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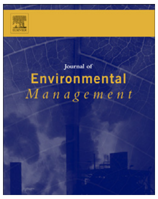

Measurement of flood peak effects as a result of soil and land management, with focus on experimental issues and scale

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ABSTRACT

As a result of several serious flood events which have occurred since 2000, flooding across Europe is now receiving considerable public and media attention. The impact of land use on hydrology and flood response is significantly under-researched, and the links between land use change and flooding are still unclear. This study considers runoff data available from studies of arable in-field land use management options, applied with the aim of reducing diffuse pollution from arable land, in order to investigate whether these treatments also have potential to reduce downstream flooding. Intensive monitoring of 17 hillslope treatment areas produced a record of flood peak data covering different mitigation treatments for runoff which occurred in the winter of 2007–2008. We investigated event total runoff responses to rainfall, peak runoff, and timing of the runoff peaks from replicates of different treatments, in order to assess whether there is a significant difference in flood peak response between different mitigation options which could be used to mitigate downstream flood risk. A mixed-modelling approach was adopted in order to determine whether differences observed in runoff response were significant. The results of this study suggest that changes in land use management using arable in-field mitigation treatments can affect local-scale runoff generation, with differences observed in the size, duration and timing of flood peaks as a result of different management practices, but the study was unable to allow significant treatment effects to be determined. We suggest that further field studies of the effects of changes in land use and land use management need to upscale towards farm and catchment scale experiments which consider high quality before-and-after data over longer temporal timescales. This type of data collection is essential in order to allow appropriate land use management decisions to be made.

1. Introduction

Flooding across Europe is currently receiving considerable public attention. Within Europe, the number of people affected by fluvial flooding has been projected to increase from 150,000 to 400,000 by 2100, during which time expected annual damages from flooding are expected to increase from €6.4 billion to at least €14 billion (Feyen et al., 2012). Across Europe, flash flooding with very short lag times (<6 h) is now considered one of the most serious natural hazards (Gaume et al., 2009; Marchi et al., 2010). There is now also increased public perception of flooding as a problem and greater focus on the politics of its management (Escobar and Demeritt, 2012).

Although it is recognized that there is an impact of land use on hydrology and flood response, this area is significantly under-researched (DeFries and Eshleman, 2004), and the links between land use change and flooding are still unclear (O'Connell et al., 2004). Although some evidence for effects of land use and land use practices on runoff and flood peaks does exist at the local scale, evidence of runoff and flood impacts at larger catchment scales is lacking, due in part to greater catchment complexities and hydrological variability at larger scales (e.g. Beven et al., 2008; McIntyre and Marshall, 2010; Sullivan et al., 2004), but also because of short hydrological records which can make it difficult to detect change given natural hydrological system variability (Beven, 2012). Beven (2012) comments that although there is 'no doubt' land

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Abbreviations: CC, Contour cultivation; MT, Minimum tillage; NTL, No tramline; PL, Plough; TL, Tramline (tractor wheel track); UD, Up-and-downslope cultivation; Q, Runoff; *QTotal*, Total runoff recorded during a rainfall event (l); *QPeak*, Peak runoff recorded during a rainfall event (l 5 min^{-1}); *QDuration*, Duration of runoff event (hours); *QLag*, Lag time between peak runoff response and onset of event rainfall.

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management can have an important impact on runoff generation processes, understanding the nature and impacts of catchment change is still in its infancy.

The major land use and flooding research focus has been on the effects of urbanization (e.g. Rose and Peters, 2001), forestry (e.g. Robinson et al., 2012) and field drainage (e.g. Armstrong et al., 1996), but there are now concerns that the effects of agricultural intensification and the impact of land use practices and land management may have increased the risk of flooding (Wheater, 2006). Major land use changes in the UK since the second world war as a result of increasing agricultural production and the Common Agricultural Policy, which may have impacted on runoff generation and storage, include: the use of heavy machinery; changes in cropping and land cultivation techniques; unchecked runoff from bare soil; plough lines, ditches and tyre tracks concentrating overland flow; and the use of compacted tramlines and farm tracks which transfer runoff rapidly to water courses (O'Connell et al., 2007). The degradation of soil structure as a result of some of these changes can reduce infiltration rates, saturated hydraulic conductivity, and soil water storage, leading to changes in surface and subsurface runoff generation which may increase the risk of flooding (e.g. Heathwaite et al., 1990; Burt, 2001). Practices which leave soil bare, or with little vegetation cover, can also affect formation of soil crusts, reduce infiltration and increase surface runoff generation (e.g. Bradford et al., 1987; Moore and Singer, 1990).

If land use and land management practices have the potential to increase flooding, it follows that they also have the potential to mitigate flood risk through reduced runoff generation and increased soil water storage (Morris et al., 2005). While some evidence is available to demonstrate that this is possible at catchment scale, for example Evans and Boardman et al. (2003) demonstrate that the frequency of 'muddy floods' can be reduced by appropriate arable management practices on autumn-sown cereal fields, the evidence is very limited. Researching the effect of land use on hydrological processes is made especially difficult because of a lack of historical data, high natural hydrological variability, and the difficulties of controlling land use changes in catchments (DeFries and Eshleman, 2004; O'Connell et al., 2007). Add the issues of extrapolating between scales (Deasy et al., 2011) and uniqueness of place (Beven, 2000), and the interpretation of the results of the small number of studies that have been undertaken in this area into information relevant for wider land use policy decisions is almost impossible. One of the major science needs for rural land use and flooding research is therefore to generate more data through implementation of extensive monitoring of runoff from land use manipulation studies at the local scale, which can then inform model development in order to upscale results to larger catchment scales (Wheater and Evans, 2009).

The significant research focus on developing mitigation options to reduce diffuse pollution from agriculture (e.g. Collins et al., 2009; Deasy et al., 2009; Dawson and Smith, 2010; Barber and Quinn, 2012; Ockenden et al., 2012) has the potential to provide some of this necessary local scale data. Although the focus of many studies is primarily on reducing soil erosion and nutrient transport, as the carrier for the majority of diffuse pollution losses, a decrease in runoff is often cited as a multiple benefit of mitigation treatments (e.g. Jin et al., 2008; Deasy et al., 2009b). Land management mitigation options are designed to reduce sediment and pollutant erosion and transport by increasing rainfall infiltration, ponding and soil water storage, therefore reducing hillslope runoff, and include practices such as conservation tillage (no-tillage/minimum tillage) (e.g. Leys et al., 2007), contour cultivation (e.g. Quinton and Catt, 2004), and tramline management (Silgram et al., 2010). As yet, however, there has been only very limited assessment of the effect of agricultural mitigation options on flooding, even at the plot scale. Although studies may report total runoff volumes in relation to control treatments, because flood impact depends on both peak discharge and hydrograph runoff volume, and the extent to which the timings of the peaks of tributary hydrographs are in or out of phase with the main channel hydrograph (O'Connell et al., 2007), a reduction in total runoff at the plot-scale will not necessarily translate into a decrease in flooding downstream, and assessment of the effect of treatments on flood peaks, in terms of their size, duration and timing, is also important.

O'Connell et al. (2007) pose the following land management research questions in relation to flood impact:

i) At the local scale, how does a given change in land use or management affect local-scale runoff generation?
ii) How does a local-scale effect propagate downstream, and how do many different local scale effects combine to affect the flood hydrograph at larger catchment scales?
iii) How can adverse effects be mitigated using economically and environmentally acceptable measures?

This study focuses on the first and third of these questions of flood impact at the local scale by presenting and analysing further data from the Deasy et al. (2009b) study into diffuse pollution mitigation options, which identified only the impact of land management treatments on runoff volumes. The data presented here allow assessment of the effect in-field mitigation measures on the size, timing and duration of flood peaks, and hence considers the research question 'is there a significant difference in flood peak response between different land use treatments which could be used to mitigate downstream flood risk?'.

2. Material and methods

2.1. Study site and experimental design

The study site is an arable farm at Loddington, Leicestershire, UK (52°36'N, 0°50'W), situated on heavy-clay soils (Gleyic Cambisol, USDA classification: Typic Haplaquept; UK Soil Series: Denchworth) with slopes of approximately 4°, and average annual rainfall of 650 mm. Seventeen unbounded hillslope lengths, 70–100 m long, were used for monitoring surface runoff under three different mitigation options in the winter of 2007–2008. The mitigation treatments trialled were selected as appropriate for the study site, which were anticipated to reduce runoff, and hence associated sediment and nutrient losses, by reducing the generation of surface runoff through increased ponding and infiltration, or by reducing the volume, erosive energy and transport capacity of runoff within the hillslope. The options chosen for comparison were:

i) Minimum tillage (MT), compared to traditional ploughing (PL): The experimental area had previously been cultivated using minimum tillage, where a Simba Solo containing shallow tines and disks was used to break up the soil. This technique results in better soil structure, and greater above-surface roughness as stubble and crop residues remain on the soil surface. Although this increased surface roughness may trap water on the soil surface, promoting infiltration and reducing surface runoff, because soils are not inverted, surface roughness at the soil level is reduced and soil compaction may be increased, thereby reducing infiltration rates and promoting surface runoff. These different effects of minimum tillage could therefore either positively or negatively alter surface runoff response. Half of the experimental area was cultivated using traditional ploughing techniques, where