Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

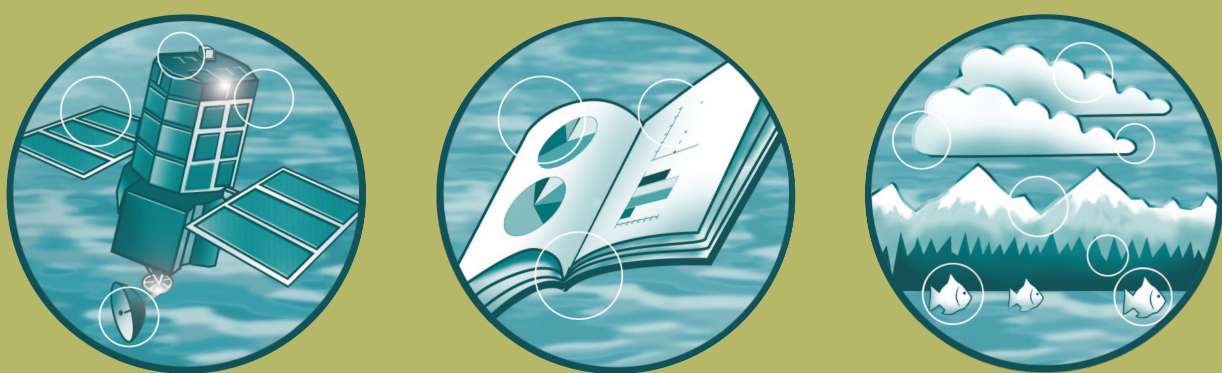
Review of impacts of rural land use and management on flood generation

Impact study report

Appendix F: River engineering and flood plain management

Appendix G: Stakeholder feedback

R&D Technical Report FD2114/TR



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R&D Technical Report FD2114/TR

Authors:
P.E. O'Connell, K. J. Beven, J. N. Carney, R. O. Clements, J. Ewen, H. Fowler, G. L. Harris, J. Hollis, J. Morris, G. M. O'Donnell, J. C. Packman, A. Parkin, P. F. Quinn, S. C. Rose M. Shepherd, and S. Tellier

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Authors:

P.E. O'Connell, J. Ewen, H. Fowler, G. M. O'Donnell, P. F. Quinn and S. Tellier

University of Newcastle upon Tyne, Water Resource Systems Research Laboratory

K. J. Beven

Lancaster University, Institute of Environmental and Natural Sciences

J. N. Carney

NERC – BGS

R. O. Clements

IGER

G. L. Harris, A. Parkin, S. C. Rose and M Shepherd

ADAS

J. Hollis and J. Morris

NSRI

J. C. Packman

NERC - CEH Wallingford

Statement of use
This report is aimed at those involved in land management. It provides the current position of knowledge and science with respect to land use management and its impact on flood generation. It will be of benefit to those seeking to reduce flood risk though specific land management practices, and those who wish to assess the impact of specific management practices on flood risk.

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Research contractor: University of Newcastle upon Tyne, NE1 7RU

Defra Project Officer: Mr E. P. Evans, Halcrow Group Ltd., Burderop Park, Swindon, SN4 0QD

Publishing organisation
Defra - Flood Management Division
Ergon House
Horseferry Road
London SW1P 2AL
Tel: 020 7238 3000
Fax: 020 7238 6187
www.defra.gov.uk/environ/fcd

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The views expressed within this report are those of the contractors and do not necessarily reflect the views of any of the funding organisations

APPENDIX F: River engineering and flood plain management

Channel modifications

A detailed review of the impacts of river channel modifications on flow regimes, peak flows and flood risk is outwith the scope of this review. However, a brief summary of the nature, geographical extent and impacts of these modifications is included here, since any impacts of land use management changes are interwoven with these at larger catchment scales. This summary draws on the recent review of Sear et al (2000) and the references therein.

Channel modifications refer to those management activities that alter the form of the river channel, specifically affecting the plan form, cross-section and longitudinal profile. In general, modifications have taken place as part of extensive land drainage schemes that required improvement in the conveyance efficiency of river channels, and as flood protection to confine high flows within river channels (Brookes, 1987; Robinson, 1990; Sear et al, 1995). For agricultural areas, design protection may vary from 1:1 to 1:10 years, and require limited channel modification. In comparison, channels in urban areas may be highly modified and reinforced to provide much higher standards of protection in the range 1:50 to 1:200, depending on the potential damage. Following channel modifications, there is a continuing annual maintenance requirement which has involved the removal of sediment accumulations, or the reinforcement of channel banks and beds, thus continually modifying the channel form.

The period 1930-1990 saw the most intensive and spatially extensive channel modification effort across the UK, driven initially by war-time demand for increased agricultural output. This was sustained by the CAP and funding for land drainage improvements to ensure high rates of agricultural productivity. However, since the 1980s, the recognition that channel modifications had substantially impacted the natural river environment has brought about a change in emphasis towards protecting and enhancing the river environment. By the late 1990s, river habilitation and enhancement had become the dominant form of channel modification, including the restoration of natural flood plains. There is now greater recognition of the wider benefits that rehabilitation can make towards the better management of floods, droughts and water quality, and the achievement of governmental strategies for improved biodiversity, CAP reforms and agri-environment support schemes (Sear et al, 2000).

Extent of UK channel modifications

Channel modification in the UK has distinct regional and geographical trends, driven partly by the nature of the land and rivers themselves, as well as by the history of water management legislation. Climate and land use also influence the geography of modifications and associated maintenance work (Newson and Sear, 1994). Determining the geography of channel modifications has been made possible by the publication of the EA's River Habitat Survey (RHS), which is a systematic framework for the collection and analysis of data associated with the physical structure of watercourses (Sear et al, 2000). The national picture emerging from the analysis of the RHS data reveals a widespread distribution of rivers that have experienced one or more of six main channel modifications: straightening, resectioning, reinforcing, embanking, culverting and the construction of weirs and sluices. The majority of modified channels are associated with lowland regions of the UK, where agricultural drainage, communications networks and urban centres all contribute to a long history of river channel management. In the uplands, reinforcement of channel boundaries represents the dominant form of modification, reflecting the high energy nature of rivers in this category. The data for straightened channels is known to be inaccurate, since many river reaches in upland and lowland UK have been straightened, although, as the RHS data suggest, this is not as extensive as other forms of modification. There are clear regional variations, with Northern Ireland accounting for the highest proportions of modifications associated with agricultural land drainage practices, while the relatively densely populated regions of England account for the highest proportions of culverted channels. Sear et al (2000) state that maintenance and capital works within England and Wales for the period 1930 – 80 account for modifications to some 35,500 km of main river, of which some 4500 km have reinforced banks. The overall national picture is one of long-term intervention extending over much of the river network with continual (though reducing) levels of maintenance concentrated in the impermeable lowlands and in major urban areas.

In England and Wales, the Environment Agency (EA) has permissive powers to undertake land drainage and flood protection works on designated main rivers. In addition to the EA, channel modifications have been and continue to be undertaken by the Internal Drainage Boards that cover approximately 8% of England and Wales, maintaining some 27000 km of intermediate water courses that usually discharge to the main river network (Robinson, 1990). Channel modifications have been grant-aided by the former Ministry of Agriculture, Fisheries and Foods (now Defra), the Scottish Office and the Department of Agriculture for Northern Ireland, after satisfying technical and cost-benefit evaluations.

Geomorphological, hydraulic and hydrological impacts of channel modifications

The morphological impacts of channel modifications are both direct and indirect. Direct modifications have generally been in the direction of increased slope and hydraulic radius, and reduced channel roughness, thus bringing about the increased flow velocities needed to evacuate water from the land more efficiently than before. Such channel modifications have in some cases increased stream power to such an extent that bed and bank protection works were often engineered into these schemes at the design stage, thus destroying the ability of the rivers to adjust their forms in response to flow and sediment transport rates, as is the case with natural channels. In cases where banks are not reinforced but channels are deepened, bank failure may occur, leading to sediment accumulation and the need for maintenance. The indirect impacts of channel modifications have been outlined by Brookes (1987), and may result in extensive upstream and downstream channel adjustments. In high energy gravel bed rivers, significant channel enlargement may occur due to bank instability, while, in low energy river systems, morphological adjustments may be characterized by accumulations of sediment, reduced channel capacity in the modified reach, and raised bed elevations upstream. Maintenance programmes are frequently put in place to mitigate these impacts.

The hydraulic and hydrological impacts of river channel modifications are clearly interlinked, but the main differentiator in viewing impacts is scale. Hydraulic impacts are observed primarily at the local scale of the modifications, which, as already noted, have traditionally been associated with increasing the hydraulic efficiency of the channel by transmitting a much higher discharge for a given change in stage. A consequence of this is a loss of hydraulic diversity e.g. the disappearance of natural sequences of pools and riffles. However, the annual growth of aquatic vegetation can lower the hydraulic efficiency, thus necessitating maintenance schemes. One of the well known consequences of improving the hydraulic efficiency of a river reach is that higher discharges are transmitted downstream, which can lead to more frequent out-of-bank flooding at downstream locations. Channel rehabilitation and restoration schemes will tend to restore the natural balance between upstream and downstream channel capacities.

The hydrological impacts of channel modifications can be viewed at a range of catchment scales, and will depend on the processes involved, and the interactions between them. For example, the increase in storage resulting from underdrainage of floodplains may locally decrease peak flows from a small catchment, but when linked to efficient arterial drainage channels on a larger catchment, may lead to increased peak flows downstream owing to the faster travel time of flood water from the upper catchment. (Newson and Robinson, 1983; Robinson, 1990; Robinson and Rycroft, 1998; Sears et al, 2000). In general, the effects of channelization on flood hydrographs is well known, but the impacts on peak discharges will depend on the extent of the modifications, and on their locations within the channel network. Large-scale arterial drainage schemes can have major impacts on flood hydrographs. For example, Bailey and Bree (1981) have demonstrated that flood peaks were 60% higher on rivers that have been arterially drained in comparison with unmodified rivers. The natural attenuation of flood hydrographs through floodplain storage is lost in many channel modification schemes, and the resulting disconnection of rivers from their floodplains also results in losses of habitat and biodiversity. More recently, restoration schemes have sought to bring rivers back into contact with their floodplains on a regular basis, with benefits for flood mitigation downstream, habitats and biodiversity.

When viewed alongside the impacts of land use management on flood generation, most channel modification works in the UK would be expected to lead to increased peak discharges downstream, with the impacts dependent on the extent and locations of works within the channel network. If land use management impacts exist at larger catchment scales, then these would be expected to be similar in terms of changes to flood hydrographs, albeit for different reasons. Disentangling these impacts at the catchment scale is a formidable challenge that requires further research. However, channel rehabilitation and flood plain restoration schemes will have a mitigating impact on peak discharges, and should be considered alongside more local-scale mitigation measures when developing Catchment Flood Management Plans.

APPENDIX G: Stakeholder feedback

This appendix to the FD2114 project ' FD2114/TR: Impact Study Report' contains responses to ten supplementary questions provided by the stakeholders (Defra, Environment Agency, English Nature, and Forestry Commission) following a meeting where a draft version of the Critical Assessment of Assembled Sources, Section 6 in FD2114/TR, was first presented.

The detailed answers to these questions lie in FD2114/TR and its other appendices, and in 'Report B: Research Plan' in which a way forward is mapped for defining and implementing best practice in flood prevention and mitigation associated with rural land use change and management practices and for operational assessment of the likely effects of prevention and mitigation measures. Rather than simply reproducing extensive parts of these reports, an attempt is made here to give concise answers.

Questions and answers

1. Can we quantify (as % change in peak flood flow, volume or timing) the range of likely impacts that different rural land management practice changes could realise on flood flows in catchments? This should be qualified to deal with different scales of catchment area and size of event if necessary?

Yes - but the uncertainty would be so large that the estimates may be of little practical use. The main reason why the uncertainty is so large is that there are many variables but very few data sets for any method or model to be validated against.

Consider what is involved when using a general-purpose method or model to quantify the impacts of a given practice applied at a given site in a given catchment. The variables affecting impact will be related to several factors, including:

- the location and area draining to the site;
- the nature of the practice;
- how well the practice is implemented;
- the catchment's physical characteristics, and their spatial variation;
- the characteristics of the rainfall and other forcing;
- the antecedent conditions in the catchment;
- downstream conditions.

Even if a quite coarse classification is used, the total number of permutations for these factors is huge. This means that a large amount of field data, from many different catchments, is needed to build and test a general-purpose method or model for quantifying impact.

At present, the amount and quality of field data on impact is extremely limited, so there are no properly-tested general-purpose methods or models. Existing, poorly tested simulation models could be used, by altering the models' parameters to reflect the physical changes. The predicted impacts will then depend on the sensitivities of the models' responses to changes in their parameters. There is, however, no generally-accepted theoretical basis for setting these sensitivities, and ultimately these must be validated against field impact data. The uncertainty in the resulting predictions would therefore be large and any quantification of this uncertainty would involve subjective assessments of the nature and magnitude of the errors involved in the simulations.

It is part of the purpose of the FD2114 Project to study this problem and to propose field and modelling work which should lead to its resolution. As part of the project work, a method was developed using the best currently available approaches for including the effects of land use change and management practices within the Flood Estimation Handbook (FEH) suite of methods for flood estimation. This is described in 'Report C1: Short-term improvement to the FEH rainfall-runoff model: User Manual' and 'Report C2: Short-term improvement to the FEH rainfall-runoff model: Technical Background'.

2. Is there a scale against which the potential flood generation capacity of soils can be measured in order to assess whether an area is in some normal state or has been changed to reduce or increase the capacity from the norm?

Research work to produce a vulnerability index is proposed in the research plan in Report B. On a national 1 km grid this would give the vulnerability to changes in land use and management: the higher the vulnerability index the more likely it is that local or downstream flooding will be affected by any local change in land use or management. This work will take into account other completed and ongoing work on vulnerability to pollution and erosion.

If a scale has to be created for the potential flood generation capacity, then this could be based on the vulnerability index, but the relationship between the scale and index may not be simple. To give an example of the relationship, in areas which are not vulnerable, it is likely that the flood generation capacity was originally low and remains low.

The HOST system and the SPR and BFI coefficients could form the basis for estimating flood generation capacity, but new work would be needed to make this possible. This new work would involve updating HOST using recent flow data, and might require a field sampling programme to measure or assess some soil characteristic associated with flood generation.

3. **What measures or changes in rural land management practice should Flood Management promote or discourage to reduce flood generation? We need to be confident that the benefits are likely to be positive and not counter productive.**

One of the aims in the research plan in Report B is to establish best practice, so that the best measures can be promoted to land managers in the best fashion. Something that must be borne in mind is that there is a risk that any change or measure may have an unforeseen detrimental effect on flooding when applied at a particular location in a particular catchment.

Common sense suggests, for example, that decreasing or delaying surface runoff using buffer strips, detention ponds, barriers in ditches, changed ploughing directions, and so forth, should be promoted to mitigate local floods. However, any resulting widespread increase in infiltration should be assessed carefully, including its impact on catchment scale flooding. Consider, for example, the consequences of causing infiltration to increase as part of runoff management measures designed for integrated on-farm pollution, erosion and flood control. The fate of the extra infiltrated water will depend on topography, geology and land cover. It will ultimately either be evaporated locally, discharge locally at seepage zones or to drains or ditches, or contribute to wider bodies of groundwater. When it contributes to groundwater it can affect catchment scale flooding, directly by increasing groundwater discharge rates and indirectly by raising the water table and causing an increase in saturation excess runoff. Increasing the capacity for infiltration can also lead to an increase in local flooding through the effect of saturation excess runoff: water infiltrated during a rain event can created and maintain saturated seepage areas (fed by lateral, sub-horizontal flow) and this can cause substantial runoff to be generated during the event or early during following events.

There are, of course, wider issues associated with promoting or discouraging changes or measures, such as how the land managers' perceptions of the changes or measures affects the final outcomes, especially in situations where there appears to be little direct benefit to the land managers.

4. **What other integrated approaches to land management can Defra/EA make or encourage that will benefit and address its objectives for sustainable development, risk reduction and environmental benefits?**

Experimental work on integrated on-farm runoff management for pollution, erosion and flood control is proposed in the research plan in Report B, as part of work to establish best practice.

It has been stated in the responses to Questions 1 and 3 that the impacts of changes or measures designed to reduce flood generation cannot yet be quantified and there is a risk that any change or measure may have an unforeseen detrimental effect on flooding when applied at a particular location in a particular catchment. This needs to be taken into account when assessing the overall risks associated with promoting measures for runoff management.

It is likely, though, that for many locations, integrated runoff management using measures for pollution and erosion control (such as using buffer strips and detention ponds) will also be beneficial for flood mitigation.

5. Current findings from the study into the effect of land use changes on flood flow records since the war indicate that any changes that may have taken place are not discernable due to 'natural' climatic variation. Is it possible to say how big a variation would be required to make any change visible in the historic record? Is it likely that the effects of rural land use change will ever be discernable in measured flow records? If not will we have to rely on theoretical modelling to determine potential benefits of land use management on flood flow reduction?

The literature review in FD2114/TR does show that past studies have concluded that any changes that may have taken place are not discernable. However, it may be that these studies did not analyse the data in a suitably robust way. The impacts of changes other than rural land use will be present in the historical time series of flows, including those of urbanisation, reservoirs, flood alleviation schemes, channel modifications and climate change. Thus, continuous change in both the forcing and catchment characteristic data must be dealt with. Identification of such change may not be suitable for consideration in classical statistical terms.

It is likely that the detection of change will be a function of both catchment size and event return period. With increasing catchment size there is typically a higher degree of spatial heterogeneity in bio-geophysical characteristics. The flood generating storm will also have a set of characteristics, in terms of the spatial and temporal variations in the rainfall field. There is therefore the additional consideration that at a certain level each historical event may be viewed as being a unique occurrence, complicating any trend analysis. However, from the assembled sources it appears that the impacts of land use and management on flooding become less significant with increasing spatial scale.

An alternative approach to time series analysis for trend detection is the use of hydrological modelling. A model acts as a control, filtering out natural variability, and allowing the specification of a control scenario against which change may be measured. As stated in the response to Question 1, significant advances must be made before modelling capability reaches a maturity in which change can be assessed. A particular problem is the quantification of the predictive uncertainty. It would therefore be inconsistent to attempt to address this question through a statement derived from modelling results.

In conclusion, it would appear that, in comparison to the natural climatic variability, the impacts of land use and management change on flooding are of second order importance. Detailed analysis of historical rainfall-runoff records is proposed in the research plan in Report B, to finally confirm or refute this conclusion.

6. What are the principle gaps in our current understanding of the impacts of rural land use and management on flood generation? If these could be addressed what will they tell us about future policy direction in this area?

This question encapsulates the objectives of the FD2114 project and is answered in detail in FD2114/TR and FD2114/PR1. FD2114/TR shows that despite there being a considerable amount of relevant literature on field work and modelling, little is actually known about the flooding effects of rural land use change and management practices. This is reflected in the list below, which summaries the main gaps in our current understanding. These gaps are quite fundamental and basic.

The main gaps in our current understanding tackled in the research plan in Report B are (not in order of priority):

- How do changes in runoff generation at the local scale propagate downstream and affect catchment scale flooding?
- What are the best measures for flood prevention or mitigation to apply at a given site and how should these measures be promoted to land managers to ensure the best outcomes? There must be integrated management of pollution, erosion and flood control.
- How should rainfall-runoff modelling be developed so that reliable estimates can be made for the impact of flood prevention and mitigation measures?
- Do historical rainfall-runoff datasets really not show the effects of land use change and management practices?
- Which data are important when predicting the impacts of changes in land use and management and how can these data be collected efficiently?
- How can national maps be created which show the vulnerability to local and downstream flooding as a result of changes in land use and management?

One of the projects proposed in the research plan in Report B is to consider future scenarios so that the effects of different future policy directions can be examined. This project would not run until most of the other project work has been completed, so it can make use of the knowledge gained in the other projects.

7. What types of effect can land use and land management regimes have on runoff generation?

Surface runoff is generated when rain falls on poorly permeable or saturated ground and flows away overland along natural or man-made flow pathways, and is also generated where subsurface water seeps to the surface and then flows away overland. Subsurface runoff is generated when infiltrated water flows laterally in the subsurface, under the action of gravity, along natural or man-made pathways through the soil or rock.

Land use and management regimes can affect runoff generation through its effect on the local water balance, the capacity for infiltration, and the flow pathways. The more water that is evaporated the less there is for runoff, so adding temporary surface storage or changing the vegetation cover can reduce the total volume of runoff. Poor soil management can cause soil capping and soil compaction and these can lead to decreased infiltration capacity and increased surface runoff during storms. The surface and subsurface flow pathways can be quite complex and are affected by almost every change in land use and every management practice. At the smallest scale, a surface pathway may be along a wheel track. At slightly larger scales it may be along a field edge and through a gate onto a road. For the subsurface, it may be along a perched water table associated with a plough layer, or through a partly blocked sluggish drain. At larger scales, the pathways can be along ditches and streams and in aquifers. Land use and management regimes can also affect the temporal variability in runoff generation. For example, altering the infiltration properties can affect the storm-to-storm variability of local flooding because infiltration during one storm affects the antecedent conditions for following storms. Saturated areas can develop in hollows and at the base of slopes, fed by lateral flow of infiltrated water. If a rainfall event causes such saturated areas to be created, there can be rapid saturated excess runoff early during following events.

Any change in land use or management can therefore affect runoff generation in many, complex, interacting ways.

8. What models are available to assess these effects at a catchment-scale and target land use/management change?

A wide range of different types of models are reviewed in FD2114/TR. Some of these have been, or have the potential to be, used in predicting the impact of changes in land use and management on local and downstream flooding. It is concluded, though, that there is no generally-accepted theoretical basis for a design of model suitable for predicting impact and there are serious limitations in the methods available for estimating uncertainty in the prediction of impact. This does not mean that the existing models and methods have no value. If they are to be used they should be used with care, in the knowledge that they may be unreliable. The models and methods proposed for development in the medium term (Question 9) are likely to be based very closely on the existing models and methods.

9. What models should be generated in the medium-term to provide better answers?

It is concluded in FD2114/TR that it is appropriate to take a distributed (rather than lumped) approach to modelling, especially now that catchment managers increasingly have access to mapped data within a GIS. Also, it is concluded that there are some advantages in using physically-based modelling as this allows there to be a direct link between point-scale physical measurements and the parameters and variables in the models. There are, though, many different approaches to modelling, and there is scope allowed for this within the modelling projects proposed in the research plan in Report B.

Considerable progress needs to be made in modelling before a reliable and generally-applicable approach can be developed which gives good estimates for the likely flood impact when given prevention and mitigation measures are applied at a particular site. This includes progress in rainfall-runoff modelling and in assessing the uncertainty in the predictions made using rainfall-runoff modelling. In one of the projects in the research plan, the purpose is to create a modelling system within which different modelling approaches (including existing approaches) can be compared rigorously and some concrete conclusions can be reached about best practice in predicting flood impacts using rainfall-runoff modelling.

10. Is there evidence that woodland creation or management practice can have a mitigating effect on flood generation?

The hypotheses *"forests reduce flooding"* and *"forests increase flooding"* are considered in FD2114/TR. Several interacting and cancelling factors need to be taken into account when analysing the effects of forests on flood generation and it is not adequate simply to assume that forests 'absorb' floods, acting as a sponge. In the report, it is concluded that, overall, there is no clear evidence to show that forests either mitigate or increase flooding to a significant extent.

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Nobel House
17 Smith Square
London SW1P 3JR

www.defra.gov.uk

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