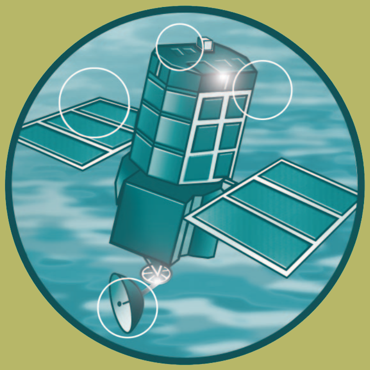
Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

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

Short-term improvement to the FEH rainfall-runoff model: Technical background

R&D Project Record FD2114/PR3



Environment Agency

defra
Department for Environment
Food and Rural Affairs

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

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

Short-term improvement to the FEH rainfall-runoff model: Technical background

R&D Project Record FD2114/PR3

Authors: J.C. Packman, P.F. Quinn, J. Hollis and
P.E. O'Connell

Produced: November 2004

Authors:

J. C. Packman

NERC - CEH Wallingford

P. F. Quinn

University of Newcastle upon Tyne, Water Resource Systems Research Laboratory

J. Hollis and P. E. O’Connell

Cranfield University, National Soil Resources Institute

Statement of use
For use as an interim method in predicting the impacts of land use and management on flood generation within the MDSF/CFMP framework.

Dissemination Status
Internal: Released Internally
External: Released to Public Domain

Keywords : Rural land use; land management; runoff; flood; Flood Estimation Handbook (FEH); rainfall-runoff model; unit hydrograph; time to peak; percentage runoff; soil; Hydrology of Soil Types (HOST); flood mitigation; soil management; flow connectivity; Floods and Agriculture Risk Matrix (FARM); Catchment Flood Management Plan (CFMP); Modelling and Decision Support Framework (MDSF); GIS; Spreadsheet.

Research contractor: University of Newcastle upon Tyne, NE1 7RU (Contact: Prof P. E. O'Connell, Water Resource Systems Research Laboratory, School of Civil Engineering and Geosciences).

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

ISBN: 0-85521-141-5

Executive summary

This report should be read in conjunction with two previous reports: ‘FD2114/TR: Impact Study Report’ (O’Connell et al, 2004a), and FD2114/PR1: Research Plan’ (O’Connell et al, 2004b), in which the purpose of the FD2114 project is introduced and results presented. FD2114/TR represents a comprehensive review of the impacts of rural land use and management on flood generation. FD2114/PR1 is a research plan which gives a way forward in 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. Project FD2114 is part of the Broad Scale Hydrology Modelling Programme (Calver and Wheater, 2001).

Pending the development of new methods of predicting impacts as scoped out in ‘FD2114/PR1: Research Plan', a short-term method is required based on suitable adjustments to the FEH rainfall runoff model. This report describes the development of a procedure by which land use/management impacts on the parameters (Tp, SPR) of the FEH rainfall runoff model can be assessed, and potential impacts on flood estimates derived. The procedure is intended to link with the Modelling and Decision Support Framework (MDSF) used in preparing Catchment Flood Development Plans (CFMPs). It uses GIS procedures and data from the MDSF, but needs additional GIS data on HOST soil class and land use to define a ‘worst case’ or ‘fully degraded’ impact of agricultural intensification on Tp and SPR. Two new spreadsheet programs are provided: SPRADJ combines HOST class and land use summaries to derive the catchment average SPR; and FEHSEN derives flood estimates for a matrix of trial Tp and SPR values. A Decision Support Matrix (the FARM tool) is used to assess the likely degree of degradation due to agricultural intensification within the catchment.

This report provides the technical background and rationale behind the procedure, while FD2114/PR2: User Manual (Packman *et al* 2004) describes how the procedure is applied in practice. Test results from applying the procedure to four catchments are given in this report.

This report also presents in Appendix A some exploratory studies to identify land use impacts on observed values of Tp and SPR. No consistent impact was found, a fact attributed to correlation between land use/management and topography, climate and soils - all of which appear in the FEH parameter equations. This conclusion was supported by the difficulty of finding test catchments within a geographical region having similar size, climate and soil type, but significantly different land use/management. The FEH methods would seem already to ‘factor in’ the typical land use/management, especially when (as recommended) local data is used to update parameter estimates from those given by the basic regression equations.

However, on the premise that agricultural intensification impacts can be seen at the plot scale and should therefore also be present at the catchment scale, and since agricultural intensification degrades soil structure, increasing surface runoff volume and speeding its flow rate over the land surface, the speculative procedure for adjusting Tp and SPR presented here is recommended for use on a precautionary basis.

It should be noted that the proposed procedures require a sound knowledge of the FEH rainfall-runoff method, of ArcView GIS, and of using spreadsheets. They are rather time-consuming, but they provide an improved rationale for adjusting FEH model parameters and determining the impact on flood estimates. The procedures could be streamlined and made more ‘user-friendly’ by additional development of GIS macros and new GIS layers, but such development was not covered by the present project

Contents

TABLES

Glossary

ALTBAR	Mean catchment altitude (m)
Base Case/Flood	Best estimate of flood prior to assessing new land use/management impacts
BFI	Base Flow Index: the long term ratio of baseflow to total river flow volume, developed for low flow studies, and evaluated for each flow gauge in the National Flow Archive
BFIHOST	Estimate of BFI based on HOST soil class.
CEH	Centre for Ecology and Hydrology
CFMP	Catchment Flood Management Plan, a Defra/EA sponsored broad scale assessment of flood defence options within a large river catchment.
DPLBAR	Mean DTM flow path length in catchment to outlet (km)
DPSBAR	Mean of DTM grid square slope within catchment (m/km)
DSM	Decision Support Matrix
DTM	Digital Terrain Model (gridded values of terrain data, such as heights and flow directions, over an area)
FARM	Floods and Agriculture Risk Matrix
FARL	Index used to assess effect of lakes and reservoirs on flood peaks (see FEH v5)
FEH	Flood Estimation Handbook (IH, 1999)
FEHCAL	Spreadsheet program supplied with the MDSF to assess impacts of local changes in Tp and SPR on flood peaks at successive locations downstream.
FEHSEN	Spreadsheet program to assess flood estimates using a matrix of Tp and SPR values
GIS	Geographical Information System
HOST	Soil classification system, see Table 2.1
IHDTM	Integrated Hydrological DTM developed by CEH
LCM	Land Cover Map
MDSF	Modelling and Decision Support Framework for use in developing CFMPs (HR Wallingford et al, 2002)
NSRI	National Soils Resources Institute
PROPWET	Proportion of days in year that soil moisture deficit is under 6mm
SAAR	Standard Average Annual Rainfall (mm), 1961-90
SPR	Estimate of Percentage of Rainfall yielding Quick Runoff under standard conditions (under 40mm of rainfall, zero soil moisture deficit)
SPRHOST	Estimate of SPR based on HOST soil class
Tp	Time to peak of Unit Hydrograph
Tp(0)	Time to peak of Instantaneous Unit Hydrograph (due to pulse of rain falling instantaneously over the catchment)

URBEXT	Fraction of catchment area that is urbanised, equal to Urban + 0.5*Suburban fractions given by censored form of CEH LCM1990 dataset (see FEH v5)
WINFAP-FEH	Program to apply FEH statistical methods of annual maximum and partial duration flood peak analysis, based on pooling groups of similar catchments

1. Introduction

For completeness this report should be read in conjunction with three previous reports: 'FD2114/TR: Impact Study Report' (O'Connell *et al*, 2004a), and 'FD2114/PR1: Research Plan' (O'Connell *et al*, 2004b), in which the purpose of the FD2114 project is introduced and results presented, and 'FD2114/PR2 (Project Record): User Manual' (Packman *et al*, 2004). FD2114/TR represents a comprehensive review of the impacts of rural land use and management on flood generation. FD2114/PR1 is a research plan which gives a way forward in defining and implementing best practice in flood prevention and mitigation associated with rural land use change and management practices. Finally, Project Record PR1 is a User Manual for the application of the recommended short-term adjustments to the FEH rainfall-runoff flood estimation model. This Project Record PR2 presents the scientific evidence and reasoning that underpins the methods described in the User Manual.

1.1 Project FD2114

Project FD2114 is part of the Broad Scale Hydrology Modelling Programme (Calver and Wheater, 2001). The programme of work for the project was divided into 2 parts, each with an overall objective:

Part 1 Objective: To review the factors contributing to runoff and flooding in the rural (managed, not natural) environment, and to scope out the research needed to improve the identification of the management policies and interventions to reduce the impact of flooding.

The scope of the work required to address the Part 1 Objective was defined by the set of Tasks described in the two previous reports; FD2114/TR: Impact Study Report presents outputs from Tasks 1-7, while FD2114/PR1: Research Plan is the output from Tasks 8-12.

Part 2 Objective: To deliver in the short term an improvement in the estimation of the effects of changes in rural land management on flood generation to the CFMP (Catchment Flood Management Plans) programme.

The Part 2 Objective, short-term improvement in rural land use modelling in CFMPs, involved Tasks 16-22 as set out in Table 1.1 below.

Tasks 16 to 18 results are reported on as Project Records 1 and 2 of the FD2114 report series. This project report, PR2, provides a detailed discussion on the underlying thinking and research upon which proposed short-term adjustments to the FEH rainfall-runoff flood estimation model have been based. The report is the second of two describing the development and implementation of the Short-term Method for predicting the impacts of land use and management on flooding within CFMPs. A separate report, PR1, is a brief User Guide to the Short-term Method.

Task	Description
Task 16	Shortlist candidate method(s) which have potential for application within a 12 month timescale in the present programme of CFMPs, which are implementable within the context of the FEH and the CFMP Modelling and Decision Support Framework (MDSF). It is likely that the most feasible method will be via modifications of the HOST catchment parameters which are incorporated in the FEH. This approach however needs to be confirmed by consensus of all the disciplines on the contractor team.
Task 17	Design a test programme and assemble test data to test the short term method(s), and test and compare the method(s).
Task 18	Recommend a method that could be used in the short term to improve the modelling of the impact of rural land use on flood generation in the CFMP programme.
Task 19	If the method is going to be of practical use in CFMPs, it must be not only a simple and high level hydrological method, but must link into related management policies and interventions. It must be complemented by a method of forecasting future landscape/agricultural scenarios. It must therefore include an appreciation of the social, financial and institutional means of achieving the desired changes and of the uncertainties involved in such forecasts and their application on the ground.
Task 20	**Carry out peer review by the review panel.**
Task 21	Uptake: subject to favourable review produce a short report or manual describing how the method should be used on CFMPs and provide training to EA and consultants' staff in its use.
Task 22	It is recognised that the method may use GIS data. The Tenderer should assess whether it will be advantageous to users for the method to be implemented within the MDSF, coded into it and issued as a revised version, and should cost separately a provisional item for this task. For this purpose the Tenderer should include the services of the MDSF long term support contractor lead by HR Wallingford as necessary.

Table 1.1 Tasks defining scope of short-term improvement modelling for CFMPs

1.2 Background

The FEH rainfall-runoff model, as detailed in volume 4 of the Flood Estimation Handbook (Institute of Hydrology, 1999), is a method of estimating a design flood hydrograph of specified return period for any location in the UK. It adopts a unit hydrograph and design storm approach, and at its simplest involves two principal model parameters, Standard Percentage Runoff (SPR) and Time to Peak (Tp), together with the use of local rainfall statistics. SPR and Tp are not directly observable or process-based parameters, but are empirically derived by fitting the model to observed rainfall and river flow data. In particular, SPR separates flow into slow and fast response components, without considering whether these relate to surface or subsurface response.

For a specific catchment, SPR and Tp can be estimated (in order of preference) by analysing at-site rainfall-runoff data:

- transposing at-site values from analogue sites, or
- using published relationships which link SPR to the catchment soil type (i.e. theHOST described by Boorman et al, 1995); and Tp to the catchment slope (DPSBAR), length (DPLBAR), and likely soil wetness (PROPWET).

These ‘catchment descriptors’, together with the rainfall statistics, can be found for any UK site using the FEH CD-ROM available from CEH. The FEH model is widely used and has been adopted in the MDSF (Modelling and Decision Support Framework for CFMPs).

However, the empirical nature of the model does not explicitly address the impacts of land use/management on runoff processes. Following a brief review of available information (Packman, 2002), the MDSF procedures (HR Wallingford *et al*, 2002, p71) adopt a sensitivity approach: forest drainage could reduce local Tp by 2-3 hours, and agricultural drainage in low PR soils could reduce local Tp by 1-2 hours, but in high PR soils increase Tp by 1-2 hours; land management practices that increase soil compaction could be assessed by increasing SPR by a factor 1.15. It may be noted that the extensive review carried out in FD2114/TR of the current project has not found additional information to refine these suggested changes in Tp and SPR.

The downstream effect of these or other local changes to Tp and SPR (e.g. due to reservoirs or urbanisation) can be assessed using the FEHCAL spreadsheet provided with the MDSF. This routes the effect of changes in Tp and SPR from individual subcatchments throughout the downstream catchment - using ‘area-weighted-average’ calculations for SPR, and ‘first-moment of area’ calculations on channel length to adjust Tp. The spreadsheet is a useful tool, but is not a true subcatchment routing model. It considers how the parameters might change but not the shape of the unit hydrograph, always using the standard triangular unit hydrograph shape (defined by the equation QpTp=220). The fixed shape and resulting fixed ratio of Tp to centroid lag is a simplification, but is at least theoretically consistent with using Tp rather than lag time in the ‘first moment of area’ calculations. A full description of the FEHCAL spreadsheet is not given in this report, but may be found, together with examples of its use, in the MDSF manual (HR Wallingford et al, 2002).

As described in the contractual annex for FD2114, short-term improvements to the MDSF guidance were to be sought, including new adjustments to HOST classes (agreed within the consortium) to reflect land use and management changes, and possible use of a time-area routing methods to give an explicit link between local land use/management impacts and downstream hydrograph shape. These short-term improvements were to be consistent with the ‘revitalisation’ of the FEH model being pursued in a parallel project. The improved model was to be linked with a "decision-support matrix" approach to help assess the likely changes in FEH parameters, recognising the general lack of field information on impacts. The approach would then be tested using four selected catchment sites covering upland forest and grass, and lowland crop and meadow.

As also described in the contractual annex, a consistent method of defining land use/management is required, and thus new catchment descriptors would be derived using the satellite-based CEH land cover maps (Fuller at al, 2002). These "pilot" land-cover descriptors would have deficiencies, such as misclassifications in the satellite data, and lack of information on land management practices, but would give the best readily available indication of likely land use/management. They would be considered alongside the HOST and the other FEH descriptors in assessing Tp and SPR. (In the longer term, the ADAS 1km agricultural land use database could be a strong candidate to help develop better descriptors.)

An exploratory analysis of potential relationships between Tp and SPR parameter values (as published in the FEH v4, pp177-237) and the “pilot” land cover descriptors has not provided any evidence or useful guidance on the effect of land use/management on flooding (see Appendix A). The analysis mirrored the findings of the Impacts Study Report (FD2114/TR) that evidence of catchment scale impacts on the flood hydrograph is lacking but this does not mean that such impacts do not exist, at least for catchments where there is evidence of substantial soil degradation. The land cover descriptors used did not reflect such effects. Consequently, for assessing changes in Tp, this report recommends that the sensitivity approach described in the MDSF is retained. However, for assessing changes in SPR, the 1.15 sensitivity factor recommended in the MDSF is replaced by a new GIS procedure based on land cover and HOST soil information, and aimed at determining the ‘worst case’ where all agricultural and lowland grass area are ‘full degraded’. A new spreadsheet FEHSEN has been developed to help assess the impact of changing Tp and SPR on local flood estimates, and another spreadsheet FARM implementing the ‘decision support matrix’ is provided to help determine the likely scale of changes to both SPR and Tp. Application of the method to four test catchments is demonstrated, and the results are discussed in the context of general uncertainty in the model parameter estimation, as evidenced by comparing predicted and observed parameters in the test catchments.

A summary of recommendations is provided at the end of this report, and a step-by step guide to the proposed methodology is given in the parallel Project Report PR1: User Manual

2. Developing the short-term improvements

2.1 HOST class and standard percentage runoff (SPR)

The procedure for adjusting SPR is based on an intuitive approach that accounts for the effects of soil degradation through a reclassification of HOST classes. In the FEH model, SPR is usually taken as the SPRHOST value from the FEH CD-ROM, being the catchment average SPR estimate based on the range of HOST classes present. The HOST system (Boorman et al, 1995) is summarised in Table 2.1 below, giving the Baseflow Index (BFI) and SPR values derived for each HOST class. The vertical position of the HOST class in Table 2.1 generally relates to geology, and horizontal position to available moisture storage, compaction/consolidation and drainage.

BFI represents the long-term ratio of baseflow to total runoff volume, and was developed for low flow analysis using flow data alone (without rainfall). It is included here because of its statistical relationship to SPR, and its generally smoother changes between HOST classes. This, together with the greater number of 'observed' BFI values (575) compared with SPR (170) used to derive the HOST relationships suggest that BFIHOST is a generally more reliable index.

<table>
<tr><th>Substrate</th><th>GW</th><th colspan="5">Impermeable / gley layer</th><th colspan="2">Peat Soils</th></tr>
<tr><td></td><td></td><td>>100cm</td><td colspan="2">40-100cm</td><td colspan="2"><40cm</td><td colspan="2"></td></tr>
<tr><td>Chalk</td><td></td><td>1 1.0
2.0</td><td colspan="2">13 1.0
2.0</td><td colspan="2">14 0.38
25.3</td><td colspan="2">15 0.38
48.4</td></tr>
<tr><td>Limestone</td><td></td><td>2 1.0
2.0</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Macropore, No bypass</td><td></td><td>3 0.9
14.5</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Consol., With bypass</td><td>Ground-water at >2m</td><td>4 0.79
2.0</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Unconsol. Macropore, no bypass</td><td></td><td>5 0.9
14.5</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Unconsol. Micropore, with bypass</td><td></td><td>6 0.65
33.8</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Macropore, no bypass</td><td>Ground-water</td><td colspan="3">7 0.74
44.3</td><td>9 0.73
25.3</td><td>10 0.52
25.3</td><td>11 0.93
2.0</td><td>12 0.17
60.0</td></tr>
<tr><td>Micropore, with bypass</td><td>at <2m</td><td colspan="3">8 0.56
44.3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Slowly permeable</td><td></td><td>16 0.78
29.2</td><td>18 0.52
47.2</td><td>21 0.34
47.2</td><td colspan="2">24 0.31
39.7</td><td colspan="2">26 0.24
58.7</td></tr>
<tr><td>Impermeable (hard)</td><td></td><td>17 0.61
29.2</td><td>19 0.47
60.0</td><td>22 0.32
60.0</td><td colspan="2"></td><td colspan="2">27 0.26
60.0</td></tr>
<tr><td>Impermeable (soft)</td><td>No ground-water or aquifer</td><td></td><td>20 0.52
60.0</td><td>23 0.22
60.0</td><td colspan="2">25 0.17
49.6</td><td colspan="2"></td></tr>
<tr><td>Eroded peat</td><td></td><td></td><td colspan="4"></td><td colspan="2">28 0.58
60.0</td></tr>
<tr><td>Raw peat</td><td></td><td></td><td colspan="4"></td><td colspan="2">29 0.23
60.0</td></tr>
<tr><td colspan="3"></td><td>High IAC</td><td>Low IAC</td><td>Low IAC</td><td>High IAC</td><td>Drained</td><td>Un-drained</td></tr>
</table>

Table 2.1 HOST class, and fitted BFIHOST (normal) and SPRHOST (bold) coefficients (For each cell: HOST class is given in top-left corner; BFIHOST in top-right corner; and SPRHOST is the figure in bold below)

Although Table 2.1 presents values of SPR and BFI for each HOST class, it cannot be directly applied because mapping of HOST class boundaries is not generally available. Published UK soil maps present ‘map units’ which can cover a number of separate HOST classes. FEH (vol 4, p248-274) summarises how map units present within a catchment are converted to proportions of the relevant HOST classes and then used to provide average SPR estimates using the tabulated SPRHOST values. The hand calculations can be lengthy. However, CEH does hold HOST data, as percentages for each of the 29 classes, on a 1km grid covering the UK. Overlaying this grid by catchment boundaries allowed average SPRHOST values to be derived for every catchment (>0.5km^2) in the UK, and then included on the FEH CD-ROM.

It should be recognised that land use/management impacts on the ‘observed’ SPR values have not been assessed in deriving the SPRHOST values in Table 2.1. Assessing such impacts would be a considerable task, well beyond the scope of this project. Instead, to assess the likely effect of soil compaction due to future land use/management practices, revised values have been proposed by Hollis (Appendix C) by assigning an appropriate analogue HOST class to represent the degraded soil. The rationale for the proposed changes is that soil structural degradation, in the form of topsoil and upper subsoil compaction or seasonal ‘capping’ and sealing of soil surfaces, causes a reduction in the effective soil storage, which in turn results in increased surface runoff (see section 3.2.1 of the Impact Study FD2114/TR). Increased surface runoff on a specific HOST class will give an increased SPRHOST value, assuming that there is no change in the proportion of surface runoff that is transferred to the surface water network. Thus the general principle is that soil structural degradation affects the soil storage / wetness component of the HOST classification but does not alter the hydrogeological component. Analogue HOST classes are therefore derived by moving from left to right across the columns in table 2.1, but not by moving vertically across the broad row groupings in table 2.1, which represent three distinct hydrogeological groupings based on permeability (HOST classes 1 to 6 are all on permeable substrates) and depth to groundwater. In addition, the current upper limit on SPR of 60 was retained and, because of the lack of smoothness in SPRHOST discussed above, BFIHOST was used to guide the revised SPRHOST value where analogue classes were particularly uncertain. The revised coefficients are given in Table 2.2 below, where the ‘*’ against specific analogues represents a greater degree of uncertainty in its appropriateness.

HOST Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Analogue	3	3	7*	6*	7*	8	7*	8	9	10
Original SPR	2	2	15	2	15	34	44	44	25	25
Revised SPR	14	14	27	15	27	44	44	44	25	25
Alternate SPR	9	9	22	11	22	39	48	44	25	25
HOST Class	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Analogue	11	12	3*	24	15	18*	18	20	22	20
Original SPR	2	60	3	25	48	29	29	47	60	60
Revised SPR	2	60	15	40	48	47	47	59	60	60
Alternate SPR	2	60	9	30	48	41	35	55	60	60
HOST Class	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	
Analogue	23	27	25	25	25*	26	27	28	29	
Original SPR	47	60	60	40	50	59	60	60	60	
Revised SPR	60	60	60	49	60	59	60	60	60	
Alternate SPR	55	60	60	47	60	59	60	60	60	

Table 2.2 HOST class, analogue, SPRHOST, revised and alternate degraded SPR

Subsequently, recognising from Table 2.1 that BFI changes more smoothly between HOST classes than SPR, an alternative and more consistent method of assessing change in SPR was developed based on the relationship between BFI and SPR presented in the FEH (v4, p28):

$$SPR = 72 - 65.5\ BFI$$

The change in BFI from original to analogue classes is read from Table 2.2 and converted to an equivalent change in SPR using the equation:

$$\Delta SPR = -65.5\ \Delta BFI$$

This change in SPR is then added to the original SPR values to give the alternative estimates of degraded SPR shown in Table 2.2.

The two degraded SPR values can be applied as two 'worst-case' or 'fully degraded' scenarios to all of the catchment areas under cereal or lowland grass cover (the impact of forest on SPR is considered less clear, particularly given the 60% upper limit that applies in most upland areas where significant forest development exists). The 'fully degraded' catchment average SPR can be found via GIS procedures, using layers for the HOST classes falling within the catchment, and classifying each into (a) degraded (lowland grass and cereals), or (b) other. The appropriate SPR values from Table 2.2 can then be applied. A simple spreadsheet SPRADJ is available to help make the calculations. The procedure is described in full in the companion FD2114/PR2.

The procedure described above is relatively flexible, and the classification of HOST layers into additional land covers (e.g. forest) could be included if the relevant degraded SPR values can be defined. However, as described previously, HOST class information is not provided on the FEH CD-ROM. It is available from CEH at a 1 km grid interval; licence fees (excl VAT) for coverage of England and Wales are £10.4k, with an annual renewal fee of £7.3k. More detailed soil information is available from the National Soil Resources Institute, Cranfield University.

2.2 Proposed Tp adjustments

Following a brief review of available information (Packman, 2002), the MDSF procedures (HR Wallingford et al, 2002, p71) adopted a sensitivity approach to adjustment of Tp:

- forest drainage could reduce local Tp by 2-3 hours;
- agricultural drainage in low PR soils could reduce local Tp by 1-2 hours, but in high PR soils increase Tp by 1-2 hours.

Exploratory work to try and improve on these simple sensitivity adjustments, relating the published FEH Tp values to the CEH LCM1990 and LCM2000 data on land cover is described in Appendix A. However, no consistent relationships were found, and for the current project, the sensitivity approach from the MDSF has been carried forward to the decision support methodology described below. Until a distributed approach to catchment routing is developed (such as the time-area method discussed in Appendix A, Section A.3), the recommended changes in Tp should be applied pro-rata based on the extent of degradration in the catchment. The ‘worst case’ extent of degraded area is found by the GIS procedures outlined in Section 2.1 above (and described in detail in Project Report PR1). The ‘worst case’ scenario may be adjusted based on the actual agricultural practices in use via the FARM tool described in Chapter 4.

2.3 Decision support

To assess the impact of changes in Tp and SPR discussed above, two decision support tools are provided. The first is a spreadsheet FEHSEN which gives the ‘three by three’ results of using three Tp and three SPR values to derive FEH flood estimates for the local catchment. FEHSEN is broadly similar to the FEHCAL spreadsheet supplied with the MDSF in that the user pastes in the catchment descriptors provided by the FEH CD-ROM, from which the original FEH Tp and SPR estimates are derived, and the base flood estimate for a user-defined return period is determined. The user then enters two test Tp values (usually the FEH estimate ±1hr) and the revised and alternate ‘fully degraded’ SPR values from the SPRADJ spreadsheet (discussed in the previous section). This provides a range of flood estimates, allowing the user to assess the likely scale of the ‘worst case’ impact.

The second spreadsheet, FARM, allows the user to assess the land use/management practices within the catchment, and thus determine how far towards the ‘worst case’ scenario the catchment response is likely to have moved.

Having determined appropriate Tp and SPR values for the degraded catchment, the values can be transferred to the FEHCAL spreadsheet provided with the MDSF to assess the effect of the changes further downstream in the catchment. Explanation of how to use the FEHCAL spreadsheet is given in the MDSF report (HR Wallingford et al, 2002).

3. Testing the short-term improvements

3.1 Selection of test catchments

Catchments for use in testing the short-term improvements were sought in pairs to represent different land use/management but with otherwise similar characteristics. Catchments were chosen also to have published Tp and SPR values in the FEH, to allow changes due to land use/management to be put in context.

Although the grass, cereal and woodland indices described in Appendix A have not provided evidence of land cover impacts on Tp or SPR, they have given a means of selecting test catchments. Table 3.1 lists the top ten FEH catchments in terms of their proportion of each land use class (cereals, woodland, and grass) from LCM 1990 and 2000. It also gives for each catchment the observed values of Tp and SPR, and the main FEH catchment descriptors. It is clear that there is considerable consistency in the woodland and cereal lists, with eight catchments common to the respective 1990 and 2000 lists. The grass list shows much greater inconsistency, with only 2 catchments common to both.

From Table 3.1, the Plynlimon and Wye catchments (54022 and 55008) would seem to form a suitable pair of upland catchments, particularly as extensive data observations are available at CEH. Unfortunately, only a short period of data from these catchments was analysed for the FEH, and the processing of additional data was beyond the scope of this project. Moreover, these catchments were considered by the project consortium to be too small and too unusual for the present testing purposes. The testing has therefore focussed on lowland test catchments.

1990 Grass	**No.**	**Name**	**SPR**	**Tp(0)**	**AREA**	**SAAR**	**SPRHOST**	**Grass**
	27051	Crimple at Burn Bridge	31.5	2.9	8.13	855	40.8	0.82
	52010	Brue at Lovington	47.3	10.2	139.52	867	36.4	0.81
	72818	New Mill Brook at Carvers	25.4	5.9	65.08	1076	39.7	0.81
	28041	Hamps at Waterhouses	42.1	-	36.91	1085	47.2	0.79
	47008	Thrushel at Tinhay	40.6	6	112.71	1144	39.1	0.77
	52020	Gallica Stream at Gallica	50.7	2.9	16.44	950	45.3	0.77
	45004	Axe at Whitford	43.1	8.2	288.58	994	38.8	0.76
	45009	Exe at Pixton	19.4	5	147.81	1375	34.6	0.75
	73008	Bela at Beetham	27.8	4.3	132.15	1290	32.5	0.75
	55022	Trothy at Mitchel Troy	47.5	11.9	142.41	887	36.9	0.75
2000 Grass	No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Grass
	55034	Cyff at Cyff Flume	54.4	1	3.11	2417	47.1	0.94
	55008	Wye at Cefn Brwyn	44.1	1.6	10.56	2458	48.5	0.92
	69034	Musbury Brook at	37.2	1.2	3.14	1453	49.1	0.91
	76805	Force Beck at M6(shop)	52.1	1.1	3.97	1514	35.2	0.89
	28041	Hamps at Waterhouses	42.1	-	36.91	1085	47.2	0.84
	66006	Elwy at Pont-y-gwyddel	44.7	5.9	191.4	1185	39.5	0.82
	27051	Crimple at Burn Bridge	31.5	2.9	8.13	855	40.8	0.82
	61003	Gwaun at Cilrhedyn Bridge	40.2	4.8	31.29	1550	39.1	0.81
	60003	Taf at Clog-y-fran	42.2	13.5	216.73	1420	34	0.81
	66002	Elwy at Pant Yr Onen	38.1	4.3	218.63	1145	38.8	0.81
1990	No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Cereals
	29004	Ancholme at Bishopbridge	29.8	7.4	58.92	615	29.4	0.81
	36008	Stour at Westmill	46	21.9	223.63	589	42.9	0.79
	29001	Waithe Beck at Brigsley	8.7	6.1	108.28	691	11.3	0.78
	33809	Bury Brook at Bury Weir	55.4	17.6	61.97	547	47.4	0.76
	37008	Chelmer at Springfield	44.9	-	190.13	584	39.3	0.76
	29002	Great Eau at Claythorpe	11.1	8.9	80.69	692	21.9	0.75
	33045	Wittle at Quidenham	21.5	17.4	27.65	608	32.7	0.75
	34007	Dove at Oakley Park	44.9	-	140.1	585	37.3	0.75
	35008	Gipping at Stowmarket	47.7	10.2	127.43	577	43.4	0.73
	37003	Ter at Crabbs Bridge	36.6	-	77.81	570	41.8	0.71
2000	No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Cereals
	29002	Great Eau at Claythorpe	11.1	8.9	80.69	692	21.9	0.81
	34007	Dove at Oakley Park	44.9	-	140.1	585	37.3	0.81
	29004	Ancholme at Bishopbridge	29.8	7.4	58.92	615	29.4	0.80
	33809	Bury Brook at Bury Weir	55.4	17.6	61.97	547	47.4	0.78
	34011	Wensum at Fakenham	12.4	10.2	162.1	698	14.4	0.78
	35008	Gipping at Stowmarket	47.7	10.2	127.43	577	43.4	0.77
	36008	Stour at Westmill	46	21.9	223.63	589	42.9	0.77
	33045	Wittle at Quidenham	21.5	17.4	27.65	608	32.7	0.77
	37003	Ter at Crabbs Bridge	36.6	-	77.81	570	41.8	0.76
	34003	Bure at Ingworth	11.8	12.4	168.09	669	20.8	0.75
1990 Wood	No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Woods
	54022	Severn at Plynlimon Flume	36.7	1.8	8.68	2482	52.7	0.51
	23005	North Tyne at Tarset	54.9	6.1	283.49	1230	54.5	0.50
	67003	Brenig at Llyn Brenig	74.3	4.7	22.17	1317	53	0.48
	39036	Law Brook at Albury	3.8	-	16	819	15.1	0.42
	54034	Dowles Brook at Dowles	33.1	-	42.07	715	19.2	0.42
	76011	Coal Burn at Coalburn	71.7	1.7	1.55	1097	58.9	0.38
	52016	Currypool Stream at	13.9	3.7	15.72	934	29.2	0.37
	23010	Tarset Burn at	54.9	-	95.85	993	52.6	0.36
	41025	Loxwood Stream at	59.6	-	93.81	812	46.5	0.35
	41022	Lod at Halfway Bridge	49.7	6.3	52.22	857	38.8	0.35
2000 Wood	No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Woods
	7006	Lossie at Torwinny	52.6	7.6	20.56	957	55.3	0.59
	23005	North Tyne at Tarset	54.9	6.1	283.49	1230	54.5	0.54
	39036	Law Brook at Albury	3.8	-	16	819	15.1	0.54
	54022	Severn at Plynlimon Flume	36.7	1.8	8.68	2482	52.7	0.54
	67003	Brenig at Llyn Brenig	74.3	4.7	22.17	1317	53	0.48
	52016	Currypool Stream at	13.9	3.7	15.72	934	29.2	0.45
	41025	Loxwood Stream at	59.6	-	93.81	812	46.5	0.44
	41022	Lod at Halfway Bridge	49.7	6.3	52.22	857	38.8	0.42
	54034	Dowles Brook at Dowles	33.1	-	42.07	715	19.2	0.41
	7003	Lossie at Sheriffmills	67.7	-	217.07	833	34.6	0.41

Table 3.1 Top ten catchments under Grass, Cereal and Woodland cover

To help select suitable test catchments from Table 3.1, the WINFAP-FEH program has been used, seeking catchments of similar topographic and climatic characteristics, by forming pooling groups for each of the cereal catchments from Table 3.1. The pooling process finds the most similar catchments (throughout the UK) in terms of AREA, SAAR and BFIHOST (termed ASB space). However, in assessing the cereal:grass ratios for the catchments in each pooling group, it became clear that catchments that were similar in ASB space were also similar in land cover. This further reinforced the indication from the regression studies in Appendix A that topography, soil and climate (as indexed by ASB) largely determine land use/cover. Many of the ‘top ten’ catchments appeared in the pooling groups for each of the others.

It may also be noted that the top ten cereal catchments are all to the east of the country, and grass catchments with remotely similar ASB combinations could only be found in the west of the country. As pairing catchments across the country divide seemed unwise, catchments outside the ‘top ten’ were considered, from which two pairings were eventually selected (see Table 3.2 below).

No.	Name	SPR	Tp(0)	AREA	SAAR	SPRHOST	Cereal	Grass	Wood
31023	West Glen at Easton Wood	29	3.8	4.4	641	41.3	0.65	0.10	0.24
41021	Clayhill Stream at Old Ship	48.3	-	7.1	805	48.3	0.17	0.60	0.21
34005	Tud at Costessey Park	23.3	23.4	72.0	649	32.6	0.66	0.24	0.05
40006	Bourne at Hadlow	24	6.7	50.2	719	29.5	0.28	0.50	0.16

Table 3.2 Selected test catchments

3.2 Application of the procedure to test catchments

The outline application procedure is described in the box below, taken from the companion Project Report PR1, which also gives detailed instructions of the steps involved.

1. Using the FEH-CDROM:

- Identify the catchment
- Find the grid co-ordinates of a bounding rectangle around the catchment
- Export the catchment descriptor data file from the CDROM

2. Using ArcView:

2.1 Import IHDTM flow direction and HOST soil grids

2.2 Generate catchment boundary (HYDRO button)

2.3 Generate HOST grids at 50m, clipped to catchment boundary.

2.4 Add CEH Land cover 2000 grid (converted from image file)

- Clip landcover to 50m grid over catchment
- Reclassify landcover as 1 for degraded (all arable and lowland grass), and 0 for all other (normal) classes

Note: only 'agriculture & horticulture' and 'improved grassland' are currently taken as degraded, with the same SPR changes applied to each. Thus a simple 0/1 classification of degrading is sufficient. Extra classes with different degraded SPR values could be added in future.

2.5 For each HOST class present

- Use GIS functions to sum degraded and normal areas within the catchment
- Transfer areas to spreadsheet SPRADJ

3. Spreadsheets:

3.1 Use SPRADJ.XLS to derive SPR estimate

- Enter normal and degraded area from step 2.5 into respective HOST class row
- Select HOST factors for degraded land, giving revised and alternate SPR values

3.2 Use FEHSEN.XLS to estimate T-year floods for matrix of Tp and SPR

- Paste catchment descriptor data from step 1.3 into spreadsheet
- Noting FEH estimate of Tp(0), enter alternate values *(e.g. minus 1h, plus 1h)*
- Noting FEH estimate of SPRHOST, enter revised and alternate SPR, step 3.1
- Enter return period, and copy matrix of flood estimates into Decision Support Matrix.

Following these procedures, three values each of SPR and Tp(0), found as described in Sections 2.1 and 2.2, have been derived for the four test catchments. The results are summarised in Table 3.3 below, while additional details of the SPR calculations are given in the sample SPRADJ spreadsheet in Appendix B. The Tp adjustments of 1 hour (rather than the 1-2 hours suggested in Section 2.2) assume approximately half of each catchment area is subject to degradation. More specific Tp adjustments could have be adopted by taking the maximum degraded proportions from the SPRADJ spreadsheet (see Appendix B).

	Tp_0= FEH eqn (base case)	Tp_1= Tp_1-1h	Tp_2= Tp_1+1h	SPR_0= SPRHOST (base case)	SPR_1= Revised	SPR_2= Alternate	SPR_3= MDSF adjust
W.Glen	5.14	4.14	6.14	41.3	47.6	45.9	47.5
Clayhill	5.62	4.62	6.62	48.3	54.4	54.1	55.5
Tud	13.40	12.40	11.40	32.6	40.9	38.3	37.5
Bourne	6.17	5.17	7.17	29.6	35.2	33.8	34.0

Table 3.3 Tp and SPR values for use in FEHSEN

Note that a final column (SPR3) has been added to Table 3.3, to compare the ‘new’ procedure for adjusting SPR with the ‘old’ MDSF recommendation of factoring SPR by 1.15. The effort needed to derive the new adjustments is considerably greater than for the old, and the difference is generally small, but the new procedure is more soundly based on good reasoning, and more easily updated or extended when better data on impacts are available.

Entering the new recommendations into the FEHSEN spreadsheet, the 2, 10, 25, and 100-year flood peak estimates have been derived for each catchment. The results are summarised in Table 3.4a below, where Tp_0, Tp_1, Tp_2 and SPR_0, SPR_1, SPR_2 are as defined in Table 3.3. Additional calculation details are shown in the sample FEHSEN spreadsheets given in Appendix B.

Tp option	Tp_0	Tp_0	Tp_0	Tp_1	Tp_1	Tp_1	Tp_2	Tp_2	Tp_2
SPR option	SPR_0	SPR_1	SPR_2	SPR_0	SPR_1	SPR_2	SPR_0	SPR_1	SPR_2
	(Base case)	(Peak flow in m^3sec^{-1})							
W.Glen									
T=2	1.33	1.57	1.51	1.5	1.78	1.71	1.2	1.42	1.36
T=10	2.62	3.08	2.96	2.97	3.49	3.35	2.37	2.77	2.67
T=25	3.47	4.05	3.89	3.96	4.63	4.44	3.12	3.63	3.49
T=100	5.05	5.84	5.62	5.8	6.72	6.47	4.5	5.2	5.01
Clayhill									
T=2	2.89	3.25	3.24	3.22	3.62	3.6	2.63	2.96	2.94
T=10	5.56	6.23	6.2	6.22	6.99	6.95	5.03	5.63	5.6
T=25	7.22	8.07	8.03	8.13	9.1	9.05	6.49	7.25	7.21
T=100	10.26	11.42	11.36	11.64	12.97	12.9	9.17	10.2	10.14
Tud									
T=2	7.99	10.38	9.63	8.37	10.88	10.1	7.66	9.93	9.22
T=10	15.49	19.76	18.43	16.24	20.75	19.34	14.83	18.88	17.61
T=25	20.22	25.54	23.87	21.26	26.89	25.12	19.3	24.34	22.76
T=100	28.94	36.05	33.83	30.53	38.08	35.72	27.54	34.26	32.15
Bourne									
T=2	10.42	12.48	11.96	11.56	13.86	13.29	9.59	11.48	11.01
T=10	20.86	24.76	23.78	23.16	27.57	26.47	19.21	22.74	21.86
T=25	27.93	32.89	31.65	31.24	36.87	35.46	25.58	30.05	28.93
T=100	41.34	48.15	46.44	46.59	54.38	52.43	37.61	43.72	42.2

Table 3.4a Flood peak estimates using FEH and ‘degraded’ values of Tp and SPR

Table 3.4b Shows the same information as Table 3.4a, but with the adjusted flood peaks expressed as percentage increases over the FEH 'Base case' of column 1. Again, Tp_0, Tp_1, Tp_2 and SPR_0, SPR_1, SPR_2 are as defined in Table 3.3.

Tp option	Tp_0	Tp_0	Tp_0	Tp_1	Tp_1	Tp_1	Tp_2	Tp_2	Tp_2
SPR option	SPR_0	SPR_1	SPR_2	SPR_0	SPR_1	SPR_2	SPR_0	SPR_1	SPR_2
	(Base case)	(Percentage increase in flood peak relative to Base Case)							
W.Glen									
T=2	1.33	18%	14%	13%	34%	29%	-10%	7%	2%
T=10	2.62	18%	13%	13%	33%	28%	-10%	6%	2%
T=25	3.47	17%	12%	14%	33%	28%	-10%	5%	1%
T=100	5.05	16%	11%	15%	33%	28%	-11%	3%	-1%
Clayhill									
T=2	2.89	12%	12%	11%	25%	25%	-9%	2%	2%
T=10	5.56	12%	12%	12%	26%	25%	-10%	1%	1%
T=25	7.22	12%	11%	13%	26%	25%	-10%	0%	0%
T=100	10.26	11%	11%	13%	26%	26%	-11%	-1%	-1%
Tud									
T=2	7.99	30%	21%	5%	36%	26%	-4%	24%	15%
T=10	15.49	28%	19%	5%	34%	25%	-4%	22%	14%
T=25	20.22	26%	18%	5%	33%	24%	-5%	20%	13%
T=100	28.94	25%	17%	5%	32%	23%	-5%	18%	11%
Bourne									
T=2	10.42	20%	15%	11%	33%	28%	-8%	10%	6%
T=10	20.86	19%	14%	11%	32%	27%	-8%	9%	5%
T=25	27.93	18%	13%	12%	32%	27%	-8%	8%	4%
T=100	41.34	16%	12%	13%	32%	27%	-9%	6%	2%

Table 3.4b Percentage changes in flood peak estimates using 'degraded' values of Tp and SPR compared to FEH 'Base Case'

However, each of these catchments is gauged, with data used in both the FEH rainfall-runoff and statistical procedures. Table 3.5 below compares the various estimates obtained for the catchments using local data adjustments.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	Rainfall-runoff model								Ann Max flood statistics				
	Q2 FEHCD	Q2 degraded	Obs events	Obs Tp(0)	Obs SPR	Q2	Q10	Q100	QMED by CD	N years	Q2 Obs	Q10 PG	Q100 PG
W.Glen	1.33	1.78	2	3.8	29	1.00	2.02	4.18	1.40	22	1.76	3.24	5.63
Clayhill	2.89	3.62	9	(7.4)	48.3	2.45	4.66	8.42	3.46	5	3.10	5.33	8.98
Tud	7.99	10.88	9	23.4	23.3	3.90	7.85	14.68	7.04	33	2.98	4.83	7.31
Bourne	10.42	13.86	17	6.7	24	7.98	16.27	32.69	5.31	29	6.80	11.49	18.83

Table 3.5 Comparison of estimates using local data

Firstly, columns 2 & 3 show the 2-year flood estimates from Table 3.4 for the normal 'base case' FEH estimates of Tp and SPR, and for the most degraded Tp1 (i.e. Tp less 1 hour) and SPR1 (i.e. revised SPR). Columns 4 to 9 show the number of observed events analysed for the FEH, the mean observed Tp and SPR values, and the 2, 10, and 100 year flood estimates using these values in the FEHSEN spreadsheet (the Clayhill Tp is shown in brackets as it was derived from LAG data rather than by full unit hydrograph analysis - see FEH Vol 4, p 21). Column 10 gives the QMED value derived from catchment descriptors. Column 11 gives the number of years of observed annual maximum data used in the FEH, and column 12 gives the derived Q2 values (n.b. QMED and Q2 are synonyms, but QMED is used in Table 3.5 for the Q2 estimate by the FEH 'QMED equation', relating Q2 to catchment descriptors). Finally columns 13 and 14 give the 10 and 100-year flood estimates found using the FEH default-pooling group to rescale the observed Q2 value from Column 12.

It is obviously difficult to draw firm conclusions from assessing just four catchments, but it is clear from columns 2 and 3 that the 'degraded' assumptions have not resulted in unreasonably large increases in Q2 estimates. However, the 'degraded' estimates (column 3) are generally much larger than the observed Q2 (column 12). In three out of four cases, the Q2 from the Catchment Descriptor methods (columns 2 and 10) give similar results, tending to underestimate observed Q2 (column 12) for the first two (smaller) catchments, and overestimate for the second two catchments. It may be noted that the Tud's ratio of QMED/Q2obs is one of the worst in the whole FEH data set (29th highest out of 916 catchments); in retrospect it may not have been a good choice of test catchment.

Using observed Tp and SPR data to estimate Q2 (column 7) has brought better agreement with the observed Q2 values (column 12) for the larger catchments, but has not had much effect on the smaller catchments (though the smaller catchment data is quite uncertain; the West Glen Tp and SPR values are based on just 2 events and the Clayhill Tp value is based on catchment lag rather than derived Tp). Overall these results show the uncertainty in flood estimation from catchment descriptors, the benefit of local data, and how identifying any effect of land use/management impacts is likely to be obscured by the underlying uncertainty.

It may also be noted that the extent to which the observed data already incorporate the effect of any existing land use/management impacts is uncertain. That is in part why the adjustments in Table 3.3 were applied to predicted rather than observed Tp and SPR (predicted values relate to a mean land use). But more importantly, observed data are not generally available for the site of interest, and were to be used here to assess the overall validity of the procedure for ungauged sites.

The results in Table 3.5 are subject to the uncertainty in FEH methods, but it may be noted that the observed SPR values in column 6 are mostly smaller than the original SPRHOST values in Table 3.3 (equal for Clayhill), and applying the revised SPR values would worsen the Q2 estimates. As stated earlier, these are only four test catchments, and broad generalisation of the results is not possible. However, they do suggest that seeking out local data from at-site or analogue gauge sites is likely to bring greater improvement in flood estimation than trying to account for land use/management impacts.

However, if it is necessary to assess land use/management specifically, the proposed procedure does give a reasonable, semi-physically based indication of the impacts. It provides a precautionary approach towards allowing for future agricultural intensification. The method may be used at ungauged and gauged sites (in the latter case changes in predicted Tp and SPR would be found and applied to the observed values). However, it would seem unwise to rely on the procedure to assess reverse impacts where agricultural de-intensification is being considered as part of a downstream flood alleviation strategy. Any predicted reduction in flood flows would be very uncertain, and as outlined in the FD2114/PR1: Research Plan, there is a need for further research to identify impacts and develop improved methods.

4. The decision support matrix

Under task 16 (see Table 1.1) of the FD2114 contractual annex, the specified response was:

" Only one approach will be considered. This is the "decision support matrix" FEH-based method…

… An outline structure for the "decision support matrix" will be developed by Newcastle, then the details will be agreed by other members of the consortium. These details will include defining the way that catchment descriptors are used and defining the range of "soft" information which can be gathered by catchment flood managers".

A user-friendly Decision Support Matrix software tool has been written that reflects the findings of FD2114/TR: Impact Study Report and links directly to the FEHSEN spreadsheet. The FARM tool will guide end-users in the use of 'soft' information and how this can help to modify the FEH SPR rainfall runoff parameter that affects flow at the catchment scale. The FARM tool attempts to describe the likely risk[1] of increased runoff that may be generated on UK farms as a result of land management.

4.1 Approach

The design and operation of the proposed 'risk matrix' was first outlined within a nutrient pollution project (the SEAL project funded by EPSRC); it was created to give an uncomplicated alternative to Decision Support Systems and Expert Systems. Thus, a Decision Support Matrix (DSM) methodolgy was devised at Newcastle and explored within the SEAL project (Quinn 2004, Heathwaite et al, 2004, Hewett et al, 2004). The DSM design shown here has to some extent been tested by academics, policy makers and farmers alike. It must also be pointed out from experience, that, when running the FARM tool, it can raise as many questions as it addresses; however the debate it stimulates is usually beneficial. The fact that a wide range of end-users, from farmers to policy makers, can argue about relative risk within a common framework is useful, and it reflects current attitudes to land management.

The DSM approach is a simple but clear visualisation/modelling tool that tries to capture both qualitative and quantitative evidence for the impacts that land use management has on local runoff. The original DSM concept was developed to study pollution control on farms, this included Nitrate, the NERM (Nitrate Export Risk Matrix, Quinn 2004,) and Phosphorus, the PERM (Phosphorus Export Risk Matrix)

---

[1] In the literature reported on here, the use of the term 'risk' is less precise than that defined in Section 2.5 of the Impact Study Report, and follows the more colloquial usage of the term.

Heathwaite et al, 2004, Hewett et al, 2004). These nutrient management tools, as well as the prototype FARM tool, can be downloaded from the following website (**www.ncl.ac.uk/wrgi/TOPCAT**).

A DSM will usually have 2 or 3 dimensions (axes) that relate to generic environmental/land management factors: -

- Local soil/geology risk factors
- Local soil management risk factors
- Local hillslope flow connectivity factors

As the tool is applied at the field/farm scale, one can assume that a similar soil/geology regime exists in the local area and therefore only a 2D matrix is required. Hence, a 2D version of a DSM for runoff risk from farming was envisaged that could also be tied to the HOST classification and SPR estimates.

The FARM tool firstly tries to reflect typical UK farming landscapes that, hopefully, the end-user can associate with. The tool also tries to build an alternative ‘vision’ of a possible future landscape that Catchment Flood Managers (CFMs) could consider as part of the future planning process. In essence, the FARM tool is meant to be a thought-provoking education tool. It is not meant to be prescriptive in its recommendations, as it can only help farmers and catchment planners to consider a range of options. The guiding principles of the DSM approach (Quinn, 2004) are thus: -

‘No matter where you are now in the matrix you can always move to a lower risk of runoff’.

‘Even though the impacts of your mitigation strategy are difficult to quantify, it is still better to start moving in the right direction by employing some or many of the options suggested’.

If the FARM tool makes the end-users (especially those preparing CFMPs) more aware of rural land use issues and management then this is a benefit. Finally, it is no coincidence that most of the questions and recommendations that appear in the FARM tool are essentially the same as those appearing in the NERM and PERM tools, as many environmental problems are tied to the runoff regime.

4.2 The Floods and agriculture risk matrix (FARM)

The goal of the FARM tool, as it is presented here, is to help end-users after having used the FEH toolkit,to decide on an appropriate catchment HOST SPR value between the fully ‘degraded’ value (i.e the maximum change or ‘worst case scenario’) and the original FEH SPR value.

The Floods and Agriculture Risk Matrix is a simple, transparent decision support tool that attempts to ecapsulate many land management and hydrological factors that may impact upon runoff rates on farms. The FARM tool is written in Excel and its user friendly interface allows end users (such as CFMs) to consider a range of possible land management options that could lower runoff risk within a common risk framework. This ‘soft’ information, when coupled with the end user’s local knowledge and the FEH toolkit, allows CFMs to evaluate the potential impacts of observable farming practices on runoff. Thus the FARM tool addresses the following objectives:-

- It provides guidance on how to modify catchment SPR values for use in the short term improvement to the FEH model;
- The FARM tool is also a stand alone tool that allows an end-user to evaluate many land use practices within a runoff context;
- The tool will inform and educate the end-user to a wide range of ‘soft’ information relating to runoff, including the potential benefits of good farming practice and proactive runoff control on farms.

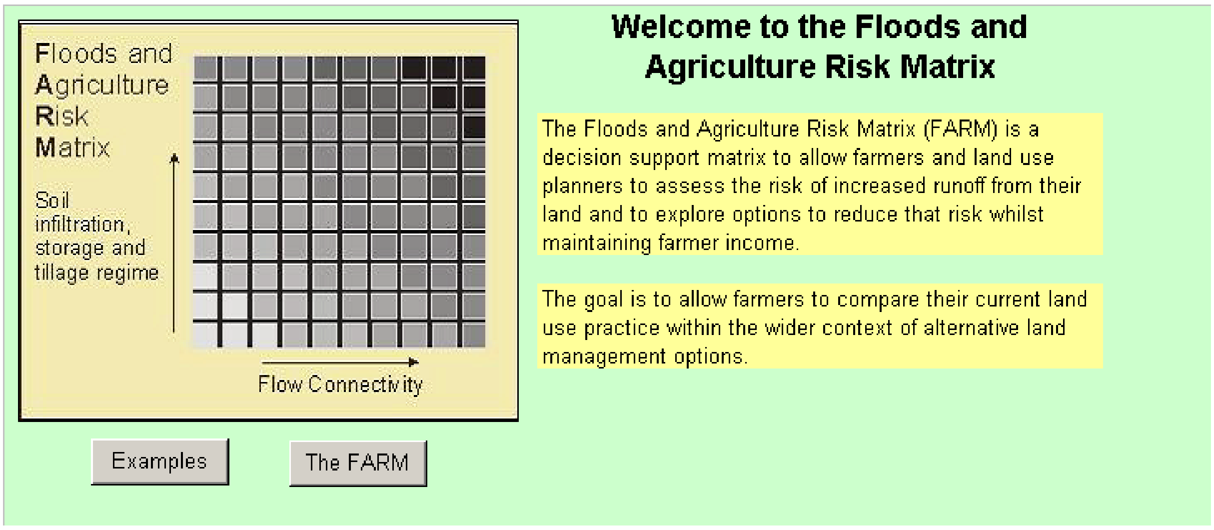
Even though objectives 2 and 3 are not specified in the short-term improvement task list, they do fit within the wider goals of the FD2114 project and demonstrate the basis of an approach that could have potential in future research.

The circumstances under which the fully revised SPR value should be used are outlined, but it is clearly still a matter of some judgement and uncertainty. Within the FARM tool, descriptive questions are posed relating to land management options, that are interpreted as being generally ‘good’ practice or ‘poor’ practice in relation to runoff generation. However, this ‘soft’ questioning should not detract from the fact that local knowledge of local farming activities can at least be ranked into low, medium or high risk activities with reference to runoff generation (such a subjective ranking was carried out and is shown in Appendix C of the Impact Study Report (p.57).

The tool is aimed at farmers and local CFMs who have a high level of local knowledge but less awareness of what constitutes a high or low runoff risk. As the Impact Study Report (ISR) has clearly stated, the factors affecting catchment scale runoff are difficult to quantify and are still open to some debate, hence, the FARM tool is deliberately aimed at the farm scale where runoff processes can at least be observed and are backed up by the ISR findings. The defintion of the field scale here, is a series of local fields and their local drainage features (land drains and ditches). Aggregation to the catchment scale is performed by the FEH toolkit.

The FARM tool is usually used after the modified FEH toolkit has been run (unless it is being used as a stand alone education tool). Hence, before the FARM tool is used, it is assumed that the user has already established the current HOST SPR value and the fully revised SPR value. The FARM tool will now help to suggest if the fully revised SPR value is appropriate or whether the original FEH SPR value is more appropriate. Moreover, the option to use an SPR value between the minimum and maximum is also allowable. The basis of the full FARM tool and its mode of operation is now outlined.

Fig. 4.1 is the welcome page for the FARM tool, as can be seen, only two axes are included. The axes try to capture the underlying factors that control runoff; here, these are soil storage factors (including infiltration and tillage regime) and flow connectivity (based on the prevailing hillslope hydrology). Subsequently, all the questions posed can be evaluated as to their impact on each axis. The first factor (on the vertical axis) is the soil ‘storage’ term as affected by land management, including soil infiltration, storage and tillage regime. The ISR should be consulted to study the reasons why these terms are used, but in principal, the ‘storage’ capacity of the land should be as high as possible and thus the infiltration and tillage regime strongly affects this. The ‘flow connectivity’ term refers to runoff once it has been mobilised within the field and how efficiently it flows into and through the local drainage network. Thus, connectivity reflects the likely speed of runoff (for example fast overland flow in tramlines), and, in this regard, the FARM tool highlights any features that can slow down or actually store runoff (such as ponds or wetlands). At this stage of the Decision Support Matrix (DSM) development, a linear pattern of relative risk values are plotted on a 10 *10 matrix (as a greyscale, see fig 4.1) ranging from low runoff risk (light grey) to high runoff risk (black).



Welcome to the Floods and Agriculture Risk Matrix

The Floods and Agriculture Risk Matrix (FARM) is a decision support matrix to allow farmers and land use planners to assess the risk of increased runoff from their land and to explore options to reduce that risk whilst maintaining farmer income.

The goal is to allow farmers to compare their current land use practice within the wider context of alternative land management options.

Figure 4.1 The FARM DSM (taken from the FARM spreadsheet) showing lowest risk of runoff (in the lower left corner) up to a maximum risk of increased runoff (top right corner)

In a general conceptual sense, the DSM must first describe the extremes of land use management within a hydrological and an agricultural land management context. By following the ‘Examples’ hyperlink, as shown on figure 4.1, the user can explore these scenarios. Figure 4.2 shows soil management and flow connectivity scenarios and how these would map onto the matrix relative to each other. The chosen idealised hill slope scenarios attempt to reflect typical UK framing practices and how they relate to the hill slope hydrology. By depicting the same hillslope with four alternate runoff risks, the important influences of land management practices on runoff can be demonstrated and, moreover, runoff management could, in principle, lower runoff risk on farms.

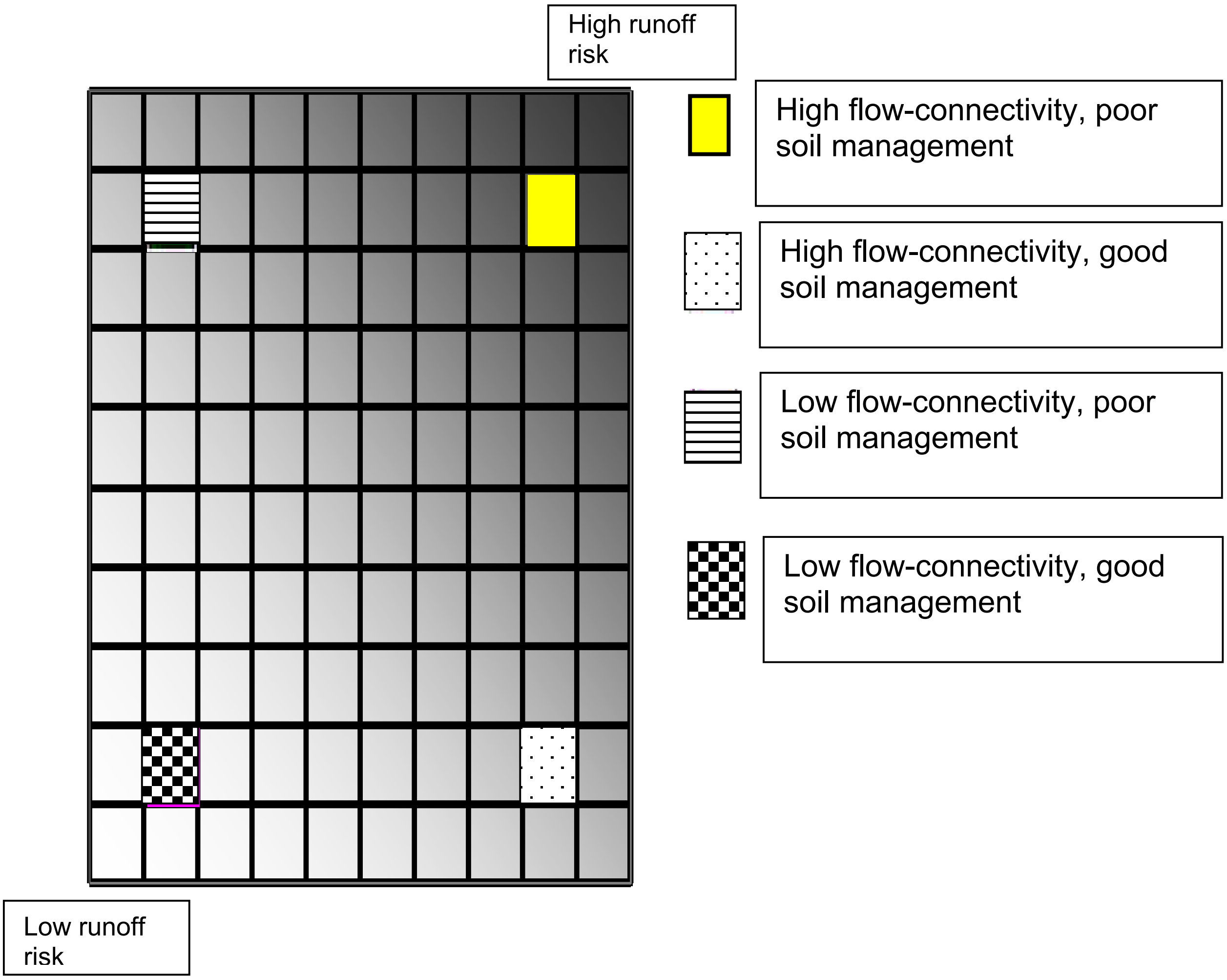


Figure 4.2 Example of current UK farms and likely impacts of land use management scenarios and how they can be mapped onto the decision support matrix.

In Figure 4.3, the four runoff scenarios (shown in figure 4.2) are created for a typical UK arable field and its associated ditch network. The four scenarios reflect the Consortium's hydrological and agricultural experience and, although highly idealised, they highlight the factors that both increase and decrease runoff at source. The diagrams aim to build up a basic conceptual understanding of how hydrological flow paths propagate across the land and within ditches.

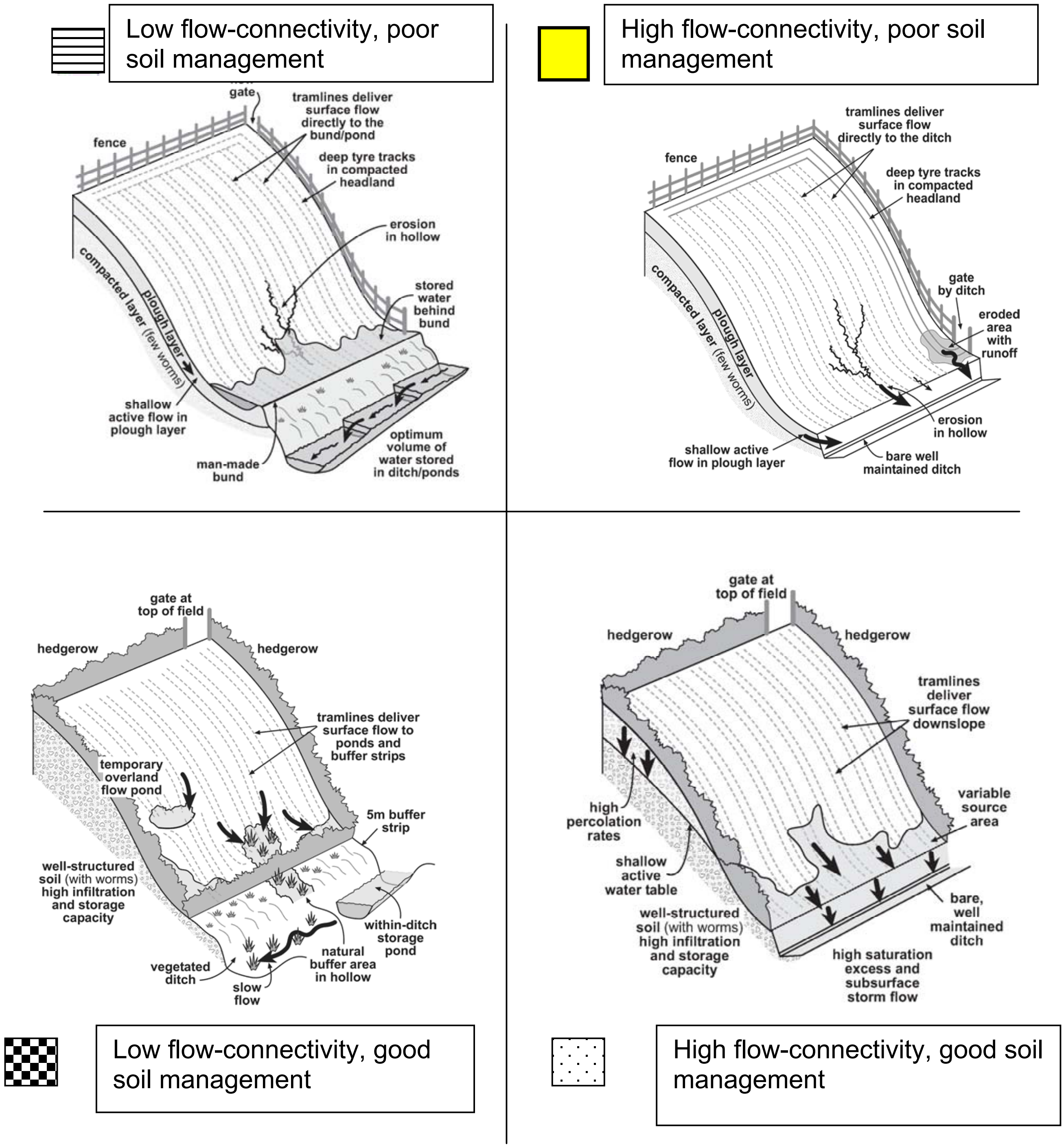


Figure 4.3 Four hill slope runoff risk scenarios for the same common land unit

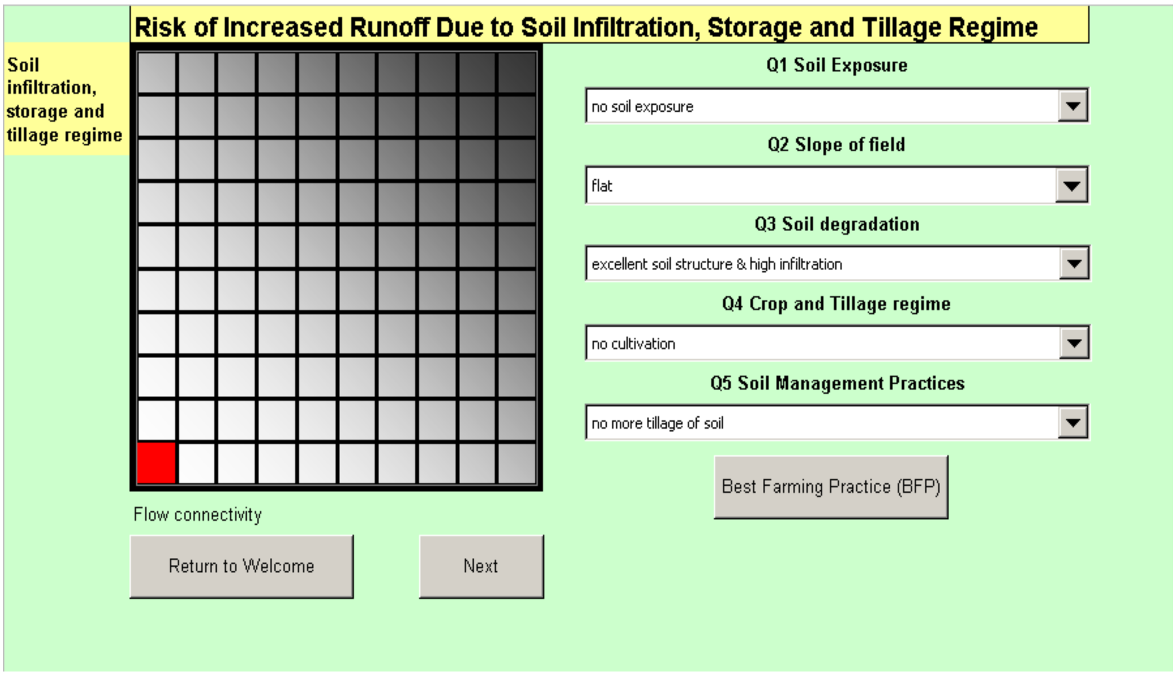
It is worth noting that some management strategies that may seem to substantially reduce surface runoff, in reality give rise to circumstances where the new runoff regime is also high (see the ISR). So for the case of high flow connectivity and good soil management, rapid runoff from overland flow could be lowered, but rapid runoff will arise from variable source areas and shallow active water table activity due to the high infiltration rates. However, there may be other associated reasons why this is still a good strategy to pursue, for example lowering erosion, lowering P loss and to create natural buffer strips with high biodiversity potential.

Within the FARM tool, the user is asked a series of questions relating firstly to soil infiltration, storage and tillage regime and secondly to the flow connectivity regime. The position in the matrix of the highlighted, animated pixel reflects the relative impact of each answer. The final position in the matrix depends on the answers to all the questions. The user should answers the questions to the best of their ability. If the user ends up with a matrix position in the top right area of the box, then they should consider changing the SPR value by the maximum amount recommended (see below).

In reality, the locally observed farms could be quite different to those suggested in the examples, and so interpretation by the end-user is needed. However, the examples do draw end-users' attention to the key factors that they should expect to see on everyday farms.

4.3 Use of FARM in managing soil storage

Figure 4.4 shows the graphical user interface for the questions relating to soil management. A drop down menu appears on each question, offering a range of possible answers which are ranked from a nominal high runoff risk to a low runoff risk. The user clicks on the most appropriate answer, the screen updates and the position of the animated pixel moves.


Risk of Increased Runoff Due to Soil Infiltration, Storage and Tillage Regime

Soil infiltration, storage and tillage regime

Flow connectivity

Q1 Soil Exposure: no soil exposure

Q2 Slope of field: flat

Q3 Soil degradation: excellent soil structure & high infiltration

Q4 Crop and Tillage regime: no cultivation

Q5 Soil Management Practices: no more tillage of soil

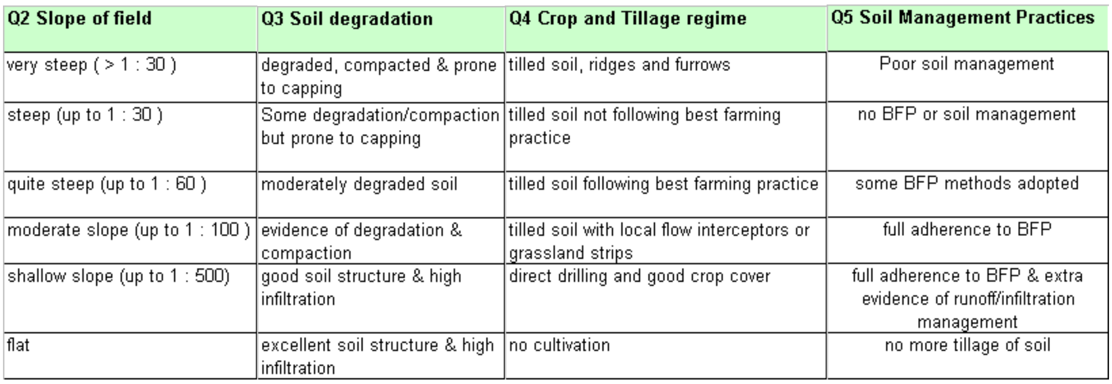
Figure 4.4 Graphical user interface for soil infiltration, storage and tillage regime. The 'Next' button will move the user directly to the 'flow connectivity' questions.

Table 4.1 shows an example question relating to soil exposure, based on the assumption that bare soil with winter arable crops poses a high risk of overland flow generation. Therefore it is the degree of soil exposure during the winter months that is questioned. A basic scoring system is in operation, ranging from 0-3 in steps of 0.5. A 'totally bare soil' (the highest risk option) will register as a jump of 3 units on the vertical axis, and the 'no soil exposure' (the lowest risk option) will result in no movement. For all the questions, there is always a simple linear progression from 0-3, for all the 6 possible replies to each question. No relative weighting is applied between questions and this is quite deliberate, as the weightings are themselves, prone to uncertainty. The ultimate goal of the FARM tool is to encourage a movement towards good practice by using a broad range of workable, low risk land management options.

Little other visual or contextual evidence is presented here to justify the questions used or how the ranking was produced; however the ranking does try to represent, as far as it is possible, the findings of the ISR. In the long term, it may be better for the tool to include a wider library of land use and runoff scenarios, but this would require substantial development and testing. One exception to this is made, which relates to the definition of Best Farming Practice, where a hyperlink button has been added that outlines some supporting references for the benefit of CFMs or farmers. These reference documents are themselves written in a simple and user friendly style and perhaps should be made available to all CFMs. Table 4.2 shows the details of the remaining questions that relate to soil storage management and the drop down menus that will appear.

Q1 Soil Exposure	**Shift in the matrix position**
bare soil	3 units
bare soil over winter	2.5
slow growing crop over winter	2
bare soil in spring	1.5
winter crop cover	1
no soil exposure	0

Table 4.1 Question 1 relating to soil infiltration, storage and tillage regime, and the movement this produces on the vertical axis of the matrix

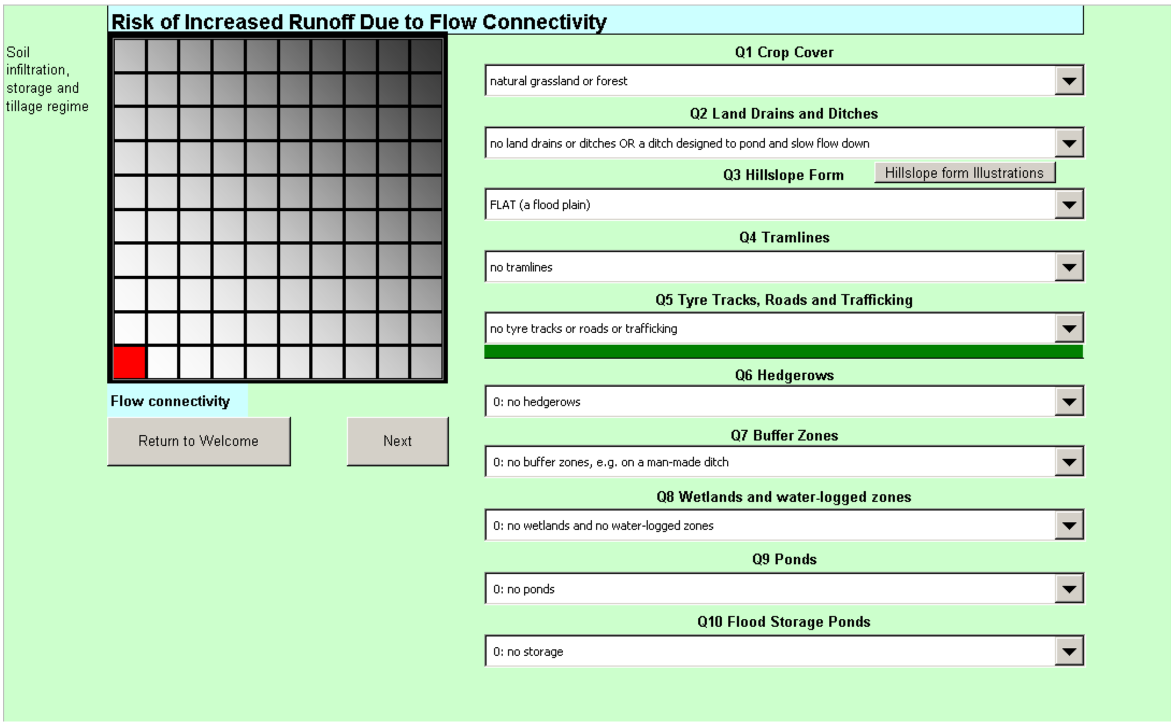


Q2 Slope of field	Q3 Soil degradation	Q4 Crop and Tillage regime	Q5 Soil Management Practices
very steep (> 1 : 30)	degraded, compacted & prone to capping	tilled soil, ridges and furrows	Poor soil management
steep (up to 1 : 30)	Some degradation/compaction but prone to capping	tilled soil not following best farming practice	no BFP or soil management
quite steep (up to 1 : 60)	moderately degraded soil	tilled soil following best farming practice	some BFP methods adopted
moderate slope (up to 1 : 100)	evidence of degradation & compaction	tilled soil with local flow interceptors or grassland strips	full adherence to BFP
shallow slope (up to 1 : 500)	good soil structure & high infiltration	direct drilling and good crop cover	full adherence to BFP & extra evidence of runoff/infiltration management
flat	excellent soil structure & high infiltration	no cultivation	no more tillage of soil

Table 4.2 The remaining soil management questions (2-5)

4.4 Use of FARM in Managing Flow Connectivity

Fig 4.5 is the graphical user interface for the questions relating to flow connectivity. Some questions may seem similar to those in Fig 4.4 but in this instance the same common factor is now controlling the propagation of the runoff and not its generation. Table 4.3 shows four of the first questions relating to flow connectivity, however question 3 will be discussed separately. Again little detailed supporting material is given for the questions and the rankings other than in question 3.



Q1 Crop Cover: natural grassland or forest

Q2 Land Drains and Ditches: no land drains or ditches OR a ditch designed to pond and slow flow down

Q3 Hillslope Form: FLAT (a flood plain)

Q4 Tramlines: no tramlines

Q5 Tyre Tracks, Roads and Trafficking: no tyre tracks or roads or trafficking

Q6 Hedgerows: 0: no hedgerows

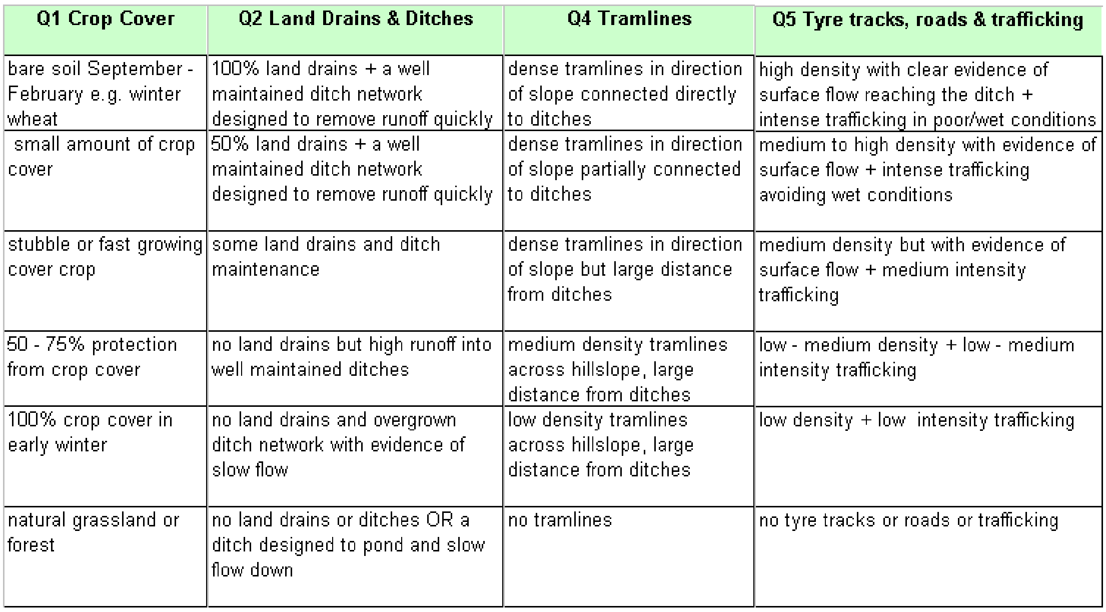
Q7 Buffer Zones: 0: no buffer zones, e.g. on a man-made ditch

Q8 Wetlands and water-logged zones: 0: no wetlands and no water-logged zones

Q9 Ponds: 0: no ponds

Q10 Flood Storage Ponds: 0: no storage

Figure 4.5 The graphical user interface for the flow connectivity questions. The 'Next' button returns the user to the previous questions.



Q1 Crop Cover	Q2 Land Drains & Ditches	Q4 Tramlines	Q5 Tyre tracks, roads & trafficking
bare soil September - February e.g. winter wheat	100% land drains + a well maintained ditch network designed to remove runoff quickly	dense tramlines in direction of slope connected directly to ditches	high density with clear evidence of surface flow reaching the ditch + intense trafficking in poor/wet conditions
small amount of crop cover	50% land drains + a well maintained ditch network designed to remove runoff quickly	dense tramlines in direction of slope partially connected to ditches	medium to high density with evidence of surface flow + intense trafficking avoiding wet conditions
stubble or fast growing cover crop	some land drains and ditch maintenance	dense tramlines in direction of slope but large distance from ditches	medium density but with evidence of surface flow + medium intensity trafficking
50 - 75% protection from crop cover	no land drains but high runoff into well maintained ditches	medium density tramlines across hillslope, large distance from ditches	low - medium density + low - medium intensity trafficking
100% crop cover in early winter	no land drains and overgrown ditch network with evidence of slow flow	low density tramlines across hillslope, large distance from ditches	low density + low intensity trafficking
natural grassland or forest	no land drains or ditches OR a ditch designed to pond and slow flow down	no tramlines	no tyre tracks or roads or trafficking

Table 4.3 Four of the first 5 questions relating to the management of flow connectivity.

As question 3 tries to address the impacts of hillslope form on runoff, more explanation is needed hence, a supporting hyperlink is used to elaborate on the hydrological concepts and the terminology used (see Figure 4.6).

Q3 Hillslope form
V. steep slope, no toeslope, tramlines/ridges and furrows in steepest slope.
steep slope, no toeslope, sensible cultivation direction
moderate/steep slope with small toeslope (2m)
moderate slope with small toeslope (5m)
moderate slope leading to a large floodplain or toeslope
FLAT (a flood plain)

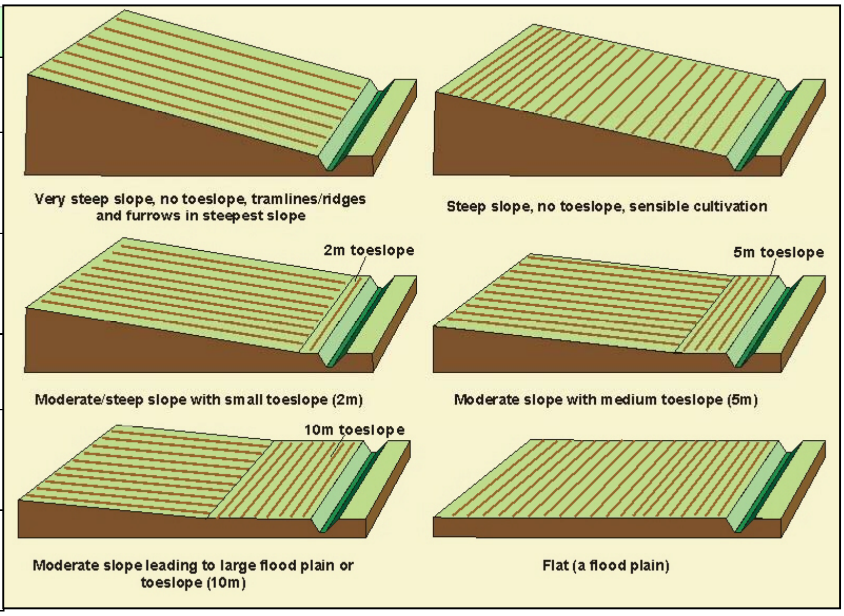
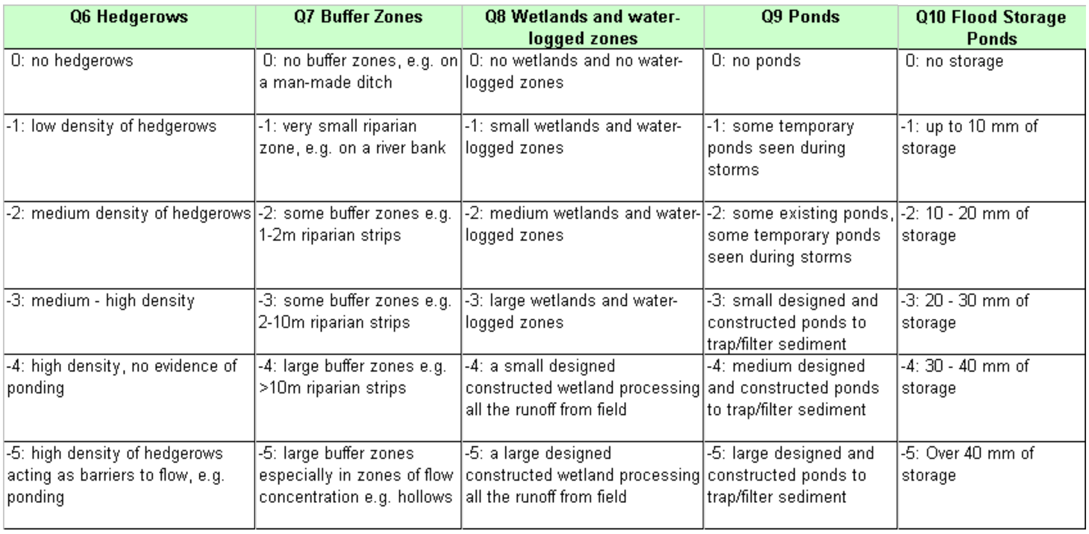


Figure 4.6 Questions 3 on Flow Connectivity and an additional 'HELP' option that shows a series of hillslope forms and 'toeslopes' that could influence runoff risk

Questions 6-10 (shown in table 4.4) are again flow connectivity questions, but this time they relate directly to features that have the potential to slow or store substantial amounts of flow. These options are labelled with a negative value to show that, if implemented, a lower risk of runoff from the land unit can be achieved. Hence, the implementation of these features can move the pixel position back along the horizontal axis, possible compensating for other higher risk factors elsewhere. These features may exist for reasons other than runoff control but they may in fact be multi-functional, i.e. the original purpose of a pond could be to reduce sediment or phosphorus loss but it has implications for flood control.

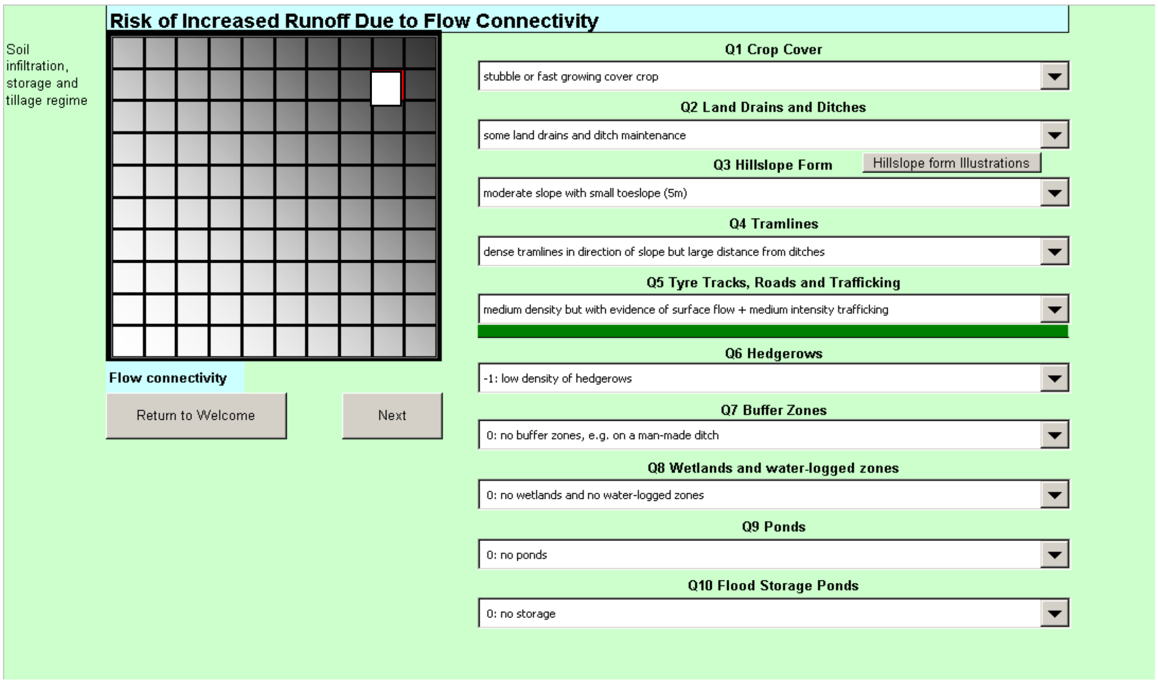


Q6 Hedgerows	Q7 Buffer Zones	Q8 Wetlands and water-logged zones	Q9 Ponds	Q10 Flood Storage Ponds
0: no hedgerows	0: no buffer zones, e.g. on a man-made ditch	0: no wetlands and no water-logged zones	0: no ponds	0: no storage
-1: low density of hedgerows	-1: very small riparian zone, e.g. on a river bank	-1: small wetlands and water-logged zones	-1: some temporary ponds seen during storms	-1: up to 10 mm of storage
-2: medium density of hedgerows	-2: some buffer zones e.g. 1-2m riparian strips	-2: medium wetlands and water-logged zones	-2: some existing ponds, some temporary ponds seen during storms	-2: 10 - 20 mm of storage
-3: medium - high density	-3: some buffer zones e.g. 2-10m riparian strips	-3: large wetlands and water-logged zones	-3: small designed and constructed ponds to trap/filter sediment	-3: 20 - 30 mm of storage
-4: high density, no evidence of ponding	-4: large buffer zones e.g. >10m riparian strips	-4: a small designed constructed wetland processing all the runoff from field	-4: medium designed and constructed ponds to trap/filter sediment	-4: 30 - 40 mm of storage
-5: high density of hedgerows acting as barriers to flow, e.g. ponding	-5: large buffer zones especially in zones of flow concentration e.g. hollows	-5: a large designed constructed wetland processing all the runoff from field	-5: large designed and constructed ponds to trap/filter sediment	-5: Over 40 mm of storage

Table 4.4 The remaining questions relating to the management of flow connectivity. ***These features may be classed as the more proactive runoff management options.***

4.5 Linking the FARM tool with the modified FEH tool

After answering all the questions in the FARM tool, the final pixel position must be interpreted in terms of the potential SPR value change. Firstly, by running the FEH toolkit, the end-user will have determined which HOST classes coincide with the sensitive land uses. The user must then decide to what degree the SPR value must be changed relative to the original FEH value and the maximum revised SPR value.



Q1 Crop Cover: stubble or fast growing cover crop

Q2 Land Drains and Ditches: some land drains and ditch maintenance

Q3 Hillslope Form: moderate slope with small toeslope (5m)

Q4 Tramlines: dense tramlines in direction of slope but large distance from ditches

Q5 Tyre Tracks, Roads and Trafficking: medium density but with evidence of surface flow + medium intensity trafficking

Q6 Hedgerows: -1: low density of hedgerows

Q7 Buffer Zones: 0: no buffer zones, e.g. on a man-made ditch

Q8 Wetlands and water-logged zones: 0: no wetlands and no water-logged zones

Q9 Ponds: 0: no ponds

Q10 Flood Storage Ponds: 0: no storage

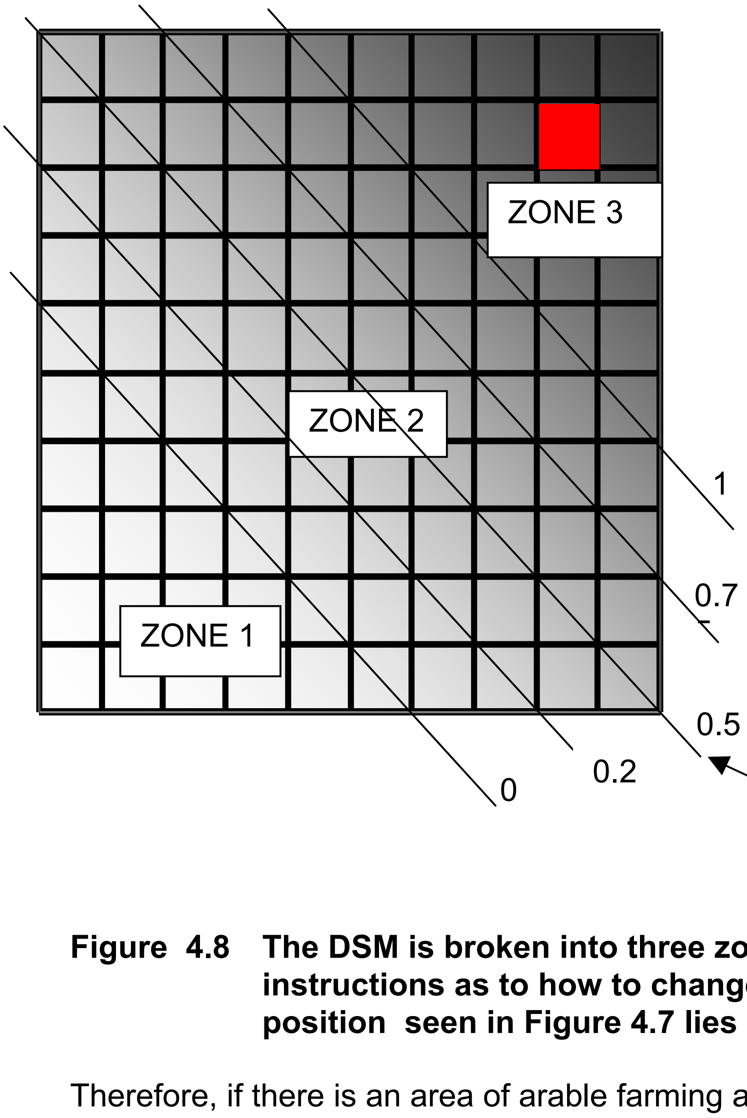
Figure 4.7 An example pixel position as determined after answering all the questions in the FARM tool

If for example the user determined a final pixel position as in Figure 4.7, then the user would appreciate that this is a high runoff risk condition. The user must then consult figure 4.8 which is a DSM diagram that has been subdivided into three zones:-

Zone 1: If the pixel position lies in this zone, then the original FEH SPR value should be used.

Zone 2: If the pixel position lies in this zone, then a value between the FEH SPR value and the maximum SPR value should be used.

Zone 3: If the pixel position lies in this zone, then the fully revised SPR value should be used.



Choosing the final SPR value.

Zone 1. If the plotting position lies in this zone, then the original FEH SPR value should be used.

Zone 2. If the plotting position lies in this zone, then a value between the FEH SPR value and the maximum SPR value should be used. Choose the nearest contour line to give the correct multiplication factor.

Zone 3. If the plotting position is in this zone, then the fully revised SPR value should be used.

Contours showing the SPR multiplication

Figure 4.8 The DSM is broken into three zones and the user must follow the instructions as to how to change the SPR values. The final pixel position seen in Figure 4.7 lies in zone 3.

Therefore, if there is an area of arable farming and the current HOST class is 16, then the SPR range could lie between 29% and 47%. As the pixel position seen in Figures 4.7 lies in zone 3, then the maximum SPR value would be chosen. Within the FEH toolkit the SPR value should be changed from 29% to 47%. The impact that this local change in SPR has on the final catchment SPR should be tested using the FEH toolkit.

The FARM tool operates at the farm scale, while the FEH tools operate at the catchment scale, so there is a need for caution when using the tools together. It is essential that the user defines a realistic estimate of the degraded SPR value and does not just ascribe a 'fully degraded' value to the whole catchment. Different parts of the catchment will have different degrees of degradation, so the user must gather together the relevant local evidence for farming practices within sub areas of the catchment (for example by collaborating with other relevant EA staff). The difference in scale between the tools needs to be addressed in future research. This issue is discussed further in Project Report PR1.

The running of the FEH tools, establishing the sensitive HOST classes, running the FARM tool and then altering the SPR values can be repeated many times. As uncertainty remains a problem, the end-user is encouraged to try many land use scenarios in order to build up understanding about the likely impacts on runoff. Within the tool, many questions are posed relating to land management options, that range from ‘good’ practice to ‘poor’ practice with regards to runoff magnitude and speed. These questions are not weighted in any special way as they are themselves subject to great uncertainty. By running the FARM tool many times, the end-user will start to see that certain ‘types’ of activity, if carried out on sensitive HOST classes, may give rise to a high runoff risk. Equally, if an area is covered with HOST classes that are insensitive to agricultural changes or the area resides with a zone of good agricultural practice (such as within an ESA) then the impacts on SPR should be lower. The presence of other landscape features such as wetlands and ponds may also need to be considered as lowering the likely impacts of intense agriculture on flood risk. In essence, the subjectivity and the final evaluation of the SPR changes is in the hands of the end-user. Once the typical local farm runoff risk is established, then the aggregated catchment SPR value will lie between the original FEH HOST SPR value or the fully revised SPR value.

5. Summary

A suite of complementary GIS and Excel spreadsheet tools has been created that can be used within the MDSF to estimate the likely impacts of soil degradation and land management on the FEH rainfall runoff model parameters SPR and Tp. The tools use GIS data on HOST classes, lands use and FEH catchment descriptors and blend this with ‘soft’ information/evidence using another new tool, the FARM tool. Implementing these new tools in the MDSF will require the HOST map and the CEH land cover LCM2000 data to be included in the MDSF in GIS form.

There is considerable scope for this methodology to be developed further (the research plan described in FD2114/PR1 addresses the need for further research to identify impacts and develop improved methods). The methodology presented here represents what is currently practical, within the constraints of Project FD2114, and gives a way for CFMs to benefit, in the short term, from the extensive reviews in the ' FD2114/TR: Impact Study Report'. The method will alert CFMs (again) to the possible effects of land use change and management practices on flooding, and the FARM tool can be used by CFMs and land managers to explore and understand the link between management practices and flooding impacts, so it might help encourage the use of Best Farming Practices.

Once revised values are calculated for SPR and Tp, the existing FEH tools can be used to estimate the impacts on flooding at the catchment scale. This has been tested on four catchments. There is considerable uncertainty associated with the revised values, and this results in considerable uncertainty in the estimation of the impacts on flooding. The new tools do, however, give a framework for revising SPR and Tp, avoiding the possibility that arbitrary and extreme revisions would otherwise be used by CFMs.

The method for adjusting Tp is exactly as currently recommended in the MDSF. Two new alternative procedures are proposed for adjusting SPR, both based on selecting an analogue HOST class that reflects degraded conditions for the current HOST class: (1) using the difference between the SPRs of the current and analogue HOST classes, with significant smoothing to avoid inconsistencies; and (2) converting the BFI difference between the HOST classes to an SPR difference using the FEH BFI-SPR relationship. In general, the BFI-HOST relationship is more consistent than the SPR-HOST relationship, and the second approach gives more consistent, smaller, adjustments to SPR. The adjustment calculated using procedure (1) or (2) is then scaled, using a weighting between 0 and 1, calculated using the FARM tool.

6. References

Boorman, D.B., 1985. *A review of the Flood Studies Report rainfall runoff model parameter estimation equations*. Institute of Hydrology Report No 94, Natural Environment Research Council, 58p.

Boorman, D.B., Hollis, J.M. and Lilly, A., 1995. *Hydrology of soil types: A hydrologically-based classification of the soils of the United Kingdom.* Institute of Hydrology Report No. 126, Institute of Hydrology, Wallingford (now CEH Wallingford).

Calver, A. and Wheater, H.S., 2001. *Scoping the Broad Scale Modelling Hydrology Programme: Stage 2 Strategic Programme.* FD2104 report to Defra and the Environment Agency.

Crooks S. M., Naden P. S., Broadhurst P. and Gannon B., 1996. Modelling the flood response of large catchments, Report to MAFF Project FD412, Institute of Hydrology, UK.

Fuller, R.M., Smith, G.M., Sanderson, J.M., Hill, R.A., Thomson, A.G., Cox, R., Brown, N.J., Clarke, R.T., Rothery, P. and Gerard, F.T., 2002. *Countryside Survey 2000 Module 7, Land Cover Map 2000, Final Report.* Centre for Ecology and Hydrology, Project T02083j5/C00878.

Heathwaite, A.L., Quinn, P.F. and Hewett, C.J.M 2004. Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation. Journal of Hydrology, In press.

Hewett, C. J. M., Quinn, P. F., Whitehead, P., Heathwaite, A. L. and Flynn, N. 2004 *Towards a Nutrient Export Risk Matrix Approach to Managing Agricultural Pollution at Source. Hydrology and Earth System Science*, In review.

HR Wallingford, Halcrow, Flood Hazard Research Centre, CEH Wallingford, Richard Eales Environmental Consultants, Cranfield University, (2002). *Catchment Flood Management Plans, Development of a Modelling and Decision Support Framework (MDSF)* HR Report EX4495, Vol 1: MDSF Procedures + Appendices, 86pp, Vol 2: Technical Annexes.

Institute of Hydrology, 1999. Flood Estimation Handbook, Vol 4: Restatement and application of the Flood Studies rainfall-runoff model.

O'Connell P.E., **Beven** K. J., **Carney** J. N., **Clements** R. O., Ewen J., Fowler H., Harris G. L., **Hollis** J., **Morris** J., O'Donnell G. M., **Packman** J. C., **Parkin** A., **Quinn** P. F. and **Rose** S. C., 2004(a). *Review of Impacts of Rural Land Use and Management on Flood Generation,* FD2114/TR*: Impact Study.* Project FD2114 Report to Defra.

O'Connell P.E., **Beven** K. J., **Carney** J. N., **Clements** R. O., Ewen J., Fowler H., Harris G. L., **Hollis** J., **Morris** J., O'Donnell G. M., **Packman** J. C., **Parkin** A., **Quinn**

P. F. and **Rose** S. C., 2004(b). *Review of Impacts of Rural Land Use and Management on Flood Generation, FD2114/PR1: Research Plan.* Project FD2114 Report to Defra.

Packman J.C., 2002. *Brief review of Land use and Climate change impacts on floods.* MDSF Technical Annexes, 11pp, HR Report EX4495

Packman J. C., Quinn P.F., Farquharson F. A. K. and O'Connell P.E., 2004. Review of Impacts of Rural Land Use and Management on Flood Generation, FD2114/PR2: Short-term Improvement to the FEH Rainfall Runoff Model: User Manual. Project FD2114 Report to Defra.

Quinn, P.F. 2004. Scale appropriate modelling: representing cause-and-effect relationships in nitrate pollution at the catchment scale for the purpose of catchment scale planning. Journal of Hydrology, 291: 197-217.

Appendix A: trial regressions of Tp and SPR against catchment descriptors

A.1 Land cover descriptors and correlation with catchment descriptors

Using satellite images (see Fuller *et al,* 2002) CEH have developed land-cover grids at 25m resolution across the UK for the years 1990 and 2000. Cross comparison between the two data sets is difficult, because different processing procedures and cover classes were used in each case. For 1990, the satellite pixels were treated independently, and land cover was estimated from their individual spectral characteristics. This resulted in misclassification of a number of pixels. For this reason, the URBEXT descriptor in the FEH used a mask to exclude 'urban' pixels falling outside known urban boundaries. For 2000, a parcel approach was adopted, where spectral characteristics were analysed for individual and adjacent pixels to define boundaries within which land cover could be considered to be the same. The parcel boundaries are stored in GIS form and can be edited manually to reflect new information.

The cover classes used in each map are given in Table A.1 below, with their assignment to the smaller number of more hydrologically relevant vegetation types used in MORECS. The MORECS assignments for 1990 are as used in the Classic model (Crooks et al, 1996); while the 2000 assignments have been chosen here to suit. Evergreen heathland (1990) was not included in the Classic mapping and has been given here as upland. The mapping of lowland bog (1990) and fen (2000) as 'upland' is peculiar, but has been retained here for the lack of a clear alternative.

Table A.1 Land cover classifications

MORECS	LCM1990 land cover classes		LCM2000 land cover classes	MORECS
	Sea	1	Sea / estuary (221)	
	Water (inland)	2	Water (inland) (131)	
	Beach	3	Littoral rock (201)	
	Saltmarsh	4	Littoral sediment (211)	
Grass	Lowland grass heaths	5	Saltmarsh (212)	
Grass	Pasture	6	Supra-littoral rock (181)	
Grass	Meadow	7	Supra-littoral sediment (191)	
Grass	Marsh/rough grassland	8	Bog (deep peat) (121)	Upland
Upland	Montane/hill grass	9	Dense dwarf shrub heath (101)	Upland
Upland	Dwarf shrub/grass moorland	10	Open dwarf shrub heath (102)	Upland
Upland	Dwarf shrub moorland	11	Montane habitats (151)	Upland
Upland	Bracken	12	Broad leaf/mixed woodland(11)	DecWood
(Upland)	Evergreen shrub heathland	13	Coniferous woodland (21)	ConWood

DecWood	Scrub / orchard	14	Improved grassland (51)	Grass
DecWood	Deciduous	15	Neutral grass (61)	Grass
ConWood	Coniferous	16	Set aside grass (52)	Grass
Upland	Upland bog	17	Bracken (91)	Upland
Cereals	Arable	18	Calcareous grass (71)	Grass
Grass	Ruderal weeds	19	Acid grassland (81)	Grass
Urb-bare	Suburban	20	Fen ,marsh, swamp (111)	Upland
Urb-bare	Urban	21	Arable cereals (41)	Cereals
Urb-bare	Bare ground	22	Arable horticulture (42)	Cereals
Grass	Felled forest	23	Arable non-rotational (43)	Cereals
Upland	Lowand bog	24	Suburban/rural development(171)	Urb-bare
Upland	Dwarf shrub/grass heath	25	Continuous urban (172)	Urb-bare
		26	Inland bare ground (161)	Urb-bare

For this study, the percentage occurrence of each MORECS land cover class has been determined for each of the FEH study catchments used in the analysis of Tp and SPR (see FEH Vol 4, Appendix A). Tables A.2 and A.3 give the standard product-moment correlation between the land cover descriptors (names in lower case) and the FEH catchment descriptors and catchment average Tp or SPR (names all in upper case). The tables, one with Tp and one with SPR, represent slightly different data sets as data for some events or catchments had been considered unsuited to Tp analysis (e.g.uneven rainfall distributions), while for others were unsuited to runoff volume analysis (e.g. uncertain rating information).

	TP(0)	SAAR	SPR HOST	PROP WET	DPL BAR	DPS BAR	URB EXT	ALT BAR	Grass	Cere-als	Dec. Wood	Con Wood	Up land
TP(0)	1.00												
SAAR	-0.50	1.00											
SPRHOST	-0.19	0.42	1.00										
PROPWET	-0.54	0.77	0.51	1.00									
DPLBAR	0.52	-0.23	-0.07	-0.05	1.00								
DPSBAR	-0.40	0.82	0.24	0.65	-0.05	1.00							
URBEXT	-0.03	-0.30	-0.16	-0.32	-0.11	-0.30	1.00						
ALTBAR	-0.48	0.75	0.54	0.75	-0.11	0.66	-0.39	1.00					
Grass	0.04	-0.14	-0.27	-0.09	0.07	-0.09	-0.08	-0.26	1.00				
Cereals	0.57	-0.62	-0.43	-0.70	0.14	-0.56	0.01	-0.62	-0.18	1.00			
Dec.Wood	0.02	-0.07	-0.30	-0.17	0.01	0.09	-0.04	-0.16	0.27	-0.15	1.00		
ConWood	-0.15	0.12	0.28	0.23	-0.04	0.11	-0.16	0.25	-0.22	-0.20	0.03	1.00	
Upland	-0.44	0.70	0.62	0.73	-0.11	0.59	-0.33	0.82	-0.53	-0.58	-0.29	0.16	1

Table A.2 Correlation of Tp with FEH Catchment Descriptors and 1990 Land cover

	SPR	SAAR	BFIHOST	SPRHOST	PROPWET	DPSBAR	URBEXT	ALTBAR	Grass	Cereals	Dec. Wood	Con Wood	Upland
SPR	1.00												
SAAR	0.30	1.00											
BFIHOST	-0.67	-0.29	1.00										
SPRHOST	0.71	0.37	-0.94	1.00									
PROPWET	0.39	0.78	-0.40	0.49	1.00								
DPSBAR	0.19	0.81	-0.14	0.21	0.70	1.00							
URBEXT	-0.19	-0.26	-0.02	-0.11	-0.26	-0.28	1.00						
ALTBAR	0.36	0.75	-0.42	0.53	0.83	0.69	-0.35	1.00					
Grass	-0.13	-0.06	0.18	-0.24	-0.11	0.01	-0.10	-0.25	1.00				
Cereals	-0.30	-0.62	0.36	-0.39	-0.70	-0.61	-0.02	-0.62	-0.23	1.00			
DecWood	-0.08	-0.01	0.23	-0.26	-0.09	0.14	-0.10	-0.17	0.32	-0.23	1.00		
ConWood	0.19	0.18	-0.15	0.23	0.30	0.20	-0.18	0.25	-0.29	-0.28	0.07	1.00	
Upland	0.43	0.65	-0.46	0.59	0.78	0.57	-0.30	0.87	-0.48	-0.57	-0.27	0.27	1.00

Table A.3 Correlation of SPR with FEH Catchment Descriptors and 1990 Land cover

Apart from noting that the ‘urb-bare’ class from Table A.1 is not given (it shows virtually the same correlations as URBEXT), these tables contain some interesting correlations. Upland (not surprisingly) is strongly correlated with ALTBAR (mean altitude), SAAR and PROPWET, and quite strongly correlated with SPRHOST and DPSBAR (slope). Most land covers show opposite correlations (more of one suggests less of the other), but (again not surprisingly) there are positive correlations between deciduous woodlands and grass, and between coniferous woodlands and the uplands. SAAR is positively correlated with uplands and inversely correlated with cereals. Of the dependent variables, Tp is correlated with PROPWET, DPSBAR and DPLBAR, but also with cereals and (inversely) with uplands - suggesting longer Tp under cereals and shorter Tp in the uplands. SPR is strongly correlated with SPRHOST (not surprisingly as the SPRHOST coefficients are defined from observed SPR) and PROPWET, but also with uplands and (inversely) with cereals - suggesting higher SPR in the uplands and lower values for cereals.

While these inter-correlations are all interesting and largely as expected, they cannot determine whether the apparent land cover relationships are indeed due to the cover type or to the underlying soil and topographic conditions that make such land cover appropriate. It should also be noted again that these land cover descriptors give little information on land management practices; ‘cereal’ and ‘coniferous wood’ do imply a general intensification of land use, but ‘grass’ contains no implication on stocking density.

A final comment on the consistency between LCM 1990 and 2000 cover information is pertinent. The Wye catchment at Cefn Brwyn, mid Wales, at an average altitude of 500 metres and with a land use of upland grazing, has been used since the early 1970’s as the control catchment (fixed land use) in a paired-catchment study to assess forest impacts in the neighbouring Severn catchment at Plynlimon. Its land cover as classified by LCM 1990 and 2000 is given in Table A.4 below.

LCM 1990		LCM 2000	
Meadow	20%	Acid grass	92%
Lowland heath	16%	Bracken	3%
Pasture	15%	Bare	3%
Upland grass moor	12%	Other	2%
Bracken	11%		
Marsh	6%		
Shrub Moor	5%		
Others	15%		

Table A.4 Comparison of 1990 and 2000 land covers for Wye at Cefn Brwyn

The startling differences underline the difficulty in developing consistent land cover indices from the existing data sets.

A.2 Exploratory assessment of the effect of land cover on Tp and SPR

To investigate the effect of land cover, exploratory regression analyses for Tp and SPR have been carried out (a) ignoring land cover variables, (b) including each of Cereal, Grass and Wood (deciduous plus coniferous) independently, and (c) using a single combined index (1-Cereal+Wood). The log-space regressions for Tp, based on a subset of 191 catchments from the FEH mean Tp(0) data set (as given in FEH vol 4, Appendix A), are presented in Box 1 below.

Box 1 Tp regressions, with coefficients, their ± standard deviations, overall coefficients of determination and factorial standard errors

Ignoring land cover

$Tp = 2.78*\ DPSBAR^{-0.25}\ PROPWET^{-.92}\ DPLBAR^{.50}\ (1+URBEXT)^{-3.02}$ $R^2=.69$
± .06 ± .14 ± .04 ± .58

fse=1.50

LCM1990 Land use descriptors

$Tp=\ 2.73*\ DPSBAR^{-0.25}\ PROPWET^{-.91}\ DPLBAR^{.49}\ (1+URBEXT)^{-3.00}$
± .07 ± .18 ± .04 ± .70

$*Cereal^{-.01} Wood^{-.01} Grass^{+.04}$ $R^2=.69$

± *.15* ± *.37* ± *.23* *fse*=1.50

$Tp=\ 2.75*\ DPSBAR^{-0.24}\ PROPWET^{-.90}\ DPLBAR^{.49}\ (1+URBEXT)^{-2.98}$
± .07 ± .15 ± .04 ± .63

$*(1-Cereal+Wood)^{-.02}$ $R^2=.69$
± *.12*

fse=1.50 LCM2000 Land use descriptors

$Tp=\ 2.78*\ DPSBAR^{-0.23}\ PROPWET^{-.87}\ DPLBAR^{.50}\ (1+URBEXT)^{-3.10}$
± .07 ± .18 ± .04 ± .77

$*Cereal^{-.01} Wood^{-.02} Grass^{-.33}$ $R^2=.69$

± *.17* ± *.43* ± *.34* *fse*=1.50

$Tp=\ 2.88*\ DPSBAR^{-0.24}\ PROPWET^{-.90}\ DPLBAR^{.50}\ (1+URBEXT)^{-2.94}$
± .06 ± .14 ± .04 ± .58

$*(1-Cereal+Wood)^{-.04}$ $R^2=.69$

± .13 fse=1.50

The ‘ignoring land cover’ equation does not exactly reproduce the normal FEH equation, which was based on more data (small catchments and Northern Irish catchments) and adopted a weighted regression approach (see FEH vol 4, p241). However, the overall coefficient of determination (R^2) is quite similar. Including the land cover terms (derived from LCM 1990 or LCM 2000), either singly or combined, has had virtually no impact on the other regression coefficients and has brought no improvement to the overall coefficient of determination or reduced the overall factorial standard error of the relationship. The regression coefficients for the land cover terms are very uncertain (nearly always well less than one standard error different from zero). Only the coefficient for grass from the 2000 land cover data approaches even minor significance, suggesting 100% grass cover might reduce Tp by up to 20%. The uncertainty of this finding is however large.

The conclusion must be that if land cover has had an impact on Tp in these catchments, then either (a) land cover is so closely related to topography that its impact can be accounted for by topographic descriptors alone, or (b) the land cover descriptors used in this analysis (based on the only data currently readily available) are inadequate for predicting land use/management impacts; the descriptors do not describe management practices such as drainage or tillage.

The regressions for SPR are presented in Box 2 below, but only for the 2000 land cover data, using a subset of 2087 events on 165 catchments from the rural catchment data set (as given in FEH vol 4, Appendix A).

Box 2: SPR regressions, with coefficients and their ± standard deviations overall coefficients of determination and standard errors

Ignoring land cover

PR= 1.09 * SPRHOST + .275*(CWI-125) - 1.1 R^2=.424
± .03   ± .014   se= 15.5

LCM2000PR = 1.06 * SPRHOST + .278*(CWI-125) + 2.5
± 0.05   ± 0.015
- 0.09 * Wood - 2.95 * Cereal - 3.33*Grass R^2=.425
± 3.45   ± 2.78   ± 2.57   se= 15.5

PR = 1.08 * SPRHOST + .275*(cwi-125) - 1.5
± 0.04   ± 0.015
+ 0.92*(1-Cereal+Wood) R^2=.425
±1.50   se= 15.5

Again, the ‘ignoring land cover’ equation does not exactly reproduce the recommended FEH equation – which was developed partly through regression and partly through intuition (see Boorman, 1985). In particular, the rainfall depth term from the FEH equation has not been included. Land cover impacts have only been assessed using the LCM 2000 data, but it is again clear that, singly or combined, their inclusion makes no improvement to the overall coefficient of determination or residual standard error. The regression coefficients for land cover are again very uncertain (usually under one standard deviation from zero), though there is a slight suggestion that increased cereal or grass cover could reduce SPR. However, this is uncertain, and if land cover has had an impact on SPR in these catchments, then again either (a) soil type so governs land use that it accounts for both influences, or

(b) the land cover indices used in this analysis are inadequate for predicting land use/management impacts.

These regression studies have not helped define suitable adjustments to Tp or SPR for use in assessing the impacts of land use/management. However, on the premise that some impact of land use/management is to be expected, a sensitivity based approach, as specified in the MDSF, remains the recommendation. Amounts by which to adjust Tp and SPR are discussed in Chapter 2 of this report.

A.3 Catchment routing and Time to peak (Tp)

The unit hydrograph can be viewed as a cumulative distribution of runoff travel times from within a catchment to its outlet. Changing land use/management affects the response times from different parts of the catchment, causing a change in unit hydrograph shape. However, the FEH method usually adopts a fixed triangular unit hydrograph shape, allowing change only in Tp (a locally derived unit hydrograph can be adopted if rainfall-runoff data exist to permit its derivation).

As part of this project, a ‘time-area’ based procedure for deriving the unit hydrograph has been developed for inclusion and testing in the ‘revitalisation’ project. The ‘time-area’ graph reflects the distribution of response times and contributing areas within the catchment, and is being estimated by rescaling the ‘distance-area’ graph (see below) using a notional velocity (optimised for the catchment), and then routing through a single linear reservoir (also optimised). The ‘distance-area’ graph is determined from the IHDTM flow direction grid (already part of the MDSF) as a frequency distribution of the distances from 50m gridpoints to the catchment outlet. Distance-area curves have been derived for each of the 170 (approx) catchments in the ‘revitalisation’ project, but optimum velocity and reservoir lag values have not yet been obtained. The model is seen as a first step towards a time-area approach because dependence of velocity and reservoir lag on local topography and land use/management has not yet been incorporated.

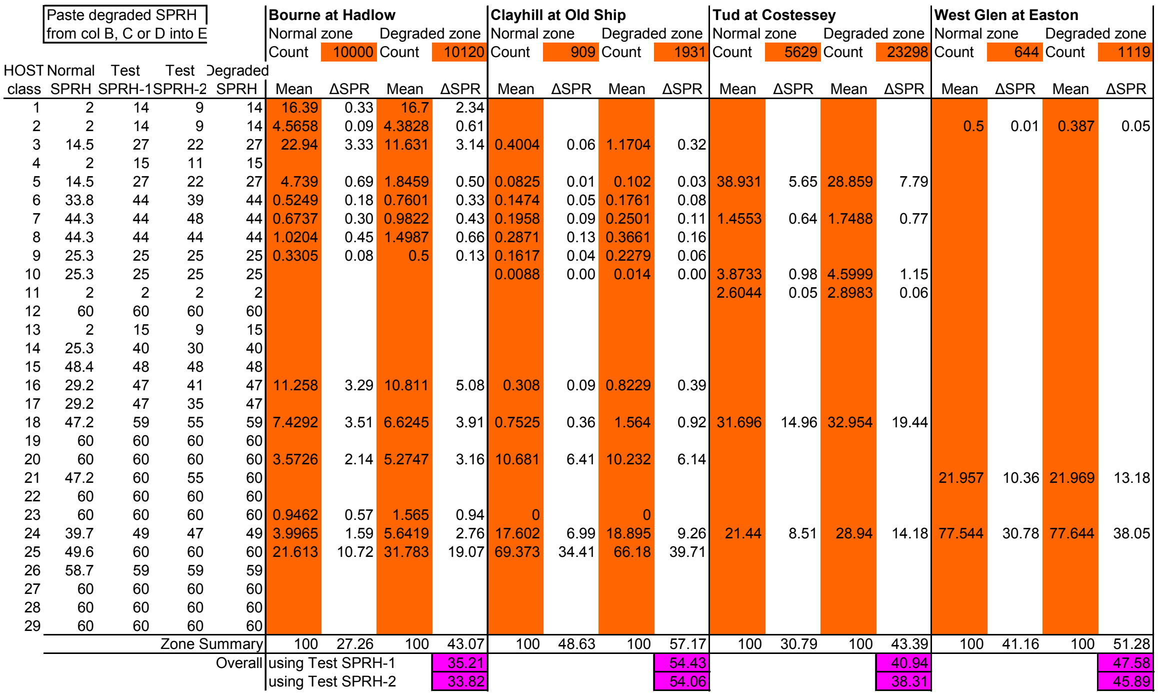
However, the ‘revitalisation’ project has been delayed, and the time-area model will not be fully calibrated within the time span of this project. Consequently, the short term improvement has had to revert to the FEH triangular unit hydrograph. Section A.1 has described how evidence for land cover impacts on the published Tp and SPR parameters is uncertain, suggesting that land cover impacts cannot be identified from among the other sources of uncertainty in parameter estimation. Consequently the sensitivity approach of the MDSF, reducing Tp by 1-2 hours to represent increased drainage rates, remains the best recommendation.

Lack of evidence of land cover impacts in the published parameters (FEH vol 4) could arise from known deficiencies (short records, small events, incorrect model form) that have lead to the ‘revitalisation’ project. That project is updating the unit hydrograph, event-based structure, with percentage runoff and baseflow models defined partly through continuous simulation using daily rainfall-runoff data. Such daily data are readily available, often extending over periods of 40 years. They provide much more stable information on storm response and potentially allow the identification of land-use effects during the record period. It has always been recommended that at-site calibration of the FEH model should be carried out where possible, and thus the latest (pre-revitalisation) FEH model has now been implemented as a continuous daily rainfall runoff model, allowing overall optimum values of Tp, SPR and Baseflow to be derived. This is giving major improvements in model performance, particularly for the larger catchments typical of CFMPs. The continuous form of the FEH model is not commercially available, but the procedures will be published in due course.

Appendix B: example outputs from spreadsheets

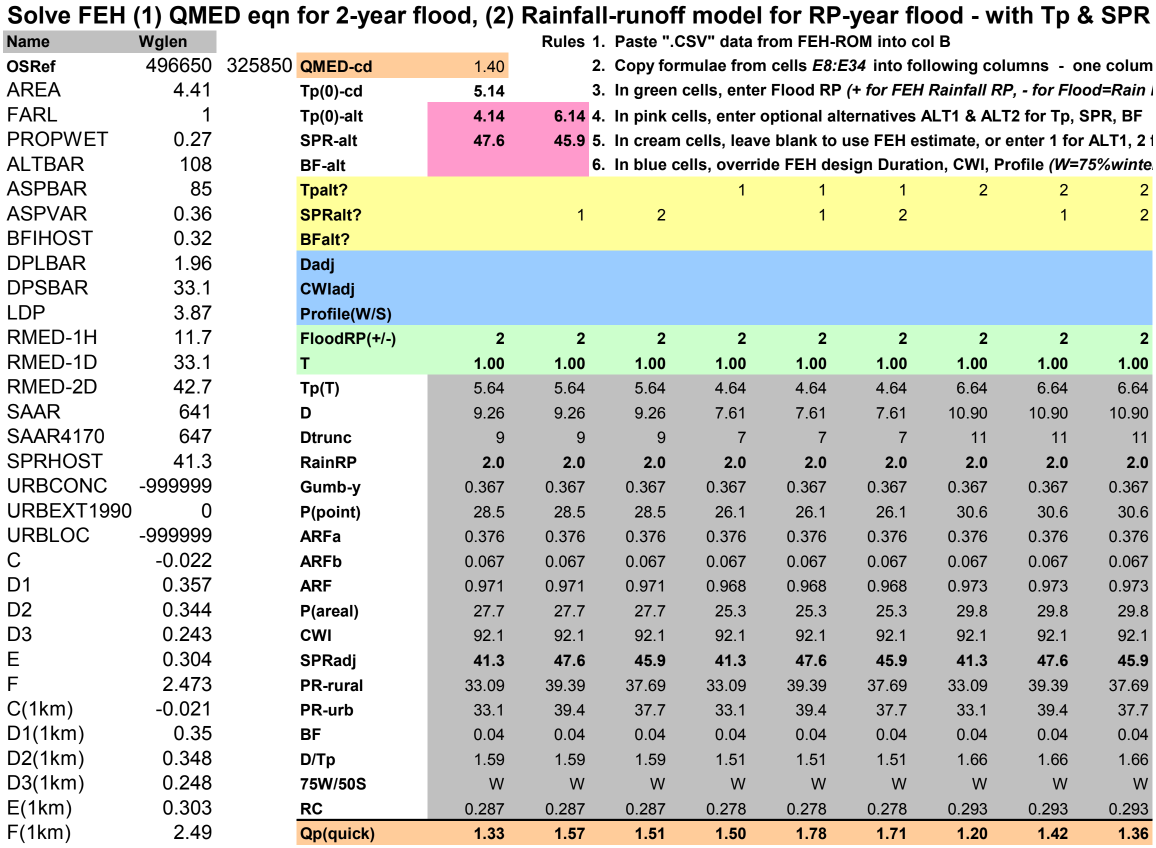
Blanks and example spreadsheets are available for ‘hands-on’ use, but the following printouts show the results obtained for the four test catchments.

SPRADJex.xls - showing the SPR estimates for two ‘degraded’ soil assumptions.



	Paste degraded SPRH from col B, C or D into E				**Bourne at Hadlow**				**Clayhill at Old Ship**				**Tud at Costessey**				**West Glen at Easton**			
					Normal zone		Degraded zone		Normal zone		Degraded zone		Normal zone		Degraded zone		Normal zone		Degraded zone	
					Count	10000	Count	10120	Count	909	Count	1931	Count	5629	Count	23298	Count	644	Count	1119
HOST class	Normal SPRH	Test SPRH-1	Test SPRH-2	Degraded SPRH	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR	Mean	ΔSPR
1	2	14	9	14	16.39	0.33	16.7	2.34												
2	2	14	9	14	4.5658	0.09	4.3828	0.61									0.5	0.01	0.387	0.05
3	14.5	27	22	27	22.94	3.33	11.631	3.14	0.4004	0.06	1.1704	0.32								
4	2	15	11	15																
5	14.5	27	22	27	4.739	0.69	1.8459	0.50	0.0825	0.01	0.102	0.03	38.931	5.65	28.859	7.79				
6	33.8	44	39	44	0.5249	0.18	0.7601	0.33	0.1474	0.05	0.1761	0.08								
7	44.3	44	48	44	0.6737	0.30	0.9822	0.43	0.1958	0.09	0.2501	0.11	1.4553	0.64	1.7488	0.77				
8	44.3	44	44	44	1.0204	0.45	1.4987	0.66	0.2871	0.13	0.3661	0.16								
9	25.3	25	25	25	0.3305	0.08	0.5	0.13	0.1617	0.04	0.2279	0.06								
10	25.3	25	25	25					0.0088	0.00	0.014	0.00	3.8733	0.98	4.5999	1.15				
11	2	2	2	2									2.6044	0.05	2.8983	0.06				
12	60	60	60	60																
13	2	15	9	15																
14	25.3	40	30	40																
15	48.4	48	48	48																
16	29.2	47	41	47	11.258	3.29	10.811	5.08	0.308	0.09	0.8229	0.39								
17	29.2	47	35	47																
18	47.2	59	55	59	7.4292	3.51	6.6245	3.91	0.7525	0.36	1.564	0.92	31.696	14.96	32.954	19.44				
19	60	60	60	60																
20	60	60	60	60	3.5726	2.14	5.2747	3.16	10.681	6.41	10.232	6.14								
21	47.2	60	55	60													21.957	10.36	21.969	13.18
22	60	60	60	60																
23	60	60	60	60	0.9462	0.57	1.565	0.94	0		0									
24	39.7	49	47	49	3.9965	1.59	5.6419	2.76	17.602	6.99	18.895	9.26	21.44	8.51	28.94	14.18	77.544	30.78	77.644	38.05
25	49.6	60	60	60	21.613	10.72	31.783	19.07	69.373	34.41	66.18	39.71								
26	58.7	59	59	59																
27	60	60	60	60																
28	60	60	60	60																
29	60	60	60	60																
				Zone Summary	100	27.26	100	43.07	100	48.63	100	57.17	100	30.79	100	43.39	100	41.16	100	51.28
				Overall	using Test SPRH-1			35.21				54.43				40.94				47.58
					using Test SPRH-2			33.82				54.06				38.31				45.89

<u>FEHSENwg.xls</u> - showing 2-year flood estimate for West Glen at Easton Wood



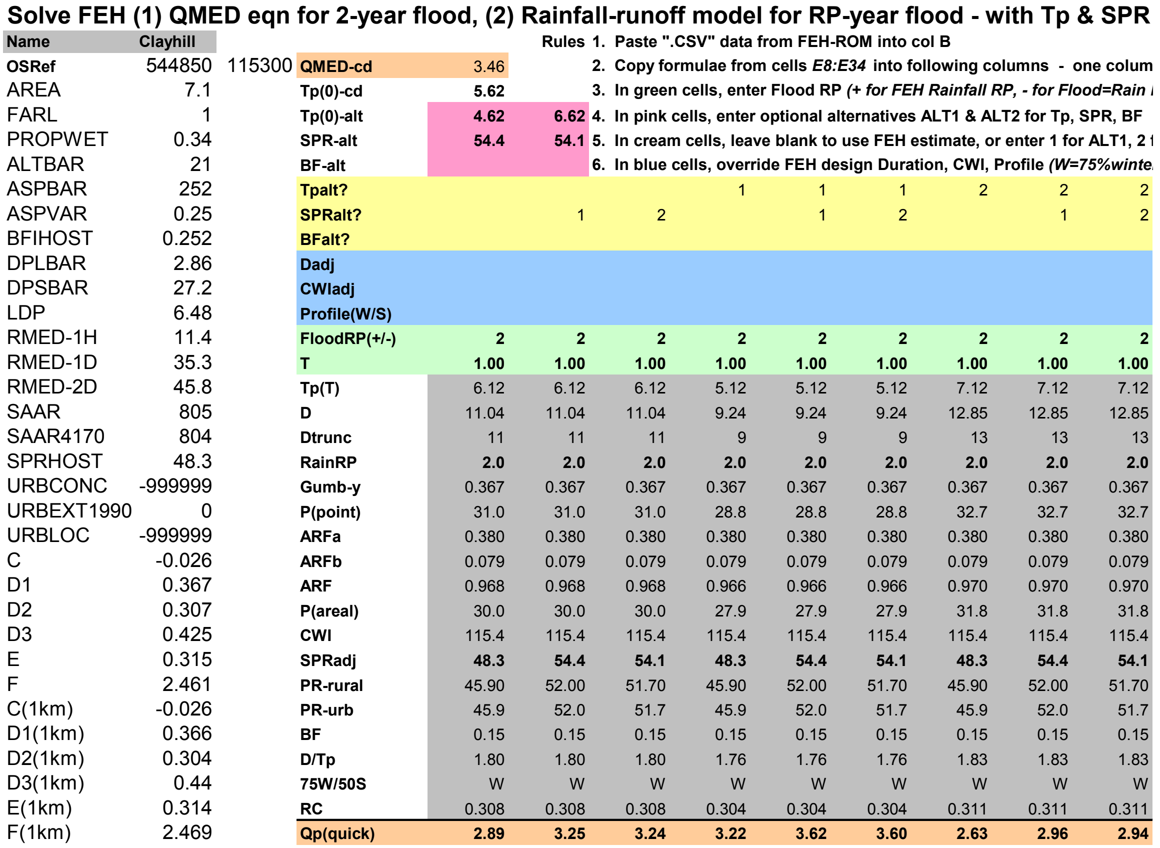
Solve FEH (1) QMED eqn for 2-year flood, (2) Rainfall-runoff model for RP-year flood - with Tp & SPR

Rules
1. Paste ".CSV" data from FEH-ROM into col B
2. Copy formulae from cells *E8:E34* into following columns - one colum
3. In green cells, enter Flood RP *(+ for FEH Rainfall RP, - for Flood=Rain*
4. In pink cells, enter optional alternatives ALT1 & ALT2 for Tp, SPR, BF
5. In cream cells, leave blank to use FEH estimate, or enter 1 for ALT1, 2
6. In blue cells, override FEH design Duration, CWI, Profile *(W=75%winte*

Name	**Wglen**	
OSRef	496650	325850
AREA	4.41	
FARL	1	
PROPWET	0.27	
ALTBAR	108	
ASPBAR	85	
ASPVAR	0.36	
BFIHOST	0.32	
DPLBAR	1.96	
DPSBAR	33.1	
LDP	3.87	
RMED-1H	11.7	
RMED-1D	33.1	
RMED-2D	42.7	
SAAR	641	
SAAR4170	647	
SPRHOST	41.3	
URBCONC	-999999	
URBEXT1990	0	
URBLOC	-999999	
C	-0.022	
D1	0.357	
D2	0.344	
D3	0.243	
E	0.304	
F	2.473	
C(1km)	-0.021	
D1(1km)	0.35	
D2(1km)	0.348	
D3(1km)	0.248	
E(1km)	0.303	
F(1km)	2.49	

QMED-cd	1.40								
Tp(0)-cd	**5.14**								
Tp(0)-alt	**4.14**	**6.14**							
SPR-alt	**47.6**	**45.9**							
BF-alt									
Tpalt?				1	1	1	2	2	2
SPRalt?		1	2		1	2		1	2
BFalt?									
Dadj									
CWIadj									
Profile(W/S)									
FloodRP(+/-)	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
T	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Tp(T)	5.64	5.64	5.64	4.64	4.64	4.64	6.64	6.64	6.64
D	9.26	9.26	9.26	7.61	7.61	7.61	10.90	10.90	10.90
Dtrunc	9	9	9	7	7	7	11	11	11
RainRP	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Gumb-y	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
P(point)	28.5	28.5	28.5	26.1	26.1	26.1	30.6	30.6	30.6
ARFa	0.376	0.376	0.376	0.376	0.376	0.376	0.376	0.376	0.376
ARFb	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
ARF	0.971	0.971	0.971	0.968	0.968	0.968	0.973	0.973	0.973
P(areal)	27.7	27.7	27.7	25.3	25.3	25.3	29.8	29.8	29.8
CWI	92.1	92.1	92.1	92.1	92.1	92.1	92.1	92.1	92.1
SPRadj	**41.3**	**47.6**	**45.9**	**41.3**	**47.6**	**45.9**	**41.3**	**47.6**	**45.9**
PR-rural	33.09	39.39	37.69	33.09	39.39	37.69	33.09	39.39	37.69
PR-urb	33.1	39.4	37.7	33.1	39.4	37.7	33.1	39.4	37.7
BF	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
D/Tp	1.59	1.59	1.59	1.51	1.51	1.51	1.66	1.66	1.66
75W/50S	W	W	W	W	W	W	W	W	W
RC	0.287	0.287	0.287	0.278	0.278	0.278	0.293	0.293	0.293
Qp(quick)	**1.33**	**1.57**	**1.51**	**1.50**	**1.78**	**1.71**	**1.20**	**1.42**	**1.36**

FEHSENwg.xls - showing 2-year flood estimate for Clayhill Stream at Old Ship

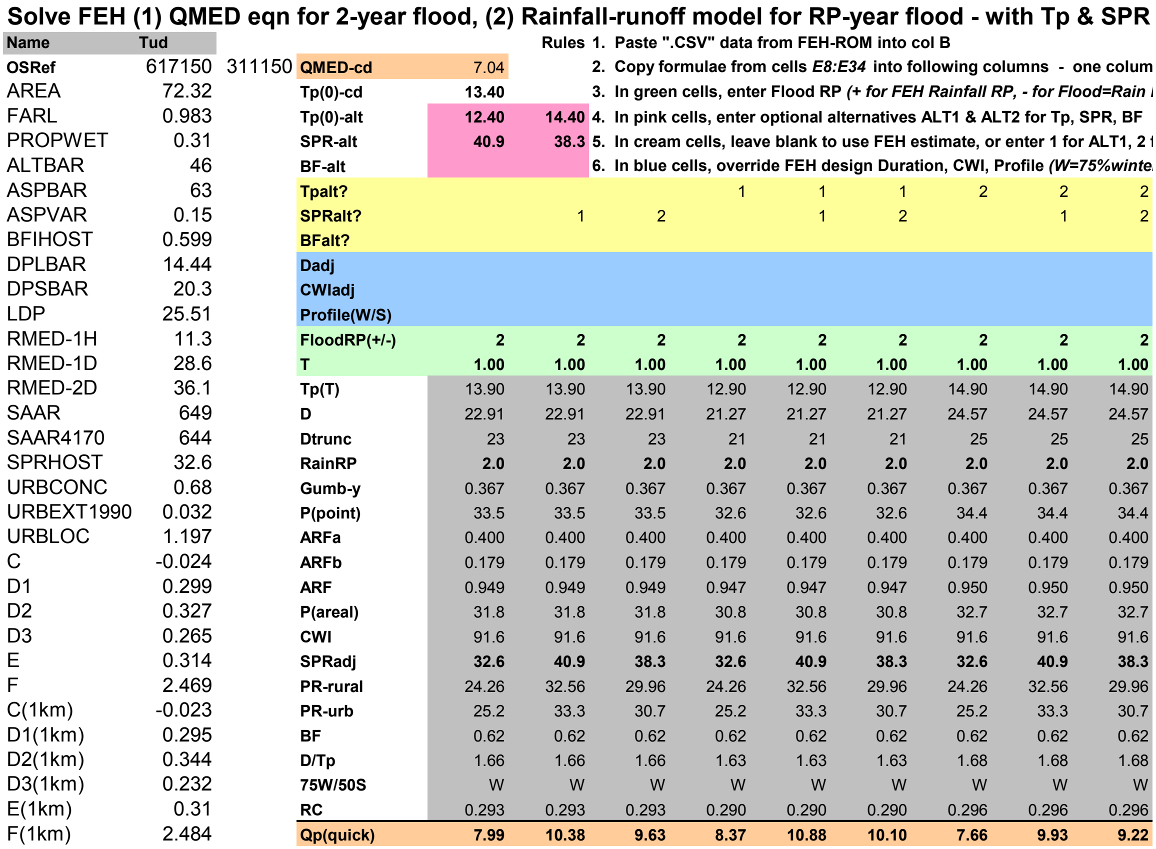


Solve FEH (1) QMED eqn for 2-year flood, (2) Rainfall-runoff model for RP-year flood - with Tp & SPR

Rules
1. Paste ".CSV" data from FEH-ROM into col B
2. Copy formulae from cells *E8:E34* into following columns - one colum
3. In green cells, enter Flood RP *(+ for FEH Rainfall RP, - for Flood=Rain*
4. In pink cells, enter optional alternatives ALT1 & ALT2 for Tp, SPR, BF
5. In cream cells, leave blank to use FEH estimate, or enter 1 for ALT1, 2
6. In blue cells, override FEH design Duration, CWI, Profile *(W=75%winte*

Name	**Clayhill**											
OSRef	544850	115300	**QMED-cd**	3.46								
AREA	7.1		**Tp(0)-cd**	**5.62**								
FARL	1		**Tp(0)-alt**	**4.62**	**6.62**							
PROPWET	0.34		**SPR-alt**	**54.4**	**54.1**							
ALTBAR	21		**BF-alt**									
ASPBAR	252		**Tpalt?**				1	1	1	2	2	2
ASPVAR	0.25		**SPRalt?**		1	2		1	2		1	2
BFIHOST	0.252		**BFalt?**									
DPLBAR	2.86		**Dadj**									
DPSBAR	27.2		**CWIadj**									
LDP	6.48		**Profile(W/S)**									
RMED-1H	11.4		**FloodRP(+/-)**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
RMED-1D	35.3		**T**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
RMED-2D	45.8		**Tp(T)**	6.12	6.12	6.12	5.12	5.12	5.12	7.12	7.12	7.12
SAAR	805		**D**	11.04	11.04	11.04	9.24	9.24	9.24	12.85	12.85	12.85
SAAR4170	804		**Dtrunc**	11	11	11	9	9	9	13	13	13
SPRHOST	48.3		**RainRP**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
URBCONC	-999999		**Gumb-y**	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
URBEXT1990	0		**P(point)**	31.0	31.0	31.0	28.8	28.8	28.8	32.7	32.7	32.7
URBLOC	-999999		**ARFa**	0.380	0.380	0.380	0.380	0.380	0.380	0.380	0.380	0.380
C	-0.026		**ARFb**	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079
D1	0.367		**ARF**	0.968	0.968	0.968	0.966	0.966	0.966	0.970	0.970	0.970
D2	0.307		**P(areal)**	30.0	30.0	30.0	27.9	27.9	27.9	31.8	31.8	31.8
D3	0.425		**CWI**	115.4	115.4	115.4	115.4	115.4	115.4	115.4	115.4	115.4
E	0.315		**SPRadj**	**48.3**	**54.4**	**54.1**	**48.3**	**54.4**	**54.1**	**48.3**	**54.4**	**54.1**
F	2.461		**PR-rural**	45.90	52.00	51.70	45.90	52.00	51.70	45.90	52.00	51.70
C(1km)	-0.026		**PR-urb**	45.9	52.0	51.7	45.9	52.0	51.7	45.9	52.0	51.7
D1(1km)	0.366		**BF**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
D2(1km)	0.304		**D/Tp**	1.80	1.80	1.80	1.76	1.76	1.76	1.83	1.83	1.83
D3(1km)	0.44		**75W/50S**	W	W	W	W	W	W	W	W	W
E(1km)	0.314		**RC**	0.308	0.308	0.308	0.304	0.304	0.304	0.311	0.311	0.311
F(1km)	2.469		**Qp(quick)**	**2.89**	**3.25**	**3.24**	**3.22**	**3.62**	**3.60**	**2.63**	**2.96**	**2.94**

FEHSENwg.xls - showing 2-year flood estimate for Tud at Costessey Park Wood

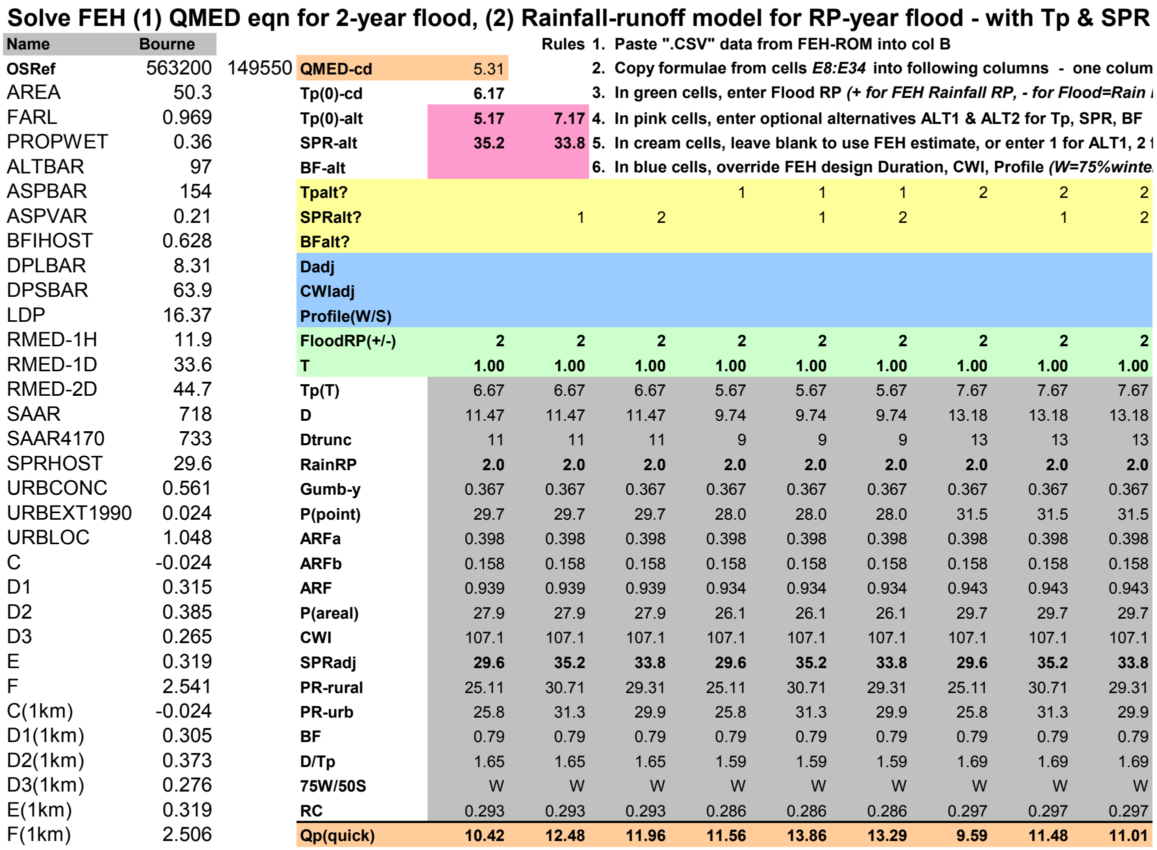


Solve FEH (1) QMED eqn for 2-year flood, (2) Rainfall-runoff model for RP-year flood - with Tp & SPR

Rules 1. Paste ".CSV" data from FEH-ROM into col B
2. Copy formulae from cells *E8:E34* into following columns - one colum
3. In green cells, enter Flood RP *(+ for FEH Rainfall RP, - for Flood=Rain*
4. In pink cells, enter optional alternatives ALT1 & ALT2 for Tp, SPR, BF
5. In cream cells, leave blank to use FEH estimate, or enter 1 for ALT1, 2
6. In blue cells, override FEH design Duration, CWI, Profile *(W=75%winte*

Name	**Tud**											
OSRef	617150	311150	**QMED-cd**	7.04								
AREA	72.32		**Tp(0)-cd**	**13.40**								
FARL	0.983		**Tp(0)-alt**	**12.40**	**14.40**							
PROPWET	0.31		**SPR-alt**	**40.9**	**38.3**							
ALTBAR	46		**BF-alt**									
ASPBAR	63		**Tpalt?**				1	1	1	2	2	2
ASPVAR	0.15		**SPRalt?**		1	2		1	2		1	2
BFIHOST	0.599		**BFalt?**									
DPLBAR	14.44		**Dadj**									
DPSBAR	20.3		**CWIadj**									
LDP	25.51		**Profile(W/S)**									
RMED-1H	11.3		**FloodRP(+/-)**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
RMED-1D	28.6		**T**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
RMED-2D	36.1		**Tp(T)**	13.90	13.90	13.90	12.90	12.90	12.90	14.90	14.90	14.90
SAAR	649		**D**	22.91	22.91	22.91	21.27	21.27	21.27	24.57	24.57	24.57
SAAR4170	644		**Dtrunc**	23	23	23	21	21	21	25	25	25
SPRHOST	32.6		**RainRP**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
URBCONC	0.68		**Gumb-y**	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
URBEXT1990	0.032		**P(point)**	33.5	33.5	33.5	32.6	32.6	32.6	34.4	34.4	34.4
URBLOC	1.197		**ARFa**	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
C	-0.024		**ARFb**	0.179	0.179	0.179	0.179	0.179	0.179	0.179	0.179	0.179
D1	0.299		**ARF**	0.949	0.949	0.949	0.947	0.947	0.947	0.950	0.950	0.950
D2	0.327		**P(areal)**	31.8	31.8	31.8	30.8	30.8	30.8	32.7	32.7	32.7
D3	0.265		**CWI**	91.6	91.6	91.6	91.6	91.6	91.6	91.6	91.6	91.6
E	0.314		**SPRadj**	**32.6**	**40.9**	**38.3**	**32.6**	**40.9**	**38.3**	**32.6**	**40.9**	**38.3**
F	2.469		**PR-rural**	24.26	32.56	29.96	24.26	32.56	29.96	24.26	32.56	29.96
C(1km)	-0.023		**PR-urb**	25.2	33.3	30.7	25.2	33.3	30.7	25.2	33.3	30.7
D1(1km)	0.295		**BF**	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
D2(1km)	0.344		**D/Tp**	1.66	1.66	1.66	1.63	1.63	1.63	1.68	1.68	1.68
D3(1km)	0.232		**75W/50S**	W	W	W	W	W	W	W	W	W
E(1km)	0.31		**RC**	0.293	0.293	0.293	0.290	0.290	0.290	0.296	0.296	0.296
F(1km)	2.484		**Qp(quick)**	**7.99**	**10.38**	**9.63**	**8.37**	**10.88**	**10.10**	**7.66**	**9.93**	**9.22**

FEHSENwg.xls - showing 2-year flood estimate for Bourne at Hadlow



Solve FEH (1) QMED eqn for 2-year flood, (2) Rainfall-runoff model for RP-year flood - with Tp & SPR

Name	**Bourne**											
OSRef	563200	149550	**QMED-cd**	5.31	**Rules**	**1. Paste ".CSV" data from FEH-ROM into col B** **2. Copy formulae from cells *E8:E34* into following columns - one colum**						
AREA	50.3		**Tp(0)-cd**	**6.17**		**3. In green cells, enter Flood RP *(+ for FEH Rainfall RP, - for Flood=Rain***						
FARL	0.969		**Tp(0)-alt**	**5.17**	**7.17**	**4. In pink cells, enter optional alternatives ALT1 & ALT2 for Tp, SPR, BF**						
PROPWET	0.36		**SPR-alt**	**35.2**	**33.8**	**5. In cream cells, leave blank to use FEH estimate, or enter 1 for ALT1, 2 f**						
ALTBAR	97		**BF-alt**			**6. In blue cells, override FEH design Duration, CWI, Profile *(W=75%winte***						
ASPBAR	154		**Tpalt?**				1	1	1	2	2	2
ASPVAR	0.21		**SPRalt?**		1	2		1	2		1	2
BFIHOST	0.628		**BFalt?**									
DPLBAR	8.31		**Dadj**									
DPSBAR	63.9		**CWIadj**									
LDP	16.37		**Profile(W/S)**									
RMED-1H	11.9		**FloodRP(+/-)**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**
RMED-1D	33.6		**T**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
RMED-2D	44.7		**Tp(T)**	6.67	6.67	6.67	5.67	5.67	5.67	7.67	7.67	7.67
SAAR	718		**D**	11.47	11.47	11.47	9.74	9.74	9.74	13.18	13.18	13.18
SAAR4170	733		**Dtrunc**	11	11	11	9	9	9	13	13	13
SPRHOST	29.6		**RainRP**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
URBCONC	0.561		**Gumb-y**	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367	0.367
URBEXT1990	0.024		**P(point)**	29.7	29.7	29.7	28.0	28.0	28.0	31.5	31.5	31.5
URBLOC	1.048		**ARFa**	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398
C	-0.024		**ARFb**	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158
D1	0.315		**ARF**	0.939	0.939	0.939	0.934	0.934	0.934	0.943	0.943	0.943
D2	0.385		**P(areal)**	27.9	27.9	27.9	26.1	26.1	26.1	29.7	29.7	29.7
D3	0.265		**CWI**	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1
E	0.319		**SPRadj**	**29.6**	**35.2**	**33.8**	**29.6**	**35.2**	**33.8**	**29.6**	**35.2**	**33.8**
F	2.541		**PR-rural**	25.11	30.71	29.31	25.11	30.71	29.31	25.11	30.71	29.31
C(1km)	-0.024		**PR-urb**	25.8	31.3	29.9	25.8	31.3	29.9	25.8	31.3	29.9
D1(1km)	0.305		**BF**	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
D2(1km)	0.373		**D/Tp**	1.65	1.65	1.65	1.59	1.59	1.59	1.69	1.69	1.69
D3(1km)	0.276		**75W/50S**	W	W	W	W	W	W	W	W	W
E(1km)	0.319		**RC**	0.293	0.293	0.293	0.286	0.286	0.286	0.297	0.297	0.297
F(1km)	2.506		**Qp(quick)**	**10.42**	**12.48**	**11.96**	**11.56**	**13.86**	**13.29**	**9.59**	**11.48**	**11.01**

Appendix C: Estimated changes to SPRHOST caused by soil structural degradation

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
1	3	1.00	2		0.90	-0.10	14	12	Soils on chalk and limestone. SPR & BFI the same for both HOST classes and degradation-induced changes to these are driven mainly by increased surface runoff, not all of which is 'intercepted' by dry valleys, etc. (see John Boardman's work on the S. Downs). HOST 3 soils (sands on soft sandstone) used as a guide to changes because they have a similar topography but appear to have a slightly denser surface water network (i.e. less distance for runoff to travel to a stream).
2	3	1.00	2		0.90	-0.10	14	12	
3	7?	0.90	14		0.79	-0.11	27	12	Free draining, sandy and/or gravelly soils. Differences in BFI & SPR between HOST 3& 5 and 7 due mainly to nearness to / density of stream network (network is closer / more dense in HOST 7 than in 3 & 5). Changes to SPR & BFI driven mainly by increased surface runoff, not all of which is 'intercepted' by dry valleys, etc. Degradation-induced changes to BFI guided by HOST 7 (closer to streams / more dense surface

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
5	7?	0.90	14		0.79	-0.11	27	12	water network). SPR for HOST 7 is very uncertain and therefore changes to SPR for classes 3 & 5 are based mainly on the changes in BFI. No change to SPR for HOST 7 because value is already large (and uncertain).
7	?	0.79	44	SPR coefficient very uncertain	0.73	-0.06	44	0	
6	8	0.64	34		0.56	-0.08	44	10	Free draining loamy soils. Differences in BFI & SPR between classes due mainly to nearness to/density of stream network (network is closer / more dense in HOST 8 than in 6). Changes to SPR & BFI driven mainly by increased surface runoff, not all of which is 'intercepted' by dry valleys, etc. HOST 8 is mainly on level ground (no changes) For HOST 6, degradation-induced changes to BFI & SPR guided by HOST 8, because it is closer to streams and/or has a more dense surface water network.
8	Level ground	0.56	44	SPR coefficient very uncertain	0.56	0.00	44	0	

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
4	6?	0.79	2	SPR coefficient very uncertain	0.65	-0.14	14.5	13	Soils mainly on relatively hard fissured or deeply weathered rocks. Differences in SPR and BFI between classes largely determined by differences in seasonal storage caused by differences in soil wetness (usually perched water). Very difficult to make judgements about this group because classes 13 and 14 are so limited and, with retrospect, class 4 probably has a very diverse range of substrate permeabilities. Values for class 15 are probably the most reliable. Changes in BFI and SPR largely based on classes with the nearest textures and water regimes
13	3?	1.00	2	SPR and BFI coefficients very uncertain	0.90	-0.10	14.5	13	
14	24?	0.38	25	SPR and BFI coefficients very uncertain	0.31	-0.07	40	15	
15	N/A	0.38	48		N/A	N/A	N/A	N/A	
9	Level ground	0.73	25		0.73	0.00	25	0	Soils on level ground. No changes in SPR or BFI
10	Level ground	0.52	25		0.52	0.00	25	0	
11	Level ground	0.93	2	SPR and BFI coefficients very uncertain	0.93	0.00	2	0	
12	N/A	0.17	60		N/A	N/A	N/A	N/A	

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
16	18?	0.78	29	SPR and BFI coefficients very uncertain	0.60	-0.18	47	18	Soils on slowly permeable substrates. Differences in SPR & BFI between classes largely determined by reduction in storage as determined by 'drainable porosity' and seasonal duration of wetness. However, the pattern is complicated by differences in slope between classes (decrease from low to high numbers) and the dominant presence of field drains in class 24. Degradation-induced changes to SPR & BFI caused mainly by reduction in storage so changes to SPR guided by differences between soils of similar wetness/storage but different overall permeability (i.e. classes 20 to 25).
18	20	0.52	47		0.40	-0.12	59	12	
21	23	0.34	47		0.22	-0.12	59	12	
24	25	0.31	40		0.21	-0.10	49.6	10	
26	N/A	0.24	59		N/A	N/A	N/A	N/A	
17	18	0.61	29		0.52	-0.09	47.2	18	Soils on hard impermeable rock substrates. Differences in SPR & BFI between classes largely determined by reduction in storage as determined by 'drainable porosity' and differences in slope (tends to increase from classes 17 to 22), both of which give increased surface runoff. Degradation-induced changes to BFI & SPR determined mainly by reduction in storage so changes to BFI guided by HOST classes in the next 'higher' category. However, for SPR, only class 17 changes as SPR is already at a maximum for other
19	22	0.47	60	SPR coefficient very uncertain	0.32	-0.15	60	0	
22	27	0.32	60	SPR coefficient very uncertain	0.26	-0.06	60	0	

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
27	N/A	0.26	60	SPR and BFI coefficients very uncertain	N/A	N/A	N/A	N/A	classes. The change in SPR for HOST class 17 is based on HOST class 18 as vales for 19 and 22 are very uncertain and would give an unrealistically large change in SPR.

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
20	?	0.52	60	SPR and BFI coefficients very uncertain	0.47	-0.05	60	0	Soils on impermeable massive clay substrates. Differences in SPR & BFI between classes largely determined by reduction in storage as determined by 'drainable porosity' and seasonal duration of wetness. However, the pattern is complicated by differences in slope between classes (decrease from low to high numbers) and the dominant presence of field drains in class 25. Degradation-induced changes to SPR & BFI caused mainly be reduction in storage. However BFI
23	25	0.22	60		0.17	-0.05	60	0	

HOST class	HOST class used to guide changes	Current HOST-BFI coefficient	Current HOST-SPR coefficient	Comments on HOST-BFI & -SPR	HOST-BFI coefficient with degradation	Change	HOST-SPR coefficient with degradation	Change	General characteristics on the basis for tics of the HOST grouping and guidance notes
25	?	0.17	50		0.17	0.00	60	10	& SPR for HOST 20 are very uncertain and there is not much scope for change in other classes (SPR & BFI already at the near limits). Where changes are possible they are based on the differences between HOST 23 and 25.
28	N/A	0.58	60	SPR and BFI coefficients very uncertain	N/A	N/A	N/A	N/A	Upland peat soils. Are these subject to degradation?
29	N/A	0.23	60		N/A	N/A	N/A	N/A	

Notes:

HOST classes used to guide changes (Analogue Classes) cannot cross major hydrogeological groupings of permeability and depth to groundwater.

HOST classes on level ground (8, 9, 10, 11 & 12) may be subject to soil degradation but this will not affect BFI or SPR indices because there is no potential for surface runoff.

Estimated changes to HOST-SPR should be guided by estimated changes in HOST-BFI.

Changed BFI-HOST coefficients cannot be less than 0.17 (current smallest values)

Changed SPR-HOST coefficients cannot be greater than 60.0% (current largest values)

PB10493

Nobel House
17 Smith Square
London SW1P 3JR

www.defra.gov.uk

ISBN 0-85521-141-5

9 780855 211417

Department for Environment
Food and Rural Affairs