# Case study 17

## River Wyre diffuse pollution study - Lancashire

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## 1. Catchment summary

### Study location

The Wyre catchment (Figure 1) in the north-west of England to the north of Preston drains the Bowland Fells to the east of Lancaster.

**Figure 1: Wyre catchment**

Source: JBA Consulting

### Catchment summary

The headwaters of the Wyre catchment consist of moorlands used for grouse shooting in the Forest of Bowland. The wider catchment includes a mixture of improved grassland and dairy farming.

The Wyre suffers from nutrient enrichment (phosphorus) and periodic issues with high suspended sediments. In recent years, Catchment Sensitive Farming (CSF) measures have been put in place to try to manage diffuse pollution through Working with Natural Processes (WwNP). There is a large water transfer system between the Lune and the Wyre, and a large amount of water abstraction in the lower catchment for irrigation. Figure 2 shows part of the catchment that was modelled upstream of the Environment Agency gauging station at St Michaels, Garstang. The issue of overland run-off in the Wyre catchment is illustrated in Figure 3.

### Study summary

The expense of a reliable catchment scale monitoring programme to assess the long-term effectiveness of agri-environment measures to reduce diffuse pollution has encouraged regulators and water companies to develop of a range of diffuse pollution models which can be used to model scenario interventions. Recently the Environment Agency has invested in a simplified, geographical information system (GIS) based model of diffuse pollution transport through the land and water phases called Fieldmouse. Fieldmouse is based around a source–pathway–receptor framework for which:

- sources of pollution are based on the Catchment Change Matrix (CCM) database of diffuse pollutants emitted from farms
- pathways are based on hydrological pathways derived from Digital Terrain Model (DTM) analysis
- receptors are the watercourses, as defined by the Detailed River Network (DRN)

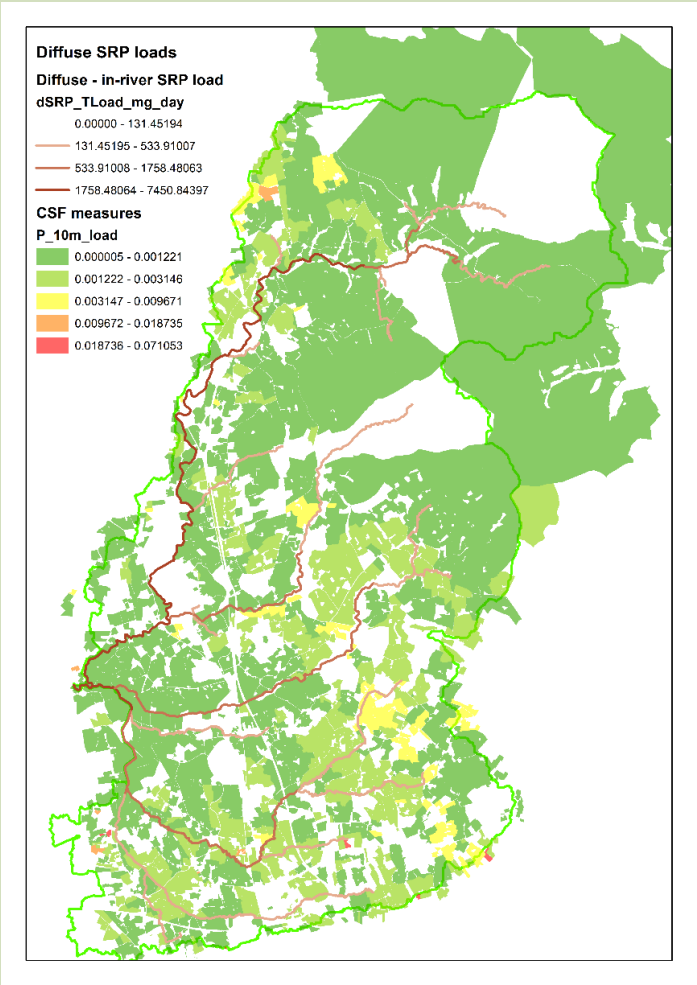


**Figure 2: Estimated diffuse loads in the Wyre upstream of the gauging station at St Michaels**

Source: JBA Consulting

**Figure 3: Overland run-off in the Wyre catchment**

Source: JBA Consulting

Fieldmouse estimates the long-term annual average concentrations, which can be compared against the Water Framework Directive  Environmental Quality Standards. The aim of this study was to:

- calibrate the land phase losses using a more complex model, the Soil and Water Assessment Tool (SWAT)
- derive generic rules based on land cover, soils and slope conditions for Fieldmouse

Once calibrated, the model was used to assess the impacts of WwNP measures through altering the predicted emissions data stored in the CCM database.

**Community involvement**

The approach was disseminated at a workshop on assessing agri-environmental schemes (Naden 2013) and demonstrated at the national CSF conference in York in 2014 to gain feedback from CSF officers on the approach to the modelling in the absence of monitoring data. The whole CSF programme is based around engagement with the farming community, but this project was about developing a modelling tool.

## 2. Data summary

**Datasets and analysis techniques used**

A detailed SWAT model was setup by Lancaster Environment Centre (LEC) and calibrated in an uncertainty framework. This was used to calibrate the land phase loss rates for Fieldmouse and attempts were made to make a generic relationship between these losses for the physical catchment descriptors.

Experts from LEC and the Centre for Ecology and Hydrology (CEH) Wallingford LEC with considerable modelling experience were needed to set up a satisfactory model. A major problem with using SWAT and other complex models is that the set up requires a lot of skill and the manipulation of complex geospatial data. However, the software is free to use and has a very open structure.

A Monte Carlo analysis was conducted to generate a range of loss rates in an uncertainty framework – the Generalised Likelihood Uncertainty Estimation (GLUE) framework. These loss rates were transposed to the Fieldmouse model in that the Fieldmouse loss rates for the 40 subcatchments of the Wyre were scaled by a common factor or pattern observed in SWAT losses. It was difficult to transfer the generic loss rates to a different catchment.

**Data restrictions**

Fieldmouse was designed using datasets accessible to the Environment Agency anywhere in the country. The more difficult dataset to license was the DTM, but this has recently been made easier through the conversion of Environment Agency light detection and ranging (LiDAR) holdings to open data. The following data were incorporated in the modelling:

- 10m resolution DTM
- Detailed River Network (DRN)
- Continuous Estimation of River Flows (CERF) or some other estimate of run-off on at least a 1km grid resolution such as Low Flows Enterprise
- CCM data on farm emissions – a dataset developed at the farm holding level by the Environment Agency’s CSF team
- Land Cover Map (LCM2007)
- National Soil Map of England and Wales (NATMAP) (1km grid)
- an analysis of water quality data – based on the Environment Agency’s monitoring programme and stored in its Water Management Information System (WIMS)

## 3. Model summary

### Catchment processes investigated

The approach is an intermediate level of complexity, falling between screening and detailed modelling. It is intended to help understand intervention options for the long term and at the catchment scale, and averages over some of the more detailed processes that are included in complex models such as SWAT. It uses the source–pathway–receptor framework and is useful to conceptualise the diffuse pollution issues. The uncertainty framework is helped by allowing batch (Monte Carlo) simulations.

The uncertainty framework could provide catchment planners with an overview of how good model predictions are – the hope being that, if planners understand the uncertainty of model predictions, this could influence the management approach.

This investigation is based around improvements to catchment water quality through putting in place measures such as improved soil management and storage of slurry or buffer strip planting.

The following processes were modelled:

- run-off generation
- mobilisation of diffuse pollutants

The investigation centred round a truly whole-catchment approach. It attempted to move away from just modelling the water phase and integrate a simplified model of land transport and in-river transport. Assessing travel and residence times of pollutants is important, so a dye tracer experiment was carried out to help improve the modelling work further (Figure 4).

**Figure 4: Dye tracer work on the Wyre to improve estimates of time of travel**

Source: JBA Consulting

**Model assumptions**

The flow balance for the model is based on analysis of CERF data and a rescaling was performed to ensure that this balanced with the flow gauging data.

The farm emissions were based at the farm holding scale, with emissions estimated on the percentage composition of different practices. To model CSF interventions, percentage changes to these, such as reduction in grazing, were incorporated and mapped at the holding level. These are stored on a 10m grid and assigned to a watercourse depending on the drainage pathways (Figure 5).

There are a large number of assumptions in Fieldmouse:

- The combined effect of different overland losses from a range of processes can be modelled using a generic approach (see Figure 5) and do not vary strongly between sub-basins (Johnes and Heathwaite 1997, Heathwaite et al. 2000).
- The long-term in-river losses can similarly be modelled as a first-order decay process, and processes such as sedimentation and resuspension are not included explicitly

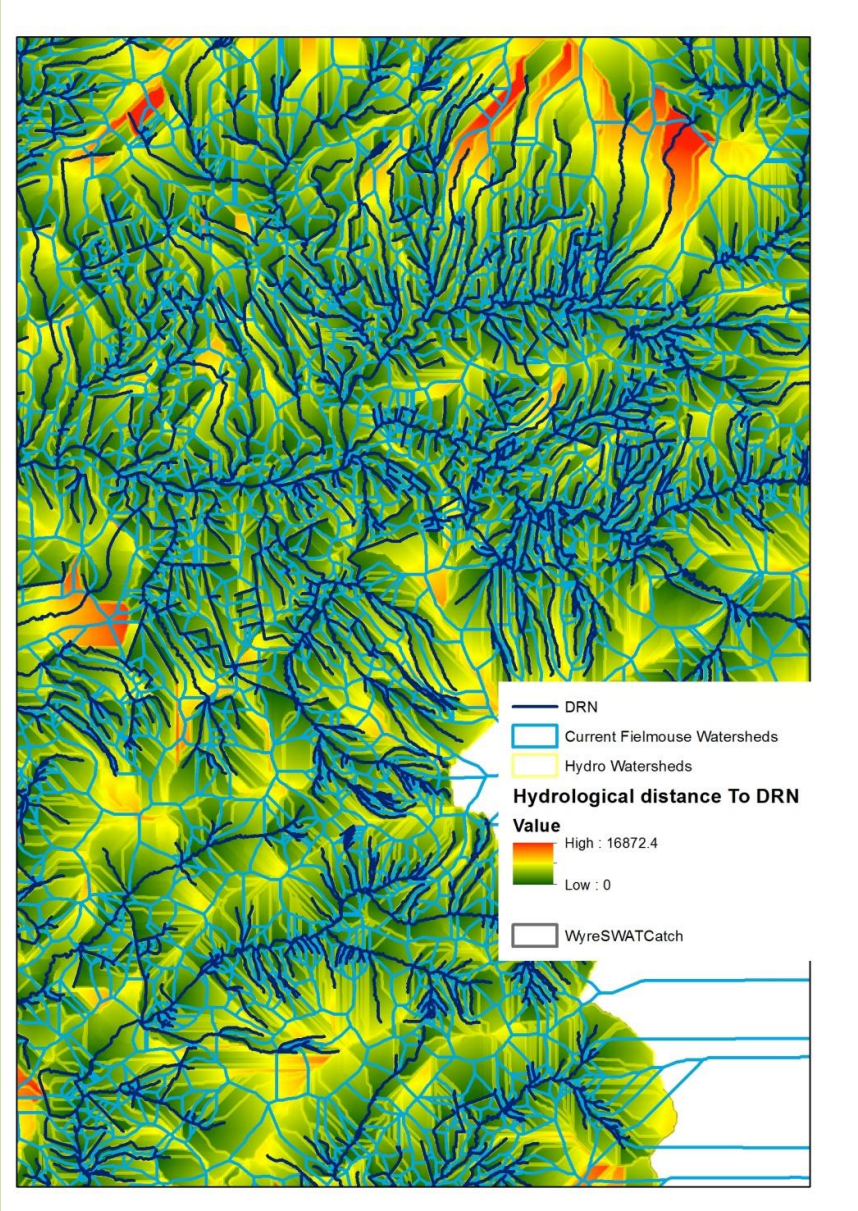


**Figure 5: Hydrological pathways and distance to watercourse (DRN) for every 10m cell represented in Fieldmouse**

Source: JBA Consulting

## Data and model outputs

Fieldmouse requires a large number of datasets to run, though care was taken in its development to use national datasets held by the Environment Agency. These include a detailed DTM, the DRN, emissions data from the CCM dataset, spatial datasets of farm holdings, CERF data, distributed water quality data and point load data. The distributed water quality data from Environment Agency WIMS database were also analysed to understand the water quality around the catchment. The Environment Agency SAGIS model was used to incorporate point source pollution loads.

Model outputs included:

- a calibrated SWAT model for phosphorus and nitrate
- a calibrated Fieldmouse model permitting the modelling of CSF measures

Fieldmouse exports outputs in spatial formats (see Figure 6) including:

- diffuse water quality concentration held against each DRN segment for up to 5 determinands – the model is coded for phosphorus, nitrate, faecal indicator organisations, suspended solids and total phosphorus
- point source concentration as above
- total concentrations as above

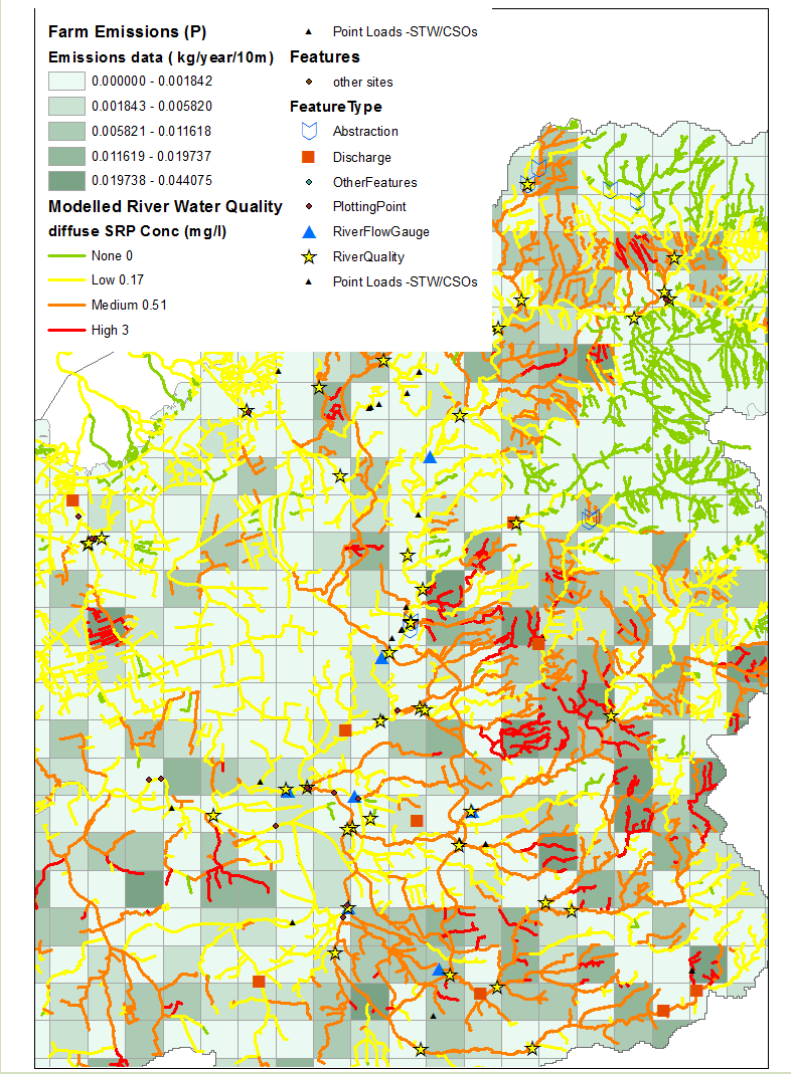


**Figure 6: Distributed soluble phosphorus levels obtained using Fieldmouse**

Source: JBA Consulting

A Microsoft® Excel spreadsheet of the predicted concentration for DRN segments where there is an observation can also be generated. This can be used to derive a goodness of fit measure, which was used on the Wyre to develop the uncertainty analysis.

A catchment performance measure of the spatial goodness of fit can be used to derive uncertainties in the model predictions following the GLUE approach (Beven and Binley 2014) (see Figures 7, 8 and 9),

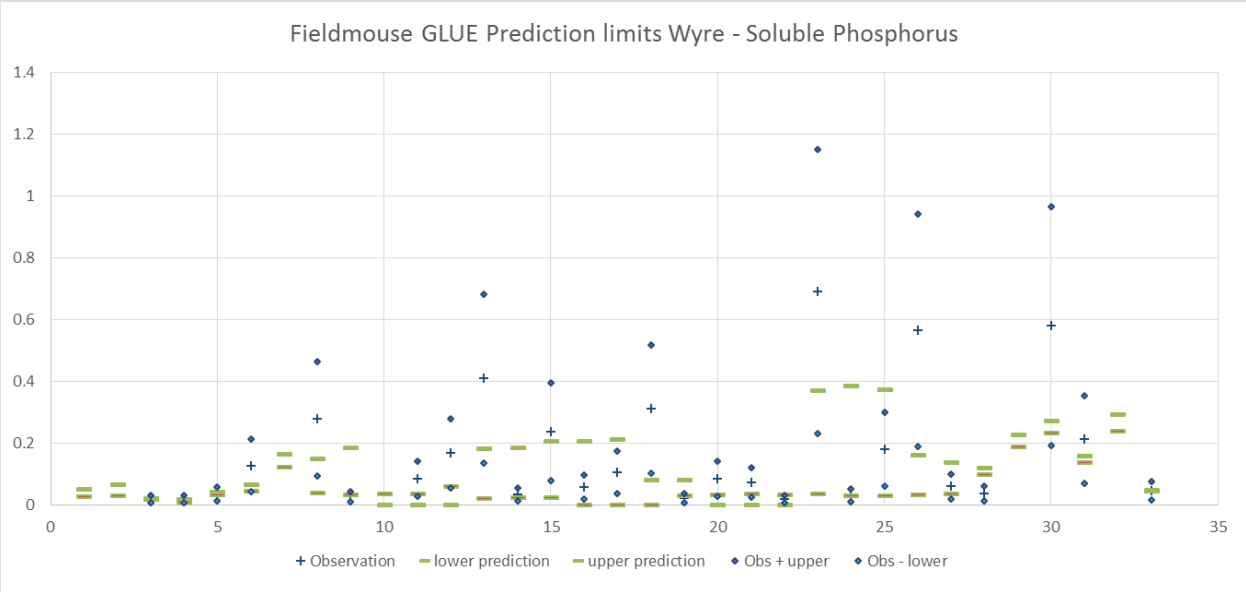


**Figure 7: Model prediction limits for soluble reactive phosphate incorporating errors in observed long-term means used to assess Water Framework Directive compliance**

Source: JBA Consulting

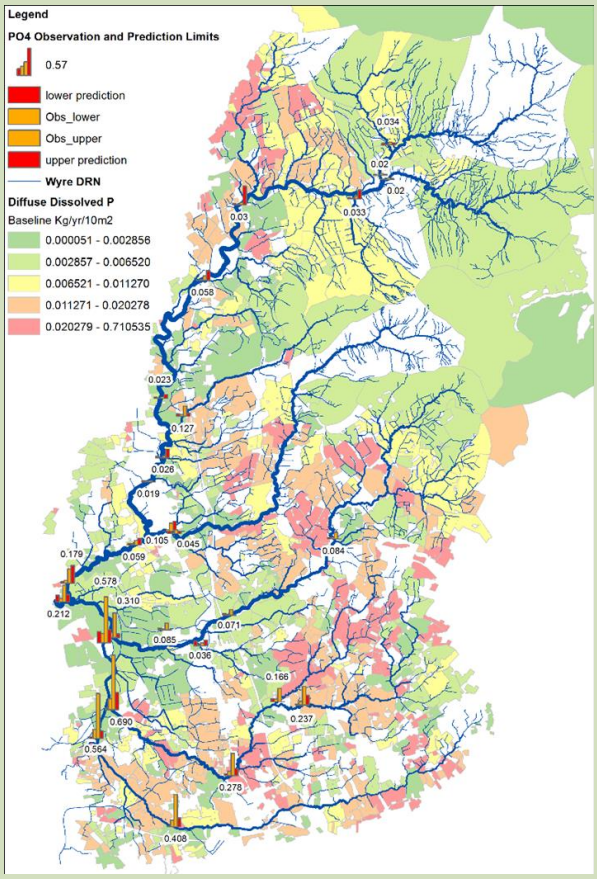


**Figure 8: Distributed model prediction uncertainties**

Source: JBA Consulting

### Model performance

The Fieldmouse model is formulated in a source–pathway–receptor framework and could be extended to model failures of measures (for example, failure of retention pond). This could be combined with weighting the predicted pollution concentrations with the probability of failure.

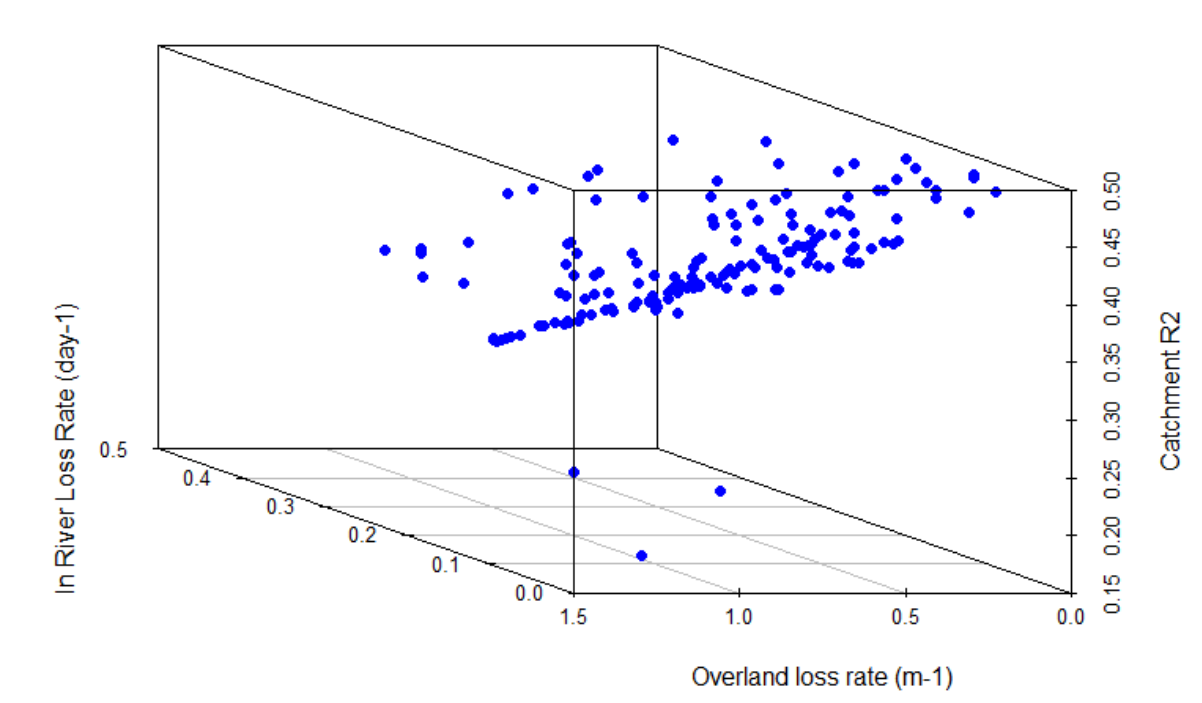


**Figure 9: Fieldmouse goodness of catchment-wide model fit for different combinations of overland losses and in-river losses**

Source: JBA Consulting

## 4. Lesson learnt

### Choice of tools

The study shows that Fieldmouse can be set up and calibrated at the catchment scale based on simple assumptions of exponential loss with distance from watercourse (Heathwaite et al. 2000) and connectivity, and using detailed spatial data that are available anywhere in the UK.

Fieldmouse is a robust tool for investigating relative changes at the catchment scale such as CSF and makes the most of widely available DTM and DRN information. Although it requires effort to calibrate, it is not necessary for this calibration to be based on a complex model. SWAT modelling requires experienced modellers and a reasonably large budget, but the software itself is open source.

Fieldmouse is designed such that multiple simulations can be carried out. It allows the generation of data necessary for an uncertainty analysis (see Figures 7, 8 and 9). The model takes up to 3 minutes to run for a catchment the size of the Wyre using 10m resolution.

The catchment-wide goodness of fit can be plotted as a function of the in-river and land phase loss rates to help understand the structure of errors and to derive prediction uncertainties. The uncertainty analysis requires strong analytical skills and a knowledge of GLUE, but the interface for Fieldmouse allows for this and tools to generate prediction uncertainties are provided. An uncertainty and trade-off analysis tool called UNCOVER has recently been developed through the European funded SWITCH-ON project (http://uncover.jbahosting.com/) to help users visualise model performance uncertainties and choose between scenarios.

### Catchment scale and typology

A detailed SWAT model was developed, and losses were aggregated to a sub-basin scale for use in

the more simplified process model, Fieldmouse. This used the same pattern of losses (that is, relative loss rates around the catchment) but required a scaling factor. When these patterns were linked to catchment descriptors based on physical characteristics of the Wyre and transferred to the Demonstration Test Catchments (www.demonstratingcatchmentmanagement.net), a similar performance was not observed.

The typologies of the different subcatchments modelled for the Wyre were considered through their soil, land cover and slope characteristics. These were used to define hydrological response unites for the Wyre and an attempt was made to characterise the overland losses as a function of these characteristics. However, it was not possible to develop a generic relationship for other catchments and it was concluded that these relationships would need to be developed based on modelling of more catchments.

**Wider benefits**

Fieldmouse is able to demonstrate the distributed improvements/benefits to water quality and associated benefits associated with CSF. Since the changes to emissions used in the model are quantified in a detailed database at the farm -holding scale, the costs of the environmental benefits are also well documented.

**Future research needs**

Fieldmouse was calibrated for the Wyre with a reasonably strong relationship for long-term annual average losses in the land and water phases, giving confidence that it could be used to assess the relative changes as a result of CSF interventions/measures. However, there are still knowledge gaps when it comes to developing the model for other catchments and, for instance, when scaling the loss rates based on catchment characteristics.

The treatment of overland losses in Fieldmouse is broadly similar to that developed in modelling studies that attempted to model phosphorus at the catchment scale using simple loss rates (for example, Heathwaite et al. 2000). It is recognised that this does not capture the complex sediment interactions of phosphorus over the long term. However, it is known that a catchment receives inputs of phosphorus and delivers some of this phosphorus via fast and slow pathways to its watercourses. The rates associated with this delivery and the in-river losses over the long term were investigated and calibrated against long-term water quality statistics.

## 5. Bibliography

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**Project background**

This case study relates to information from project SC120015 'How to model and map catchment processes when flood risk management planning'.

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