme (Boorman *et al.*, 1995).

Land-use information for each reference year (1970, 1980, 1995, 2000, 2004) was based on the ADAS land-use database. This data set is founded on the holding level Parish Agricultural Census returns by farmers, completed in June for the Department for Environment, Food and Rural Affairs (Defra). Census data are distributed across agricultural land delineated using the Centre for Ecology and Hydrology's Land Cover Map of Great Britain (LCMGB). In order to represent the impact of changing livestock density on soil compaction and poaching risk, grazing livestock units (GLUs) for each reference year were mapped at the national scale using standard conversion factors. The resulting stress was applied to those HOST classes susceptible to soil structural degradation and supporting improved or rough pasture (Packman *et al.*, 2004).

The comparison of predictions made by PSYCHIC with catchment-scale empirical data on sediment response is hampered by a number of problems including the need to correct sediment yield information for sources not included in the model, e.g. channel bank erosion (Stromqvist *et al.*, 2008). Bank erosion data are not readily available for most catchments across England and Wales. Accordingly, modelled estimates of field-scale soil erosion provided by PSYCHIC have been compared with empirical measurements assembled for various locations (Evans, 2005). Whilst this evaluation exercise is ongoing, the results computed to date for 640 fields (Fig. 1) demonstrate that PSYCHIC provides acceptable predictions, especially given the fact that the variance of measured data invariably constrains soil erosion model performance (cf. Nearing, 1998).

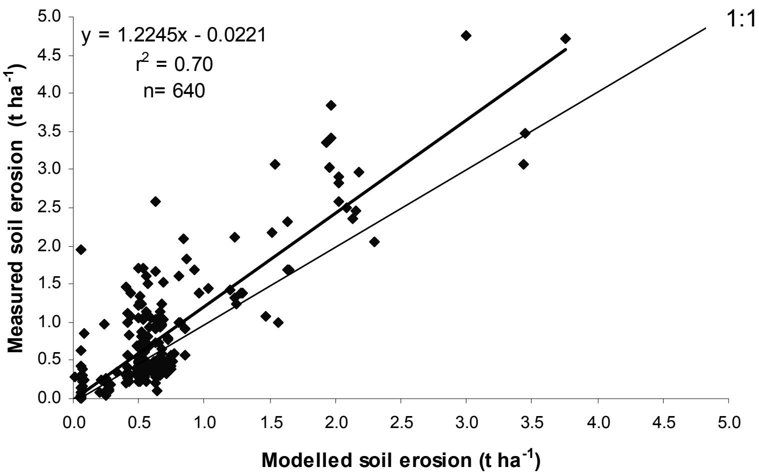

Fig. 1 Evaluation of modelled field-scale soil erosion predicted using PSYCHIC.

RESULTS AND DISCUSSION

The period 1970–2004 was characterised by a number of important land-use changes. Detailed discussion of these changes is beyond the scope of this short contribution, but two important pressures involve the area used for wheat cropping and secondly, grazing livestock numbers and the resulting risk of compaction. Over the period 1970–2004, wheat production expanded westwards across England and Wales (Table 1). Much of the wheat production involves autumn sowing which exposes bare tilled soils to the risk of surface runoff and erosion. Livestock numbers peaked around 1980, thereby resulting in a substantial rise in GLUs between 1970 and 1980 in many areas (Fig. 2(a)). Conversely, the outbreak of foot-and-mouth disease in 2001 resulted in a substantial decrease in livestock numbers in many areas. The model scenarios were used to compute information for each EU Water Framework Directive (WFD) River Basin District (RBD) (Fig. 2(b)). Figure 3 summarises the output from the PSYCHIC model. Generally speaking, soil erosion and sediment delivery to rivers in each RBD peaked in 1980. Over the period 1970–2004, total sediment delivery to rivers in the South East and Thames RBDs decreased by 31%, whereas the corresponding change for the Dee and Western Wales RBDs amounted to a 1% increase. At the national scale, total sediment delivery to watercourses from agricultural sources peaked in 1980 at 2980 kt (193 kg ha^{-1}), falling by 9% between 1970 (2774 kt, 186 kg ha^{-1}) and 2004 (2518 kt, 169 kg ha^{-1}). Other workers have reported a similar temporal trend (Evans, 2006).

Table 1 Summary of change in the area of wheat cropping across England and Wales.

River Basin District	% change 1970–1980	% change 1970–1995	% change 1970–2000	% change 1970–2004
Anglian	51.6	66.2	84.1	74.7
Dee	6.5	115.8	181.3	161.7
Humber	33.8	105.0	130.4	123.5
Northwest	–15.9	116.9	154.2	191.6
Northumbria	33.5	257.2	312.5	283.1
Severn	35.6	66.1	98.7	96.6
Solway Tweed	25.3	181.8	241.0	302.9
South East	42.2	56.5	78.1	59.1
South West	44.5	108.1	162.6	151.2
Thames	46.0	54.7	86.0	68.9
Western Wales	–23.9	37.6	135.0	137.6

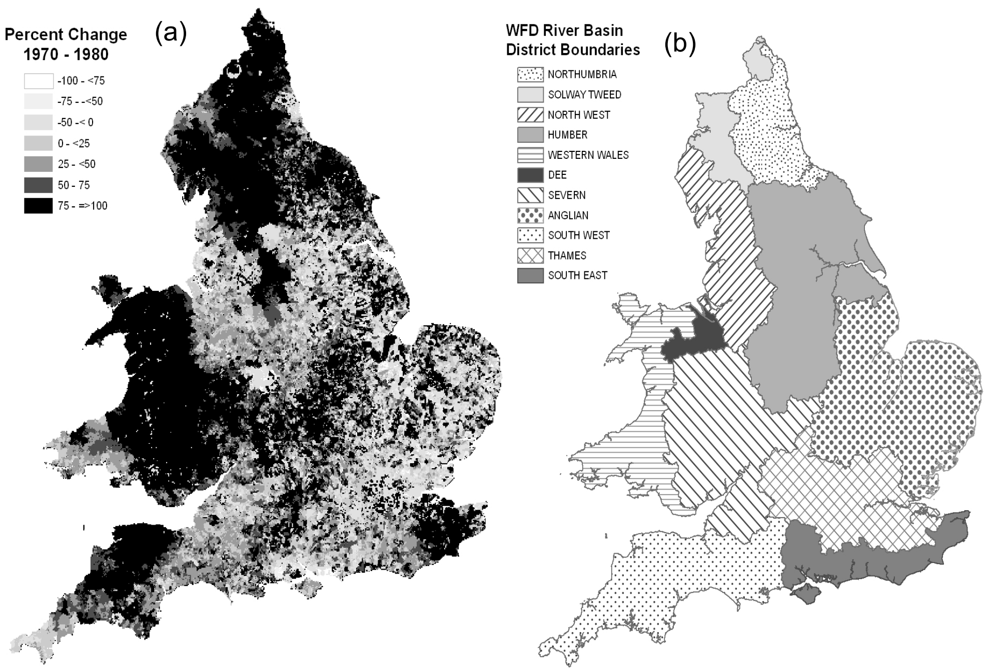

Fig. 2 (a) Percentage change in GLUs between 1970 and 1980. (b) EU WFD River Basin Districts (RBDs) for England and Wales.

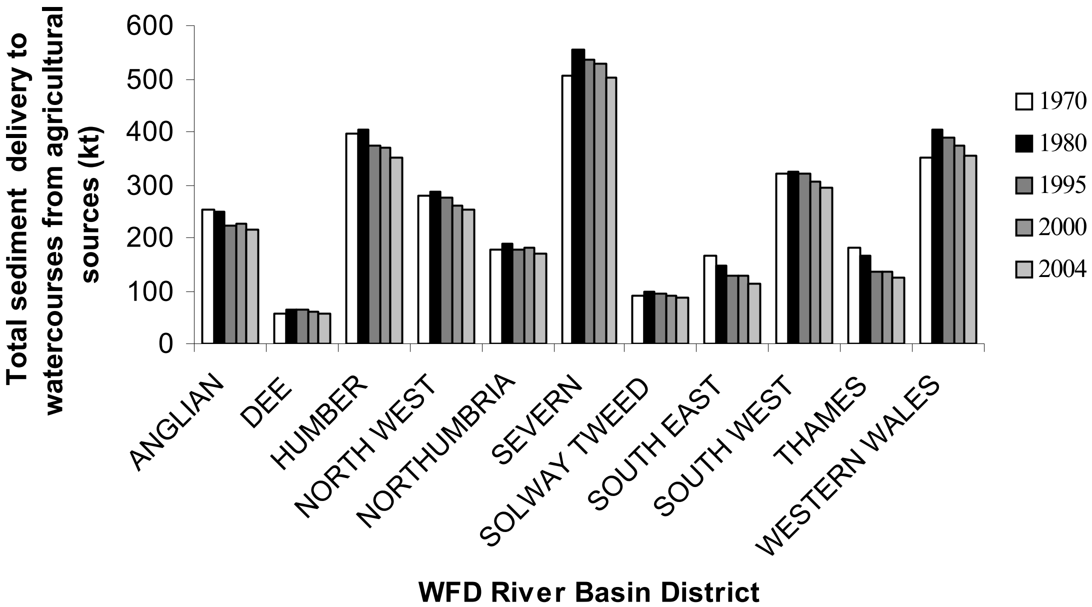

Fig. 3 Simulated sediment delivery to rivers using PSYCHIC.

CONCLUSION

Ongoing work aims to continue with the validation of PSYCHIC and to refine model input. For example, information is needed to assess whether sediment delivery via drains needs to be attenuated further on account of the deterioration of some drainage systems.

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