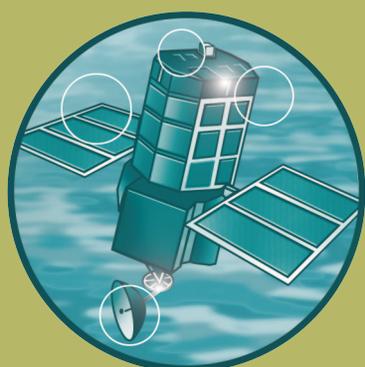# Review of impacts of rural land use and management on flood generation

Short-term improvement to the FEH rainfall-runoff model: User manual

R&D Project Record FD2114/PR2

ENVIRONMENT AGENCY

defra
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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: User manual

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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
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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.

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Executive summary

This report should be read in conjunction with two previous reports: 'FD2114/TR: Impact Study Report' (O'Connell *et al*, 2004), and 'FD2114/PR1: Research Plan', in which the purpose of the FD2114 project is introduced and results presented. FD2114/TR presents 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 for 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 FD2114/PR2 provides guidance on the use of a procedure whereby 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 use of the Decision Support Matrix tool entitled 'The Flood and Agriculture Risk Matrix' (FARM) is also described. The report is therefore a User Manual describing how the proposed short-term FEH adjustment model and the FARM tool should be applied. The technical background supporting development of these guidelines is given in the companion FD2114/PR3: Technical Background (Packman *et al* 2004).

It should be noted that the proposed methodology is not one that can be applied by an inexperienced user. The methods require that users have a sound knowledge of the FEH rainfall-runoff methodology, have a good understanding of ArcView GIS, and are reasonably familiar with Excel. The methodology is rather time consuming, but it is based on an improved rationale for adjusting FEH model parameters, and it provides the best outputs possible within the scope of the current project. If there is sufficient interest in this proposed interim approach to assessment of the possible impacts of land management changes, a more streamlined, 'user-friendly' methodology could be developed in due course, but as stated above, this was beyond the scope of the current project

Contents

Glossary

ArcView	Commercial GIS software from Environmental Systems Research Institute
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)
Excel	Commercial spreadsheet program from Microsoft
FARM	Floods and Agriculture Risk Matrix
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)
PROPWET	Proportion of days in year that soil moisture deficit is under 6mm
SPR	Estimate of Percentage of Rainfall yielding Quick Runoff under standard conditions (less than 40mm of rainfall, zero soil moisture deficit) – see FEH
SPRADJ	Spreadsheet program to assess SPR values from (a) fractions of HOST classes within a catchment and (b) land management impacts.
SPRHOST, SPRH	Estimate of SPR based on HOST soil class

| Tp | Time to peak of Unit Hydrograph – see FEH |
| Tp(0) | Time to peak of Instantaneous Unit Hydrograph (due to pulse of rain falling instantaneously over the catchment |

1.   Introduction

For completeness this report should be read in conjunction with three previous reports: 'FD2114/TR: Impact Study Report', and 'FD2114/PR1: Research Plan', in which the purpose of the FD2114 project is introduced and results presented, and 'FD2114/PR3: Technical Background'. 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, FD2114/PR3 presents the scientific basis for the recommended short-term adjustments to the FEH rainfall-runoff flood estimation model described in this 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 two previous reports: FD2114/TR: Impact Study Report presents outputs from Tasks 1-7, and 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, addressed Tasks 16-22 as set out in Table 1.1 below.

This report, **FD2114/PR2**, is the first 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, and is a brief user guide to the methods proposed to account for land-management change. A separate report, **FD2114/PR3,** provides a more detailed discussion on the underlying thinking and research upon which this current user guide is based. Readers who require a greater understanding of the scientific rationale underlying the current report should refer to project record PR3. FD2114/PR1 and PR2 present the outputs of Tasks 16 to 18 and 21 below, with this Report FD2114/PR2, being the output of Task 21.

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 which 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 using local rainfall statistics. The model basically has two principal model parameters, standard percentage runoff (SPR), that controls the proportion of the rainfall input producing runoff, and the time to peak of the unit hydrograph (Tp), that controls the routing process, or speed of response of the runoff.

For a specific catchment, SPR and Tp can be estimated (in order of preference) by:

- analysing at-site rainfall-runoff data;
- transposing values from analogue sites; or
- using published relationships of SPR to 'catchment descriptors' such as soil type (i.e. the HOST class 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). Volume 4 of the FEH (pp144-6) discusses the effects of agriculture and forestry on Tp and SPR, and additional guidance is given in the MDSF (HRWallingford *et al*, 2002, vol 1, pp70-1, and vol 2, pp 21-8).

As described in the contractual annex for the current project, 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 method 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 quantifiable field information on impacts. Thus the FARM tool attempts to maximise the use of 'soft', qualitative information relevant to estimating runoff risk and catchment descriptors. The approach would then be tested using four selected catchment sites covering upland forest and grass, and lowland crop and meadow.

In addition, a consistent method of defining land use/management is required, and thus new catchment descriptors were derived using the CEH land cover (satellite-based) maps. 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. (In the longer term, the ADAS 1km agricultural land use database would be a strong candidate to help develop better descriptors). These land-cover descriptors would be considered alongside the HOST and the other FEH descriptors in assessing Tp and SPR.

Agricultural intensification degrades soil structure, leading to increased surface runoff volume and speed of travel over the land surface, both factors causing increased flood peaks. In response therefore to the premise that agricultural intensification impacts can be seen at the plot scale and should therefore be present at the catchment scale (although evidence to support this has not been found: see FD2114/TR), the speculative procedure for adjusting Tp and SPR presented here is recommended for use on a precautionary basis. It must be emphasised however that these suggested modifications are based on limited, qualitative data, and that findings can often be both counter-intuitive and contradictory at a catchment scale.

Using the procedure to assess how agricultural de-intensification could form part of a downstream flood alleviation strategy would involve great uncertainty. As outlined in the FD2114/PR1: Research Plan, there is a need for further research to identify impacts and to develop improved impact prediction methods.

2. Developing the short-term objectives

2.1 Overview

The proposed short-term improvement method presented here has two components: adjustment of the standard percentage runoff (SPR), and adjustment of the unit hydrograph Tp.

Determining a suitable SPR adjustment is intuitively simpler, and is the main focus of the short-term improvements. As described in Report PR2, for each HOST soil class an analogue class was chosen to represent degraded (compacted) conditions (Packman et al, 2004), from which a revised SPR value was assessed. Two alternative ways of using the analogue classes were applied, and the resulting SPR values shown in Table 2.1 give some indication of the uncertainties involved.

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 2.1 HOST class, analogue, SPRHOST, revised and alternate SPR values

Catchment average 'worst case' (*i.e.* 'fully degraded') SPR values are obtained by applying:
* revised (or alternate) SPR values to <u>all</u> arable and improved grassland in the catchment;
* original values to all other land covers.

Forestry is assumed to have no consistent overall effect on SPR.

GIS procedures are used to assess the areas in each HOST and land use class combination, and a spreadsheet SPRADJ is provided to calculate the resulting catchment average estimate of SPR. The 'worst case' scenario may later be adjusted based on the actual agricultural practices in use using a decision matrix procedure (the FARM tool – described in Section 3.3). Note that the 'fully degraded' estimate based on the revised SPR values is denoted below as SPRH-1, and the estimate based on the alternate SPR values is denoted as SPRH-2.

For adjusting Tp, following unsuccessful attempts to relate Tp to land cover (FD2114/PR3, Appendix A), a more intuitive procedure is recommended. Based on guidance in the FEH and MDSF, a 1 hour test reduction in Tp is recommended to reflect faster local runoff for 'fully degraded' conditions, and a 1 hour increase in Tp to represent any local flow calming measures. Until a distributed approach to catchment routing is developed (such as the time-area method discussed in FD2114/PR3, Section A.3), 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 mentioned above (and described in detail in Section 3.3). Again, the 'worst case' scenario may later be adjusted based on the actual agricultural practices in use using the FARM tool.

Having obtained the 'worst case' scenario, a spreadsheet FEHSEN is provided to assess the sensitivity of peak floods in the local catchment to the matrix of SPR and Tp values representing 'fully degraded' conditions. The FARM tool is than used to assess the likely degree of the degradation present in the catchment, and thus select appropriate local SPR and Tp values.

Finally, the spreadsheet FEHCAL may be used to assess the effect of local changes in SPR and Tp on peak flows further downstream. FEHCAL was originally supplied on CD for use in the MDSF, and was intended for application with relatively large subareas, typically of 100 km^2 (FEHCAL uses the term sub-catchment for the total area draining to a point, and sub-area for any intervening area draining between two such points). For the short term improvements, FEHCAL should now be applied at a progressively finer scale to represent sub-areas of more uniform land use/management.

In their current form, the various spreadsheets are independent of the GIS based MDSF. For ease of use, they could and should be incorporated within the GIS structure, and macros should be developed for some of the GIS aspects. This however was not within the scope of the present project. It should also be noted that FEHCAL and FEHSEN require repeated abstraction of data from the FEH CD-ROM. This would be greatly streamlined if the relevant FEH CD-ROM catchment descriptors were to be included within the GIS structure of the MDSF.

The following section presents a step-by-step guide to application of the interim short-term methodology for adjustment of the standard FEH rainfall-runoff approach to design flood estimation. The FARM tool can be run at anytime but it should usually be used after the user has processed the FEH GIS data.

3. Application of the short-term procedure

3.1 Data sources and software requirements

The procedure requires access to various data sources and software:

1.   FEH CD-ROM

2.   Spreadsheet and GIS software (Excel and ArcView - with spatial analyst, IMAGINE image support, and HYDRO extensions, and with 'define catchment' script from MDSF)

3.   GIS layers of the   (a) 50m IHDTM 'flow direction grid'
                              (b) 1km HOST class (aggregate percentages) grid
                              (c) 25m CEH land cover 2000 grid

4.   A copy of the FARM tool

MDSF users will already have 1 to 3a above, but will need new GIS layers 3b and 3c.

The HOST aggregate data (3b) comprises the percentage of each HOST class falling within each 1 km grid square within the UK. The data can be supplied by CEH with instructions for loading into ArcInfo. No procedures were available for supplying the data in a form suitable for loading into ArcView. A program has thus been written to extract, for any given map rectangle, a separate grid in ArcView ASCII import format for each of the HOST classes present in that rectangle (up to 29 of them).

The CEH land cover data (3c) is supplied as separate ArcView shape files for each 100km grid square, or as an ERDAS image file for the whole UK, giving the dominant land use (26 categories) in each 25m grid square. These procedures are based on the image file, loaded and converted in ArcView into grid format. However, the data could also be supplied as an ASCII grid file similar to the HOST grids above (but for a 25m grid size).

Currently, the GIS procedures are rather labour-intensive and take a considerable time for each sub-catchment being assessed. In practice, the calculation of degraded SPR could be fully automated in the same way that SPRHOST was calculated for the FEH CDROM. However, this would remove the flexibility offered by the GIS approach described here.

The effect of changes to individual sub-catchments on the response of a larger downstream sub-catchment can be assessed using the **FEHCAL** spreadsheet provided with the MDSF. Full descriptions of the use of FEHCAL are given by HR Wallingford et al (2002).

In addition to FEHCAL, three new spreadsheets are also required:
SPRADJ to generate a catchment's 'fully degraded' SPR value from ArcView 'summarise zones' outputs, and

FEHSEN which was developed from **FEHCAL**, but generates flood estimates for a single subcatchment using a matrix of three values each for Tp and SPR.
The **FARM** tool to assess the extent of degrading which should be applied to the SPR and Tp values for the current catchment.

3.2   Outline steps in the procedure

1.   Using the FEH-CDROM

- Identify the catchment;
- Find the grid co-ordinates of a bounding rectangle around catchment;
- Export the catchment desciptor data to file from the CDROM.

2.   Using ArcView

- Import IHDTM flow direction and HOST soil grids
- Generate catchment boundary (HYDRO button)
- Generate HOST grids at 50m, clipped to catchment boundary
- Add CEH Land cover 2000 grid (converted from image file)
    - i.   Clip landcover to 50m grid over catchment
    - ii.   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.
      For each HOST class present:
    - iii.   Use GIS functions to sum degraded and normal areas within catchment
    - iv.   Transfer areas to spreadsheet SPRADJ

3.   Spreadsheets

- Use SPRADJ.XLS to derive SPR estimate (Table 3.1)
    - i.   Enter normal and degraded area from step 2.5 into respective HOST class row
    - ii.   Select HOST factors for degraded land, giving revised and alternate SPR values
- Use FEHSEN.XLS to estimate T-year floods for matrix of Tp and SPR (Table 3.2)
    - i.   Paste catchment descriptor data from step 1.3 into spreadsheet
    - ii.   Noting FEH estimate of Tp(0), enter alternate values *(e.g. minus 1h, plus 1h)*
    - iii.   Noting FEH estimate of SPRHOST, enter revised and alternate SPR, step 3.1

iv.   Enter return period, and extract matrix of flood estimates for further analysis or presentation.

- Run the FARM tool to analyse the degree to which the SPR values should change for the current catchment. The tool can be either used on each HOST or on groups of HOST classes. The results of running the FARM tool will be to determine the degree to which the SPR should be changed between the original SPR value and the fully degraded, revised SPR value. The FEHSEN.XLS spreadsheet can then be updated as appropriate.

Paste chosen degraded SPRH values from column B, C or D into E					Bourne at Hadlow			
					Normal zone		Degraded zone	
A	B	C	D	E	Count	10000	Count	10120
HOST class	Normal SPRH	Revised SPRH-1	Alternate SPRH-2	Degraded SPR	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
3	14.5	27	22	27	22.94	3.33	11.631	3.14
4	2	15	11	15				
5	14.5	27	22	27	4.739	0.69	1.8459	0.50
6	33.8	44	39	44	0.5249	0.18	0.7601	0.33
7	44.3	44	48	44	0.6737	0.30	0.9822	0.43
8	44.3	44	44	44	1.0204	0.45	1.4987	0.66
9	25.3	25	25	25	0.3305	0.08	0.5	0.13
10	25.3	25	25	25				
11	2	2	2	2				
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
17	29.2	47	35	47				
18	47.2	59	55	59	7.4292	3.51	6.6245	3.91
19	60	60	60	60				
20	60	60	60	60	3.5726	2.14	5.2747	3.16
21	47.2	60	55	60				
22	60	60	60	60				
23	60	60	60	60	0.9462	0.57	1.565	0.94
24	39.7	49	47	49	3.9965	1.59	5.6419	2.76
25	49.6	60	60	60	21.613	10.72	31.783	19.07
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
				Overall	using Revised SPRH-1			35.21
					using Alternate SPRH-2			33.82

Table 3.1 Example based on spreadsheet SPRADJ for the Bourne at Hadlow
(N.B. Overall values for Alternate SPRH-2 pasted into last line for comparison)

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

Name	Bourne			
OSRef	563200 149550	QMED-cd	5.31	
AREA	50.3	Tp(0)-cd	6.17	
FARL	0.969	Tp(0)-alt	5.17	7.17
PROPWET	0.36	SPR-alt	35.2	33.8
ALTBAR	97	BF-alt		
ASPBAR	154			
ASPVAR	0.21			
BFIHOST	0.628			
DPLBAR	8.31			
DPSBAR	63.9			
LDP	16.37			
RMED-1H	11.9			
RMED-1D	33.6			
RMED-2D	44.7			
SAAR	718			
SAAR4170	733			
SPRHOST	29.6			
URBCONC	0.561			
URBEXT1990	0.024			
URBLOC	1.048			
C	-0.024			
D1	0.315			
D2	0.385			
D3	0.265			
E	0.319			
F	2.541			
C(1km)	-0.024			
D1(1km)	0.305			
D2(1km)	0.373			
D3(1km)	0.276			
E(1km)	0.319			
F(1km)	2.506			

Rules
1. Paste ".CSV" data from FEH-ROM into col B
2. Copy formulae from cells *E8:E34* into following columns - one column per flood estimate
3. In green cells, enter Flood RP *(+ for FEH Rainfall RP, - for Flood=Rain RP)* and model timestep (Tp/5)
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 for ALT2 value
6. In blue cells, override FEH design Duration, CWI, Profile *(W=75%winter, S=50%summer)*

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)	6.67	6.67	6.67	5.67	5.67	5.67	7.67	7.67	7.67
D	11.47	11.47	11.47	9.74	9.74	9.74	13.18	13.18	13.18
Dtrunc	11	11	11	9	9	9	13	13	13
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)	29.7	29.7	29.7	28.0	28.0	28.0	31.5	31.5	31.5
ARFa	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398
ARFb	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158
ARF	0.939	0.939	0.939	0.934	0.934	0.934	0.943	0.943	0.943
P(areal)	27.9	27.9	27.9	26.1	26.1	26.1	29.7	29.7	29.7
CWI	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.1
SPRadj	29.6	35.2	33.8	29.6	35.2	33.8	29.6	35.2	33.8
PR-rural	25.11	30.71	29.31	25.11	30.71	29.31	25.11	30.71	29.31
PR-urb	25.8	31.3	29.9	25.8	31.3	29.9	25.8	31.3	29.9
BF	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
D/Tp	1.65	1.65	1.65	1.59	1.59	1.59	1.69	1.69	1.69
75W/50S	W	W	W	W	W	W	W	W	W
RC	0.293	0.293	0.293	0.286	0.286	0.286	0.297	0.297	0.297
Qp(quick)	10.42	12.48	11.96	11.56	13.86	13.29	9.59	11.48	11.01

Table 3.2   Example of spreadsheet FEHSEN for the Bourne at Hadlow

3.3 Detailed instructions

(N.B. A reasonable level of experience in FEH, Arcview and Excel is required).

In this text, the following font styles denote specific information:

Bold	Menu names, menu options, button names, GIS coverage names, and table or column headings used in the respective software packages
<Bold>	Names of files or GIS coverages supplied by the user. The generalised names used here (within the braces) are both distinct and consistently applied to the respective file or coverage.
<Italics>	Values or names provided by ArcView procedures that the user must note and use elsewhere
Italics	Brief comments to help the user

1. FEH-CDROM:

   - Identify the catchment (e.g. enter 'Numeric GR' and press **Locate** button);
   - Find co-ordinates of bounding rectangle around catchment *(for use in generating ArcView HOST grids)* by moving cursor over map;
   - Export catchment desciptor data to file *(for input to **FEHSEN**)* by pressing **Query** button and then **Export** button.

2. *ArcView* (with spatial analyst, IMAGINE, & HYDRO extensions and also define catchment script loaded as ArcView button– supplied with MDSF). *Note: example ArcView coverages with blank and completed 'apr' files are supplied on a separate disk.*

   Import data: from the **File** menu, **Import** the IHDTM **flow direction** and HOST soil grids (**<Host grid 1>** etc) for bounding rectangle *(defined in step 1.2)*

   Generate **<catchment>** grid (or ***<watershed grid>***):
   - o Make **flow direction** grid active and from the **Hydro** menu select **Flow accumulation**.
   - o Make the derived ***<flow accumulation>*** grid active and click on the legend to reclassify in two classes (0-199, 200 and above: 200 cells=0.5km^2). *Note: a bug in ArcView reclassify causes small accumulations (effectively the tops of the rivers) not to be plotted. The MDSF provides a script that can correct this - if considered necessary.*
   - o Use **Theme** menu to save and rename the ***<flow accumulation>*** grid; then zoom in as necessary to locate the grid cell at the catchment outlet *(see 1.1 above)*.
   - o Click the **Define catchment** button and then the outlet grid cell. Select the **flow accumulation** and **flow direction** grids from pop-up menus, and when prompted, Save the ***<watershed grid>*** to a suitable file location and name (e.g. **<catchment>**). Make the derived grid active and use the **Theme** menu to rename **<catchment>**. *Note: <catchment area (cells)> is saved in each grid cell within the catchment grid (see legend).*

- Generate HOST grids at 50m, clipped to match **<catchment>** grid:
  - From Analysis menu select Properties and set Analysis extent and Analysis cell size to Same as <catchment>.
  - From **Analysis** menu select **Map calculator** and click on or type
  - <HOST grid 1> * <catchment> / *<catchment area (cells)>*
  - where the number **<catchment area (cells)>** was found in step 2.2d.
  - Use **Theme** menu to save and rename the *<map calculation>* grid to a suitable name (e.g. **<ClpHst01>**).
  - Repeat 2.3b & c for other HOST classes.

- Add **<landcover>** theme, clip to **<catchment>** and define **<degraded>** grid:
  - *First time:* from **View** menu select **Add theme** and browse to CEH UK land cover 2000 image file. Make image active and in **Theme** menu select **Convert to grid** and **Save** for future as **<landcover>**.
  - *Subsequent times:* from **View** menu **Add theme**, type **grid** called **<landcover>**.
  - To clip **<landcover>** to 50m grid over **<catchment>,** from **Analysis** menu use **Map calculator** and click and click on or type
  - <landcover> * <catchment> / *<catchment area (cells)>*.
  - Use **Theme** menu to save and rename the map calculation grid to a suitable name (e.g. **<ClpLand>**).
  - Make **<ClpLand>** active, and in **Analysis** menu select **Reclassify**. Select classification field **Value**, click **Unique,** and set all **New Values** to zero - except for 41, 42, 43, 51 & 52 which should be set to 1. Use **Theme** menu to save and rename grid **<degraded>**.
  - Note: <landcover> codes are described in FD2114/PR3, and shown below in Table 3.3. Only 'agriculture & horticulture' (codes 41,42,43) and 'improved grassland' (codes 51,52) are currently taken as degraded, with the same SPR changes for each. Thus a simple 0/1 classification of degrading is sufficient. Extra classes could be added in the future.

- Determine degraded proportions in each HOST class:
  - Make **<degraded>** grid active and from **Analysis** menu select **Summarise zones.** Select **<ClpHst01>** from pop-up menu of themes to summarise, and cancel the menu of statistics to chart *(no charts need be plotted)*;
  - Scroll across the displayed results window (**Stats of ClpHst01**) and enter on spreadsheet *(see 3.1a below)* the total cell **Count** in each zone (0=normal, 1=degraded), and the **Mean** percentage of HOST class 1 in each zone;
  - Repeat 2.5a & b for other HOST classes.

Class	LCM2000 land cover classes	MORECS Equivalent
1	Sea / estuary (221)	
2	Water (inland) (131)	
3	Littoral rock (201)	
4	Littoral sediment (211)	
5	Saltmarsh (212)	
6	Supra-littoral rock (181)	
7	Supra-littoral sediment (191)	
8	Bog (deep peat) (121)	Upland
9	Dense dwarf shrub heath (101)	Upland
10	Open dwarf shrub heath (102)	Upland
11	Montane habitats (151)	Upland
12	Broad leaf/mixed woodland(11)	DecWood
13	Coniferous woodland (21)	ConWood
14	Improved grassland (51)	Grass
15	Neutral grass (61)	Grass
16	Set aside grass (52)	Grass
17	Bracken (91)	Upland
18	Calcareous grass (71)	Grass
19	Acid grassland (81)	Grass
20	Fen, marsh, swamp (111)	Upland
21	Arable cereals (41)	Cereals
22	Arable horticulture (42)	Cereals
23	Arable non-rotational (43)	Cereals
24	Suburban/rural development(171)	Urb-bare
25	Continuous urban (172)	Urb-bare
26	Inland bare ground (161)	Urb-bare

Table 3.3   CEH 25m land cover classes (2000)

3. Spreadsheets: Note: simple instructions are included in spreadsheets; blank and example completed spreadsheets are supplied on a separate disk.

- Use SPRADJ.XLS to derive SPR estimate (see Table 3.1 above):
  - o Open SPRADJ; enter catchment name in cell F1 and enter total cell **Count** *(from step 2.5b)* for normal and degraded zones in cells G3 & I3.
  - o Enter zone **Means** *(from step 2.5b)* for HOST class in relevant row, cols G & I.
  - o Repeat 3.1b for each HOST class in catchment.
  - o Copy revised SPRH values for degraded area from col C or D into Col E; note resulting overall SPR estimate in cell I36.
  - o Repeat 3.1d for alternate values of SPRH.

- Use FEHSEN.XLS to estimate T-year floods for matrix of Tp and SPR (see Table 3.2 above):
  - Open FEHSEN; open 'csv' file exported from FEH-CDROM *(See 1.3 above)* and copy data from AREA to F(1km) into FEHSEN col B. Also enter catchment name and Map reference if required.
  - Noting the FEH 'catchment descriptor' estimate of Tp(0) in cell E4, adjust calculation timestep T in green cell E15 to approximately Tp(0)/5. The resulting 2-year flood estimate is given in buff cell E34. *Note: this estimate may be compared with the FEH QMED equation in buff cell E3.*
  - Noting again the FEH estimate of Tp(0) in cell E4, enter alternate Tp(0) values to test *(e.g. minus 1h, plus 1h)* in pink cells E5 & F5.
  - Noting FEH estimate of SPRHOST in cell B19, enter alternate SPR values to test *(see 3.1d above)* in pink cells E5 & F5.
  - Copy formulae from cells E8:E34 out to column M.
  - Select use of alternate Tp(0) and SPR values in each col by entering <blank>, 1 or 2 as appropriate in cream cells E8:M9.
  - Note down flood estimates in row 34 for evaluation using the FARM tool.
  - Enter other return period of flood estimate in green cells E14:M14 and note down new flood estimates in row 34. Repeat as required.

- The Floods and Agriculture Risk[1] Matrix
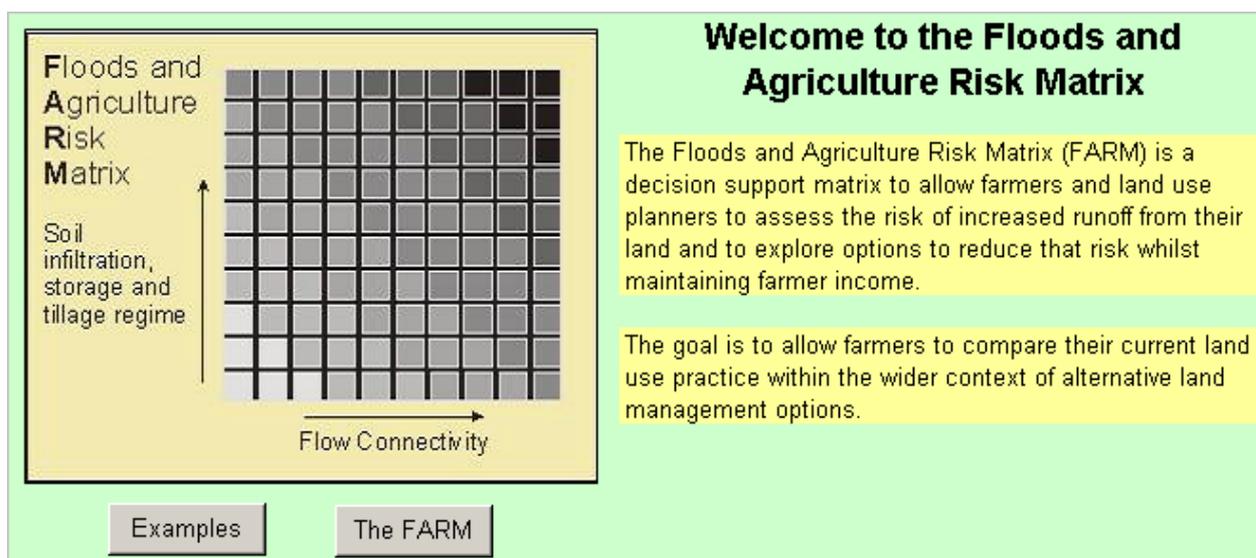 - Open the FARM tool spreadsheet. Figure 3.1 shows the opening welcome page.

Figure 3.1. Opening welcome page for the FARM tool

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[1] In the literature reported on here, the use of the term 'risk' is less precise than that defined in Section 2.5 of FD2114/TR: Impact Study Report, and follows the more colloquial usage of the term.

o   If this is the first time you have used the package you should use the 'Examples' button to get a conceptual overview of the background to the FARM tool concepts (Figure 3.2), including examples of the runoff and land use management scenarios. Use the hyperlinks on the matrix to see each example runoff management scenario, or use the 'Return to Welcome' button to go back to the front page.
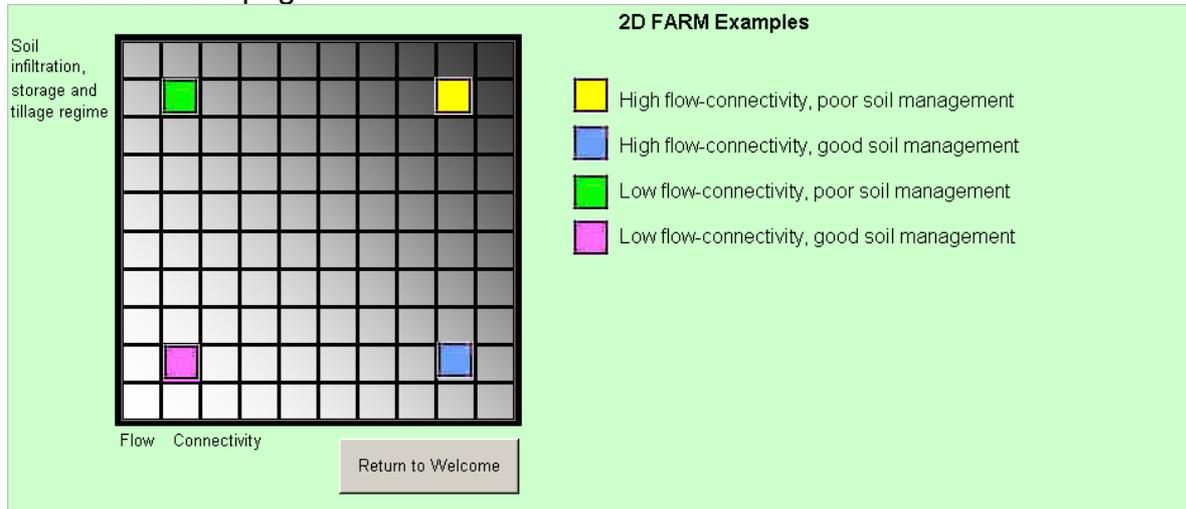

Figure 3.2   FARM tool matrix, showing positions in matrix corresponding to four different scenarios

o   You should select one of the scenarios, for example the 'High flow connectivity, poor soil management option', from the matrix and then Figure 3.3, will appear. You should look at each example scenario in turn and start to build an understanding of how they map onto the matrix relative to each other. Use the hyperlink button to either to 'Return to Examples' page or 'Return to Welcome' to see the front page again.
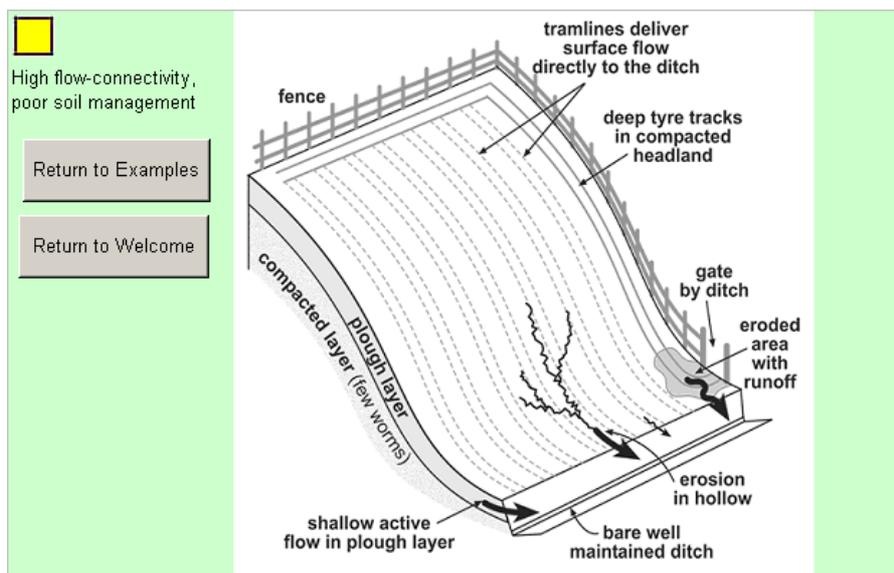

Figure 3.3   Hillslope features corresponding to poor soil management, high flow connectivity scenario

o   Press the 'Return to Welcome' option and then choose the 'FARM' button to start the question and answer session. The screen that appears can be seen in

Figure 3.4. This page refers to all questions and factors that impact upon soil infiltration, storage and tillage regime (i.e. the vertical axis). The content of each question can be seen by putting the mouse over each drop down menu. Roll the cursor over the option that most suits the farming practises seen in your catchment.

Figure 3.4   Question and answer menu for FARM tool: soil infiltration, storage and tillage regime

o   Note that the animated pixel is in the bottom left hand corner initially, corresponding to answers to the questions which result in the lowest runoff risk. As you start to answer the questions the pixel will move. Therefore you should answer **all** the questions in the FARM tool to get a final position in the matrix which reflects the risk of increased runoff.

o   Use the 'Next' hyperlink button to bring up all the questions relating to the flow connectivity management options (i.e. the horizontal axis). Figure 3.5 will then appear.

Figure 3.5   Question and answer menu for FARM tool: flow connectivity

o   Again, answer all the questions on this page to get a final position in the matrix.

o   The 'Next' hyperlink will move you back to the 'Soil storage' questions; please note that all the answers to the questions will be as they were before. The 'Return to Welcome' button allows you to return to the front page. If you enter the Farm Tool using the 'FARM' button again from the front page, the answers will not have reset, and will be the same as those entered in the last question and answer session. To reset the answers, either select the lowest risk option on each drop down menu or close the FARM tool completely and restart the exercise.

o   Please note that several extra hyperlink buttons provide some extra information relating to the questions, for example The 'Best Farming Practise' button and the 'Hillslope Form Illustrations' button.

o   Once the question and answer session is complete, the final position in the matrix will have been determined. You now have to use Figure 3.6, to decide the degree that you wish to alter the SPR value.

o   If you were studying HOST class 16 then the minimum SPR value is 29% and the maximum fully degraded value of SPR is 47%. If the plotting position was in Zone 3 of Figure 3.6, then the full value of 47% is needed. As you can see the in the SPRADJ.XLS sheet that the scenarios are already set up to run with this value.

o   If you were in Zone 1 of Figure 3.6, then the original SPR value of 29% is needed, once again you will see that the SPRADJ.XLS is already set up to run this value.

o   The SPRADJ.XLS in its default mode is set up for the original and the fully degraded values of the SPR term. However, the upper SPR value for each HOST class does not need to be set to the maximum in the SPRADJ.XLS tool. If you wish to only partially change/degrade the SPR value (i.e. your matrix

position is in Zone 2 of Figure 3.6) then an SPR value between the upper and lower limit is needed. If for example, you were using HOST class 16 and the nearest contour line gave a multiplication factor of 0.5 (that is, a 50% increase in SPR) then the final degraded SPR value in SPRADJ.XLS should be entered as 38% that is:-

(maximum SPR-minimum SPR)*0.5).

o   It is advisable that the user should become familiar with operation of these spreadsheet tools first. The FEH tool will now give simulations of the new degraded values against the original FEH values.
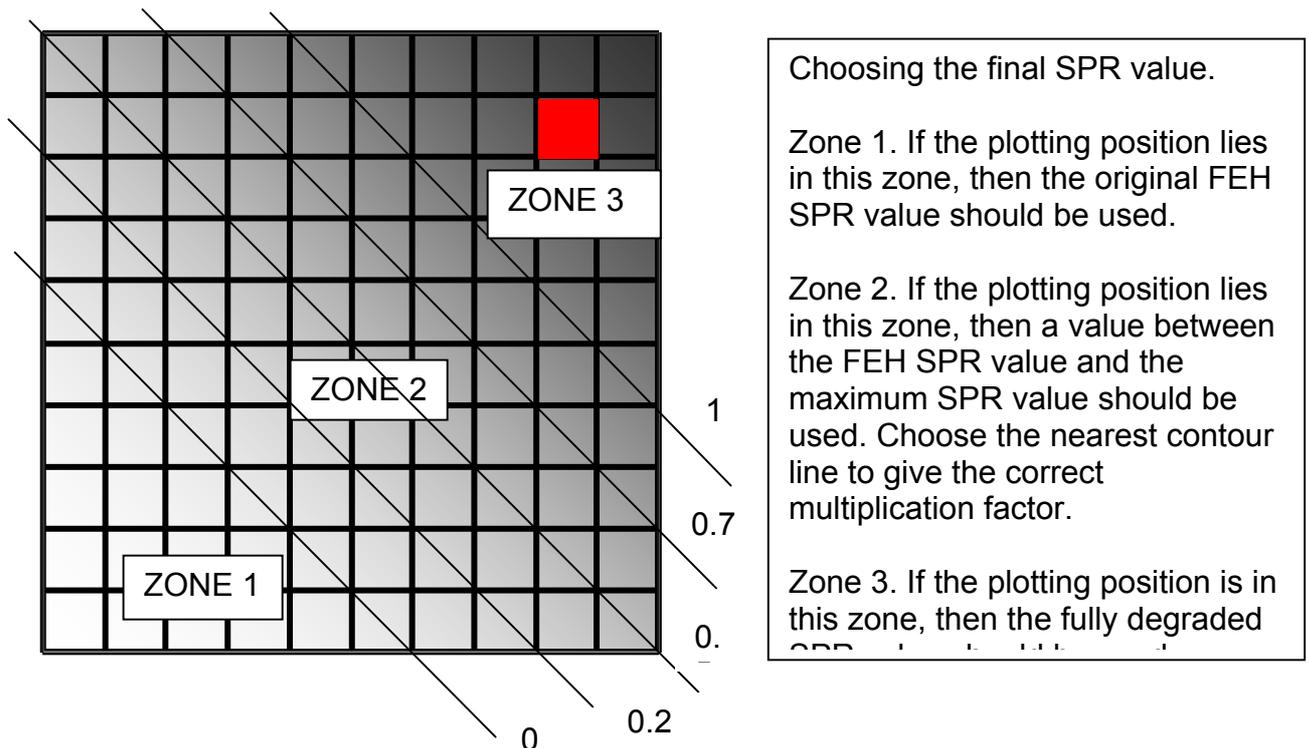

Choosing the final SPR value.

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 degraded

Figure 3.6   Zones for SPR, showing the gradation between Zone 1 (original SPR value) and Zone 3 (fully degraded SPR value)

o   Once the GIS analysis has been carried out, the user should be familiar with the realistic range of SPR values for their catchment. In this case, the user has the option to test the impact of SPR changes directly in the FEHCAL.XLS by altering the input SPR value in the appropriate cell. Again, familiarity with the spreadsheet tools should be built up first.
o   To save a session and close the FARM tool you can use the 'Save As' option of Excel. You are advised to use an appropriate name for the file created for each session (perhaps the catchment name or the HOST class name).

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