The Floods and Agriculture Risk Matrix (FARM): A decision support tool for effectively communicating flood risk from farmed landscapes.

M. E. Wilkinson[1,3], P. F. Quinn[1] and C.J.M. Hewett[2,4]

[1]School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK.
[2]Department of Geography, Durham University, Durham, DH13LE, UK
[3]The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK
[4]The Great Debate, Newcastle upon Tyne, UK.

Correspondence:
Mark Wilkinson, the James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK
Email: mark.wilkinson@hutton.ac.uk
Telephone: +44 (0)1224 395158

ABSTRACT

Intense farming plays a key role in high runoff rates. It is vital to communicate this risk to stakeholders and policy makers effectively. There is great potential for agriculture to become a major component in managing flood risk. It is proposed here that lower flood risk can be achieved by reducing runoff rates from farmed landscapes. Hence, tools to evaluate and communicate management options are needed alongside improved understanding of runoff generation from farming systems. The Floods and Agriculture Risk Matrix (FARM) is a decision support tool designed to assess the relative risk of flooding from farm land. The tool includes a series of pre-determined runoff scenarios to provide the end-user with a number of potential land management practices and flood runoff management options to reduce runoff rates. Visual scenarios are used to illustrate the impact of good and bad practice on runoff rates. The level of risk associated with particular land management options is represented by mapping a position on a Decision Support Matrix (DSM). Multiple questions allow the user to explore different management options and see the impact of decisions on the DSM. A nominal scoring system is used to rank higher or lower runoff risk. The end user can then assess numerous land use management options to lower the risk of rapid runoff. The objective is to encourage policy makers and farmers to produce resilient local landscapes.

Keywords: Flood risk, runoff, farming, decision support tool, land management,

1. Introduction

Large parts of Europe have been hit by major floods in recent decades. For instance, in 2010, there were many severe flood events in Europe: in Central Europe (Poland, Germany, Czech Republic, Slovakia, Hungary), Southern Europe (south of France, Greece, Italy, Albania, Serbia, Croatia, Montenegro, Bosnia and Herzegovina), Western Europe (Spain, Portugal, Belgium, UK), and Eastern Europe (Lithuania, Russia, Ukraine, Moldova, Romania, Bulgaria) (Kundzewicz 2012) and the costs of floods have exhibited a rapid increase (Barredo 2009). In the UK alone it is estimated that 1.8 million homes, 130,000 commercial properties and 14,000 km^2 of agricultural land (12% of the total) are at risk from flooding (Environment Agency 2007). The estimation of future flood risk is difficult due to a number of uncertainties (Hall and Solomatine 2008, Wilby and Keenan 2012). However, future climate scenarios point to substantial increases in flood risk (FORESIGHT 2004, Feyen *et al.* 2012). A major contributor to flooding in the UK is runoff from the rural environment. Agricultural land use management is known to have an influence on downstream flood risk in the UK (Burton *et al.* 2003, O'Connell *et al.* 2004, O'Connell *et al.* 2007, Wilby *et al.* 2008, Parrott *et al.* 2009, Wheater and Evans 2009, Hess *et al.* 2010, McIntyre and Marshall 2010). There is substantial evidence that modern land-use management practices have increased surface runoff at the local scale (O'Connell *et al.* 2007, Parrott *et al.* 2009, Hess *et al.* 2010). Land management practices that contribute to increased likelihood of floods include intensification of stocking, leading to soil degradation; installation of artificial drainage such as tile drains and ditches; removal of natural wetlands; and deforestation (Bronstert *et al.* 2002, Holman *et al.* 2003, O'Connell *et al.* 2004, Wheater *et al.* 2008, Marshall *et al.* 2009, Wheater and Evans 2009, McIntyre and Marshall 2010). Recent research suggests that there is great potential for agriculture to become part of the solution to flood risk management rather than being part of the problem (Kenyon *et al.* 2008). However, to date it appears as if few organisations and countries globally have developed frameworks and strategies to optimise integrated delivery at the catchment scale (Ormerod 2004, RRC 2005, Gilvear *et al.* 2012).

There is an urgent need for interventions to reduce the risk of flooding now. Interventions at the source of runoff generation can have a positive impact on the local flood hydrograph. An integrated approach to managing runoff can also have multiple benefits on pollution and ecology, leading to beneficial impacts at the catchment scale. A report (FD2114) produced by the UK Department for the Environment, Fisheries and Rural Affairs (Defra) on the impacts of rural and land use and management on flood generation highlighted two factors that make a major contribution to high runoff rates: the role of soil degradation and the loss of intrinsic storage capacity of the land (O'Connell *et al.* 2004). In addition, the loss of riparian areas and the management of land drainage and ditches contribute towards faster well-connected flow pathways. These findings gave rise to the thinking behind the Floods and Agriculture Risk Matrix (FARM) tool. One major aspect of the FARM tool is the promotion of farming methods that improve soil function and minimise the impacts of intense tillage regimes. The tool attempts to capture the state of the art in recent thinking about soil and crop management, promoting the use of codes of good practice and modern soil management protocols (Think Soils 2008).

The potential to return the landscape to a lower runoff regime through mitigation was also considered in the FD2114 Defra report (O'Connell *et al.* 2004). Work by Quinn *et al.* (2007, 2010) investigated the potential to manage flow pathways directly. These types of mitigation measures reduce the risk of runoff by disconnecting flow pathways, slowing ditch flow and storing runoff and are often referred to as Sustainable or Natural Flood Management (Werritty 2006, Scottish Environment LINK 2007, Howgate and Kenyon 2009, European Commission 2011, Parliamentary Office for Science and Technology 2011). There are other European examples on how mitigation measures can reduce the risk of runoff. Measures installed to prevent muddy floods in the Belgian loam belt region have been investigated by (Evrard *et al.* 2007). Here, mitigation measures have been installed in several catchments in the Flanders to tackle the problems of muddy floods. A similar case study was presented by Fiener et al. (2005) for a small catchment in Germany. The Adaptive Land Use for Flood Alleviation (ALFA) project provides many examples of runoff management mitigation measures (ALFA 2012). Similarly, Strand (2007) indicates how wetland creation in Sweden is being used to manage runoff from farm land.

This paper sets out the rationale behind the FARM tool, explaining how it evolved initially from the Defra FD2114 project (O'Connell *et al.* 2004, Packman *et al.* 2004), the Strategic Management of Non-point Source Pollution from Sewage Sludge (SEAL) project (Hewett *et al.* 2004) and was further developed in the Ripon Multi-Objective Project (Posthumus *et al.* 2008). The tool is presented in its current form as supported by the Environment Agency For England and Wales under the Making Space For Water initiative (Parrott 2008). An example application is taken from the Belford study site (Wilkinson *et al.* 2010a, Wilkinson *et al.* 2010b, Nicholson *et al.* 2012), showing both the FARM tool in operation and an example implementation of Runoff Attenuation Features (RAFs).

2. The Floods and Agriculture Risk Matrix: The FARM tool

The FARM tool approach is a new way of thinking about dealing with flood risk, uncertainty and nutrient export from complex multi-functional landscapes. Its development rests on the recognition of the need to communicate with stakeholders which is now embedded in government policy, for example in the UK policy document Making Space for Water (Defra 2005) and in the European Directive (2007/60/EC) on the Assessment and Management of Flood Risks. Hall and Solomatine (2008) draw attention to the need for new ways to convey risk and policy making, '*This places an increasing emphasis upon effective communication and mechanisms to reach consensus*.' The tools are designed to improve farmers', land managers' and catchment advisors' understanding of the risk of runoff from the field to hillslope scale.

The FARM tool is an example of a Decision Support Matrix (DSM). These may be considered as Decision Support Systems (DSS) under the broadest definition of the term (Power 1997). In the past, DSS have been defined as computer-based tools that assist managers with solving ill-structured problems (Morton 1971, Sprague and Carlson 1982, Loucks 1995, de Kok *et al.* 2009). However, recognising the poor uptake of DSS by farmers historically (see McCown (2002)), DSMs are designed to be simple tools intended for use by the non-expert (Hewett *et al.* 2009, Hewett *et al.* 2010). The DSM approach provides a set of tools designed to support policy and decision making. DSMs combine expert hydrological evidence with local knowledge of runoff patterns and are used both as decision support tools and as effective communication and education tools.

In the FARM tool, a ranking methodology is combined with a simple mapping of information onto a visual matrix. Despite the residual uncertainty in the methods used, the FARM tool can contribute to policy makers having greater confidence in making decisions to make landscapes more resilient (Ben-Haim 2006). One key element of the FARM tool is that it describes extremes of land use management within a hydrological and agricultural land-management context. A variety of conceptual models gives the user a number of ways to visualise the effects of different land management practices. These visualisations provide examples of good and bad practice along with suggestions for improving practice. Stakeholders can use exercises on the website and within software tools to examine the risk associated with varying land management. Even though soil type is important to runoff rates and there may be more than one soil type in a field, a simplifying assumption is made that the soil is locally homogeneous. Therefore it was decided to represent the problem on two axes: soil management and flow connectivity (Figure 1).

[FIGURE 1]

Figure 1: The FARM - the lowest risk of runoff corresponds to the lower left corner of the matrix and the highest risk in the top right corner.

The axes capture the underlying factors that control runoff: the abscissa, or 'horizontal' axis, is flow connectivity and relates to runoff once it has been mobilised and how efficiently it flows into and through the local drainage network; and the ordinate, or 'vertical' axis, is soil storage as affected by land management, and includes soil infiltration, storage and the tillage regime. The risk associated with runoff generation due to land management practices is represented by a position plotted on the matrix. In Figure 1, the risk levels run from bottom left (lightest grey – lowest risk) to top right (black – highest risk) of the matrix. Connectivity reflects the likely speed of runoff (for example fast overland flow in tramlines). Here the FARM tool highlights any features that can slow down or store runoff (such as ponds or wetlands).

Conceptual models of good and bad farming practice provide the user with visualisations of the features and practices that increase or decrease the risk of flood generation. Figure 2 shows four example arable land management scenarios and how these would map onto the matrix in Figure 3. The chosen idealised hillslope scenarios are intended to reflect typical UK farming practices and how they relate to hillslope hydrology. These practices are similar in many European countries and so the scenarios should look familiar to farmers and land managers across Europe. By depicting the same hillslope with four alternative runoff risks, the influences of land management practices on runoff are communicated. Moreover the scenarios illustrate how runoff management can lower the risk of rapid runoff from farms. The scenarios shown in Figure 2 reflect the Defra Project Consortium's hydrological and agricultural experience and, although highly idealised, highlight the factors that both increase and decrease runoff at source (O'Connell *et al*. 2004). The diagrams help to build up a conceptual understanding of how hydrological flow paths propagate across the land and within ditches.

[FIGURE 2]

Figure 2: Four hillslope runoff risk scenarios for the same land unit.

[FIGURE 3]

Figure 3: The four scenarios shown in Figure 3 mapped onto the DSM.

Engaging with these examples (Figure 2 and 3), especially in a workshop environment, helps users to understand the concepts behind the tool and identify some risks before beginning to answer specific questions about their own practice.

O'Connell et al. (2004) used the FARM tool to alert flood risk managers to the potential impacts soil degradation due to agriculture on runoff. Packman *et al.* (2004), established a modelling exercise that would reflect increases in runoff by increasing the SPR (Standard Percentage Runoff) value for each of the HOST (Hydrology Of Soil Types) classifications used in UK studies. Equally, the time to peak (Tp) of intensively farmed catchments was also thought to change as any runoff generated would reach the receiving channels quicker. Thus, estimates for the change in Tp were included in the modelling study. Essentially the runoff generation and the flow connectivity were being changed, which matches the two axes of the matrix. The FARM tool was therefore interpreted as the criteria for addressing changes in SPR and Tp which, when fed into a model, could simulate the peak runoff (Qp). Tests were carried out in a number of catchments, using a HOST classification map, a land cover map (LCM, 2000) and the FARM tool. Together this information was fed into the MDSF (Modelling Decision Support Framework), a catchment modelling toolkit being used in Catchment Flood Management Plans for the UK (Defra 2005). The results of this study are shown for one example catchment for the River Bourne, England (50 km^2), that had a good mix of HOST classes and land uses (Holman *et al.* 2003). Vulnerable HOST classes, where intense agriculture was taking place, would score a high runoff risk on the FARM tool and therefore alterations of between 10-40% in SPR were made (Packman *et al.* 2004). The MDSF was then run for a series of return interval events. The resulting SPR changes and the Tp scenarios are shown in Table 1.

Table 1: Impact of increased Standard Percentage Runoff generation and the change in time to peak for the Bourne catchment (Packman et al. 2004)

[TABLE 1]

The results in Table 1, show several key points: degradation in SPR increases Qp; degradation in SPR combined with a smaller Tp compounds the effect on Qp significantly; the potential to counteract SPR effects and the potential for improved management of Tp through runoff attenuation, could reduce Qp. The change in Qp from the worst to the best case management scenario is 45.5% and 44.5% change in Qp for a return interval events of 25 years and 100 years respectively. This illustrates how the FARM tool can be combined with other modelling frameworks to help show the impacts of land use management on flooding at the catchment scale. Similar research by Hess *et al.* (2010) used the USDA Curve Number (USDA 2004) method to approximate runoff rates under degraded conditions and showed a similar range of impacts, though they suggest the impact on Qp would decrease with increased return interval.

The FARM tool suite includes an interactive Microsoft Excel-based toolkit containing questions associated with each axis. A series of well-focussed questions and answers allows the relative risk of different farming activities to be ranked from high to low. The choice of platform for implementing the interactive element of the FARM tool was driven by the fact that most stakeholders are familiar with, and have access to Excel. The interactive FARM tool allows the user to answer the questions according to the current or proposed management of a particular field or farm and generates a visual plot of the risk level on the matrix. The final position plotted on the matrix depends on the answers to all of the questions.

If the user ends up with a high risk on either axis of the matrix then changes in practice that could reduce this risk can be considered. By opting for different management strategies (e.g. use cover crops to improve soil structure or install hedgerows to reduce connectivity) the risk of flood generating runoff can be reduced. Thus different scenarios can be tested by answering the questions in different ways, enabling the user to compare the levels of risk associated with particular practices, and to establish ways of improving on current practice.

Given current common agricultural practices the likelihood of ending up with a high-risk plot is high. It is only when good farming practice and runoff management are clearly evident, that a lower risk plot is obtained. This points the user towards options that could lower the risk of rapid runoff. It is a means of making the user consider what improvements could be made.

It should be noted that the FARM tool gives a relative rather than an absolute result. What is important is whether a change in land-use increases or decreases the risk, not the absolute level of risk. The principal message is that if you are farming there are ways of reducing flood risk. Thus the scale on the matrix is a simple scoring system in which all questions are given equal weighting. While it is possible to weight questions differently, discussions with researchers and stakeholders made it clear that agreeing on those weights would be a long and drawn out (possibly never-ending) process. Similarly, while models and experiments hold the promise of quantifying the improvements associated with changes in practice, the datagathering and modelling of the range of practices at various scales required is a long term project. Keeping the model simple makes it possible to generate tools that can be used now. The aim is to encourage good farming practice that still allows intense profitable farming to occur over most of the land while a few carefully designed Runoff Attenuation Features (RAFs) such as ponds, buffers and wetlands reduce the risk of flooding both on the farm and downstream.

The FARM tool presented here is free and simple to use. The tool can be downloaded from the FARM tool website (http://research.ncl.ac.uk/thefarm/; accessed February 2013). The types of question used in the FARM tool were first trialled during the SEAL project, working closely with farmers and policy makers (Hewett *et al*. 2004), and further developed in consultation with stakeholders in the Ripon Multi-Objective Project (Posthumus *et al*. 2008). The tool was then further developed after a report by the Environment Agency for England and Wales suggested that there would be value gained from more widespread usage of the FARM tool (Parrott 2008). This resulted in a six month contract with the Environment Agency in which a new FARM tool website was developed along with a consultation period with the Environment Agency, Natural England and landowners. In a survey of 11 Environment Agency and Natural England officers, 86% found the FARM tool website to be useful and the tool easy to use. The FARM tool is now supported by the Environment Agency for England and Wales and is available as an advisory tool on the Environment Agency website (Environment Agency 2010).

There are two versions of the tool: Arable FARM and Animal FARM for arable and livestock farming respectively. The questions and examples in the interactive tools incorporate feedback from experts such as hydrologists, farmers and agronomists and are backed up by experimental data and modelling at different scales. The initial set of questions arose from the conclusions of Defra Report FD2114, in particular Appendix C (Harris *et al.* 2004), where many detailed technical, agricultural and hydrological issue are reviewed. Table 2 presents an early example of an attempt to rank or prioritise runoff risk using a qualitative, nominal scale. It is based on more detailed analysis and reflects a consensus of scientific opinion (Harris *et al.* 2004).

Table 2: Relative erosion / runoff risk (Harris et al. 2004).

[TABLE 2]

The importance of direct storage retention was also highlighted in FD2114, Appendix C (Harris *et al.* 2004), '*Flow retardation is probably the most useful in agricultural situations, as it has the following benefits:*

- *All visible evidence or danger of the flood is removed*
- *The flow in the stream is more uniform, thus providing greater recharge of the groundwater and a more adequate water supply*
- *An important step toward the conservation of natural resources is achieved*
- *Higher crop production results [irrigation]*
  A reduction in sedimentation in lower tributaries is accomplished'

A complete set of questions for the interactive element of Arable FARM is given below.

2.1. Arable FARM

Currently there is a concern about the sustainability of conventional land-use practices on arable land throughout the world (Stoate *et al.* 2009, Furlan *et al.* 2012). The Arable FARM tool is designed for users who manage arable crop fields who wish to explore the risk of runoff from their fields and sustainable runoff management options. Figure 2 shows the conceptual models used in the tool. The questions which determine the risk in the interactive tool are tailored to the farming system. The first set of questions relates to soil infiltration, storage and tillage regime (Table 2), which corresponds to the vertical axis (ordinate) of the matrix. The second set relates to the flow connectivity regime (Table 4) which corresponds to the horizontal axis (abscissa) as shown in Figure 1. The position on the matrix of the highlighted, animated pixel (the risk marker) depends on the answers to the questions.
The use of the Arable FARM tool is broken up into three stages (Figure 4):

1) Answer the first two sets of questions (Tables 3 and 4: one for each axis) – this results in an initial plot on the matrix which usually corresponds to current practice (Figure 4; matrix above menu 1).
2) Menu 1: Users can either change their answers to see what the results would be of a new management strategy or proceed straight to runoff management options (Table 5). A new scenario may help to reduce the risk level on both axes. Runoff management options only help to disconnect flow pathways and thus only influence the connectivity axis.

3) If the user re-answers the questions for a new land management scenario then they are presented with Menu 2. On this menu they can apply runoff management options (Table 5) to either the current management plan or the new scenario they have developed (Figure 4). The user can then experiment and answer the questions multiple times to see how different answers change the level of risk of rapid runoff.

[FIGURE 4]

Figure 4: A schematic flow diagram for using the FARM tool. The first stage is to answer the two sets of questions, the second stage is to either re-answer the questions (dashed loop arrow) or apply runoff management measures and the third stage is to apply measures to the initial or adjusted answers to the questions.

Table 3: Questions related to soil infiltration, storage and tillage regime (corresponding to the vertical axis).

[TABLE 3]

Table 4: Questions related to flow connectivity (corresponding to the horizontal axis).

[TABLE 4]

[FIGURE 5]

Figure 5: Supporting diagram providing visualisation of the different hillslope forms referred to in Question 8 (Table 4).

The answers to the questions are ranked from highest risk to lowest risk and this is used to calculate the plot position on the matrix. The form of the questions has been adapted based on feedback from stakeholder consultation. For example, in Table 4, question 8, stakeholders suggested that the descriptions of 'hillslope form' needed further explanation or visualisation; hence a supporting diagram was created (see Figure 5). On the flow connectivity (horizontal) axis the impact of certain land use management changes on runoff propagation have been ranked and the impact of features that disconnect the flow are captured. In the case of flow connectivity management options the risk marker can move left along the horizontal axis (representing a decrease in risk) once runoff management measures have been introduced (Table 5).

Table 5: Questions for the implementation of runoff management measures to reduce the risk of rapid runoff by altering flow connectivity (Wilkinson et al. 2010a)

[TABLE 5]

2.2. Animal FARM

Animal FARM is designed for users who farm livestock and grow feed crops. The activities which determine the risk are related to stocking of fields and the choice of feed crops.
As with Arable FARM, there is an interactive tool which enables the user to answers questions about current or potential future farming practice and obtain a plot of risk level on the matrix. The questions in the interactive Animal FARM tool are similar to those in Arable FARM but are tailored to livestock and feed crop scenarios. Thus questions on soil compaction, degradation, soil management practices and ground cover are based on livestock farming. Table 6 lists only those questions in Animal FARM which differ from those in Arable FARM, including questions on feed crops and stocking densities. Use of the interactive Animal FARM tool is divided into three stages which are identical to those of the Arable FARM (see Figure 4).

Table 6: Animal FARM questions which differ from those in Arable FARM.

[TABLE 6]

Animal FARM was developed and trialled with farmers in the Laver and Skell catchments as part of the Ripon Multi-Objective Project (Posthumus *et al*., 2008). When using the FARM tool in a workshop setting, dialogue is first established to elicit the participants' hydrological expertise and local knowledge of runoff patterns. Illustrations of example fields such as those in Figures 6, 7, and 8 are presented and participants are asked to plot the level of risk for each field onto the matrix. Although a lot of discussion ensues, nearly all the stakeholders eventually agree what constitutes high and low runoff risk and agree on the viability of particular management options to lower the flood risk.

[FIGURE 6]

Figure 6: A high risk runoff scenario and the plotting position on the matrix.

[FIGURE 7]

Figure 7: A medium risk of runoff generation scenario with a runoff attenuation feature.

[FIGURE 8]

Figure 8: A second medium risk land management option with good soil management.

Discussion of Figure 6 invariably gives rise to a high risk plot on both axes; helping to establish some consensus early on in the engagement process. Figure 7 shows a field with a high runoff soil with some runoff management, using a bund to create a runoff pond. Such a field has a low risk related to flow connectivity but high risk due to poor infiltration and storage. Thus the risk plot on the matrix agreed by the participants should be somewhere in the top left corner of the DSM, i.e. in the region of the square marked in white on the matrix in Figure 7. This example shows the benefit of temporary storage but equally shows that the pond can be filled and bypassed in larger events meaning that there is still a medium risk of rapid runoff contributing to flooding downstream. Figure 8 shows that simple adherence to good farming practice with respect to soil and livestock does not automatically generate a low runoff risk. High infiltration soils and saturated zones in riparian areas can give a rapid and high runoff response. Only a combined good farming practice and low connectivity scenario such as that shown in Figure 9 will provide a low risk of rapid runoff.

Following the discussion of medium and high risk scenarios, participants are encouraged to think about possible future management options for livestock systems and the possible funding mechanisms to address current problems. Farmers are often willing to allow these types of flood management schemes to proceed and will actively help to install them, provided they are cost neutral to them. In the case of the Ripon Multi-Objective Project the plan shown in Figure 9 was endorsed by the farmers and principal funding stakeholders (Posthumus *et al*., 2008). It was also suggested that other fields in the catchment were used as wet meadows which could have large flood-storage potential.

[FIGURE 9]

Figure 9: A possible future land use scenario to reduce runoff and pollution.

There has been input from many stakeholders in the development and evolution of Animal FARM. In the early stages of development there was input from farmers in the Laver-Skell catchment, Yorkshire, UK obtained during semi-structured interviews held in late 2005 (Posthumus *et al*., 2008). Following the Defra Making Space for Water report 2008, the Environment Agency (2008a) recommended "*Promotion of advice tools such as the FARM (Flood and Agricultural Risk Matrix) through advisory initiatives such as ECSFDI (Ecological Catchment Sensitive Farming Development Initiative).*" Following this, the Environment Agency suggested that the tool could be more widely used and further development of FARM tools took place (Environment Agency, 2008a). Testing with farmers and land managers in the upper Eden catchment led to the refinement of some parts of the tool, such as the ability to re-answer questions on menu 2 (Figure 4) and a reset button. Livestock farmers in the Eden catchment, Cumbria preferred the conceptual models shown in Figures 6 to 9 to photographs as they do not show real examples of bad farming practice and thus could not be used against farmers. More recently the Animal FARM tool has been used in the Morland catchment, Cumbria, UK as part of the UK NERC funded Environmental Virtual Observatory pilot project (Environmental Virtual Observatory 2012, Mackay *et al.* 2012) and the Defra funded Demonstration Test Catchment project (Demonstrating Test Catchments 2012, Owen *et al.* 2012). Here, the Animal FARM conceptual models were used in stakeholder workshops to convey how some farming practices could increase the risk of rapid upstream runoff and how introducing features in the landscape can reduce that risk (Wilkinson *et al.* 2013). In the EVO pilot local landscape learning tool (Wilkinson et al., 2013), the impact of these changes were estimated by means of a web-based flood impact toolkit using TOPMODEL. This pilot study indicated the potenital of using cloud technologies to bring together environmental data, models, decission support tools and visualisation techinques in one place (Environmental Virtual Observatory 2012), although the predictions of impacts still need to be refined. As identified, the Animal FARM tool has been used as an educational tool to highlight and draw attention to the links between livestock farming and runoff generation where there are few or no case studies to demonstrate the effectiveness of interventions. Animal FARM is currently being used in the Demonstration Test Catchments project and monitored runoff management measures in the Eden catchment are soon to be installed (Owen *et al.* 2012).

3 Case Study

The village of Belford, situated in the Belford Burn catchment (6km^2), northern England, has suffered from numerous flood events. There was a desire by the Local Environment Agency Flood Levy team to deliver an alternative catchment-based solution to the problem. It was thought unlikely that radical changes to farm practices and cultivation were likely. Hence a variety of Runoff Attenuation Features (RAFs) have been implemented throughout the catchment to address both of the fast runoff issues (Wilkinson *et al.* 2010b, Nicholson *et al.* 2012). The RAF measures include low cost bunds disconnecting flow pathways, diversion structures in ditches to spill and store high flows, ‘Beaver dams’ placed within the channel, and riparian zone management. The Arable FARM tool was applied, with the farmer, to a small 18 hectare agricultural sub-catchment of the Belford Burn catchment before and after runoff management measures were installed (Figure 10). The lower catchment is dominated by three arable fields, two of which drain via land drains into an open ditch. The east of the catchment is mainly woodland which covers a rocky outcrop and rock scree. The catchment is steep, the land management is intensive and the soils are relatively degraded. The Dunkeswick soil series (typically stagnogley soils with a fine loamy topsoil and clayey subsurface horizons) covers the catchment study area (Soil Survey of England and Wales 1983). This type of soil is prone to waterlogging in winter and local farmers have commented on runoff occurring during heavy rainfall events (Wilkinson *et al.* 2010b). There is good underground field drainage which exports flow into a main farm ditch (Figure 10). The three fields are in a rotation, switching between arable crops and grassland. At the time the Arable FARM tool was applied to this sub-catchment the three fields were planted with winter wheat. The location of the white square in Figure 10 shows the high risk of runoff for all three fields before runoff management measures were considered.

[FIGURE 10]

Figure 10: FARM tool outputs for the Chapel Crag catchment before (white square on matrix) and after (red square on matrix) the introduction of Runoff Attenuation Features (RAFs) and improved soil management.

Figure 10 indicates that the risk of rapid runoff in all three of these fields is high. This was to be expected as these fields generate a large amount of surface runoff which has been observed during storms. The high risk was attributed primarily to the intense cropping, little land cover over winter and steep topography of these fields. The interactive Arable FARM questions were re-answered in order to simulate an alternative runoff scenario. In the middle field, the farmer was rotating the crop type to grassland. This meant that bare exposed soil over winter was no longer likely. Figure 10 (Middle field matrix, red square) indicates that the risk on both axis decreased owing to the rotation to grassland. The other fields remained in winter wheat. Hence, three Runoff Attenuation Features were suggested to the farmer to help disconnect the major overland and ditch flow pathways:

- RAF A – A soil bund which disconnects a major overland flow pathway, ponding runoff during storm events.

- RAF B – A bund similar to RAF A, but larger, situated in the corner of the field before the land drains empty into an open channel.
- RAF C – A flood storage pond/wetland beside the ditch which acts as a wetland during low flows with extra storage capacity during high flows.

Out of these features the farmer was willing to install RAFs A and C but not B as RAF B would block a major gateway in the corner of the field. The results of this exercise are plotted in Figure 10 (red square on top and bottom field matrix). The implementation of runoff management measures disconnects major overland flow pathways in the top and bottom fields resulting in a reduction of risk on the flow connectivity axis as shown in Figure 10.

It was calculated that it would be possible to create RAF A (a large pond and sediment trap) by building a 1 metre bund at the base of the field. RAF C was also constructed at the same time but in this case the ditch was widened and deepened in a small woodland area. RAF A has a capacity to hold 490m^3 of runoff (maximum depth of 1 metre). Qualitative data illustrated by the photograph at the bottom of Figure 10 shows that this pond is actively disconnecting the flow pathway during intense storms. Quantitative data from RAF A indicates this RAF is functioning as planned (Figure 11). Figure 11 shows how RAF A performed during a series of short convective rainfall events. The first event was the most intense: 27mm rainfall was recorded in 1.5 hours. This resulted in rapid runoff generation and within 2 hours the pond had reached a peak level of 51cm. The pond bund is 1m high so it had filled to half its depth at this point, though not half its volume. During this first peak (Figure 11), the maximum volume of water stored in the pond was 110m^3. RAF A can store a maximum of 490m^3, which for a catchment of 0.12 km^2 represents a total surface runoff of 4.1mm. A further slowing/attenuation of the flow will also be occurring; hence, a 'transient' storage effect will also be in operation (see Wilkinson *et al.* (2010b)). RAF A is designed to drain quickly through an outlet pipe and a sub-surface drain to allow for further storage in later events. During this first event the pond drained from its peak to empty in 10 hours. Again, RAF A performed well storing subsequent storms on the 9th and 11th July 2012 (Figure 11). These two storms were smaller, but owing to the saturation of the soil in the previous event, these small storms resulted in 10.5m^3 and 51m^3 of surface runoff being stored in the RAF respectively.

[FIGURE 11]

Figure 11: A series of convective storm events and water level response in RAF A from the 6th to 12th July 2012

[FIGURE 12]

Figure 12: A single convective storm event and water level response in RAF A on the 28th June 2012.

Figure 12 shows the rainfall and depth of water in RAF A for a single convective event which occurred on 28th June 2012, nine days prior to the first event discussed above. The conditions for this event were similar to those of the first event of 9th July: in this case 26.4mm of rainfall fell in two hours. This resulted in rapid filling of RAF A which peaked at a level of 53cm. As with the first 9th July event the RAF went from full to empty in 10 hours. The rainfall return period of these two convective events was calculated using the FEH rainfall frequency software (Institute of Hydrology, 1999) and found to be 5 years (using a 6 hour maximum rainfall period), highlighting the severity of rainfall recorded for these events with such a short period of time between them. The depths given are the maximum levels recorded in the pond using a pressure transducer. The level sensor was installed in late 2010 as a direct response to the largest recorded storm in Belford, the 30th March 2010 event in which 62.4mm of rainfall was recorded in just over a day (large scale synoptic event). The rainfall return period for this event is 12.5 years (calculated using 24 hour maximum rainfall period). No RAF data was collected during this event. However, visual evidence indicated that the RAF was at full capacity around the time of the peak stream level in Belford. This indicates that RAF A works for storms with return periods of up to 12.5 years (for synoptic scale events) and is effective for convective storm return periods of about 5 years (half capacity), i.e the RAF works effectively for events of a small to medium storm return period. However, visual evidence suggests the pond was full for events with a high return period. It is worth noting also that the accumulation of sediment within RAF A will reduce the capacity for further surface runoff. This could slightly reduce the storage estimates of the later events highlighted in Figure 11. (Palmer 2012) estimated that 0.99 tonnes of sediment were retained in RAF A during an event on 11th January 2011, the equivalent of 91 kg ha^{-1}. This is evidence that the feature is working to retain sediment. In this case the dominant fractions were clay/silt and fine-sand (Barber and Quinn 2012). In between the events of January 2011 and June 2012 the sediment stored in the pond was removed and re-ploughed back into the field. In recent years RAF C has been optimised for both runoff storage and water quality (Barber and Quinn 2012).

For the top and bottom field there is little or no opportunity to greatly improve the soil conditions and thus the addition of more RAFs to the system may be the only option to further decrease the risks associated with rapid runoff. All fields are in crop rotation so it is likely at some point that all fields will change to grassland for a period which will result in a risk reduction on both axes. The middle field will go back to crop at some point in the future, so it is wise to consider runoff management for this change. After seeing RAF A and C as a success, the farmer is now willing to build RAF B in the near future. The FARM tool approach was helpful in persuading both the landowners and the local villagers about the benefits of rural land-management for reducing flood risk. This site has now been visited by over 200 scientists, policy makers and local stakeholders. The role of the FARM tool in encouraging land use and management change has been high.

4 Conclusions

The ability of certain farming practices to cause high volumes of rapid runoff and hence contribute to downstream flooding is a serious matter. The evidence from localised muddy floods reveals the intrinsic problem of high runoff from farmland. There is large potential to control runoff at source on farms and thus the potential to lower local flood risk by managing farms is great. The FARM tool presented here is designed to capture and communicate the understanding of the surface runoff generation problems and show how runoff can be controlled at source. It facilitates the recognition of problems by both policy-makers and farming communities and encourages them to take steps to reduce high runoff risk. The use of a 2D matrix to commutate the risk of runoff from farming has proved an efficient way to communicate the nature of flood risk and catchment management options to a wide range of users. The ability to show a spectrum of land use change scenarios and measures and summarise the relative impact local flow rates has not been disputed in trials and the tool has contributed towards the successful uptake of sustainable flood risk management measures which have multiple benefits in flooding projects. Generally, the FARM tool has proven a beneficial step in setting the surface runoff generation problem and providing solutions for land management projects. The tool is relevant to diverse groups including those who give advice to farmers as well as those who carry out detailed modelling analysis. It has been deployed for a range of applications, such as during training days, farmer meetings and public meetings. The 2D matrix and the discussion of the scenario diagrams are the key components of the FARM tool that are required to raise awareness and stimulate the debate on farming and flooding. For more comprehensive applications and training days the use of the full FARM tool is more beneficial.

The FARM tool and the potential impacts of the 'extremes' of land use management on the percentage runoff (SPR), peak flow (Qp), and time of peak (Tp) of flood events have been captured in modelling exercises such as the MDSF and the EVO project. Even though it is difficult to validate the outcome of models used in these projects, it is thought that large shifts in Qp and Tp are likely if the appropriate runoff management and farming practices are applied. Hence, the role of the FARM tool could be viewed as part of broader set of tools in communicating flood risk from farming. The tool is an efficient way of communicating hydrological, agricultural and flood risk management options in a simple and integrated way. It is noted though that some risk of rapid and or high runoff will inevitably remain under certain intensive profitable farming conditions (such as bare soil with young crops). In the Belford case study the FARM tool has successfully supported the introduction of Runoff Attenuation Features (RAFs) to actively slow and store runoff. Using the Animal FARM tool with a farmer in Belford ultimately led to the construction of two RAFs in a small sub-catchment. Data from RAF A have proved its local effectiveness, by demonstrating its ability to easily attenuate a 1 in 5 year convective storm. However, capturing the runoff associated with a 1 in 12.5 year synoptic scale event is beyond the limitations of this particular feature. Its efficiency could be improved by increasing the bund height or creating a second bund further up the field. By slowing, storing and filtering runoff, RAFs not only reduce flood risk at the local scale but provide multiple other benefits. In Belford, RAFs designed for managing flood risk at source, have been also used to reduce diffuse pollution (Barber and Quinn 2012) and improve habitat (Lewis *et al.* 2011). In addition, some RAFs (including RAF A) are currently accumulating a lot of sediment (Palmer 2012). This has the benefit of improving water quality, but has the downside that it decreases the RAF's storage volume. The potential for the farmers to remove captured sediment from RAFs and re-apply this back to the fields (as it is usually rich in nutrients) is also being tested at Belford.

The FARM tool can be used as the early stage, front-line engagement tool for communities, policy makers and regulators, in aid of encouraging contribution to lower flood risk. Farmers involved in the test projects at Belford and Morland have stated they are willing to take part in schemes as long as activities are cost neutral to them (see farmer interview video - (Newcastle University/Environment Agency 2011). As of January 2013, over 40 RAFs have been installed in the Belford catchment. The Belford study may reflect the preference of farmers for a direct catchment based solution involving the management of flow connectivity rather than altering the soil management and tillage regime. A Defra commissioned report (Frontier Economics 2013) identified the need to undertake wider stakeholder engagement (including activities at the community level) to raise awareness of natural flood management measures and enhance acceptance where appropriate. The current Environment Agency's uptake of the FARM tool supports the approach. Since the FARM tool website was launched in March 2008 there have been 2300 unique first time visitors worldwide to the home page (as of February 2013). The prospective to reduce runoff through good farming practices and the ability to convince farmers of the benefits of attenuating and storing additional flow have been higher than many practitioners would expect. The potential for the rural community to grasp and help solve water quantity and quality problems has not been fully exploited. The interactive and informative FARM tool is freely available and is a useful addition to those contributing to the concept of holistic catchment management.

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Table 1: Impact of increased runoff generation and the change in time to peak for the Bourne catchment (Packman et al. 2004)

Bourne catchment 50.2 km^2	Return interval	QP (m^3/s)	QP (m^3/s) with Tp - 1 hour	QP (m^3/s) with TP + 1 hour
Original SPR=29.6	25 year	27.93	31.24	***25.38***
Degraded SPR=35.2	25 years	32.89	***36.87***	30.05
Original SPR=29.6	100 years	41.34	46.59	***37.61***
Degraded SPR=35.2	100 years	48.15	***54.38***	43.72

Table 2: Relative erosion / runoff risk (Harris et al. 2004).

Least Risk	Forestry / Woodland
	Permanent Pasture
	Spring Cereals
	Autumn Cereals
	Short Term Grass Ley
Greatest Risk	Sugarbeet / Potatoes / Horticultural Crops

Table 3: Questions on the vertical axis – soil infiltration, storage and tillage regime.

Score	***Q1 Soil Exposure***	***Q2 Slope of field***	***Q3 Soil degradation***	***Q4 Crop and Tillage regime***	***Q5 Soil Management Practices***
3	bare soil	very steep	degraded, compacted & prone to capping	tilled soil, ridges and furrows	Poor soil management
2	bare soil over winter	steep	Some degradation/compaction but prone to capping	tilled soil not following best farming practice	no BFP or soil management
2	slow growing crop over winter	quite steep	moderately degraded soil	tilled soil following best farming practice	some BFP methods adopted
1	bare soil in spring	moderate slope	evidence of degradation & compaction	tilled soil with local flow interceptors or grassland strips	full adherence to BFP
½	winter crop cover	shallow slope	good soil structure & high infiltration	direct drilling and good crop cover	full adherence to BFP & extra evidence of runoff/infiltration management
0	no soil exposure	flat	excellent soil structure & high infiltration	no cultivation	no more tillage of soil

Table 4: Questions on the horizontal axis – flow connectivity.

Score	Question 6: Crop cover	Question 7: Land drains and ditches	Question 8: Hillslope form	Question 9: Tramlines	Question 10: Tyre tracks, roads and trafficking
3	bare soil September – February e.g. winter wheat	100% land drains and a well maintained ditch network designed to remove runoff quickly	very steep slope with no toeslope, tramlines/ridges and furrows in steepest slope	dense tramlines in direction of slope connected directly to ditches	high density with clear evidence of surface flow reaching the ditch and intense trafficking in poor/wet conditions
2	a small amount of crop cover	50% land drains and a well maintained ditch network designed to remove runoff quickly	steep slope, no toeslope, sensible cultivation direction	dense tramlines in direction of slope partially connected to ditches	medium to high density with evidence of surface flow and intense trafficking avoiding wet conditions
2	stubble or fast growing cover crop	some land drains and evidence of ditch maintenance	moderate/steep slope with a small ~2m toeslope	dense tramlines in direction of slope but long distance from ditches	medium density but with evidence of surface flow and medium intensity trafficking
1	50 – 75% protection from crop cover	no land drains but high runoff into well maintained ditches	moderate slope with small ~5m toeslope	High density tramlines across hillslope which are a long distance from ditches	low to medium density and low to medium intensity trafficking
1	100% crop cover in every year	no land drains and overgrown ditch network with evidence of slow flow	moderate slope leading to a large floodplain or toeslope	low density tramlines across hillslope which are a large distance from ditches	low density and low intensity trafficking
0	natural grassland or forest	no land drains or ditches designed to pond and slow flow down	Flat – a flood plain	no tramlines	no tyre tracks or roads or trafficking

Table 5: Questions for the implementation of mitigation measures to reduce the risk of runoff by altering the flow connectivity (Wilkinson et al. 2010a)

Score	***Question 11: Hedgerows***	***Question 12: Buffer Zones***	***Question 13: Wetlands and waterlogged zones***	***Question 14: Ponds***	***Question 15: Flood storage ponds***
-3	high density of hedgerows or stone walls acting as barriers to flow, e.g. ponding	large buffer zones especially in zones of flow concentration e.g. hollows	a large designed constructed wetland processing all the runoff from field	large designed and constructed ponds to trap/filter sediment	over 40mm of rainfall storage
-2	high density, no evidence of ponding	large buffer zones e.g. >10 metre riparian strips	a small designed constructed wetland processing all the runoff from field	medium designed and constructed ponds to trap/filter sediment	30-40mm of rainfall storage
-2	medium to high density	some buffer zones e.g. 2-10 metre riparian strips	large wetlands and waterlogged zones	small designed and constructed ponds to trap/filter sediment	20-30mm of rainfall storage
-1	medium density of hedgerows or stone walls	some buffer zones e.g. 1-2 metre riparian strips	medium wetlands and waterlogged zones	some existing ponds/some temporary ponds seen during storms	10-20mm of rainfall storage
-1	low density of hedgerows or stone walls	very small riparian zone e.g. vegetation on a river bank	small wetlands and waterlogged zones	some temporary ponds seen during storms	up to 10mm rainfall of storage
0	No hedgerows or stone walls	No buffer zones e.g. on a man-made ditch	no wetlands and no waterlogged zones	no ponds	no storage

Table 6: Animal FARM questions which differ to those in Arable FARM.

Question 3: Soil degradation	***Question 4: Compaction***	***Question 5: Feed crops***	***Question 6: Soil management practices***	***Question 7: Stocking density***	***Question 8: Ground cover***
highly degraded – eroded or over 80% poached	very severe compaction	maize	poor soil management	very high	bare soil most of the year
some degradation – soil eroded and/or high degree of poaching	severe compaction	turnips	no BFP or soil management	High	very little ground cover
moderately degraded soil	moderate to severe compaction	high intensity silage	some BFP methods adopted	Medium	small level of protection from ground cover
evidence of poaching or erosion	moderate compaction	silage field	full adherence to BFP	Low	medium level of protection from ground cover
good soil structure and high infiltration	degree of compaction	low intensity silage	full adherence to BFP and evidence of runoff and infiltration management	very low	high level of protection from ground cover
excellent soil structure and high infiltration	no compaction	none	Land out of use	no livestock	no bare soil

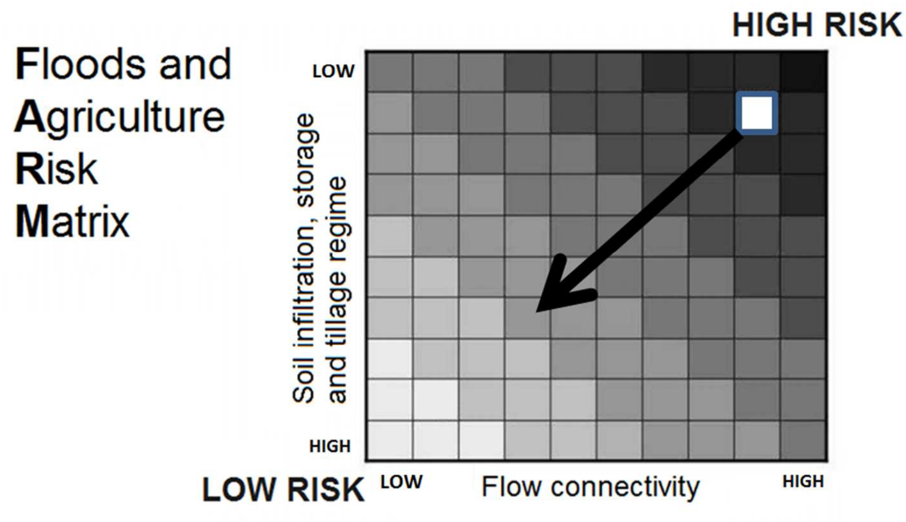

Figure 1: The FARM - the lowest risk of runoff corresponds to the lower left corner of the matrix and the highest risk in the top right corner.
257x144mm (96 x 96 DPI)

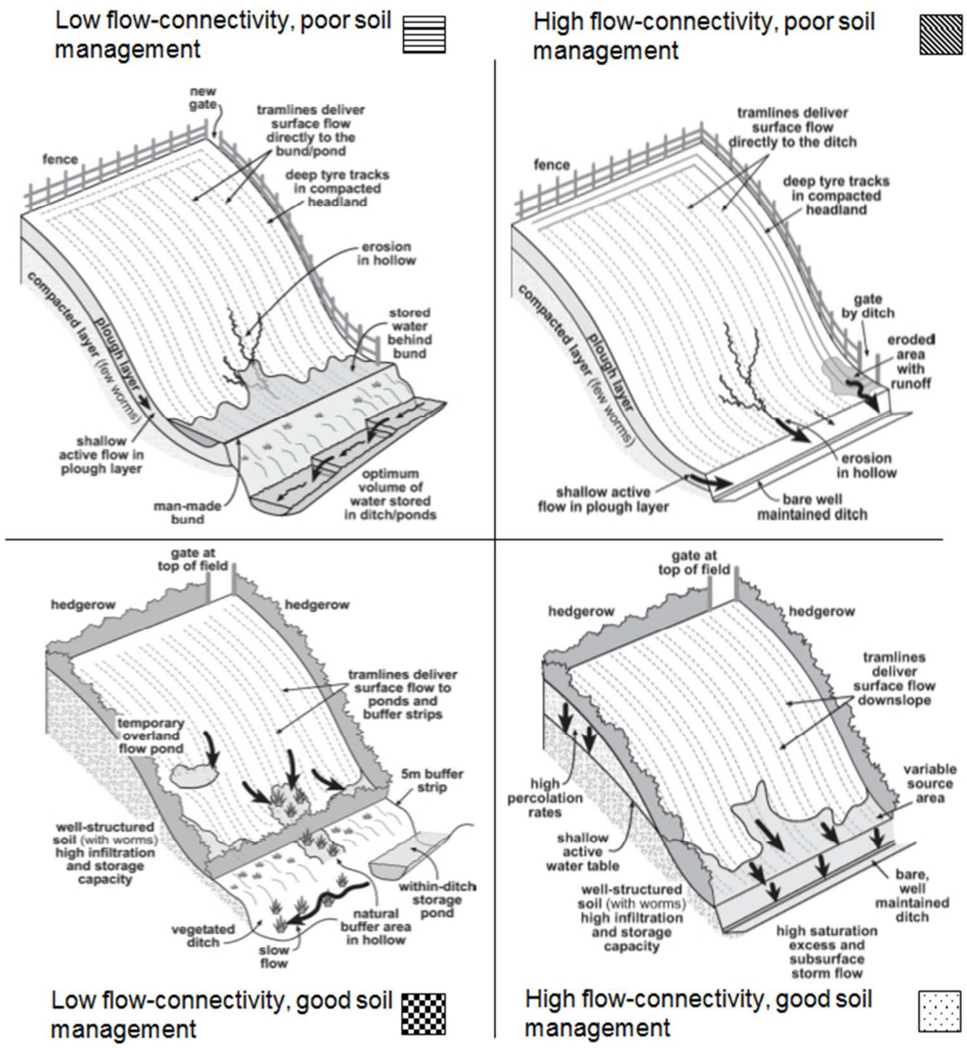

Figure 2: Four hillslope runoff risk scenarios for the same land unit.
191x202mm (96 x 96 DPI)

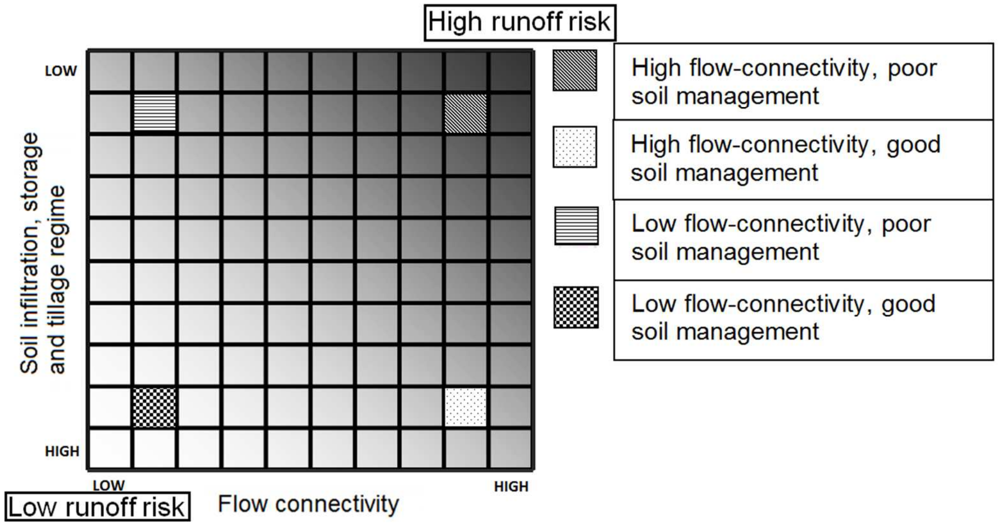

Figure 3: The four scenarios shown in Figure 3 mapped onto the DSM.
310x161mm (96 x 96 DPI)

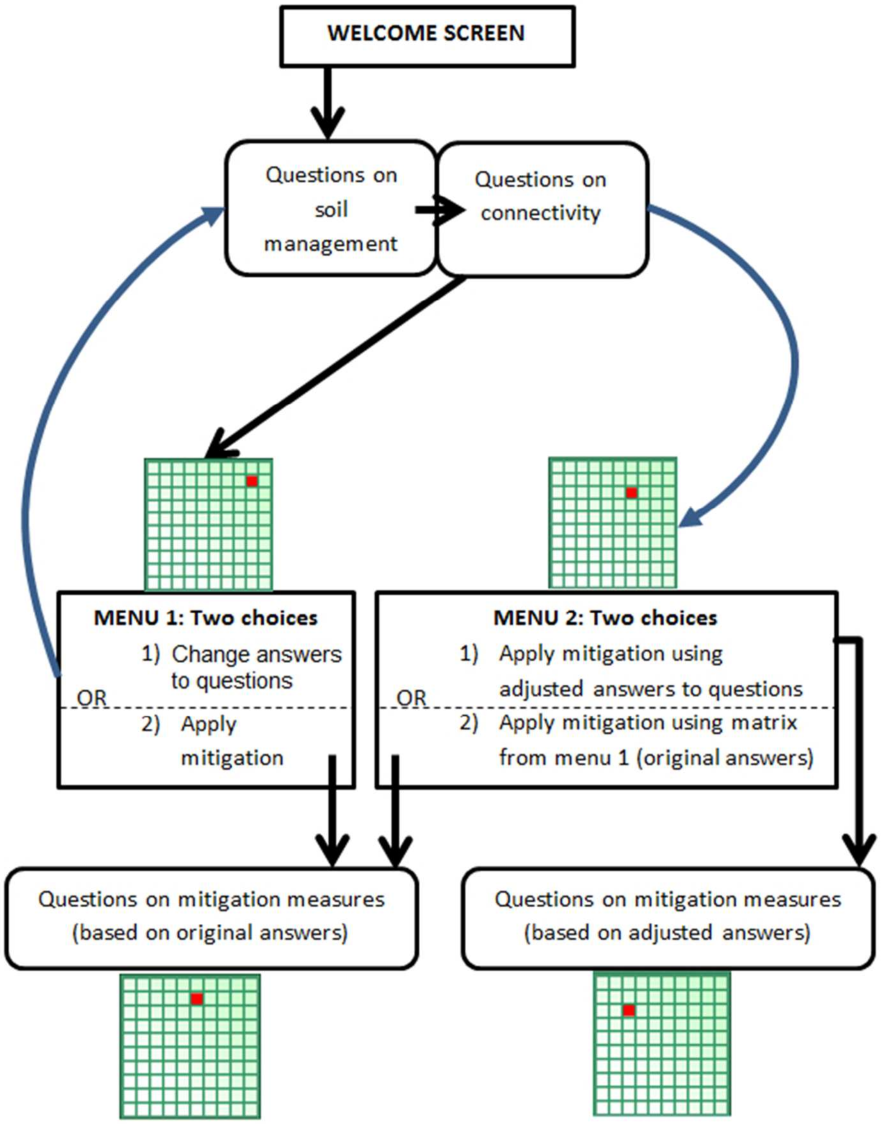

Figure 4: A schematic flow diagram for using the FARM tool. The first stage is to answer the two sets of questions, the second stage is to either re-answer the questions (dashed loop arrow) or apply runoff management measures and the third stage is to apply measures to the initial or adjusted answers to the questions.
172x196mm (96 x 96 DPI)

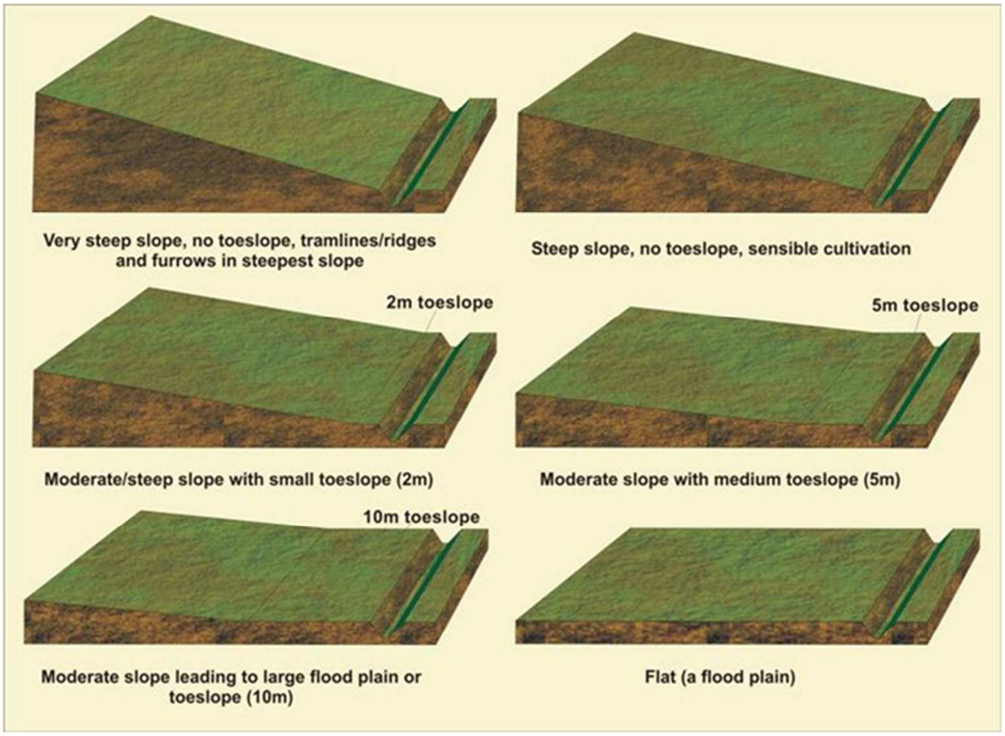

Figure 5: Supporting diagram providing visualisation of the different hillslope forms referred to in Question 8 (Table 4).
199x145mm (96 x 96 DPI)

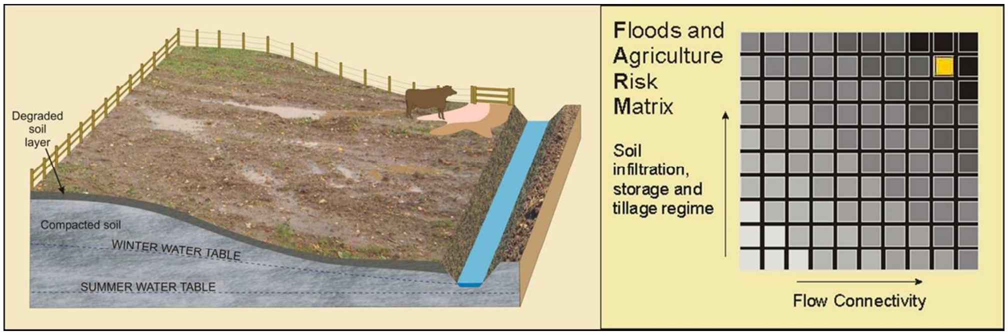

Figure 6: A high risk runoff scenario and the plotting position on the matrix.
232x75mm (150 x 150 DPI)

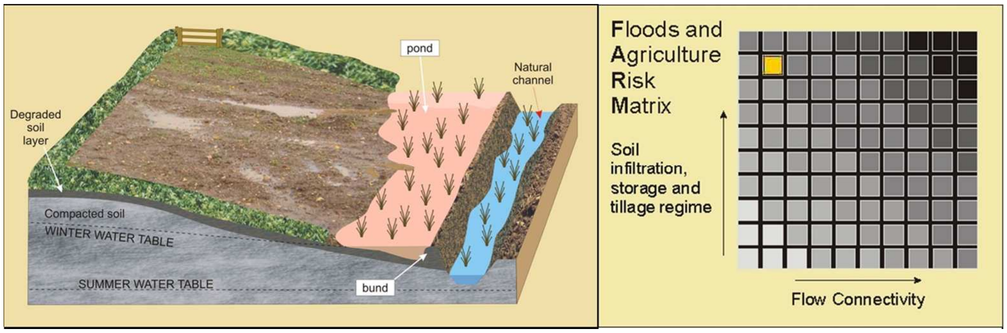

Figure 7: A medium risk of runoff generation scenario with a runoff attenuation feature.
363x118mm (96 x 96 DPI)

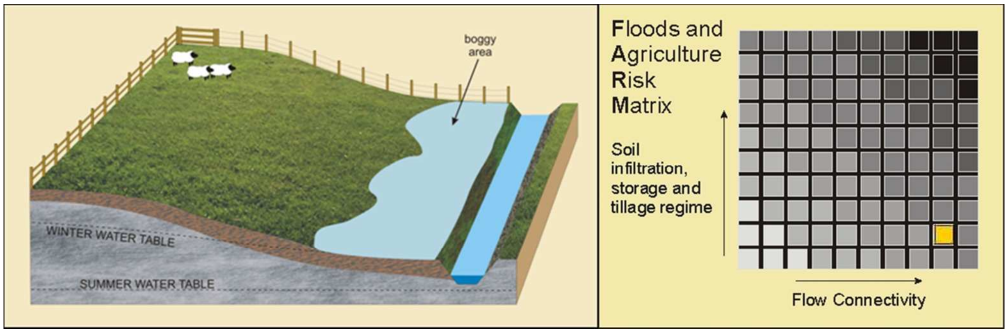

Figure 8: A second medium risk land management option with good soil management.
233x75mm (150 x 150 DPI)

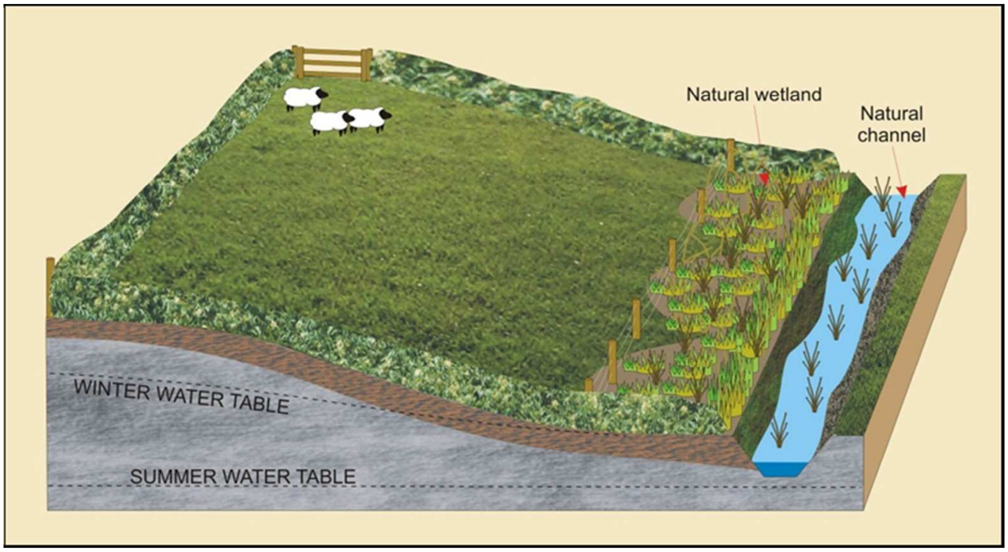

Figure 9: A possible future land use scenario to reduce runoff and pollution.
216x118mm (96 x 96 DPI)

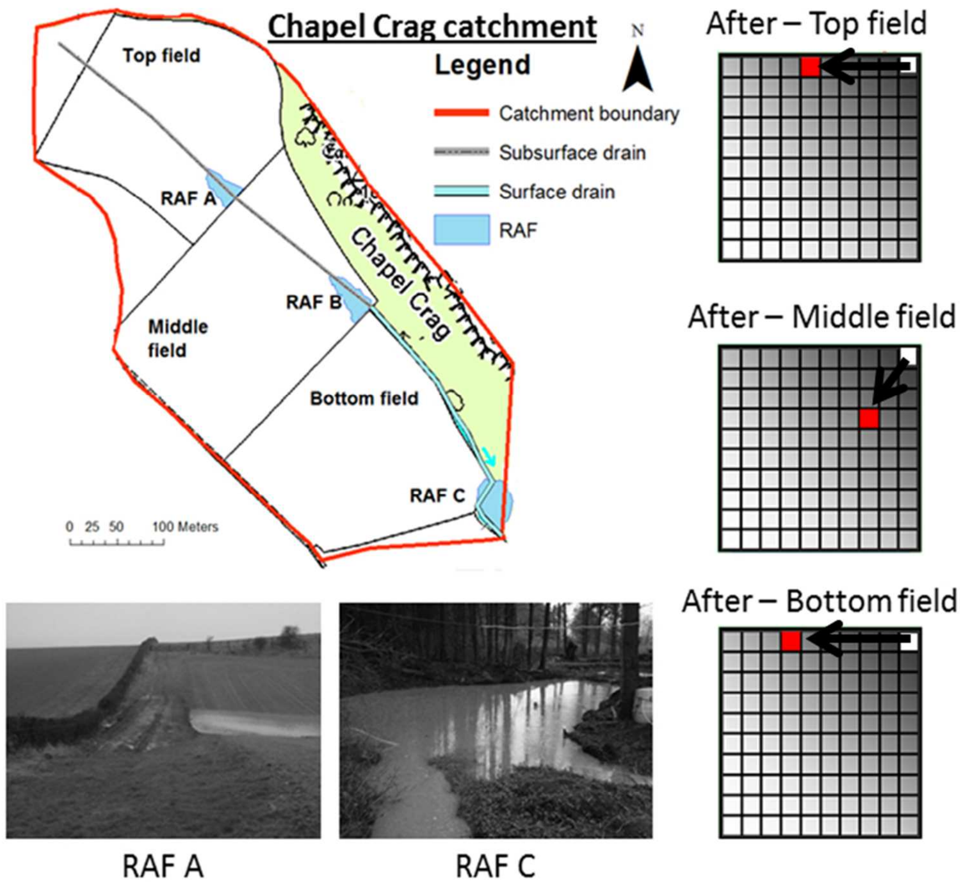

Figure 10: FARM tool outputs for the Chapel Crag catchment before (white square on matrix) and after (red square on matrix) the introduction of Runoff Attenuation Features (RAFs) and improved soil management.
222x198mm (96 x 96 DPI)

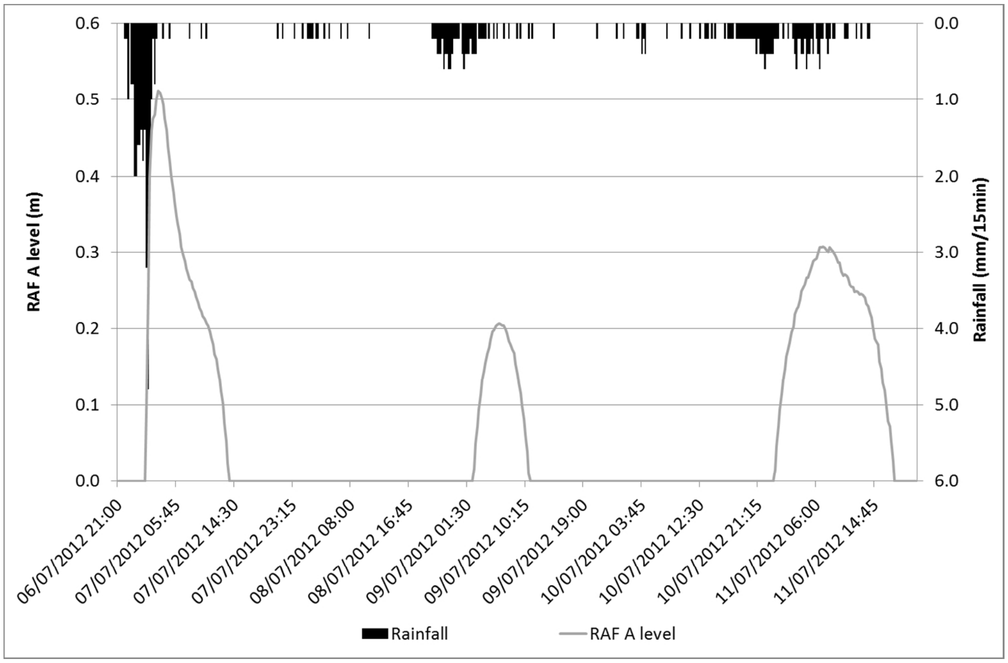

Figure 11: A series of convective storm events and water level response in RAF A from the 6th to 12th July 2012
258x168mm (150 x 150 DPI)

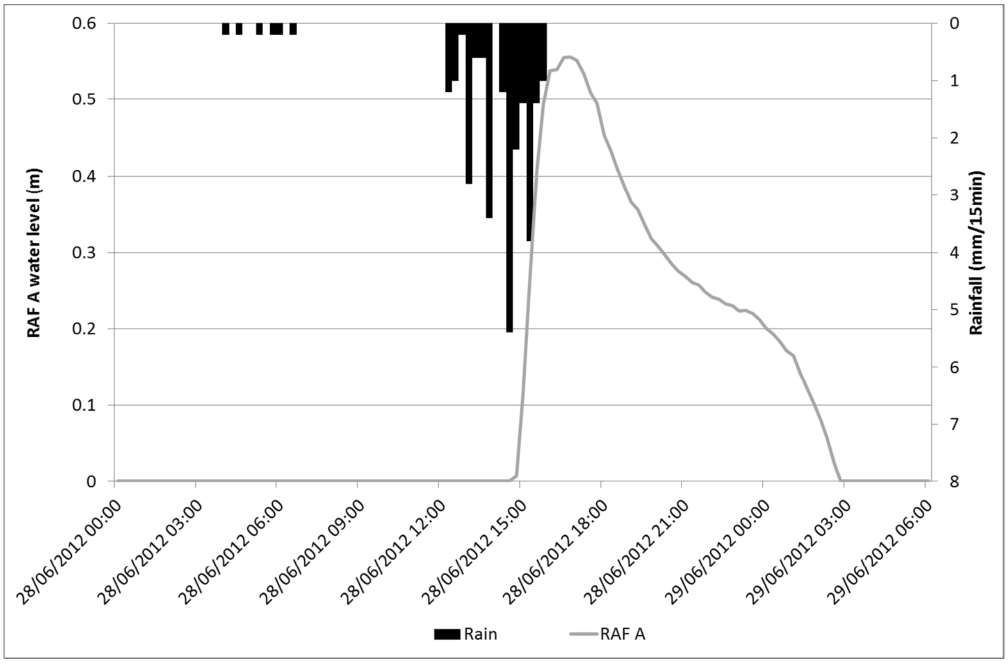

Figure 12: A single convective storm event and water level response in RAF A on the 28th June 2012.
258x169mm (150 x 150 DPI)