Definition of vegetative filter strip scenarios for Europe

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FINAL REPORT

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I, the undersigned, hereby declare that this study was performed under my direction and that this report represents a true and accurate record of the results obtained.

22nd May 2012

C. Brown, Project Manager

Date

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1 INTRODUCTION

The FOCUS Surface Water Scenarios group developed standardised approaches to estimating predicted environmental concentrations of pesticides in surface water and sediment for use in aquatic risk assessment for Europe (FOCUS, 2001). FOCUS Steps 1-3 adopt standardised approaches that account for transfer of pesticides to water in spray drift, drainflow and surface runoff. At Step 3, these processes are simulated by a spray drift calculator, the MACRO model and the PRZM model, respectively. The TOXSWA model is used to incorporate the fate of pesticides within surface waters.

FOCUS Steps 3 is designed to provide realistic but conservative estimates of exposure concentrations under idealised conditions. If unacceptable risk is demonstrated based on Step 3 simulations, there is the opportunity to refine the exposure estimate by considering the range in likely use conditions, including additional environmental processes, or considering the influence of mitigation measures on the various transport processes. The FOCUS Landscape and Mitigation Group considered and made recommendations on the options for refining the exposure estimate in Step 4 modelling (FOCUS, 2007). The Group's report was considered by the EFSA Panel on Plant Protection Products and their Residues (EFSA, 2006).

Vegetative filter strips (VFS) are the most widely implemented mitigation measure to reduce transfer of pesticides and other pollutants (e.g. sediment, phosphorus) to surface waters in surface runoff. These are densely vegetated strips of land designed to intercept surface runoff, often located at the downslope field border. The VFS acts as a physical impediment to surface runoff, reducing the kinetic energy of the flowing water and reducing passage of water, sediment and diffuse pollutants across the strip through infiltration of water and trapping of sediment. VFS are a readily accessible measure for farmers which are cheap to install and maintain; they are widely promoted through environmental stewardship schemes across Europe (see Section 7).

The FOCUS Landscape and Mitigation Group reviewed the available literature on efficacy of VFS for reducing pesticide transport in surface runoff (FOCUS, 2007). The Group concluded that whilst there was considerable variability in the efficacy of buffers under the range of conditions that had been tested, it was possible to recommend conservative factors for the reduction in water, sediment and pesticide load transferring across a VFS. They recommended a set of empirical factors for use in exposure assessment with factors varying with (i) size of the VFS, and (ii) transport primarily in the aqueous or sediment phases. At the time that the FOCUS Landscape and Mitigation Group undertook its work (2002-2004), there were no appropriate modelling tools available to simulate reduction in pesticide load in surface runoff across a VFS. Subsequently, work has been undertaken in the USA to develop and evaluate such a model (VFSMOD-W; Sabbagh et al., 2009; Poletika et al., 2009). There is widespread interest in applying this model within regulatory exposure assessment. This project looks at the parameterisation of the model needed to underpin application for regulatory purposes in Europe.

1.1 VFSMOD-W

Numerical process-based models have been available for some time for predicting runoff and sediment reduction across a vegetative filter strip (Sabbagh et al. 2010). VFSMOD-W is a finite-element, field-scale, storm-based model developed to route the incoming surface flow hydrograph and sedigraph from an adjacent source area through a VFS and to calculate the resulting outflow, infiltration (based on the extended Green-Ampt equation for unsteady rainfall) and sediment trapping (based on the GRASSF model) (Muñoz-Carpena et al., 1999; 2004). More recently, research by Sabbagh et al. (2009) and Poletika et al. (2009) has developed and evaluated an empirical model for trapping of pesticide by vegetative filter strips. The model has a foundation of hydrological, sediment- and chemical-specific parameters:

$$\Delta P = a + b(\Delta Q) + c(\Delta E) + d\left(\ln\left(F_{pH} + 1\right)\right) + e(\%C)$$

where *ΔP* is the pesticide removal efficiency (%), *ΔQ* is water infiltration into the buffer (% of runon plus rainfall incident on the buffer), *ΔE* is the sediment reduction (%), *%C* is the clay content of the sediment entering the VFS, F_{pH} is a phase distribution factor, and *a*, *b*, *c*, *d* and *e* are regression parameters with values of 24.8, 0.54, 0.53, -2.42 amd -0.89, respectively. F_{pH} defines the distribution of pesticide in runon between solution and sediment phases:

$$F_{pH} = \frac{Q_i}{(K_{oc}(\%OC/100)E_i)}$$

where Q_i and E_i are the volume of water (L) and mass of sediment (kg) entering the VFS, *Koc* is the organic carbon coefficient of the pesticide (L kg^{-1}) and *%OC* is the organic carbon content of the sediment entering the VFS (Sabbagh et al., 2009).

The model was developed through statistical analysis of an extensive dataset (n=47) of experimental results for pesticide removal from runoff across vegetative filter strips. The dataset included a range in chemical properties, soil types, buffer sizes and hydrological conditions. Plotting predicted vs. measured ΔP for the training dataset yielded an r^2 of 0.86 (Figure 1a; Sabbagh et al., 2009). The model was then evaluated against an independent dataset of experimental measurements (n=120) yielding a plot with r^2 of 0.82 (Figure 1b).

1.2 Aim and objectives

The overall aim of this project was to develop scenarios for vegetative filter strips that would be suitable for use with the VFSMOD-W programme within Step 4 modelling for aquatic risk assessment in Europe.

The specific objectives were:

1. To consider the relative sensitivity of input parameters for VFSMOD-W;
2. To assign conservative default values to relatively insensitive parameters that are representative of vegetative filter strip conditions across Europe;
3. To characterise the range of conditions across Europe for the more sensitive parameters and recommend appropriate parameter values to represent this variation within regulatory modelling;
4. To assess the nature of existing vegetative filter strip structures across Europe;
5. To make recommendations on the approach for incorporating simulation of vegetative filter strips into risk assessment procedures.

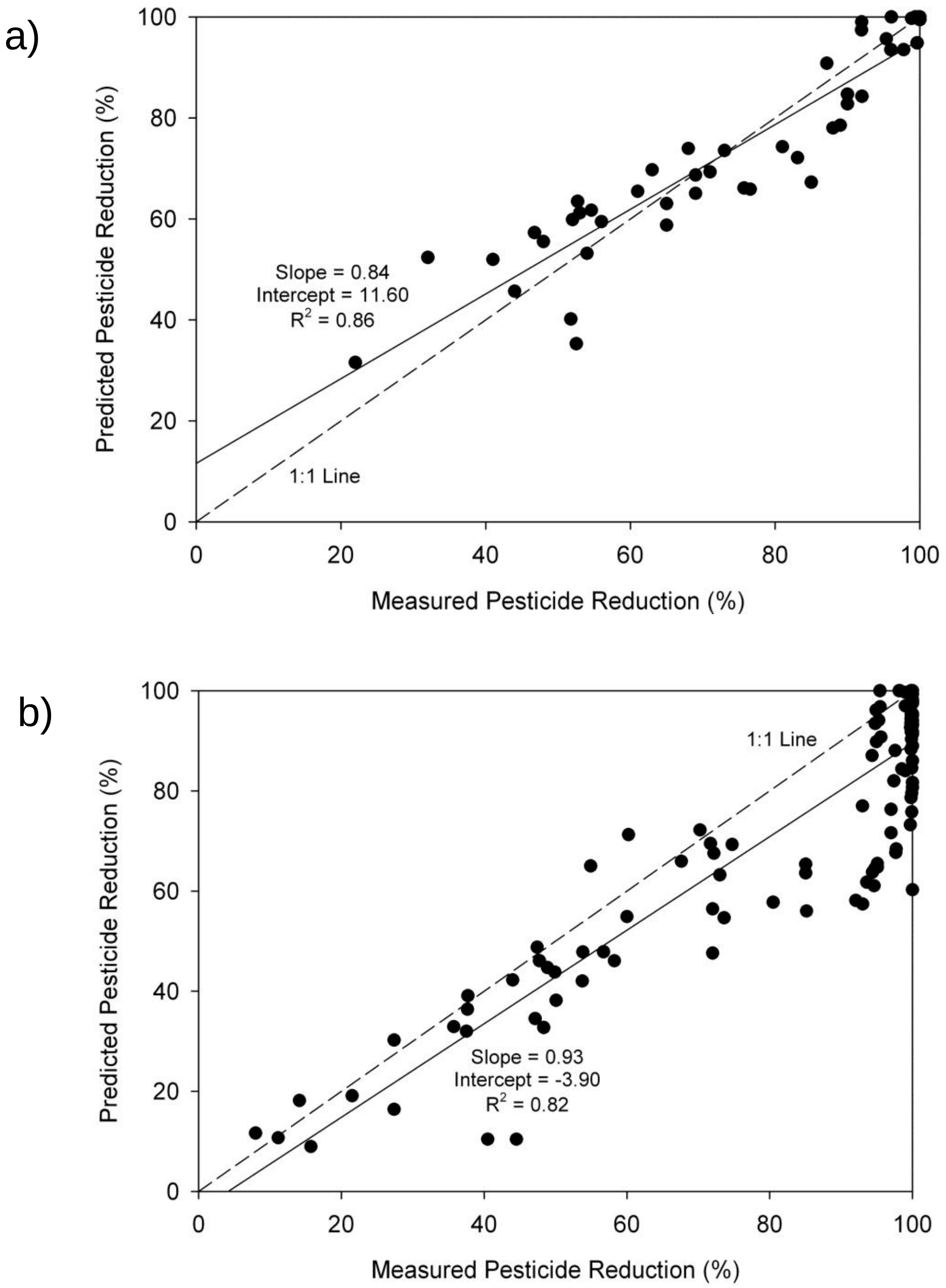


Figure 1. Predicted *vs*. measured reductions in pesticide transfer across vegetative filter strips for a) development (n=47) and b) independent evaluation (n=120) of an empirical model for pesticide trapping (Sabbagh et al., 2009).

2 Identification of sensitive and insensitive input parameters

The VFSMOD-W model has 18 primary input parameters (Table 1). An initial task was to separate these parameters into those that are relatively sensitive or relatively insensitive for predictions of changes in pesticide load in transit through vegetative filter strips. Greatest effort would then be invested into determining the actual range of values that occur for the more sensitive parameters; for the less sensitive parameters, the determination of realistic, conservative values is considered the most appropriate approach.

Table 1. Input parameters for the VFSMOD-W model

Parameter	Units	Description
FWIDTH	M	Effective flow width of the strip (perpendicular to the flow)
VL	M	Length in the direction of the flow
RNA(I)	s $m^{-1/3}$	Filter Manning's roughness *n* for each segment
SOA(I)	m m^{-1}	Filter slope for each segment
VKS	m s^{-1}	Soil vertical saturated hydraulic conductivity in the VFS
SAV	M	Green-Ampt's average suction at the wetting front
OS	m^3 m^{-3}	Saturated soil water content, θ_s
OI	m^3 m^{-3}	Initial soil water content, θ_i
SCHK	-	Relative distance from the upper filter edge where check for ponding is made
SS	cm	Average spacing of grass stems
VN	s $cm^{-1/3}$	Filter media (grass) modified Manning's *n*
H	cm	Filter grass height
VN2	s $m^{-1/3}$	Bare surface Manning's *n* for sediment inundated area in grass filter
DP	cm	Sediment particle size diameter (d_{50})
COARSE	-	Fraction of incoming sediment with particle diameter >0.0037 cm
KOC	-	Pesticide organic carbon partition coefficient
PCTOC	%	Percentage of organic carbon in sediment
PCTC	%	Percentage clay in sediment

An existing, comprehensive sensitivity analysis was used to identify the most sensitive parameters (Muñoz-Carpena et al., 2010). This study used measured field experiments as base cases in order to evaluate the sensitivity of all 18 input parameters under a range of conditions. The primary features of the study were:

- Three VFS experiments undertaken on three different soil types known to be vulnerable to surface runoff.
- Six contrasting pesticides with ranges in Koc from 70 to 13,400 L kg^{-1}.
- All 18 input parameters were considered to avoid subjectivity associated with any *a priori* selection. Parameters assigned distributions (normal, log-normal, triangular or uniform) based on available data and the range of conditions in the field experiments.
- Two state-of-the-art sensitivity analysis methods were employed to minimise any influence of methodology on the outcome. The screening method of Morris (1991) is a one-at-a-time approach with each parameter varied a discrete number of times within its probability distribution space. The Fourier Amplitude Sensitivity Test (FAST)

method of Saltelli (1999) is a variance-based method where all parameters are varied simultaneously to determine the fraction of the total output variance that is attributable to each input parameter.

Figure 2 and Figure 3 summarise parameter sensitivity based on the screening method for infiltration/sedimentation and change in pesticide load in transit through the VFS, respectively (Muñoz-Carpena et al., 2010). Results show that the saturated hydraulic conductivity of the soil (VKS) was the most sensitive parameter for all three components - infiltration (ΔQ), sedimentation (ΔE), and pesticide trapping efficiency (ΔP). VKS was the dominant parameter for ΔQ with other parameters significantly less sensitive for all three experiments. The particle diameter of the sediment (DP) and Manning's n for the filter media (VN) were also sensitive for ΔE for at least one of the experiments (Figure 2b and 2d). Change in pesticide load in transit through the VFS is the primary output in modelling for pesticide risk assessment. Here saturated hydraulic conductivity was consistently the most sensitive parameter and it was dominant in sensitivity for the experiments of Poletika et al. (2009) and Patzold et al. (2007). Clay content of the sediment (PCTC) was also relatively sensitive for the Arora et al. (1996) study with several more minor influences on model results.

Full results of the Fourier Amplitude Sensitivity Test are given by Muñoz-Carpena et al. (2010) and they are not reproduced here because of the complexity of the analysis. Results showed that the influence of individual parameters was dominant for the studies of Arora and Patzold, explaining >84% of the total variation in outputs. The Poletika study had a particularly high hydraulic loading rate and here there was a greater contribution of interactions between parameters (first-order effects explained 48-64% of the total variation in outputs). The FAST results supported the conclusion that VKS was the single most sensitive input parameter, especially for ΔQ and ΔP. VKS explained 49-85% of the total variance in ΔQ across the three experiments and 50-80% of the total variance in ΔP. The results also confirmed that clay content of the soil (PCTC) was an important influence on ΔP for the Arora study.

The sensitivity analysis shows that VKS is the dominant parameter within VFSMOD-W in terms of sensitivity. Saturated soil water content (OS) is less sensitive but closely related to VKS. Section 4 describes work to assess the range in these two parameters within the areas of the FOCUS R scenarios and to define realistic worst-case values for use in risk assessment. Section 5 describes work to look at key characteristics of eroded sediment in terms of size, clay and organic carbon content (DP, COARSE, PCTC, PCTOC). Recommendations for the remaining input parameters to VFSMOD-W are set out in Section 3.

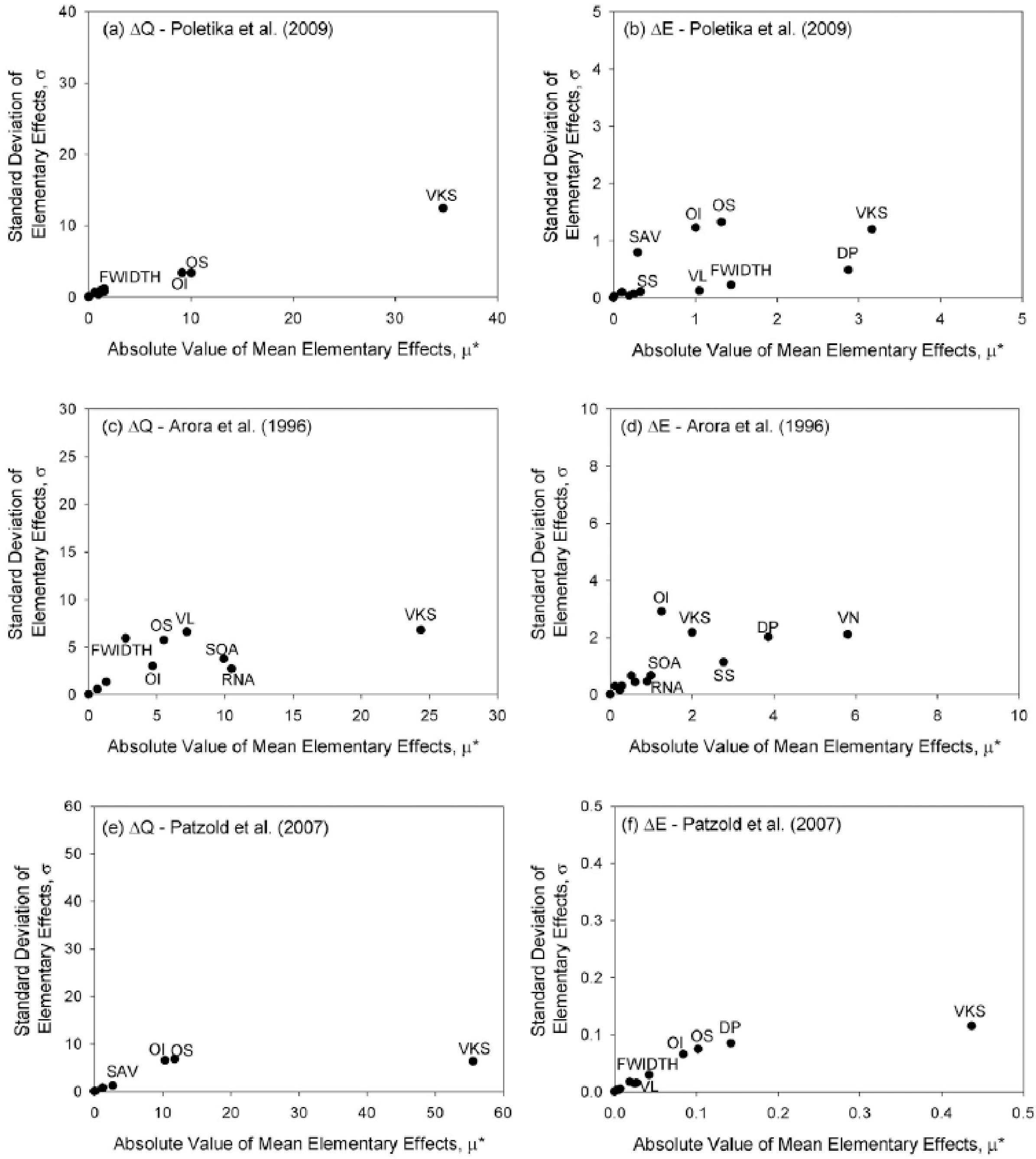


Figure 2. **Parameter sensitivity determined using the Morris (1991) screening method for infiltration (ΔQ) and sedimentation (ΔE) across the vegetative filter strip for the three experiments used as base cases (Muñoz-Carpena et al., 2010). The most sensitive parameters are furthest from the origin; least sensitive parameters are closest to the origin and are not labelled to aid clarity.**

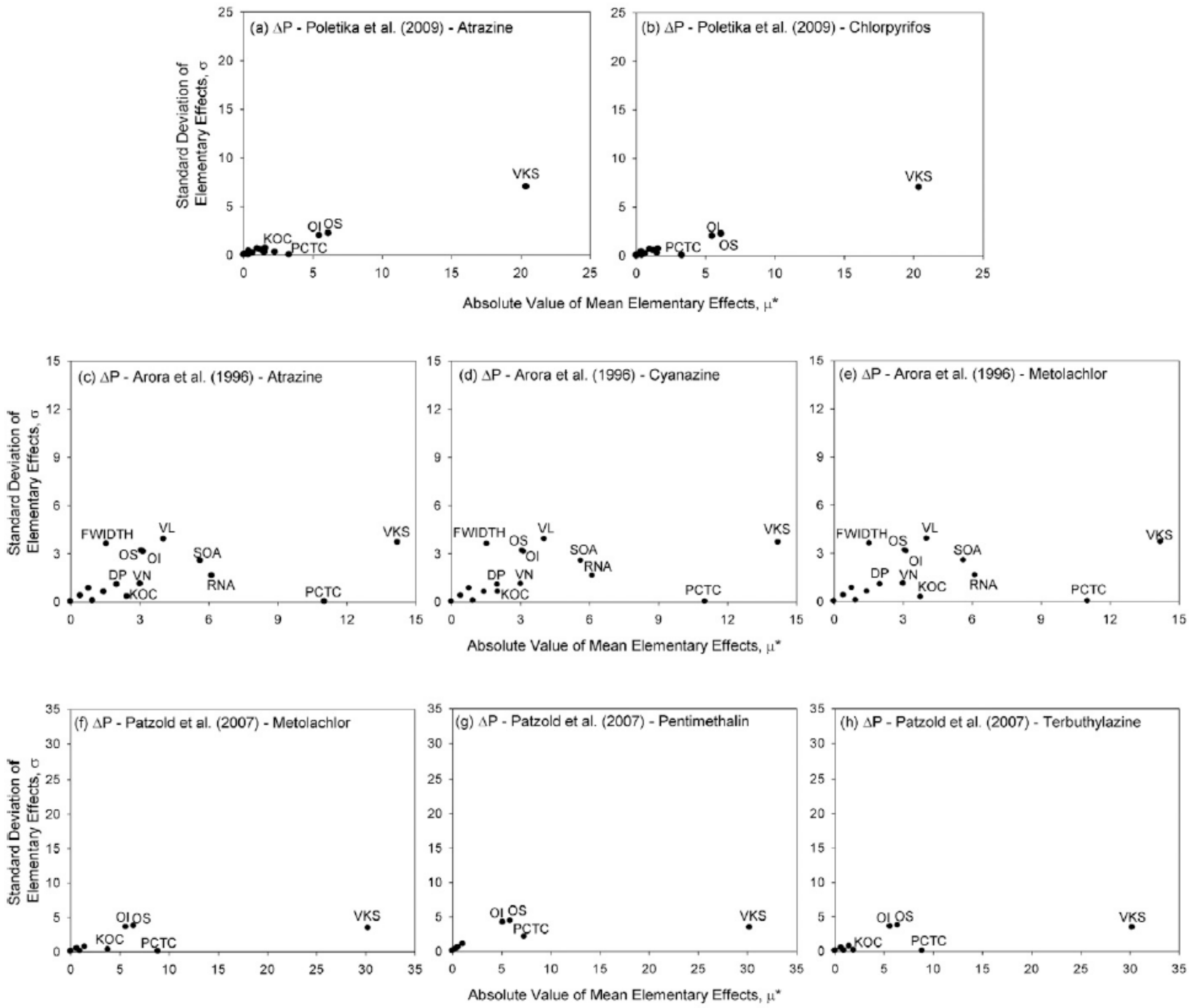


Figure 3. **Parameter sensitivity determined using the Morris (1991) screening method for reduction in pesticide load (ΔP) across the vegetative filter strip for the three experiments used as base cases (Muñoz-Carpena et al., 2010). The most sensitive parameters are furthest from the origin; least sensitive parameters are closest to the origin and are not labelled to aid clarity.**

3 Recommendations for input parameters that are relatively less sensitive, case-specific or pre-defined within the FOCUS Surface Water Scenarios

3.1 User-defined parameters

Several parameters will be entered by the user dependent on the case that they are simulating. These are summarised in Table 2 together with the proposed approach to assigning values.

Table 2. Suggested approach to assign values to case-specific input parameters

Parameter	Approach to assigning value
VL - length of the VFS in the direction of flow	This parameter will be varied by the user to determine the strip size required to achieve the required amount of mitigation. This will operate in the same way as the optimisation of no-spray buffer distances for mitigation of transport in spray drift. As with the spray drift calculation, it is likely that strip size will be evaluated within realistic categories (e.g. 5, 10, 15 m etc) rather than treated as a continuous variable.
Koc – pesticide organic carbon partition coefficient	This parameter will be determined by the pesticide being simulated. Standard FOCUS guidance should be followed to select the appropriate value from regulatory datasets.
Runon characteristics	Incoming runoff, eroded sediment and associated pesticide load should be taken directly from the existing regulatory model (FOCUS-PRZM). Work external to this project is coding a link into the SWAN programme between Step 3 runoff simulations with FOCUS-PRZM and input to the VFSMOD-W model. Output from VFSMOD-W is then read into FOCUS-TOXSWA.
OI – initial soil water content	Use of VFSMOD-W at Step 4 will be as a continuous model receiving input from FOCUS-PRZM and feeding output into FOCUS-TOXSWA. Within this system, soil water content within the VFS will be simulated dynamically and used to determine OI at the start of each individual runoff event.

3.2 Parameters derived directly from the FOCUS R Scenarios

3.2.1 Buffer width perpendicular to the flow (FWIDTH)

FOCUS (2001) defines standardised dimensions for areas contributing surface runoff and for receiving surface water bodies. It is recommended that these dimensions are retained as scenario defaults within VFSMOD-W for consistency. Hence, FWIDTH will take the value 100 m for runoff into the FOCUS stream and 30 m for runoff into the FOCUS pond (Table 3).

3.2.2 Slope (SOA)

SOA is a slightly sensitive parameter in terms of influence on ΔP. VFS structures are frequently located on breaks in slope and have shallower slope than the bulk field, and thus a greater potential for infiltration of runoff water and trapping of sediment. Given the limited sensitivity of this parameter, it is recommended that a worst-case approach is used where the slope within the VFS is set to the same as that within the field (Table 3). It would be possible in future to use a fine-resolution digital elevation model to determine representative slopes at field edges and thus to provide a more realistic estimate of SOA.

3.2.3 Manning's roughness within the filter (RNA)

Data for Manning's roughness are only rarely available and it is not currently possible to evaluate the range in this parameter across the FOCUS R scenario. Muñoz-Carpena et al. (1999) estimated Manning's roughness coefficients from literature values to match field conditions (Woolhiser, 1975; Engman, 1986; Woolhiser et al., 1990; Arcement and Schneider, 1989). These values change seasonally as a function of the vegetative conditions of the cover (higher values in summer, lower values in winter). Based on the references, the range representing most field conditions was 0.10-0.60 s $m^{-1/3}$ for grass buffers. A representative value of 0.40 s $m^{-1/3}$ is recommended for use with the FOCUS R soils and European buffer conditions (Muñoz-Carpena, personal communication). RNA can be moderately sensitive for ΔP in certain circumstances, so further work is warranted to estimate this parameter under a range of European conditions.

3.2.4 Green-Ampt's average suction (SAV)

This parameter is normally fitted against measured data and it has only slight sensitivity within the model. It is recommended that representative values for the FOCUS R soils are taken from guidance on parameterising VFSMOD-W (Muñoz-Carpena and Parsons, 2011 p161; Table 3). This gives mean values for SAV by soil texture with values of 0.17, 0.11, 0.21, and 0.22 m for silt loam (R1), sandy loam (R2), clay loam (R3) and sandy clay loam (R4) soils, respectively.

Table 3. Suggested values for input parameters directly related to the existing FOCUS R scenarios

Parameter	Units	Description	Recommended parameter value			
			R1	R2	R3	R4
FWIDTH (FOCUS R stream)	m	Buffer width perpendicular to the direction of the flow	100	100	100	100
FWIDTH (FOCUS R pond)	m	Buffer width perpendicular to the direction of the flow	30	30	30	30
RNA(I)	s $m^{-1/3}$	Filter Manning's roughness *n* for each segment	0.4	0.4	0.4	0.4
SOA(I)	m m^{-1}	Filter slope for each segment	0.03	0.05	0.05	0.05
SAV	m	Green-Ampt's average suction at the wetting front	0.17	0.11	0.21	0.22

3.3 Input parameters relating to vegetation in the VFS

The sensitivity analysis shows that four parameters related to the grass growing within the VFS are all relatively insensitive for ΔP. A review was undertaken to collate any information on the vegetation most likely to be present within European VFS (Section 7). There are no guidelines on types of grass to be grown within the VFS, but it is considered that ryegrass (*Lolium spp.*) is the species most likely to represent European conditions for low biodiversity grassland. In the absence of more detailed information on vegetation composition, it is recommended that input parameters representative of ryegrass are used as default for these four relatively insensitive parameters (Table 4).

Table 4. Recommended default values for parameters relating to vegetation in the VFS.

Parameter	Value	Units	Rationale
SS – average spacing of grass stems	1.63	cm	Value for perennial ryegrass; VFSMOD-W manual p.163
VN – filter media (grass) modified Manning's n	0.012	s $cm^{-1/3}$	Value for perennial ryegrass; VFSMOD-W manual p.163
H – filter grass height	10	cm	Expert judgement on worst-case value for a recently mown buffer
VN2 – bare surface Manning's n for sediment inundated area in grass buffer	0.05	s $m^{-1/3}$	Value for fallow soil with no residue; VFSMOD-W manual p.162

3.4 Miscellaneous

SCHK is a non-physical, non-sensitive parameter relating to the point in the VFS at which the model checks for ponding. It is recommended that this parameter is given the default value of 0.5 (checking occurs at the mid-point within the buffer).

4 Analysis of variation within the FOCUS R scenarios in soil hydraulic conductivity and water content at saturation

4.1 Spatial analysis of variation in soil hydraulic properties within the FOCUS R scenarios

A spatial analysis was undertaken for soil hydraulic conditions within the areas of Europe categorized as belonging to each of the FOCUS runoff scenarios (R1, R2, R3 and R4). Work was undertaken with ESRI ArcMap 9.3, Mathwave EasyFit 5.4 and its extension for MS Excel 2007. The following spatial datasets were used as input to the analysis:

- Shapefile sgdbe4_0 from the Soil Geographical Database of Eurasia at a scale of 1:1,000,000 (version 4 beta, 25/09/2001).
- The database SPADE2v11.dbf that is the SPADE-2 Version 1.1 database.
- The shapefiles containing the distribution of the FOCUS surface water scenarios (R1, R2, R3, R4v2; FOCUS, 2001; note that the latest versions for R1-R3 are v1, whereas that for R4 is v2).
- The Corine Land Cover map (CLC2000; seamless version May 2010).

4.1.1 Pre-processing of spade2v11.dbf

The database spade2v11.dbf contains 17,082 records and 37 fields defining location, area, land use, water regime, horizon nomenclature and soil properties. The primary key is unique combinations of land use (USE) within the soil typological units (STU) that make up each soil mapping unit (SMU). First, any updated information on soil use (USE_NEW) was copied across into the USE field and then a new field SMU-STU-USE was created as a unique key for database processing. A total of 62 duplicates of SMU-STU-USE were identified (Appendix 1) and eliminated from the database. The area associated with each SMU-STU-USE record was calculated by combining the area of the SMU with the percentage of that SMU comprising different STU's.

The VFSMOD-W model only considers the properties of the upper soil layers, so all horizons other than topsoil were removed from the database. Soils with Hystic or Organic layers were removed from the database as the former have little relevance to arable agriculture and the latter are not represented within the FOCUS R scenarios.

The SPADE database contains three fields relating to soil bulk density (DB, DB_CALC, DB_UK_PTF), but all values are set as missing for the Netherlands and Spain. Missing bulk density values were calculated using the SPAW model (Saxton and Rawls, 2006; Soil-Water Characteristics-Equations.xls; http://hydrolab.arsusda.gov/SPAW/SPAWDownload.html accessed 27 May 2011). The SPAW model calculated bulk density based on texture, sand content, clay content, organic matter content and gravel content of the respective horizon (Saxton and Rawls, 2006). Where any of these data were missing from the SPADE database, bulk density could not be calculated and the record was removed (n=3,652). Wilting point was an additional output of the calculation and quality control was also undertaken by checking for non-credible values for this parameter (again, any such records were deleted; n=137). Finally, the bulk density for use in subsequent calculations was selected in order of preference DB > DB_CALC > DB_UK_PTF > DB_SPAW.

4.1.2 *Calculation of soil hydraulic parameters*

Three soil hydraulic parameters were calculated for the topsoil horizon of each SMU-STU-USE record within the SPADE database. The HYPRES pedotransfer functions were used as these are the best validated and most widely accepted for use with European soils (Wösten and Nemes, 2004).

Saturated soil water content (θ_s, cm^3 cm^{-3}) was calculated from *bulk density* (g cm^{-3}) and percent *clay*, *silt* and organic matter (*OM*) according to:

$$\begin{aligned}\theta_s = 0.7919 &+ (0.001691 \cdot clay) - (0.29619 \cdot bulk\ density) - (0.000001491 \cdot silt^2) \\ &+ (0.0000821 \cdot OM^2) + (0.02427 \cdot clay^{-1}) + (0.01113 \cdot silt^{-1}) \\ &+ (0.01472 \cdot \ln[silt]) - (0.0000733 \cdot OM \cdot clay) \\ &- (0.000619 \cdot bulk\ density \cdot clay) - (0.001183 \cdot bulk\ density \cdot OM) \\ &- (0.0001664 \cdot topsoil \cdot silt)\end{aligned}$$

where *topsoil* is a qualitative operator taking the value 1 for all topsoils.

Saturated vertical hydraulic conductivity (K_s, cm d^{-1}) was also calculated from bulk density and percent clay, silt and organic matter:

$$\begin{aligned}K_s = 7.755 &+ (0.0352 \cdot silt) + (0.93 \cdot topsoil) - (0.967 \cdot bulk\ density^2) - (0.000484 \cdot clay^2) \\ &- (0.000322 \cdot silt^2) + (0.001 \cdot silt^{-1}) + (0.0748 \cdot OM^{-1}) - (0.643 \cdot \ln[silt]) \\ &- (0.01398 \cdot bulk\ density \cdot clay) - (0.1673 \cdot bulk\ density \cdot OM) \\ &+ (0.02986 \cdot topsoil \cdot clay) - (0.03305 \cdot topsoil \cdot silt)\end{aligned}$$

For consistency, soil water content at field capacity (θ_{fc}, cm^3 cm^{-3}) was calculated using van Genuchten's water retention parameters. First, van Genuchten's *α*, *m* and *n* were calculated using the HYPRES equations (Wösten and Nemes, 2004). θ_{fc} was then calculated as:

$$\frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \frac{1}{(1 + (\alpha \cdot h)^n)^m}$$

where θ_r is residual water content (cm^3 cm^{-3}), *h* is the soil water pressure (100 cm at field capacity) and *α*, *m* and *n* are empirical shape parameters.

4.1.3 *Identification of unique soils within the FOCUS R scenarios*

An initial check was undertaken to assess the spatial differentiation of the FOCUS R scenarios. It was found that the shapefiles have small areas where two R scenarios co-locate (Figure 4). This co-location was relatively minor in extent, but it should be considered that a small number of SMU-STU-USE records will be represented in either R2 and R4 scenarios or in R3 and R4 scenarios. This minor overlap arises due to the definitions of the shape files developed to support FOCUS SW rather any subsequent data handling associated with the research efforts described here.

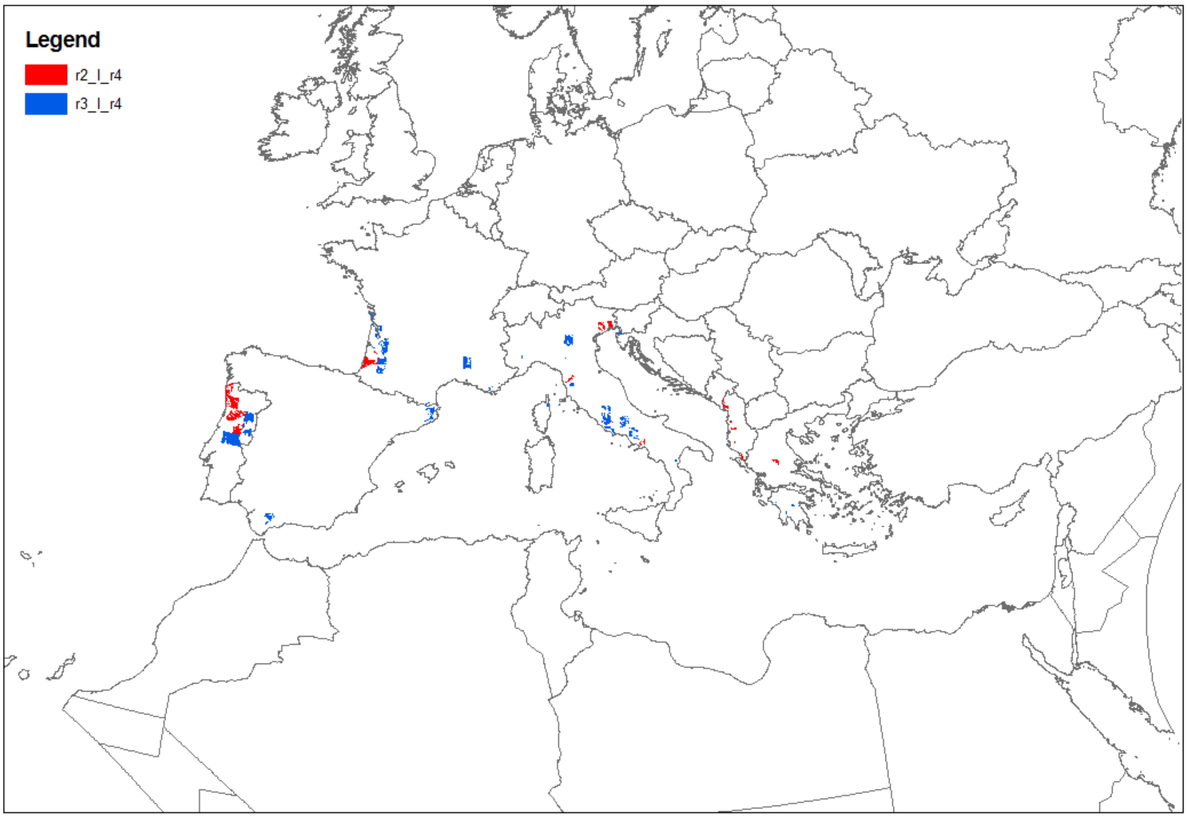
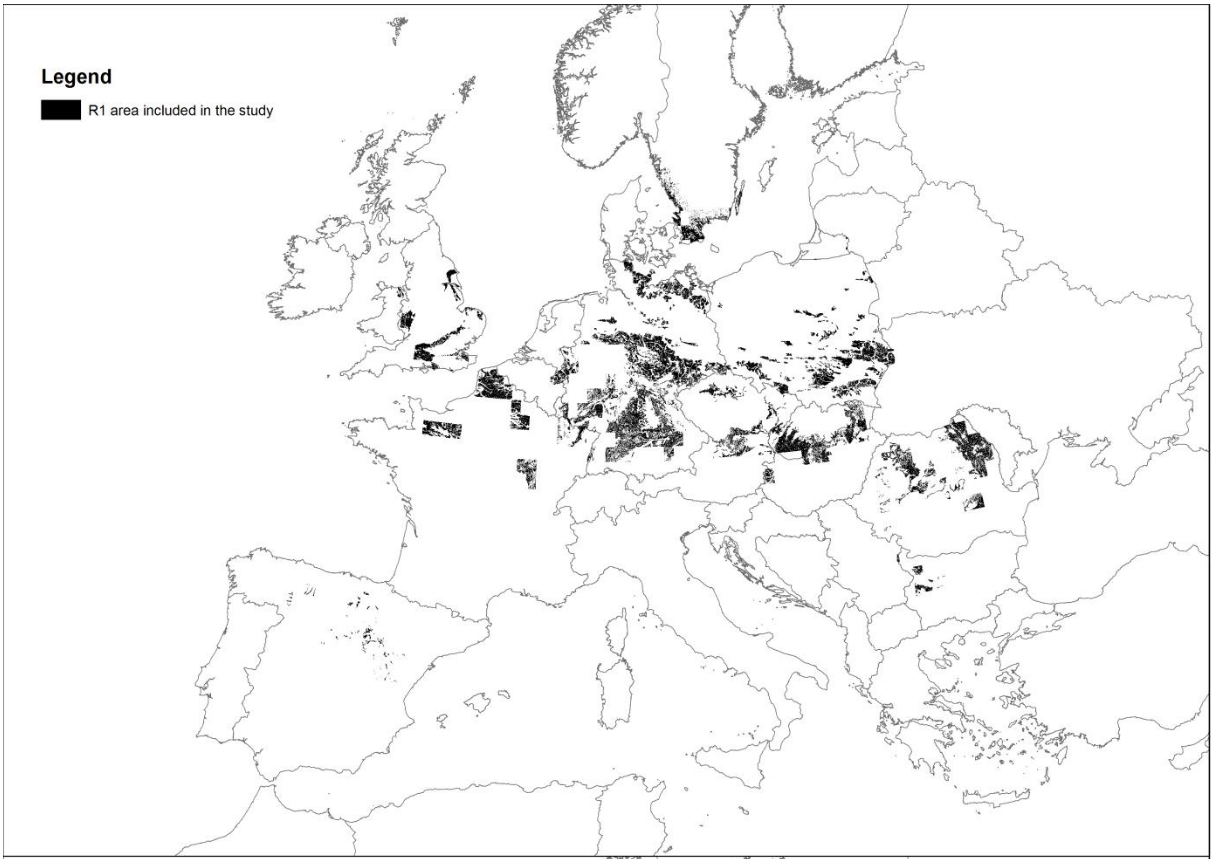


Figure 4. **Areas that are categorised as relevant to more than one FOCUS R scenario within the shapefile defining the distribution of the FOCUS surface water scenarios**

The soil geographical database of Eurasia (shapefile sgdbe4_0) was clipped with the agricultural area (class 2) of the Corine Land Cover map. The resulting shapefile was clipped with the shapefiles R1, R2, R3, R4v2 and the total polygon area was calculated. Finally, these clipped shapefiles were joined with the database derived from SPADE containing dominant land use and with soil hydraulic parameters calculated using the HYPRES methodology (Section 4.1.2). This process yielded final databases for each of the four FOCUS R scenarios containing unique SMU-STU-USE records with arable as the dominant land use. Each of these records was associated with the area contained within the FOCUS R scenario and the full set of soil properties and hydraulic parameters.

Figure 5 shows the spatial extent of the FOCUS R scenarios projected as the shapefiles derived for the current analysis. Some small areas of the original R scenarios were excluded because use of a finer-scale land use classification identified that no agricultural land was actually present and/or soils data were missing within the Soil Geographical Database of Eurasia.


Legend
R1 area included in the study


Legend
R2 area included in the study

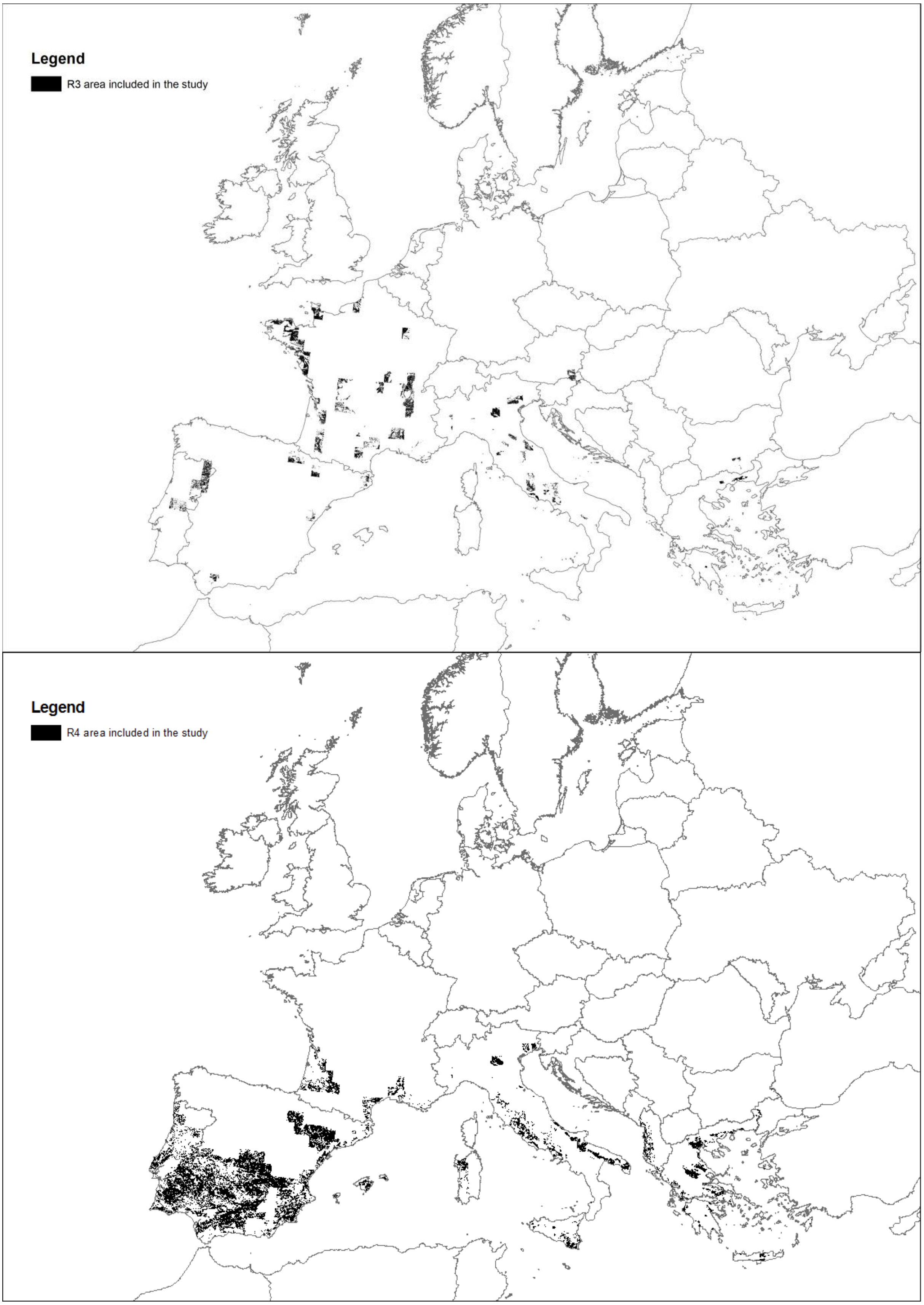


Figure 5. Comparison between spatial extent of the FOCUS R scenarios (FOCUS, 2001) and the study datasets

4.1.4 Assessment of distribution functions for K_s, θ_s and θ_{fc}

EasyFit 5.4 was used to fit log-normal functions to the distribution of K_s, θ_s and θ_{fc} within each FOCUS R scenario and with the area of each SMU-STU-USE record used as density:

$$f(x) = \frac{exp\left(-\frac{1}{2}\left(\frac{lnx-\mu}{\sigma}\right)^2\right)}{x\sigma\sqrt{2\pi}}$$

Results are given in Table 5. Figure 6 and Figure 7 compare histograms for K_s and θ_s in individual STU's with the log-normal distributions fitted to these data. In several cases, data availability is a limitation on the agreement between the histogram and the fitted distribution; this is particularly the case for R2 where only 69 unique STU's were present.

Table 5. Numbers of unique STU's and descriptive statistics defining log-normal functions for the distributions of K_s, θ_s and θ_{fc} within each FOCUS R scenario

Scenario	n	K_s (cm d^{-1})		Θ_s (cm^3 cm^{-3})		Θ_{fc} (cm^3 cm^{-3})	
		Mean	St. dev.	mean	St. dev.	mean	St. dev.
R1	348	23.075	20.307	0.458	0.038	0.377	0.049
R2	69	98.626	77.479	0.478	0.044	0.336	0.059
R3	171	49.487	59.455	0.456	0.045	0.347	0.060
R4	222	53.934	56.329	0.433	0.054	0.325	0.068

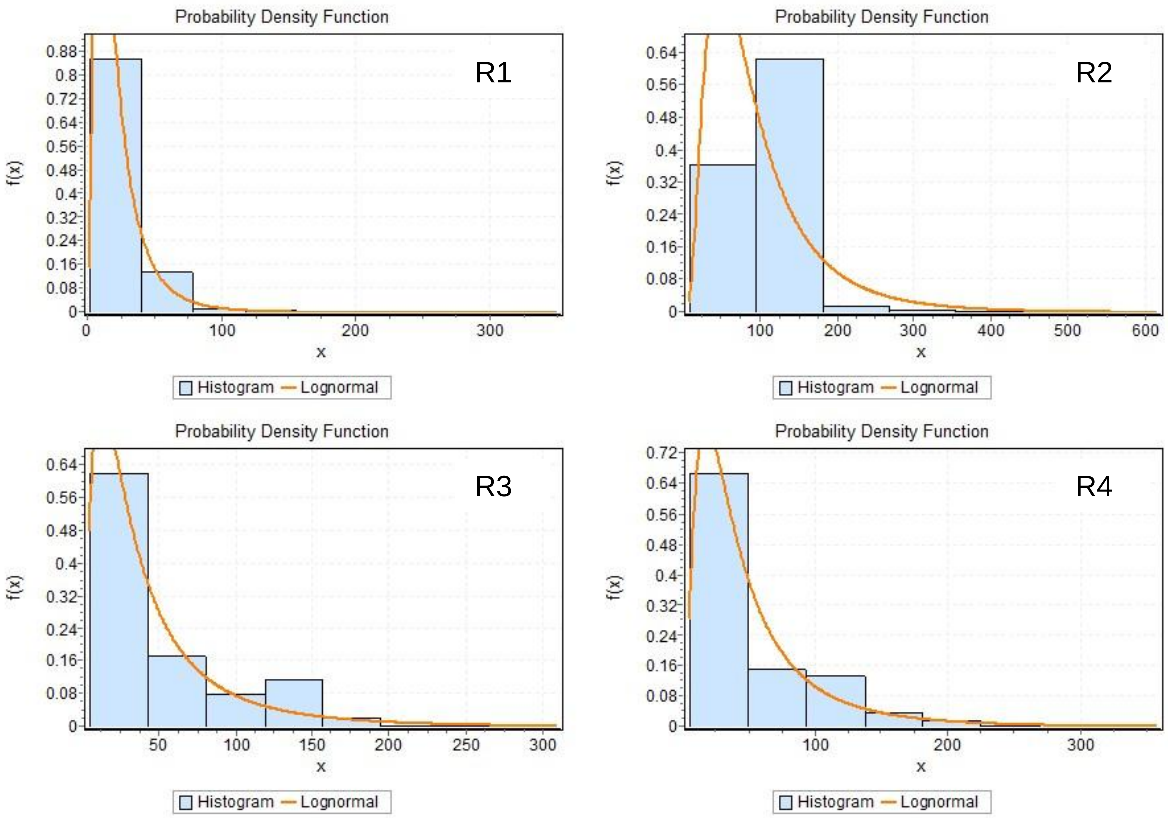


Figure 6. Histograms and fitted log-normal distributions for the variation in K_s (cm d^{-1}) across the four FOCUS R scenarios (soil typological units weighted by area represented)

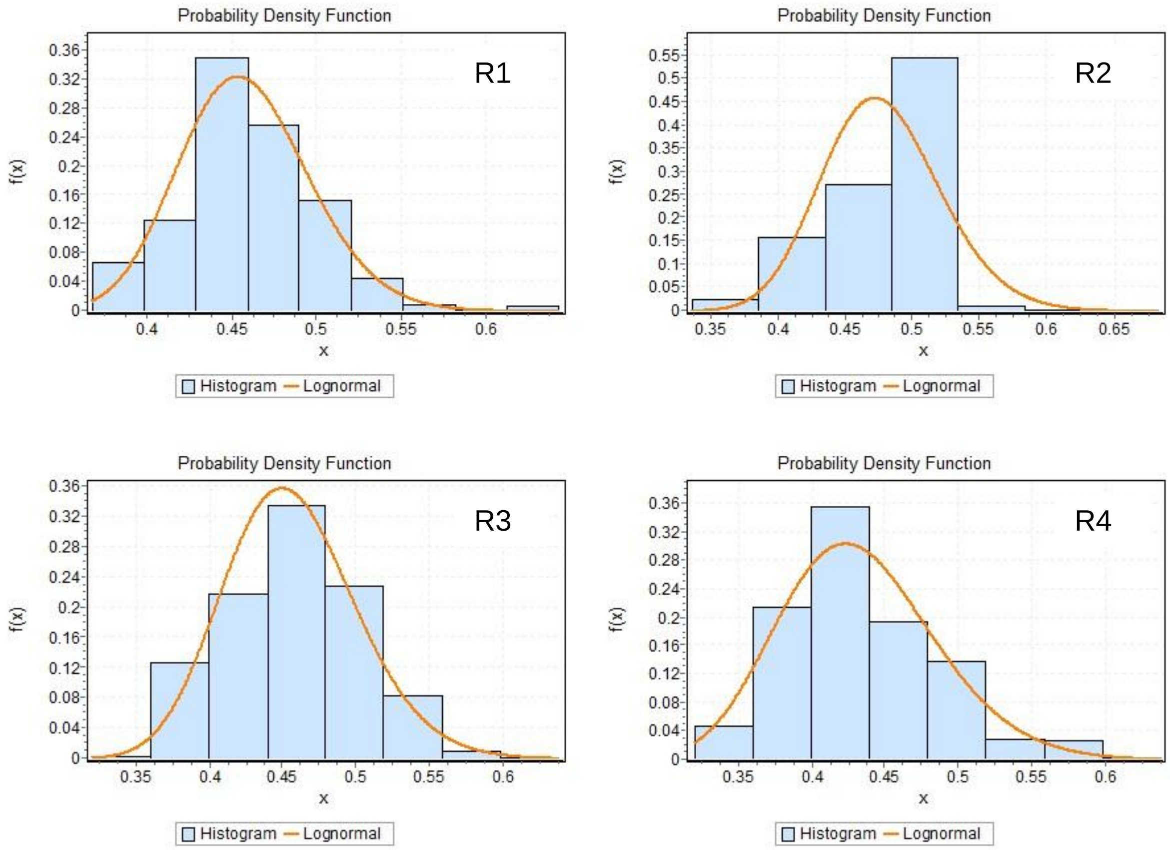


Figure 7. **Histograms and fitted log-normal distributions for the variation in θ_s (cm^3 cm^{-3}) across the four FOCUS R scenarios (soil typological units weighted by area represented)**

4.2 Modelling with VFSMOD-W to define conservative values for K_s and θ_s

Model simulations were undertaken to assess how VFS efficiency for pesticide removal from runoff/eroded sediment varied with variation in K_s and θ_s. This allowed non-linearities in system behaviour and any effects of soil type, runoff volume, eroded mass and pesticide properties to be factored into the definition of reasonable worst-case values for these two parameters.

The number of unique STU's within each FOCUS scenario was considered insufficient to assign robust log-normal distributions to the datasets (Figure 6 and Figure 7). In addition, there is a close correlation between K_s and θ_s. Hence it was decided to run model simulations with all unique combinations of soil typological unit (STU) represented within the respective scenario rather than sampling from the statistical distributions given in Table 5. Thus results are based on between 69 and 348 simulations per scenario (Table 5).

4.2.1 Generation of run-on hydrographs

The UH utility that is supplied with VFSMOD-W was used to generate runoff hydrographs and rainfall hyetographs for use as input to VFSMOD-W. Separate simulations were undertaken for each FOCUS R scenario, using the characteristics of the FOCUS R scenarios as the basis for parameterisation (Table 6).

Table 6. Parameter values used for UH simulations for the four FOCUS R scenarios

Parameter	Unit	R1	R2	R3	R4	Justification
Curve number	(-)	86	83	86	86	FOCUS SWS report (residue value as intermediate between fallow and cropping)
Slope	(-)	0.03	0.05	0.05	0.05	FOCUS SWS report
Soil erodibility (K)	t.ha.h/ ha.MJ.mm	0.055	0.025	0.033	0.034	FOCUS values (multiply by 0.1317 to convert units; VFSMOD-W manual p25)
Soil type	(-)	Silt loam	Sandy loam	Clay loam	Sandy clay loam	FOCUS SWS report
Organic matter	%	2.1	6.7	1.7	1	FOCUS SWS report (%OC*1.72)
Crop factor (C)	(-)	0.4	0.4	0.4	0.4	FOCUS SWS report (residue value as intermediate between fallow and cropping)
Particle class diameter (dp)	cm	0.002	0.002	0.002	0.002	Current review (see Section 5.2)
Storm type	(-)	II	IA	II	IA	FOCUS SWS report Appendix D

It was originally decided to generate two hydrographs for each scenario based on 20 mm rainfall over periods of either 1 or 8 hours. The purpose of this was to evaluate the influence of different VFS parameter sets under contrasting runoff conditions. The 20 mm rainfall event was found to generate relatively little runoff and some of the subsequent VFSMOD-W simulations gave 100% removal of pesticide (e.g. for R2 soils). This meant that relative vulnerability of different VFS parameter sets could not be evaluated. To counteract this, UH simulations were revised based on 30 mm rainfall over periods of 1 or 8 hours. These are entirely artificial events, but the high-intensity, short-duration event (30 mm in 1 hour) is conceptualised as a convection-storm event as occasionally occurs in European summers whilst the low-intensity, long-duration event (30 mm in 8 hours) is conceptualised as a depression-led rainfall event. Additional simulations were undertaken with a 20-mm and 40-mm event to check the influence on pesticide removal efficiency and relative vulnerability of different soil types.

Rainfall frequency data for a variety of European locations are summarised in Table 7. These show that 30 mm rainfall over 8 hours is a frequent event, occurring approximately once a year in Weiherbach, Germany and much more frequently at the selected locations in France and Italy. 30 mm rainfall over 1 hour occurs roughly once every 6-13 years at the selected locations in France, Germany and Italy, whereas it is a very infrequent event at Birmingham.

Table 7. **Return periods for rainfall events of 30 mm over 1 or 8 hours at different locations across Europe**

Location	Return period (years) for storm event of	
	30 mm over 1 hour	30 mm over 8 hours
Chiroubles, Beaujolais, France	ca. 13	<<1[a]
Weiherbach, Germany	9	ca. 1
Osimo, Marche, Italy	ca. 6	<<1
Birmingham, UK	25	ca. 4

[a] Frequency of seven times per annum for the period 1995-2007

4.2.2 Methodology for VFSMOD-W simulations

VFSMOD-W simulations were undertaken to select conservative values of saturated hydraulic conductivity and saturated water content. Separate simulations were undertaken for all unique soil units within each of the four FOCUS R scenarios. The parameters derived from the SPADE database for each soil unit were:

- K_s derived according to the HYPRES pedotransfer functions
- θ_s also derived according to HYPRES
- θ_{fc} derived from van Genuchten parameters.

VFSMOD-W requires a value for volumetric soil water content at the start of the runoff event. Soil water content at a given tension is correlated with θ_s, so it would be inappropriate to use a constant value for initial soil water content that was independent of θ_s. To ensure consistency between simulations, the initial water content was taken to be the water content at field capacity (θ_{fc}) for the respective soil unit. Conceptually, this errs on the side of conservatism and is considered an appropriate means of addressing uncertainties with definition of initial conditions.

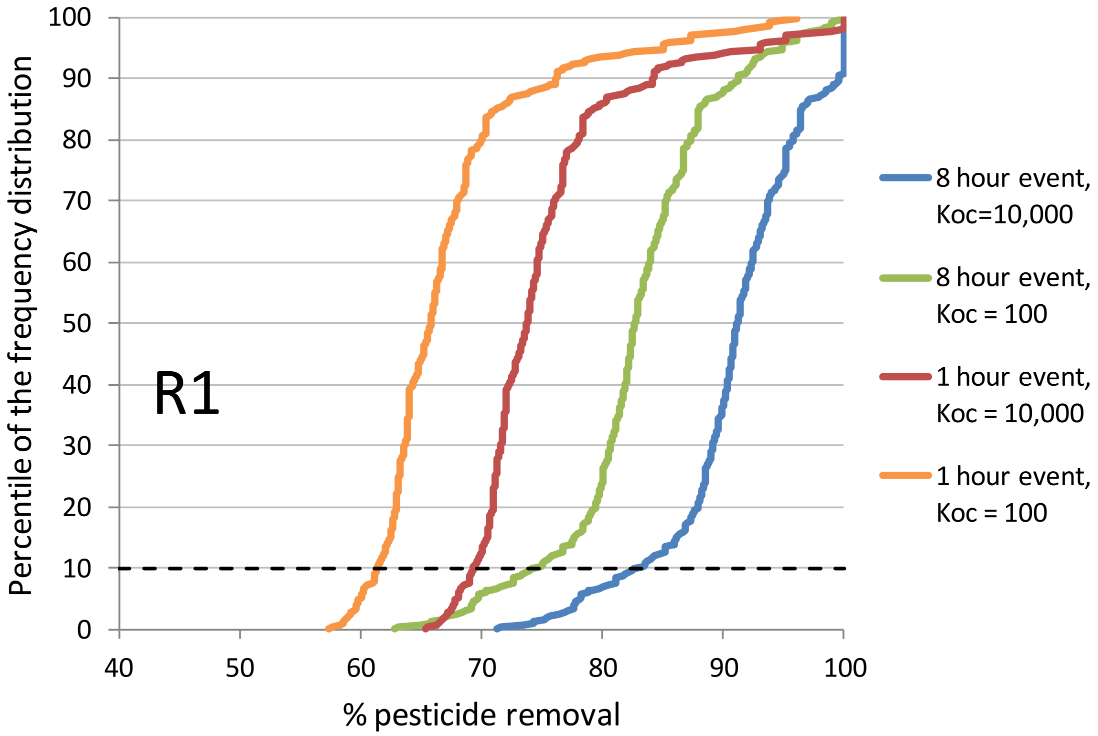
All simulations were undertaken for pesticides with Koc of 100 and 10,000 L kg^{-1} to evaluate vulnerability for runoff of contrasting compounds. This yielded four sets of simulations for each of the four FOCUS R scenarios as summarised in Table 8. All other VFSMOD-W parameters were set constant for the respective FOCUS R scenario as described in Section 3 and summarised in Table 10.

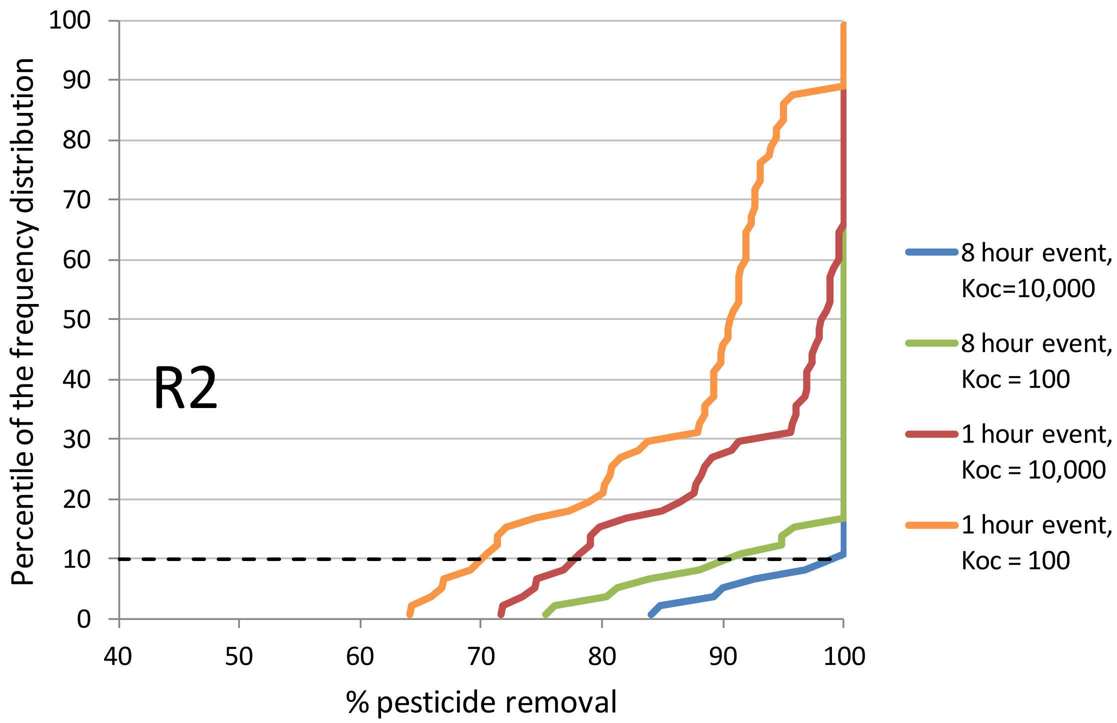
Table 8. **Summary of VFSMOD-W simulations**

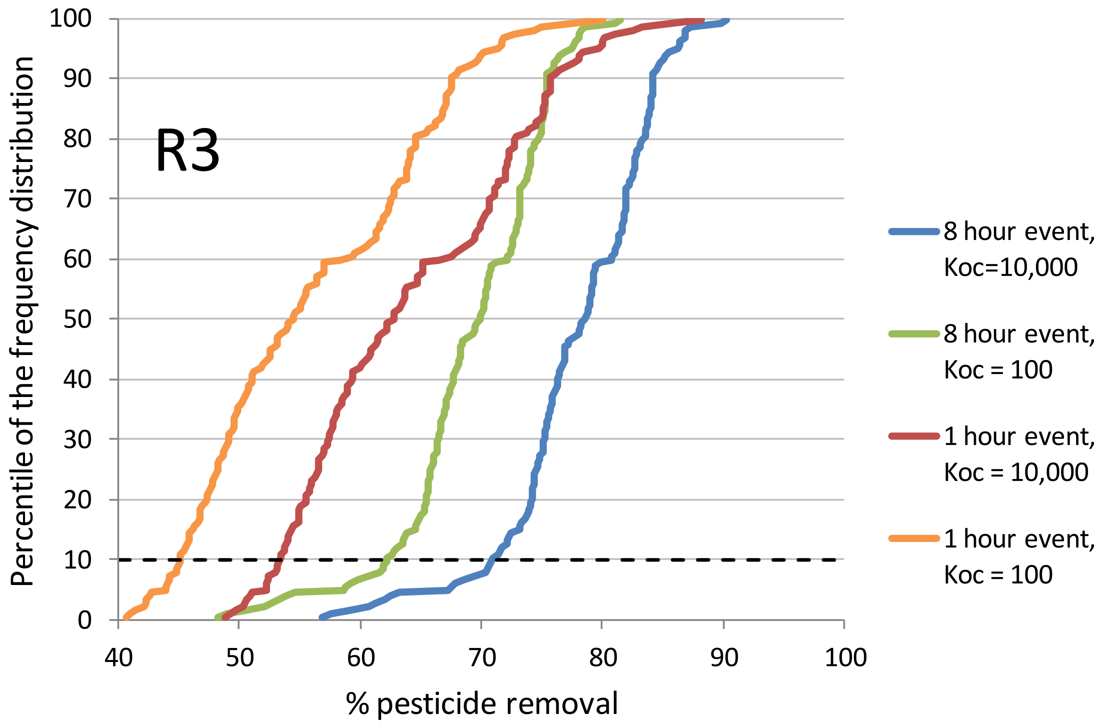
FOCUS R scenario	Pesticide Koc (L kg^{-1})	Rainfall duration (h)	Rainfall amount (mm)	Buffer size (m)	Number of simulations per set
R1	100 or 10,000	1 or 8	30	10	348
R2					69
R3					171
R4					222

4.2.3 Results for VFSMOD-W simulations

Figure 8 gives frequency distributions for pesticide removal within the VFS (ΔP) for the four simulations for each FOCUS R scenario. Pesticide removal for the equivalent simulation set was least for R3, greatest for R2 and intermediate for R1 and R4. ΔP was consistently smaller for the simulations with pesticide Koc of 100 L kg^{-1} than for those with Koc of 10,000 L kg^{-1}.







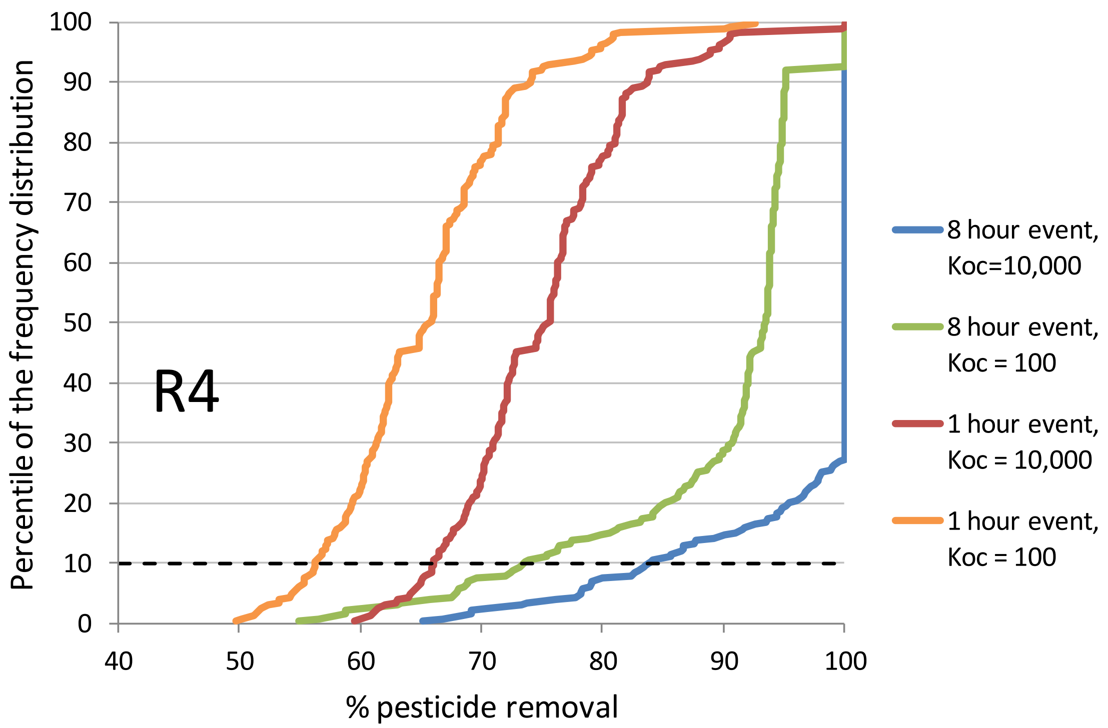


Figure 8. **Frequency distributions for four sets of simulations for each of the FOCUS R scenarios. Each set comprises 348, 69, 171 or 222 simulations, one for each unique soil unit within the R1, R2, R3 or R4 scenarios, respectively. The dashed horizontal line indicates the 90th percentile worst-case of the distribution.**

An additional set of simulations was undertaken for the R1 scenario to investigate the effect of alternative assumptions on predictions for ΔP. Figure 9 shows that there is a marked influence on ΔP from changing either the total volume of rainfall or the size of the VFS.

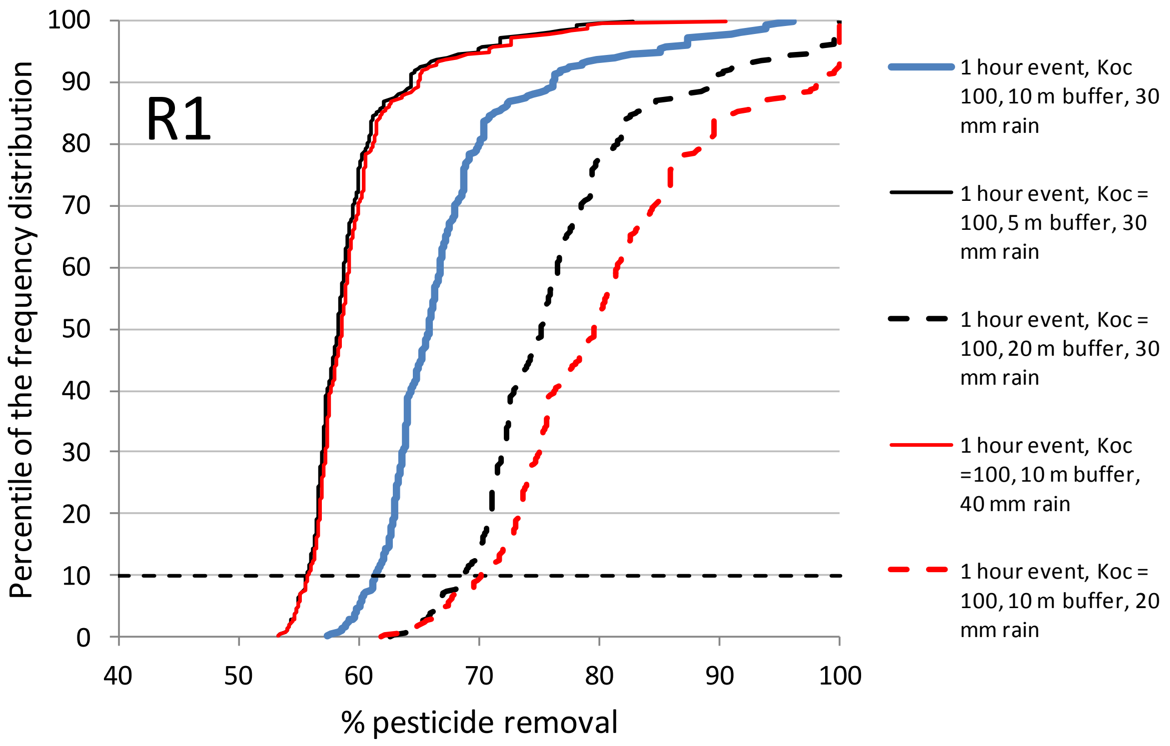


Figure 9. **Extension of the analysis of influence of input parameters on reduction in pesticide load across the vegetative filter strip for the R1 scenario. The figure shows the frequency distributions for the simulation shown in Figure 8 (1 hour event, Koc = 100 L kg^{-1}, 30 mm rainfall), and extends to show the influence of (i) changing the buffer size from 10 m to either 5 or 20 m; and (ii) changing the rainfall amount from 30 mm to either 20 or 40 mm. The dashed horizontal line indicates the 90th percentile worst-case of the distribution.**

The simulation sets undertaken with the FOCUS R scenarios can be used to define realistic worst-case values for the soil hydraulic parameters. An important consideration for this is whether the same set of hydraulic parameters provides a realistic worst-case independent of the simulation characteristics. This was investigated through a ranking exercise. The relative vulnerability of each separate soil typological unit was calculated for each individual set of simulations (e.g. R1 – 30 mm rain over 1 hour – Koc = 100 L kg^{-1} – 10 m VFS). The relative vulnerability was then compared between different simulation sets to evaluate how ranking varied with the simulation characteristics.

Figure 10 shows that the relative vulnerability of the different STU's is almost identical for simulations with different volumes of rainfall over the same period. Figure 11 shows the same identical vulnerability for a relatively mobile pesticide and an immobile pesticide (Koc = 100 and 10,000 L kg^{-1}, respectively). Rainfall intensity had a slightly larger influence on the relative vulnerability at STU's, although ranking was identical at the extremes of the distribution (Figure 12). Finally, there were no differences in vulnerability of the different STU's when simulations considered VFS with different sizes (Figure 13). The data presented indicate that simulation characteristics have almost no influence on the relative vulnerability of different soil typological units. It is thus valid to define generalised VFS scenarios with respect to soil hydraulic parameters that will represent realistic worst-case conditions across the range of situation for which they may be used.

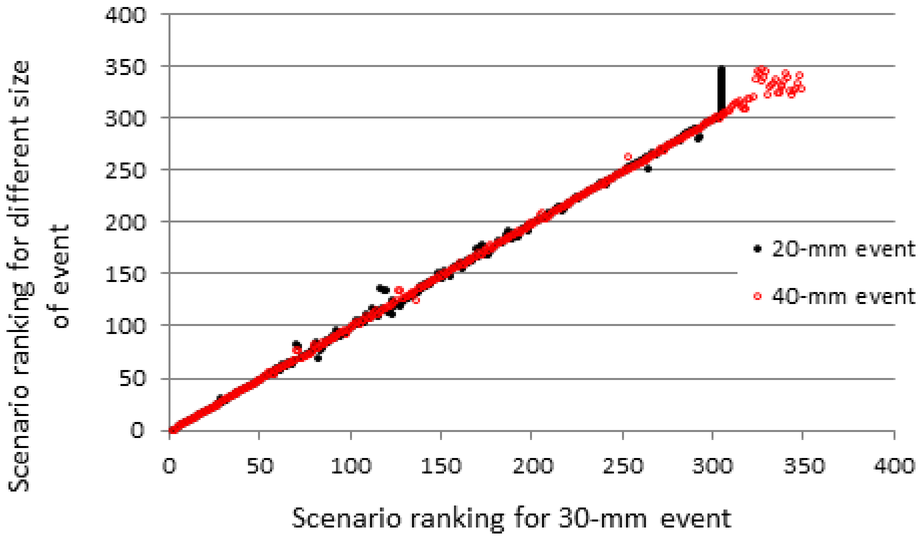


Figure 10. Relative vulnerability of individual soil typological units categorised by ΔP for simulations with FOCUS R1, 10 m buffer, a given rainfall event over 1 hour and pesticide Koc 100 L kg-1. Relative vulnerability with rainfall amount of 20 or 40 mm are plotted against those with rainfall of 30 mm (points on the 1:1 line have identical relative vulnerability).

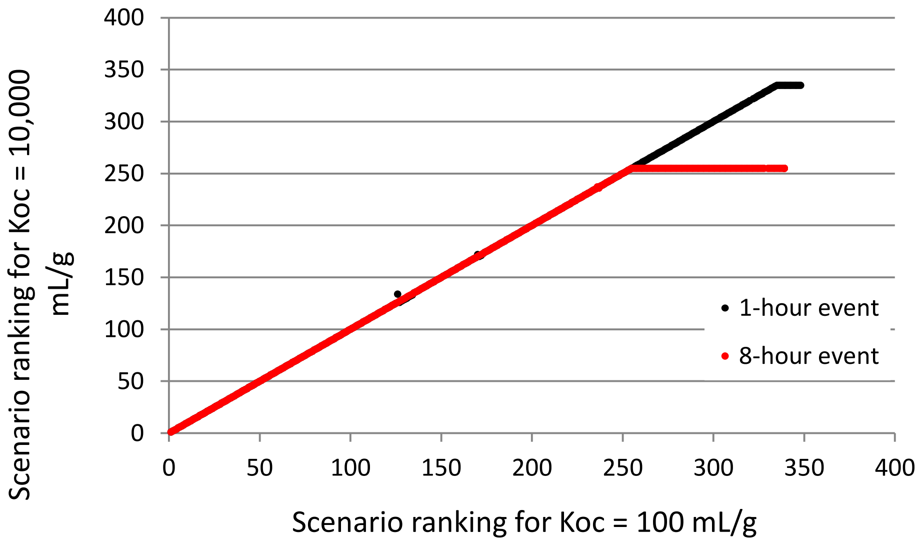


Figure 11. Relative vulnerability of individual soil typological units categorised by ΔP for simulations with FOCUS R1, 10 m buffer, and a 30-mm rainfall event. Relative vulnerability for pesticides with contrasting Koc are plotted for simulations based on an event lasting either 1 or 8 hours (points on the 1:1 line have identical relative vulnerability).

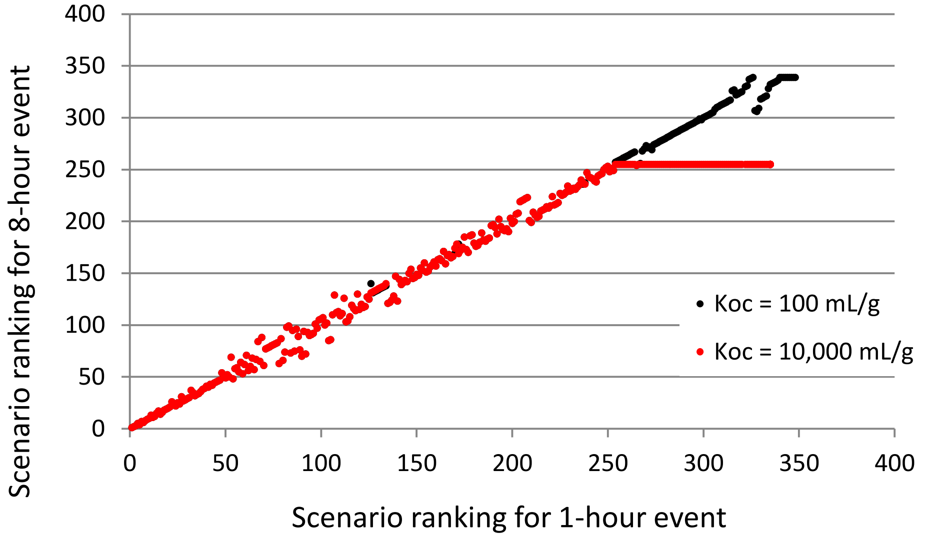


Figure 12. **Relative vulnerability of individual soil typological units categorised by ΔP for simulations with FOCUS R1, 10 m buffer, and a 30-mm rainfall event. Relative vulnerability for events of contrasting length are plotted for simulations based on pesticide Koc of either 100 or 10,000 L kg^{-1} (points on the 1:1 line have identical relative vulnerability).**

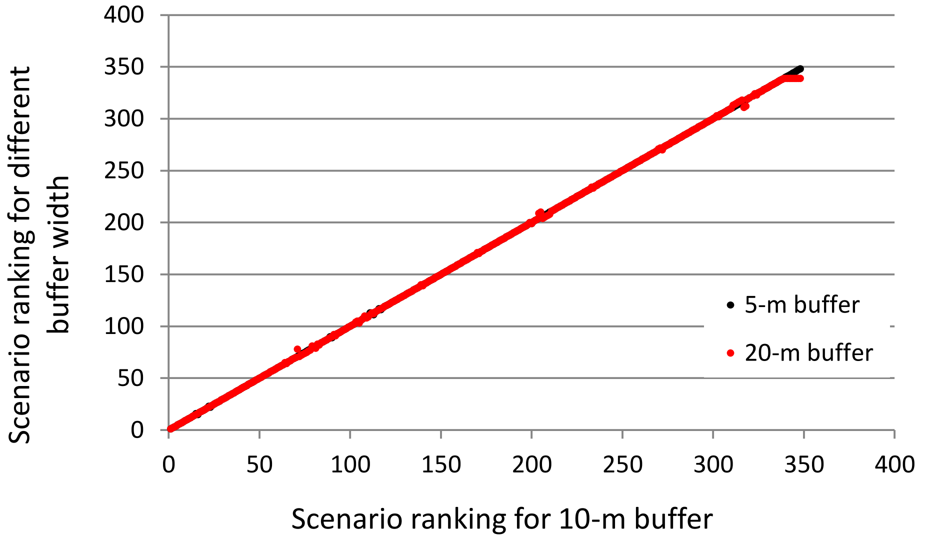


Figure 13. **Relative vulnerability of individual soil typological units categorised by ΔP for simulations with FOCUS R1, 30 mm rainfall over 1 hour and pesticide Koc 100 L kg^{-1}. Relative vulnerability with buffer size of 5 or 20 m are plotted against those with buffer size of 10 m (points on the 1:1 line have identical relative vulnerability).**

Figure 14 shows how pesticide removal efficiency varies with soil hydraulic properties of the VFS. There is a strong relationship between ΔP and K_s for each of the FOCUS R scenarios and this relationship is modified by the characteristics of each scenario. In contrast, there is no direct relationship between ΔP and either θ_s or θ_{fc}. The results shown in Figure 14 reflect the outcome of the sensitivity analysis reported by Muñoz-Carpena et al. (2010; Section 2).

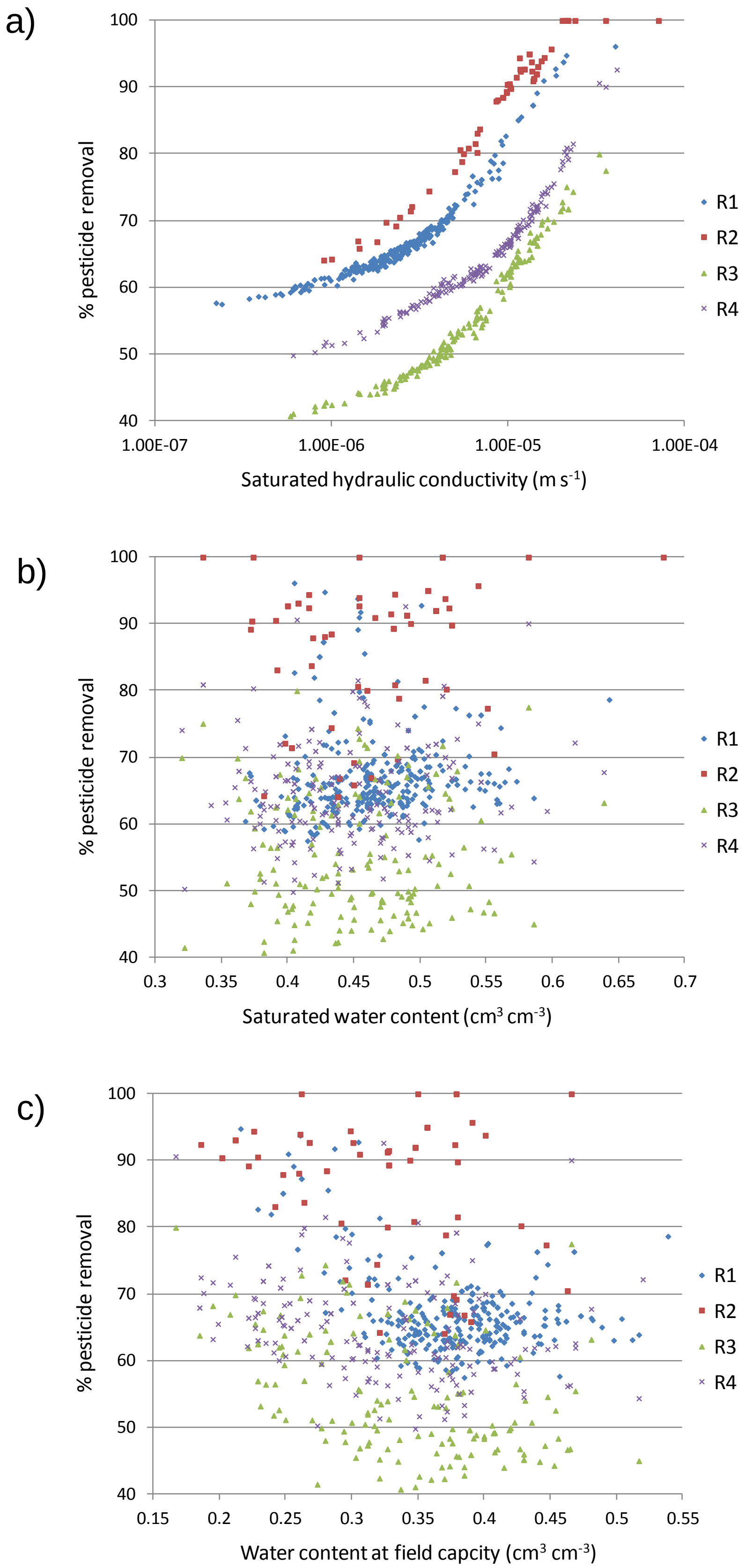


Figure 14. **Graphs showing change in % pesticide removal across the VFS as a function of a) K_s, b) θ_s and c) θ_{fc}. Graphs compare simulations for the four FOCUS R scenarios with 30 mm rainfall over 1 hour, a 10-m VFS and a pesticide with Koc = 100 L kg^{-1}**

The regulatory precedent is to aim for a 90th percentile worst-case output for the calculation of predicted environmental concentrations for pesticide risk assessment; this has been achieved by selecting appropriate values for chemical properties, scenario characteristics and model output (e.g. FOCUS 2000; FOCUS 2001). Given the sensitivity of soil hydraulic parameters within VFSMOD-W, it was decided that the parameter combination generating a 90th percentile worst-case output from the model should be used in defining a realistic worst case for soil hydraulic parameters within VFS. Table 9 shows three different versions of this calculation. The first two sets of calculations are based on model simulations and consider actual combinations of K_s, θ_s and θ_{fc} (i.e. the soil typological unit representing the 90th percentile worst-case). The first is based on an area-weighted approach whereby the proportion of each FOCUS R scenario represented by each STU is used to weight the frequency distribution curve. The second model-based simulation assumes that each STU counts equally into the frequency distribution independent of the proportion of the FOCUS R scenario that it represents. Finally, Table 9 provides the 90th percentile hydraulic parameters calculated from the log-normal frequency distributions presented in Table 5. In this instance, the hydraulic parameters are treated independently and cannot be expected to co-occur in the field, making this option unrealistic.

The appropriate values for use in VFS scenarios for Europe are those calculated based on VFSMOD-W simulations and weighted by area (shown in bold). This is because the area-weighted approach takes full account of the relative prevalence of each soil type within the FOCUS R scenario. Table 9 indicates that these values are either very similar to or more conservative with respect to K_s than the other two calculations.

Table 9. 90th percentile values for saturated hydraulic conductivity and soil water content at saturation and field capacity for the four FOCUS R scenarios. Values are either derived from VFSMOD-W simulations weighted by area of the soil or by ranking unique soils or are calculated directly from lognormal distributions for each parameter across each R scenario (note that the latter are three independent distributions for the three parameters, so do not constitute a realistic combination if taken together)

Parameter	R1	R2	R3	R4
90th percentile from VFSMOD-W simulations (weighted by area)				
K_s (m s^{-1})	**7.04×10^{-7}**	**2.79×10^{-6}**	**9.25×10^{-7}**	**1.52×10^{-6}**
θ_s (cm^3 cm^{-3})	**0.447**	**0.403**	**0.472**	**0.420**
θ_{fc} (cm^3 cm^{-3})	**0.395**	**0.312**	**0.385**	**0.372**
90th percentile from VFSMOD-W simulations (soil ranking)				
K_s (m s^{-1})	9.57×10^{-7}	2.43×10^{-6}	1.77×10^{-6}	2.54×10^{-6}
Θ_s (cm^3 cm^{-3})	0.478	0.556	0.415	0.374
Θ_{fc} (cm^3 cm^{-3})	0.397	0.463	0.321	0.283
90th percentile from probability density function				
K_s (m s^{-1})	7.59×10^{-7}	3.69×10^{-6}	1.09×10^{-6}	1.44×10^{-6}
Θ_s (cm^3 cm^{-3})	0.411	0.423	0.400	0.367
Θ_{fc} (cm^3 cm^{-3})	0.317	0.264	0.274	0.244

4.3 Influence of conversion of arable land to grassland on soil hydraulic parameters

The distributions for saturated hydraulic conductivity and saturated soil water content derived in Section 4.1 are based on values for soils under arable cultivation. Conversion of arable land to permanent, managed grassland as for vegetative filter strips will tend to increase soil porosity due to absence of ploughing and other soil cultivation, increase in organic matter content of the soil and increase in activity of soil macro- and microfauna. This increase in porosity leads to an increase in both saturated hydraulic conductivity and saturated soil water content. Thus both K_s and θ_s are expected to increase over time in the vegetative filter strip relative to values in the bulk arable field. A review of available data was undertaken to determine whether this effect should be incorporated into the parameterisation of VFS scenarios.

The SEISMIC soils database provides soil properties for a large set of soils series in England and Wales (Hallett et al. 1995). The database provides soil properties for the different land uses, whether arable land or permanent grassland. The soil properties under permanent grassland give an indication of the soil properties under an established grass buffer strip.

It is important to note that some soil properties in SEISMIC were calculated using pedotransfer functions (Hallett et al. 1995). For example the bulk density values in SEISMIC are predicted from the soil texture and OC%, and water retention characteristics were predicted from bulk density, organic carbon, clay, silt and sand content. Then the saturated hydraulic conductivities (K_s) were predicted from the saturated moisture content and the field capacity of the soils. The pedotransfer functions were derived from measured data for some of the soil series, taking into account different land uses (arable, rotational grassland, permanent grassland or other).

To quantify the effect of the vegetation on the soil properties, a comparison was made between the soil properties under arable land and under grassland in SEISMIC. Not all 434 soil series are suitable for arable crops and grassland; properties for both arable and grassland soils were available for 352 soil series. Organic soils (peats) were omitted from the comparison. Figure 15 shows the comparison of the saturated hydraulic conductivities (K_s) between grassland and arable land. The saturated conductivity is generally larger for grassland than for arable soils. The trendline suggests that it is on average a factor 1.5 larger.

Figure 16 identifies a possibility for a realistic worst-case estimate of K_s within a VFS. The worst-case situation is that saturated conductivity in the VFS equals that in the bulk field and this is likely to be the case in freshly-constructed VFS. A more realistic conservative estimate that is relevant to established VFS would be to assume that the K_s in the VFS is increased by a factor of 1.2 relative to the bulk field. A total of 9.9% of the 351 datapoints represented in Figure 16 lie below the line where K_s under grass is 1.2 times larger than that under arable crops. The soils beneath the line have particularly large organic carbon content and/or particularly large K_s under both land uses; neither of these situations is expected to be particularly vulnerable for losses of pesticide in surface runoff.

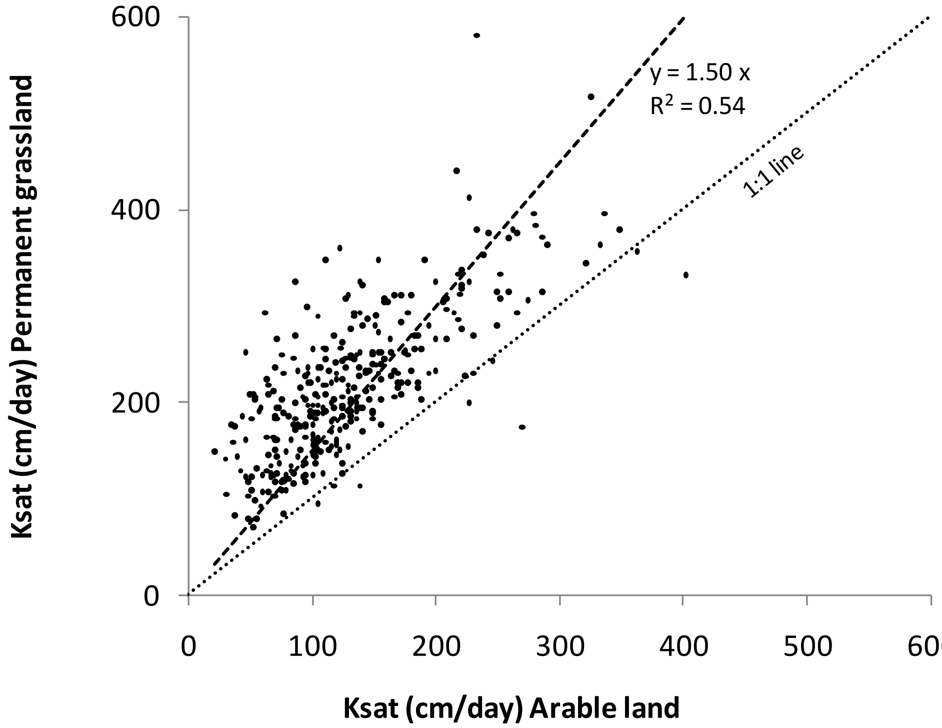


Figure 15. **Comparison of saturated hydraulic conductivities (K_s) for soils under permanent grassland and for arable soils (data from SEISMIC). Each dot represents one of the soil series. Dashed line is the best-fit-regression**

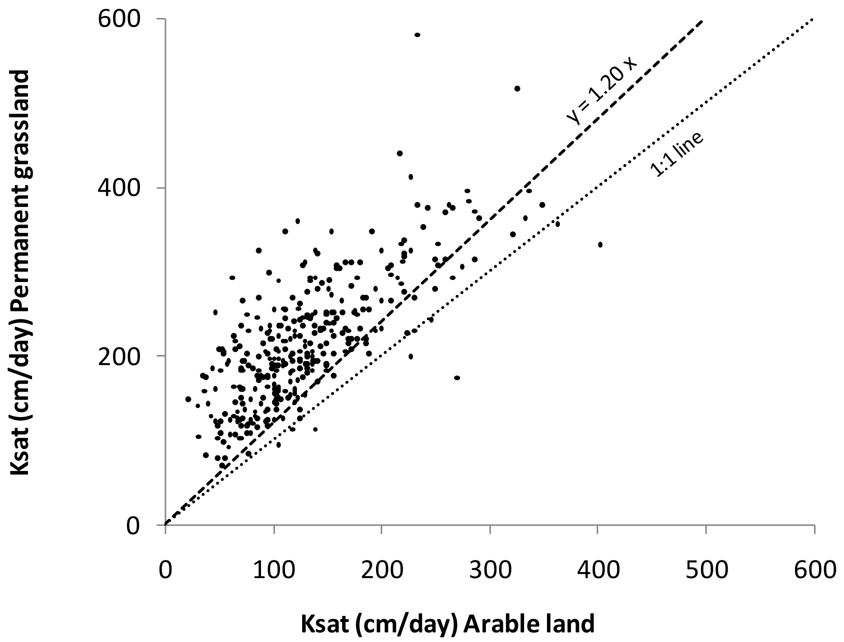


Figure 16. **Proposed approach to a realistic worst-case estimate of K_s within established vegetative filter strips based on the assumption that K_s in the VFS is 1.2 times larger than that in the bulk arable soil**

Figure 17 shows the comparison of the saturated soil water content between grassland and arable land. The saturated moisture content is generally larger for grassland than for arable soils. The trendline suggests that it is on average a factor 1.11 larger. A conservative estimate for the saturated moisture content within an established VFS is suggested in Figure 18. A conservative estimate would be that the saturated moisture content (%) is only 2% larger than in the bulk field soil. In this instance, 6.9% of the 351 soil series lie beneath the line representing field θ_s + 2%. Again, these soils tend to be characterised by relatively large organic carbon content.

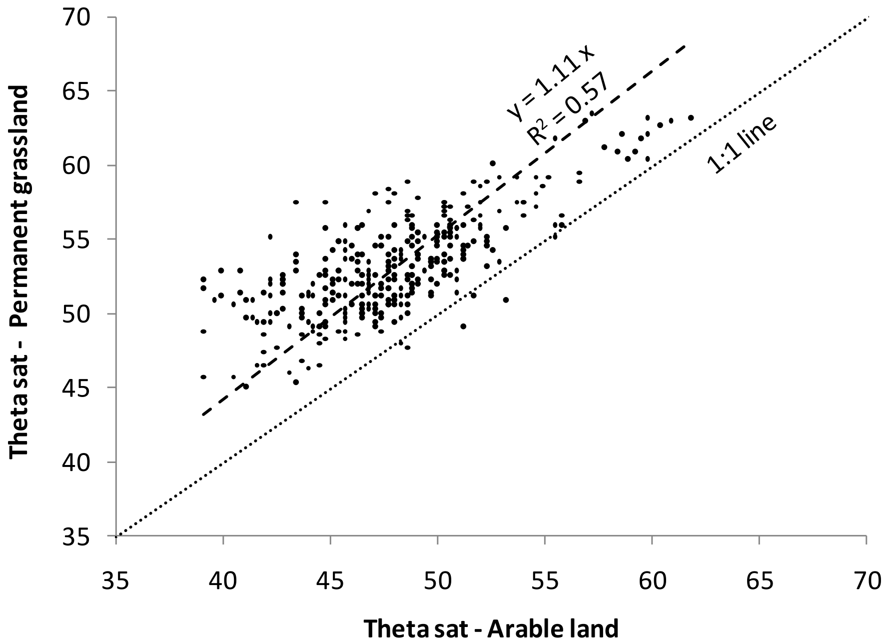


Figure 17. Comparison of saturated water content (θ_s, %) for soils under permanent grassland and for arable soils (data from SEISMIC). Each dot represents one of the soil series. Dashed line is the best-fit regression.

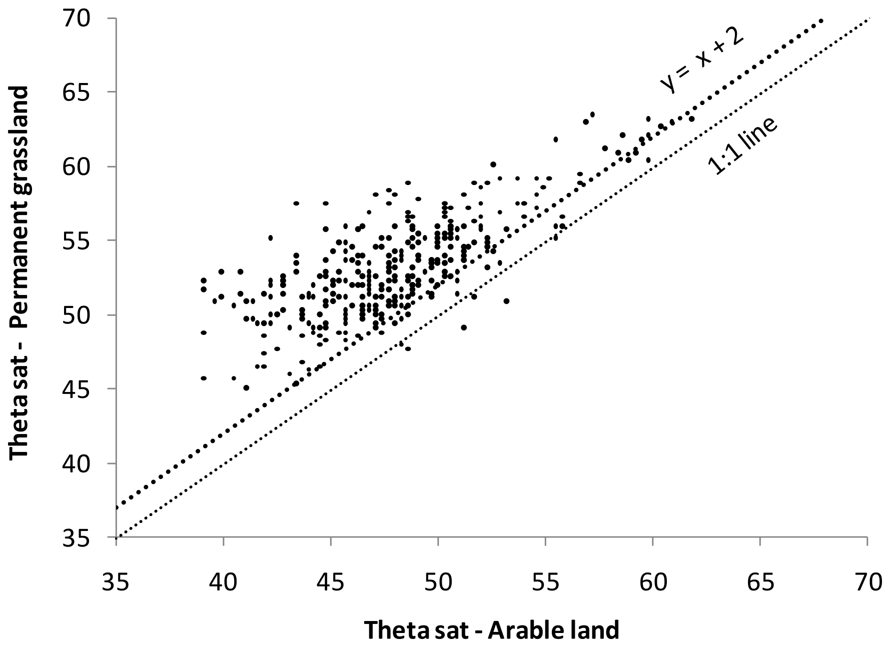


Figure 18. Suggested conservative estimate for saturated water content (θ_s, %) in the grass buffer strip

4.3.1 Conclusion regarding changes to hydraulic parameters within vegetative filter strips

Soils within established VFS can be expected to have larger K_s and θ_s relative to the same soil under arable cultivation. Larger values for these two input parameters will increase the efficiency of the VFS in reducing pesticide loading in runoff that is simulated by VFSMOD-W. This is particularly the case for Ks because of the sensitivity of model output to this parameter.

The literature review did not yield any examples where soil hydraulic parameters had been measured at a single site under grassland and arable cultivation. The soil database system SEISMIC provides an indication of the likely change in hydraulic parameters with change in land use. Risk assessment for pesticides will need to consider a range of VFS situations for mitigation of pesticides. The worst-case will be newly-installed VFS where little change in hydraulic properties can be expected relative to the same soil under arable cultivation. It is recommended that the default modelling assumption is that K_s and θ_s within the VFS are the same as those under arable cultivation (Section 4.1). However, it should be recognised that this introduces a significant element of conservatism into the modelling where simulations are considering established vegetative filter strips.

The efficacy of vegetated filter strips in removing water and sediment may change over time if they become partially blocked with sediment. This process is explicitly simulated by VFSMOD-W both within individual events and across multiple events. Hence, it was not considered within the selection of input parameters to the model.

5 Properties of eroded sediment

FOCUS (2001) defines properties of the parent soil for the four FOCUS R scenarios. Eroded sediment may have different characteristics to the parent soil due to (i) the action of rainfall in breaking up aggregates and dislodging particles, and (ii) the kinetic energy of overland flow to carry particles of different sizes and densities. In general, eroded sediment will be enriched in organic matter and clay fractions relative to the bulk soil. The average size of eroded particles will be less than that of soil aggregates in the bulk soil, but greater than that of the individual sand, silt and clay particles as there will likely still be some aggregation in the eroded sediment. The extent of any enrichment and differentiation in particles that can be carried in surface runoff will be a function of runoff intensity (less enrichment/differentiation in more intense runoff events), but also a function of the properties of the parent soil, the site (e.g. slope) and the energy of falling rain droplets.

The average diameter of eroded sediment particles (DP) and the percentage clay in eroded sediment (PCTC) are moderately sensitive parameters within VFSMOD-W, so literature searches were performed to collate published data on size distribution and enrichment of sediment in runoff (see Appendix 2). Percentage of organic carbon in eroded sediment (PCTOC) is a less sensitive parameter, but was included in the searches given the close relationship with clay content. The original derivation of the pesticide trapping routines within VFSMOD-W was based on using incoming sediment properties to define PCTC and PCTOC (Sabbagh et al., 2009). Thus, it was considered useful to evaluate the evidence on sediment enrichment.

The searches yielded 15 references that reported data on sediment diameter (d50), and on enrichment ratios (ER) for clay and organic matter in the runoff sediment (Table 9). Most of the publications in Table 9 were aimed at comparing soil management practices and focused on only one or two locations. The most extensive datasets were provided by Wang et al. (2010) who measured runoff throughout a catchment in Belgium, and by Elliot et al. (1989) who studied runoff from arable fields throughout the USA. Other authors measured runoff events over several years, but only reported the averages of the enrichment factors they measured.

Table 10. Publications with data on sediment enrichment with clay (ER clay), organic carbon (ER oc), organic matter (ER om), and/or median particle diameter (d50) of the sediment

Reference	Location	Crops	Type of data
Wang et al., 2010	Belgium	various crops	ER clay, ER oc
Slattery and Burt, 1997	England	mixed arable	ER clay, d50
Quinton, et al., 2001	England	various crops/fallow	ER clay*
Quinton, et al., 2006	England	various crops/fallow	ER oc
Withers, et al., 2009	England	weeds or fallow	ER clay, d50
Uusalito, et al., 2001	Finland	barley & wheat	ER clay, d50
Le Bayon, et al., 2002	France	maize	ER om
Chisci and Martinez, 1993	Italy	tilled fallow	ER clay, ER om, d50
Truman, et al., 2007	Georgia	winter rye	ER oc
Polyakov and Lal, 2008	Ohio	tilled fallow	ER oc
Sharpley and Kleinman, 2003	Pennsylvania	till/no till/grass	ER clay
Bernard, et al.,1992	Quebec	tilled fallow	ER om
Elliot, et al., 1989	USA	rilled fallow	d50
Spargo, et al., 2006	Virginia	corn	ER oc
Grande, et al., 2005	Wisconsin	corn/soybean/oat	ER clay*

*data only published as data plots

5.1 Enrichment of eroded sediment with clay and organic carbon

An extensive dataset of enrichment factors was published by Wang et al. (2010). The studies were performed in two catchments in Belgium during 2008 and 2009 in fields with different crops. Runoff was measured from small plots (0.85 x 0.85 m) with simulated rainfall of 45 mm h^{-1}. Measurements were taken from 79 plots in the first year and 51 plots in the second year. The total runoff from the catchments (250 ha and 117 ha) was also measured. The authors found larger enrichment factors for carbon than for clay (Figure 19). Both enrichment factors were related to the suspended sediment concentration (SSC) in runoff. Enrichment factors approached unity for runoff events that contained large concentrations of suspended sediment.

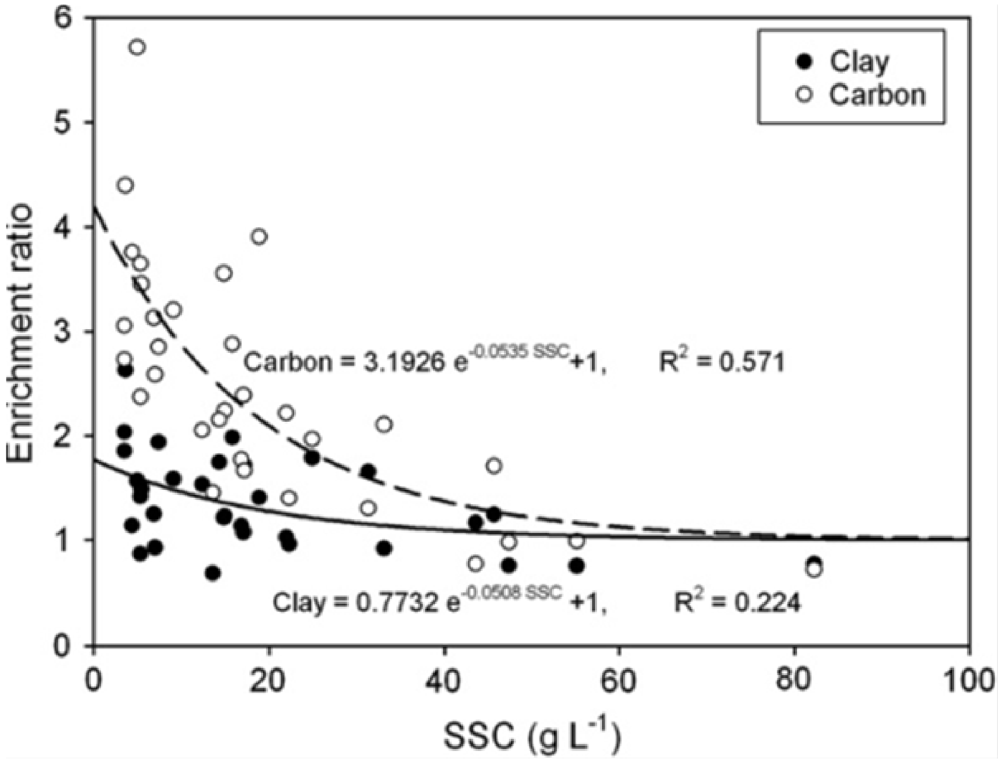


Figure 19. Clay and carbon enrichment of the sediment in runoff from interrill plots, plotted against the suspended sediment concentration (SSC) during each runoff event (Wang, et al. 2010)

The total runoff from the catchments was also measured. The enrichment ratios for the catchment runoff samples (Figure 20) were also related to the suspended sediment concentrations. A comparison between the results from the small plots and from the catchments is shown in Figure 21. The plots show are the trend lines that were derived by Wang, et al. (2010). The trend lines suggest that enrichment in runoff is similar for the small plots as for the catchments. Enrichment by clay was somewhat larger in catchment runoff. It should be remembered that the relationships shown in Figure 21 are very weak as demonstrated by the low r^2 values on Figure 20.

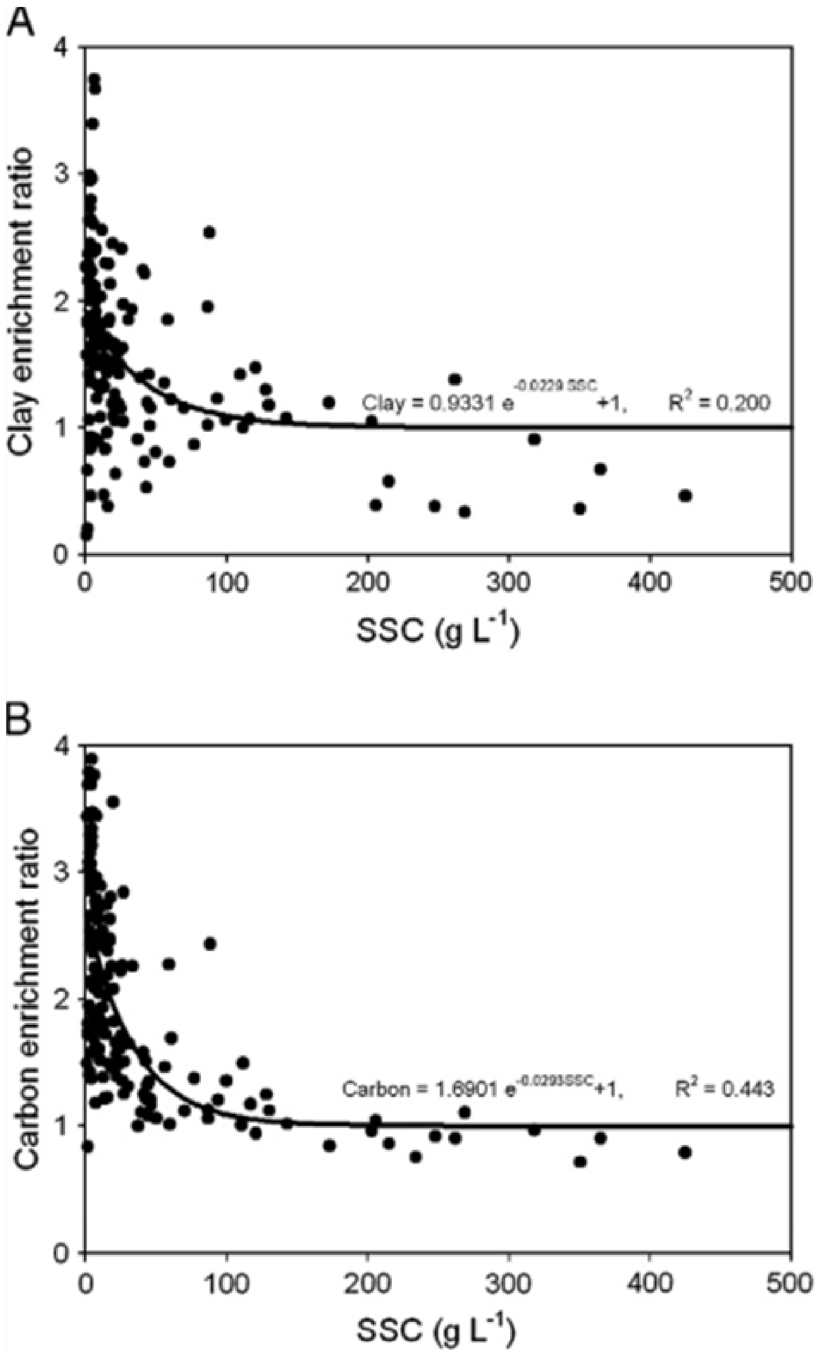


Figure 20. Clay enrichment (A) and carbon enrichment (B) of the sediment in runoff from the total catchments, plotted against the suspended sediment concentration (SSC) during each runoff event (Wang, et al. 2010)

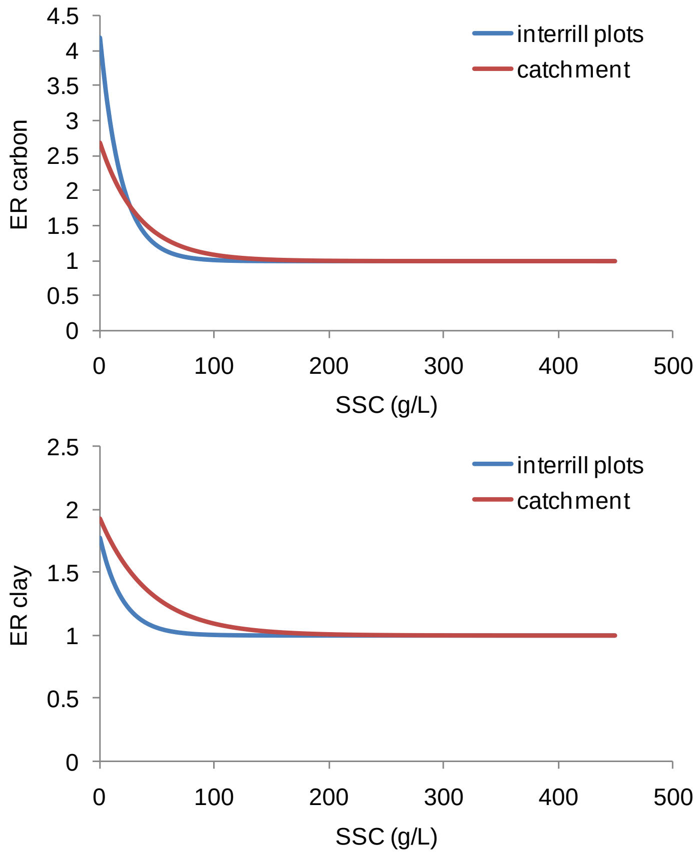


Figure 21. Comparison of carbon enrichment (A) and clay enrichment (B) between runoff from the interrill plots and from the total catchments.

The main driver for enrichment of the sediment seems to be the erosion intensity (suspended sediment concentration in runoff), albeit that these relationships are rather weak. Artificial rainfall events were used in this study and there were no differences in irrigation intensity. The differences in erosion were probably caused by differences between fields and seasons. No information was available on the parent soils in the catchments, so no relationships with the texture or organic carbon content of the parent soil could be established.

Concentrations of suspended sediment in Wang et al.'s study are significantly larger than those likely to be predicted within the FOCUS surface water scenarios (typical values up to a maximum of around 20 g/L suspended sediment). Enrichment factors are generally larger at lower concentrations of suspended sediment (Figure 20).

5.1.1 Conclusion for clay and organic carbon content of the sediment (PCTC, PCTOC)

PCTC and PCTOC have opposing influences on the pesticide trapping efficiency of a VFS. Whereas enrichment with clay (increase in PCTC relative to the bulk soil) would decrease the pesticide trapping efficiency, enrichment with organic carbon (increase in PCTOC relative to the bulk soil) would increase the pesticide trapping efficiency. The available data suggest that enrichment with organic carbon tends to be greater than that with clay for a given situation. No relationships are available at the present time to estimate enrichment on the basis of rainfall or runoff intensity, sediment loading in runoff, or properties of the parent soil. It is recommended that in the absence of site-specific sediment information, the soil and organic carbon contents defined by FOCUS (2001) for the four soils within the FOCUS R scenarios should be used as input to the modelling.

5.2 Mean particle diameter in suspended sediment

Two methods were reported for measuring the size distribution of the sediment particles. The first method measures the 'dispersed' particle sizes. The sediment is dispersed chemically or by ultrasonic waves, to separate the aggregates into individual particles. The resulting particles are analysed for particle size distribution (e.g. Withers, et al. 2009). This method is consistent with the standard method used for soil texture analysis but is less relevant for the behaviour of the particles during runoff.

The second method is to analyse the particle size distribution directly without dispersing the individual particles (e.g. Elliot et al. 1989). This gives the actual size distribution of the small particles/aggregates that are present during runoff and is therefore more relevant for the behaviour of the particles during runoff.

A large dataset on particle size distribution in runoff was published by Elliot et al. (1989). The authors measured runoff from 33 agricultural sites across the USA. The fields were rilled in the direction of the slope and runoff was collected from a single rill (0.46 x 9 m) for three periods (A,B,C) during a simulated rainfall event. The authors measured the size distribution of the non-dispersed particles (or aggregates) in the runoff.

Figure 22 shows an example of the cumulative aggregate size distributions that were measured in the runoff samples. The cumulative aggregate size fractions are plotted against the log-normal diameter. The size distribution of the parent soil (top soil in the field) is plotted for comparison, based on the reported texture fractions for clay, silt, fine sand and course sand. Due to aggregation, the non-dispersed particles in the runoff are larger than the dispersed particles of the parent soil. The median diameter (d50) of the aggregates in runoff was derived from the particle distribution by interpolation of the curve, as demonstrated in Figure 22 (dotted lines).

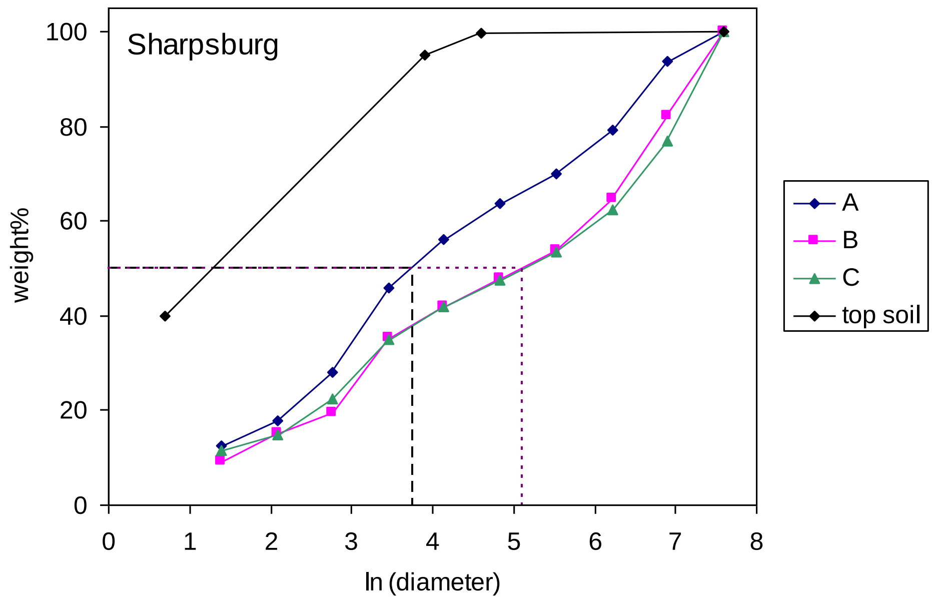


Figure 22. Aggregate size distribution in runoff (natural log value of diameter in µm) that was collected during 3 periods (A,B,C) of a simulated rainfall event, in comparison to the particle size distribution of the parent soil (data from Elliot et al. 1989).

The d50 values were derived for 178 measurements from 33 locations. No significant relationship was found between the d50 and the properties of the parent soil (silt, clay, sand or organic carbon content). A weak relationship was found between the d50 and the silt content of the soil (Figure 23).

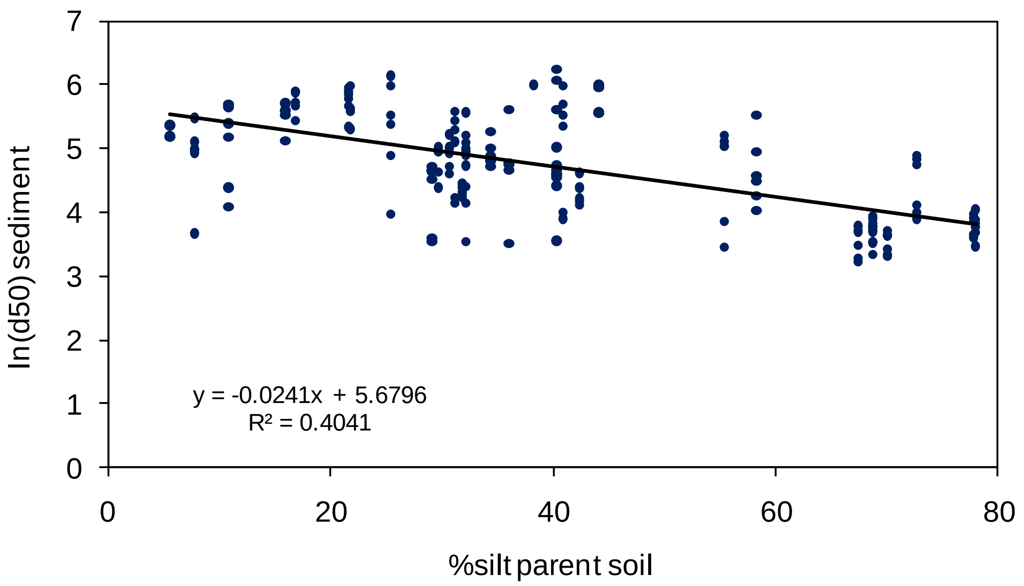


Figure 23. Natural log values of the median aggregate diameter (d50 in µm) in runoff plotted against the silt content of the parent soil (derived from data by Elliot et al. 1989)

Other measurements for aggregate size in sediment were reported by Chisci and Martinez (1993) and Slattery and Burt (1997). Chisci and Martinez reported a d50 of 300 µm for runoff sediment from an agricultural field in Sicily, and Slattery and Burt reported d50 values between 15 and 140 µm in runoff sediment in six events from a field in England. Other authors reported only size fractions of the dispersed sediment.

Figure 24 shows a comparison of the d50 values measured for runoff sediment, plotted against the d50 of the parent soil. As discussed before, the d50 of the non-dispersed sediment is often larger than the d50 of the dispersed parent soil. The graph shows no relationship between the d50 in runoff and the d50 of the parent soil.

Figure 25 shows a histogram of all measurements for aggregate size in runoff sediment (derived from data by Elliot et al., 1989, Chisci and Martinez, 1993, and Slattery and Burt, 1997). Only one sample had a d50 smaller than 20 µm (0.5%). The majority of samples had a d50 value smaller than 200 µm (74%).

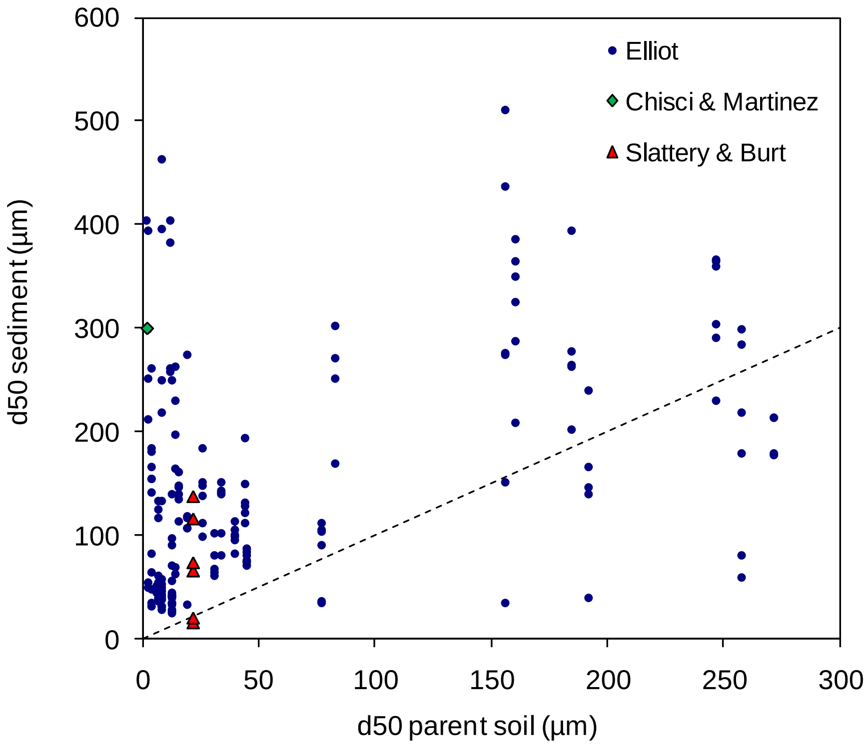


Figure 24. **Values for median aggregate diameter (d50) in runoff sediment, from data by Elliot et al. (1989), Chisci and Martinez (1993) and Slattery and Burt (1997)**

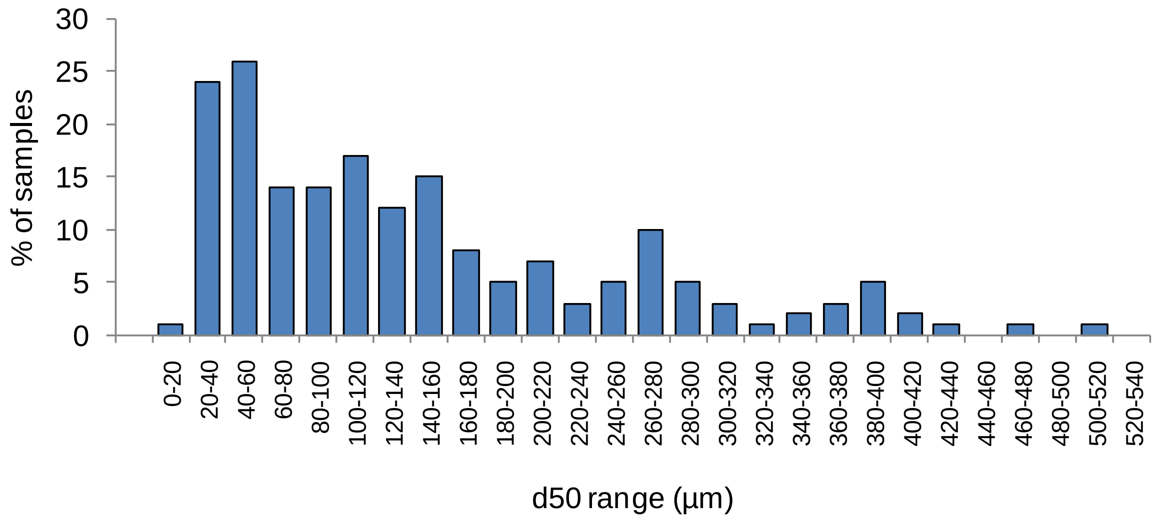


Figure 25. **Histogram of sediment d50 values shown in Figure 24. From data by Elliot et al. (1989), Chisci and Martinez (1993) and Slattery and Burt (1997), n=185.**

5.2.1 Conclusion for sediment particle size diameter (DP)

In the absence of measured inflow sediment characteristics, the VFSMOD-W users guide (Muñoz-Carpena and Parsons, 2011) recommends that an estimate of the average diameter of eroded particles can be made based on the soil texture of the contributing field (Table 11). However, in the current review no relationships were found between the d50 in runoff and the properties of the parent soil. Enrichment and particle size distribution in runoff is very much determined by the intensity (droplet impact) of the rainfall event, and ensuing runoff rate rather than the soil properties. It is not possible to predict these properties for the FOCUS scenarios.

Table 11. Estimates of d50 based on texture of the parent soil (Woolhiser et al., 1990)

Soil texture (USDA)	Expected DP (µm)	Soil texture	Expected dp
Clay	0 - 45	Clay-loam	5 - 30
Silty-clay	2 - 45	Sandy-loam	35-160
Silty-clay-loam	3 - 46	Loamy-sand	90 - 180
Silt-loam	3 - 50	Sandy - clay	2 - 130
Silt	8 - 30	Sandy-clay-loam	21 - 160
Loam	9 - 60	Sand	140-200+

Given the lack of relationship between d50 and parent soil texture and the wide ranges for DP shown in Table 11, it was decided to propose a constant, conservative value for DP independent of parent soil texture. The majority of measurements for d50 were larger than 20 µm (Figure 25). A default value for DP of 20 µm would give the smallest reduction of particles in runoff and therefore a conservative worst-case for pesticide removal.

The parameter COARSE (proportion of eroded sediment particles with diameter >0.0037 cm) is directly related to the value for DP. If DP is 0.0037 cm (37 µm), then COARSE takes the value 0.5. COARSE is relatively insensitive within the model; a value of 0.4 is recommended for use within the scenarios to fit with a definition of DP that is smaller than 0.0037 cm.

6 Summary of parameter values for vegetative filter strip scenarios for Europe

Table 12 provides an overview of the recommended parameterisation of European VFS scenarios for use with the VFSMOD-W at Step 4 of aquatic risk assessment. Several conservative assumptions are built into the parameterisation:

- VKS (saturated hydraulic conductivity in the VFS) is the dominant input parameter to the model, accounting for 50-80% of variability in ΔP in sensitivity analyses with experiments on three soils and with a range in pesticides. The 90th percentile worst-case value has been taken for this parameter to ensure that the overall parameter set achieves at least this level of conservatism.
- Soils within established vegetative filter strips will generally have larger saturated hydraulic conductivity and saturated water content relative to the same soil under arable cultivation. In turn, this will increase the potential for infiltration of runoff water within the VFS and thus increase the potential for reduction in pesticide loading. This change in hydraulic parameters within the VFS is ignored within the parameterisation and the parameters are set conservatively to those within the bulk field.
- An absolute worst-case value is taken for the sediment particle size diameter (DP). This approach is taken because literature review did not yield any robust relationship between DP and properties of the parent soil or of the runoff event.
- SOA (slope within the VFS) is set to the same as that within the agricultural fields defined within the FOCUS Surface Water Scenarios (FOCUS, 2001). This is a worst-case assumption as VFS structures are frequently located on breaks in slope and have shallower slope than the bulk field, and thus a greater potential for infiltration of runoff water and trapping of sediment.

ΔP is negatively related to percentage clay content in the sediment and positively related to the percentage organic carbon content. Literature review did not yield any robust approach to calculate enrichment of sediment with clay and organic carbon relative to the bulk soil. Hence, it is assumed that eroded sediment has the same clay and organic carbon content as the bulk soil. The assumption for the two components will have opposing effects and thus cancel out to some extent. Nevertheless, it would be useful to update this simplification in the parameterisation as the science base develops.

Table 12. Summary of recommended input parameters for European VFS scenarios for use in conjunction with the VFSMOD-W model

Parameter	Units	Description	Recommended parameter value			
			R1	R2	R3	R4
VL	m	Length in the direction of the flow	User input			
FWIDTH	m	Effective flow width of the strip (perpendicular to the flow)[1]	100	100	100	100
RNA(I)	s $m^{-1/3}$	Filter Manning's roughness *n* for each segment	0.4	0.4	0.4	0.4
SOA(I)	m m^{-1}	Filter slope for each segment	0.03	0.05	0.05	0.05
VKS	m s^{-1}	Soil vertical saturated hydraulic conductivity in the VFS	7.04×10^{-7}	2.79×10^{-6}	9.25×10^{-7}	1.52×10^{-6}
SAV	m	Green-Ampt's average suction at the wetting front	0.17	0.11	0.21	0.22
OS	m^3 m^{-3}	Saturated soil water content, θ_s	0.447	0.403	0.472	0.420
OI	m^3 m^{-3}	Initial soil water content, θ_i	Dynamic modelling within SWAN[2]			
SCHK	-	Relative distance from the upper filter edge where check for ponding is made	0.5	0.5	0.5	0.5
SS	cm	Average spacing of grass stems	1.63	1.63	1.63	1.63
VN	s $cm^{-1/3}$	Filter media (grass) modified Manning's *n*	0.012	0.012	0.012	0.012
H	cm	Filter grass height	10	10	10	10
VN2	s $m^{-1/3}$	Bare surface Manning's *n* for sediment inundated area in grass filter	0.05	0.05	0.05	0.05
DP	cm	Sediment particle size diameter (d_{50})	0.002	0.002	0.002	0.002
COARSE	-	Fraction of incoming sediment with particle diameter >0.0037 cm	0.4	0.4	0.4	0.4
KOC	-	Pesticide organic carbon partition coefficient	User input			
PCTOC	%	Percentage of organic carbon in sediment	1.2	4.0	1.0	0.6
PCTC	%	Percentage clay in sediment	13	14	34	25

[1] It is anticipated that simulations will most frequently consider entry of surface runoff into the FOCUS stream; where the FOCUS pond is considered, FWIDTH will be 30 m

[2] SWAN is a higher-tier modelling tool designed to incorporate the effect of mitigation measures into calculations for European aquatic exposure assessment (contact: gerhard.goerlitz@bayer.com)

7 Nature and legislative basis of existing vegetative filter strip structures across Europe

7.1 Roles for vegetative filter strips

While vegetative filter strips clearly have a common role in reducing runoff of pesticides and nutrients and reducing impact of erosion there is variation in design, management and legal acceptance across the European Union. A literature review was undertaken to evaluate information on the nature of VFS in different Member States. In parallel, data from the legal frameworks in place were collated to better understand the potential support for implementation of VFS. Artificial wetlands and riparian buffers are also effective mitigation measures, with a common purpose of reducing contamination of surface waters through trapping and retention of residues, these systems have been omitted from this review because the complexity of implementation, management and modelling representation of such systems differ considerably from the edge of field vegetative buffers and thus lie outside the remit of the current research project.

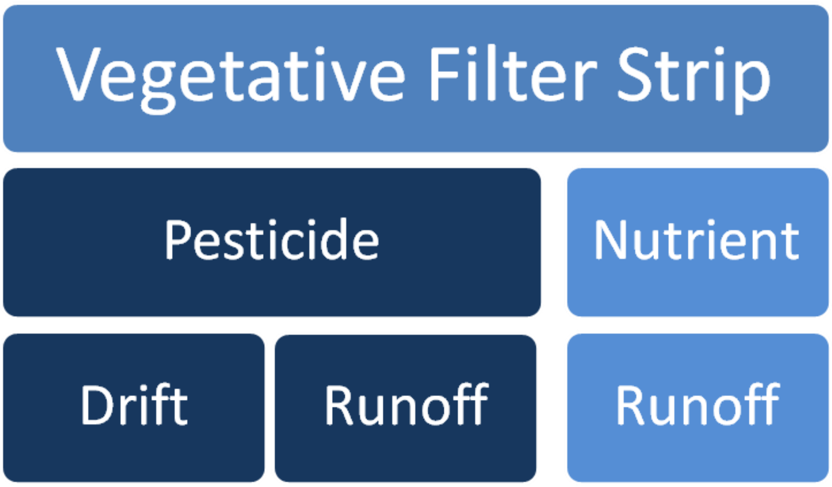


Figure 26. Different functions of vegetative filter strips

Vegetative filter strips have recently gained a prominent position within various policy instruments because of their multi-functionality (Figure 26). Moreover, they can offer benefits in terms of mitigation of high profile environmental risks and extend provision of the various ecosystem services. Basically, they are implemented where and when they serve specific policy objectives. Thus, VFS can be effective measures to support many protection goals. For example, they can be developed in order to address erosion and nutrient losses, but they are also considered an effective mitigation strategy for pesticides.

A range of research has been undertaken in Europe and elsewhere to investigate the role of VFS as mitigation measures for diffuse contamination. Appendix 3 provides a summary of literature sources of information. Appendix 4 provides photographs of VFS structures within different EU Member States.

7.2 Legislative basis

At the EU level, when considering environmental risk prevention and mitigation, there are three main policies that include VFS as a tool for risks reduction or ecosystem improvement. The three policy areas refer to:

- Protection of water from pollution with nitrates;
- Sustainable use of pesticides; and
- Common Agricultural Policy (CAP).

Council Directive 91/676/EEC of December, 12th 1991 - concerning the protection of waters against pollution caused by nitrates from agricultural sources - requests Member States to designate vulnerable areas from the point of view of nitrate pollution and to establish national action plans to manage this risk. Within such action plans they are required to establish recommendations of good agricultural practice in order to reduce the impact of nitrates. In many Member States the good agricultural practice guidelines include references to establishing vegetative strips or buffer zones along water courses.

However, the framework of guidelines for implementation and management is not uniform, as the decision regarding the setting of the relevant requirements for the strips was left to the Member States. Size, position, restrictions related to the implementation and management of the strips and other conditions are specific to each Member State and sometimes they can differ from one region to another within the same State. Moreover, even if the requirements of this Directive are applicable to all Member States, only EU 15 Member States currently have an obligation to perform checks within the cross-compliance schemes for the implementation of the provisions of the Directive at farm level.

Directive 2009/128/EC of October, 21st 2009, establishing a framework for Community action to achieve the sustainable use of pesticides, in Article 11.2.c) requires Member States to support the use of mitigation measures which can minimize the risk of off-site pollution caused by spray drift, drainflow and runoff. These measures include the "establishment of appropriately-sized buffer zones for the protection of non-target aquatic organisms and safeguard zones for surface and groundwater used for the abstraction of drinking water, where pesticides must not be used or stored".

The Directive was approved in 2009, but Member States had to transpose it into national legislation by the end of 2011 and they will be expected to draft National Action Plans to reach the objectives set by the Directive by the end of 2012. Hence the implementation into practice of this requirement is rather low across the EU, and it is effectively underway mainly in those Member States that already had action plans for the use of pesticides such as Belgium, Denmark and France.

In the framework of the CAP, when granting direct payments to farmers, Member States need to check the compliance of the farm with the statutory standards (Annex III of Regulation 73/2009), which include the protection of water from nitrates, as described above. As already mentioned, this is currently required only in the EU 15 Member States. Additionally, when judging whether a farmer has complied with maintaining land in Good Agricultural and Environmental Conditions, there is a requirement to preserve landscape features which include field margins. However, there is no EU evaluation of the size and scale of such field margins with respect to either their structure, position or function.

The draft legislation for the future CAP includes a provision requiring farmers to devote 7% of their land to ecological focus areas with the purpose of enhancing the provision of ecosystem services with a focus on biodiversity. Such areas could include the establishment of vegetative field strips or field margins. The decision on this legislation will be taken during 2012-2013 and it will be enforced starting from 2014.

7.3 Examples of stakeholder support for vegetative filter strips as mitigation measures

There is clearly an increasing need to explore how mitigation measures can be supported and implemented in a flexible and intelligent manner to maintain registrations and agricultural production. Effective support for practical and effective implementation of mitigation measures by farmers and recognition of a role within the regulatory system as problem-solving techniques requires:

- Demonstration of efficacy;
- Demonstration of practicality;
- Demonstration of flexibility;
- Increased stakeholder awareness of techniques;
- Improved communication and recognition;
- Capability to represent within risk assessments; and
- Clarification of role of legislative drivers and instruments for adoption.

The primary challenges from the perspective of the farmer are practicality and financial motivation for adoption of mitigation measures aiming to reduce non-point source pollution inputs. Thus the key drivers for take-up from the farmer's perspective are:;

- A need to demonstrate that measures can be implemented in a simple, flexible manner;
- A need to emphasise that they be customised to vulnerable landscapes; and
- A need to demonstrate cross-compliance benefits (including economic) in the context of other environmental goals.

The European Crop Protection Association has developed a network of research stakeholders to develop a support framework for improving take-up and recognition of mitigation measures focusing upon the considerations highlighted above. Initially efforts were directed at addressing point source releases through the TOPPS initiative. This was subsequently expanded to consider non-point source releases through the PROWADIS initiative that built upon the successful foundation established by TOPPS. The mitigation concept developed by this initiative to support vegetative filter strips (amongst a wide range of other mitigation techniques) to reduce run-off and erosion releases is summarised below .

Diagnosis. The aim of the diagnosis is to understand the water pathways in a catchment and field in order to describe situations reflecting different runoff / erosion risk scenarios. Available data for the catchment but also field observations are needed to describe the risk situations. This is most effectively carried out through reference to field methods and decision tree techniques developed to support decision making.

Toolbox of mitigation measures. The PROWADIS initiative has developed a list of effective measures with descriptions of how each measure functions, how to establish and how to maintain them (full details available at: www.topps-life.org/). In some cases there are broader benefits from implementation of such measures and these are also noted. A wide range of measures may be considered by farmers including soil management options, changes to cropping practices, development of retention structures for run-off, implementation of vegetative buffers and recommendations for effective, low-vulnerability product use. Techniques should be customised to the agricultural landscape to address localised problems/vulnerabilities. CORPEN/CEMAGREF illustrate how six structures may be integrated into the farming landscape (Figure 27):

1. In-field buffer, used to break up a long slope inside a cultivated field;
2. Edge of field buffer zone;
3. Edge of field buffer zone in down slope corner of a field, where water is concentrated;
4. Grassed talweg, to reduce concentrated water flow;
5. Large grassed buffer zone, used to intercept, disperse and infiltrate concentrating water flow exiting from the upslope talweg; and
6. Riparian Buffer: grassed buffer strip between edge of field and a surface water body, used to intercept and diffuse runoff from the upslope field.

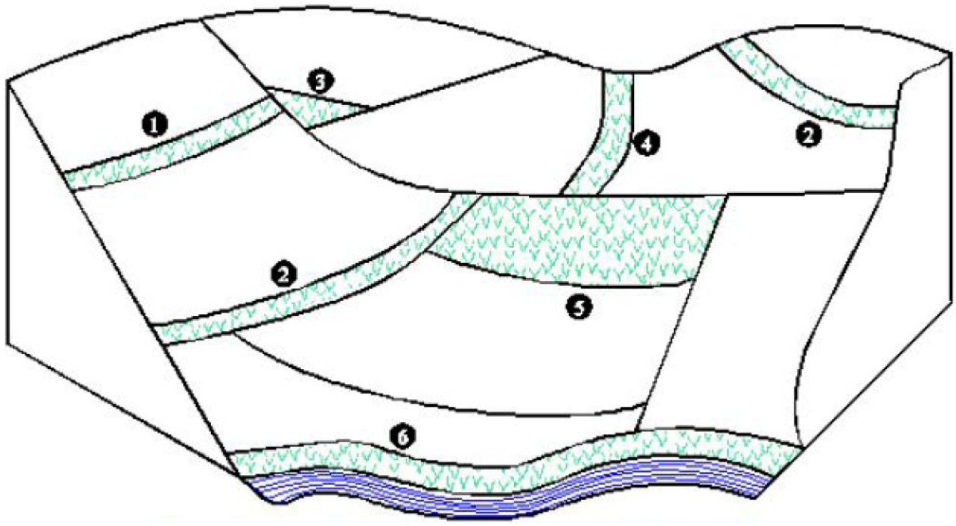


Figure 27. Examples for buffer positioning in a landscape *(Source: TOPPS PROWADIS from CORPEN / CEMAGREF)*

<u>Best management practices (BMPs)</u>. Ultimately, the background of individual measures developed within the toolbox has been condensed into practical recommendations for implementation and maintenance through the development of best management practices. It is noted that a wide range of vegetative buffers may be implemented, directed at addressing specific roles within the agricultural landscape. The best management practices proposed by PROWADIS for edge-of-field VFS most directly represented within VFSMod are summarised in brief below.

<u>Buffer location and sizing</u>. Buffers may vary in size, largely based on the buffering objectives, the soil and landscape characteristics and their interaction with other mitigation measures. A thorough analysis and diagnosis are necessary to determine the optimum buffer size and location. VFSMOD is a helpful modelling tool to size the respective buffer in consideration of the environmental properties. The correct positioning of the buffer in the landscape is usually more important than its width for its effectiveness to reduce runoff. Other parameters such as soil permeability, soil saturation, size and slope of the runoff area also have to be considered.

Water infiltration may be more effective in buffers planted with tall and ligneous vegetation due to the more extensive root system. Dense grass vegetation is more efficient to slow down surface water flow and thus enhances trapping of eroded soil particles. Combinations of both systems may be able to combine the benefits of both vegetation types. Selection of species for vegetated buffer strips needs to consider local requirements. Species selection may also be influenced by other buffer functions, such as providing bee forage or habitat for selected plants.

Maintenance and care. Buffers need to be maintained and managed to remain functional. Good surface roughness in the VFS is important to trap soil particles in runoff water. For grassed buffers a regular mowing of the grass is necessary. The average height of the grass should be around 10 cm and the maximum height should not exceed 25 cm to maintain erect grass. Buffer efficiency is also reduced by soil sediment accumulating on the buffer: therefore a regular sediment removal or dispersion of sediment on VFS is needed.

Use of buffer zones as animal pasture might be possible, but grazing with large animals increases soil compaction and therefore can negatively impact infiltration capacity of the soil. In this respect also the contamination of surface water with additional nutrients and pathogenic microbes from animal faeces needs to be considered. The trafficking of heavy machinery on VFS should be minimised as far as possible to prevent soil compaction.

7.4 Implemention of VFS at the EU level

Due to the agricultural and environmental policies currently under implementation in Europe VFS will be extensively adopted in the different Member States. The green economy and the greening of the supply chain with the efforts to reduce non-point source pollution will be another reason for a rapid application of this ecological infrastructure at farm and basin level.

The current status in quantitative terms is difficult to estimate and requires specific research. For illustrative purposes we report below the example of Italy.

7.4.1 National situation for Italy

Buffer strips in Italy have been introduced by the Ministerial Decree of December, 22nd 2011, amending the DM 30125 (22.12.2009) on the management requirements for the access to the rural development programme funds. Those buffer strips are defined according to Annex III of the Council Regulation (EC) 73/2009 for protecting water (Figure 34).

The standard 5.2 states that 5-m buffer strips have to be created along rivers, streams and ditches. The administrative region can authorise a reduction to:

- 3 m if the water body quality status is sufficient or good; and
- 0 m if the water body quality status is high.

Fertilisation and tillage are forbidden in the buffer zone. Tillage is allowed only when necessary to maintain the effectiveness of the VFS. In the case of orchards or vineyards with integrated pest management or organic management, and when the water quality status is good or high, the restriction regarding fertiliser use is reduced from 5 to 3 m.

The Health Ministry via the Plant Protection Product Committee (Commissione Consultiva per i Prodotti Fitosanitari) proposed in 2009 the introduction of VFS in order to address the request of the Directive 2009/128/EC concerning the sustainable use of pesticides. In this document, two definitions are given:

- Untreated respect area: an area close to a water body on which the pesticide application is forbidden. It is developed to mitigate drift and runoff.
- Untreated vegetated area: a grassy area close to a water body on which the pesticide application and transit of tillage equipment is forbidden. It is developed to mitigate runoff.

7.4.2 Examples of regional support in Italy

Emilia Romagna and Lombardia adopted rural development programmes with the aim to allocate resources in order to reach the EU policy goals. In Lombardia the programme is organised in four sections and 22 measures with a description of VFS in Section 2 ("Improvement of the environment and of the rural space"), Measure 214, Action F - "Management of VFS and woodland buffer strips" - and in Measure 216 "non productive investment".

The goal of these actions is to increase the diversity of the ecosystem and to develop ecological networks. These areas are considered as refuge for fauna. A secondary goal is to reduce the transfer of nutrients and trace elements from agricultural fields to surface water. Pesticides are not mentioned.

Few definitions are given:

- A hedge is a linear structure made of different native plant species (herbaceous plants, shrubs and trees).
- A plant row is a linear and regular structure, made of native trees organised in a simple line. The maximum width of this structure is 25 m.
- Woodland buffer strips are riparian structures close to water bodies. The maximum width of this structure is 25 m.

In these areas any pest management strategy is forbidden (including use of herbicides) and the farmer has to irrigate and to replant when necessary. Close to these structures a non-cropped area has to be set with a minimum width of 1.5 m for plant rows or 2 m in other cases. The required minimum width of the structure and the "respect" strip is reported in Table 13.

Table 13. VFSs sizes descibed in the measures 216 of the Lombardy rural development programme

Structure	Width (structure + “respect” strip) (m)	Minimum surface (ha)
Hedge	4	0.15
Hedge between farm properties	6	0.15
Plant row	4	0.15
Plant row between farm properties	5.5	0.15
Double plant row	6.5	0.2
Double plant row between farm properties	8	0.4
Woodland buffer strip	2.5 + 2 * (no. of rows)	0.4

Through Measure 216 the region of Lombardia provides money to farmers in order to implement these structures and via Measure 214 money is provided to maintain them (525 €/ha in lowlands and 450 €/ha in hilly and mountainous areas).

For access to this programme the farmer must respect the management requirements stated in legislation DGR no. IX/2738 (December 22nd 2011) in Lombardia and DGR no. 94 (January 31st 2012) in Emilia Romagna). Annex 2 reports the standards to respect in order to maintain the soil in good environmental and agricultural conditions; standard 5.2 introduces buffer strips along water bodies starting from 2012.

In Lombardia buffer strips have to be created along the rivers, streams and ditches as stated in Part 5 of the Po basin management plan, of the Fissero, Tartaro, Canalbianco basin management plan and of the Eastern Alps basin district. In Emilia Romagna this is more general and, from 2012, 5-m buffer strips are mandatory along rivers, streams and ditches.

In Lombardia the buffer strip is defined as a VFS or a riparian strip with a minimum width equal to:

- 5 m if the water body quality status is scarce, bad or not defined;
- 3 m if the water body quality status is sufficient or good; and
- 0 m. if the water body quality status is high.

In the buffer zone tillage and fertilisation are forbidden when it is not necessary to maintain the efficiency of the zone. In the case of orchards or vineyards with IPM or organic management, and when the water status is good or high, the restriction regarding the use of fertiliser is reduced from 5 to 3 m. Rice paddy fields are excluded from this regulation.

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Appendix 1 Duplicate fields identified within the SPADE database (spade2v11.dbf) organized by soil mapping unit, soil typological unit and land use

Duplicate fields (SMU-STU-USE)

310034-310141-5
310052-310196-3
310052-310197-1
330641-332340-5
330686-332471-3
330686-332471-5
3510390-3511318-7
3530427-3531487-19
3530427-3531487-5
3530428-3531490-19
3530430-3531497-19
3530437-3531520-1
3530441-3531522-1
3530441-3531522-3
3530445-3531546-19
3530446-3531548-1
3530446-3531548-5
3530447-3531551-19
3530447-3531551-5
3530449-3531557-19
3590005-3590024-3
360018-360063-3
360056-360195-3
360057-360200-1
360064-360227-1
410014-410014-1
4400466-4401627-19
4400487-4401735-1
4400488-4401741-1
4400488-4401741-19
4400489-4401745-19
4400489-4401745-5
4400490-4401751-10
4400490-4401751-19
4400517-4401888-19
4400517-4401888-5
4400520-4401910-4
4405071-4401835-1
4410531-4411947-19
4410534-4411960-19
4410540-4411979-1
4410541-4411985-1
4410541-4411985-5
4410544-4412001-19
4410544-4412001-5
4410545-4412003-19
4410545-4412003-5
4410546-4412007-19
4410546-4412007-5
4410547-4412010-19
4410547-4412010-5
4410548-4412016-19
4410548-4412016-5
4410549-4412019-19
4410549-4412019-5
4410550-4412024-19
4410550-4412024-5
4410551-4412027-19
4410551-4412027-5
490037-490137-3
490078-490276-3
490079-490278-3

Appendix 2 Literature search for enrichment of eroded sediment

All databases were searched on Web of Science. Searches were performed on words in the title (search terms 1-3) or on words in the topic or abstract (search terms 4-5). The results from searches 1-3 were narrowed down using search terms 4-5, to limit the search to literature relevant to sediment enrichment and particle sizes.

Search key words

1. TITLE (overland flow)
2. TITLE (runoff)
3. TITLE (erosion)
4. TOPIC(enriched OR enrichment)
5. TOPIC(clay OR organic OR particles OR particulate OR particle size*)

* symbol for wildcard

Combining the search terms resulted in 268 references. From these 59 relevant articles were selected based on their abstracts and then checked for available data. Articles were not considered relevant if they measured runoff from melting snow or ice or from tropical soils. Only runoff from arable soils was considered. Publications on runoff from grassland, paddy fields, forestry or nurseries, or deforested areas were omitted. Only field measurements were included; Runoff measurements from soil trays or cores were not included. The resulting articles were scanned for data on particle sizes in sediment and enrichment of the sediment with organic matter or clay, resulting in the 15 publications listed in Table 9.

Appendix 3 Literature search for research into the role of vegetated filter strips as mitigation measures for diffuse contamination

As an illustration of the diversity of roles and range of recent research surrounding VFS in Europe a search conducted with the SCOPUS search engine was undertaken using the terms: ((VEGETATIVE and FILTER and STRIP) or VFS or (BUFFER and STRIP and (RUNOFF or EROSION)). Results are given in Table 14. A complementary search has been conducted to consider the available 'grey literature' that may provide useful advisory documentation, but without the accompanying peer review of conventional scientific literature. Consideration of 'grey literature' is considered appropriate as this is the most typical basis for best management practice recommendations geared towards farmers and, therefore, represents the most realistic and practical indication of how this methodology may be implemented by farmers.

The few specific pesticide studies found at the European level were primarily based upon research activities in Denmark, France, Germany and Italy. Searches also revealed general reviews of VFS directed at evaluating evidence for effectiveness as tools in mitigation of pesticide contamination.

From the literature review it appears that VFS were developed initially for mitigating sediment transfer to surface water. Subsequently, the focus expanded to include transfer of nutrients (mainly nitrogen and phosphates), pesticides and, most recently, pathogenic organisms. However, the greatest scientific interest focuses on the capacity of VFS to mitigate nutrient transfer.

The earliest studies and case studies were undertaken in the USA. Studies have also been undertaken in China, Korea, Australia and Canada. The European Union supported COST Action 869 on riparian buffer strips as a multifunctional tool in agricultural landscapes; this lead to a Special Issue in the Journal of Environmental Quality (2012, 41).

Table 14 Summary of literature review for research into the use of VFS

Location	Country	Type of work	Specific for pesticides	Paper
-	-	Review	No*	Arora et al., 2010
-	-	Review	No*	Stutter et al., 2012
-	-	Review	No*	Yuan et al., 2009
-	-	Review	Yes	Carluer et al., 2011
-	-	Review	Yes	Otto et al., 2008
-	-	Review	Yes	Lacas et al., 2005
-	-	Review	Yes	Krutz et al., 2005
-	-	Review	Yes	Reichenberger et al., 2007
Asia	China	Case study	No*	Pan et al., 2010
Asia	China	Case study	No*	Pan et al., 2011
Asia	China	Case study	No*	Wang, et al. 2010
Asia	China	Case study	No*	Wang, et al. 2010

Location	Country	Type of work	Specific for pesticides	Paper
Asia	China	Case Study	No*	Wu et al., 2008
Asia	China	Case Study	No*	Wang et al., 2008
Asia	Korea	Case study	No*	Choi et al., 2010
Asia	Korea	Case study	No*	Gil and Shin, 2012
Asia	Korea	Case study	No*	Chung et al., 2011
Australia	NSW	Case Study	No*	Wang et al., 2012
Europe	Denmark	Case study	No*	Kronvang et al., 2012
Europe	Denmark	Case study	Yes	Rasmussen et al., 2011
Europe	France	Case study	Yes	Delphine and Chapot, 2001
Europe	France	Case study	Yes	Lacas et al., *in press*
Europe	Germany	GIS modelling	No*	Ohliger and Schulz, 2010
Europe	Germany	Case study	Yes	Pätzold et al., 2007
Europe	Italy	Review	No*	Borin, et al. 2010
Europe	Italy	Case study	No*	Pavanelli and Cavazza, 2010
Europe	Italy	Case study	Yes	Vianello et al., 2005
Europe	Italy	Case study	Yes	Otto et al., 2012
Europe	Scotland	Case Study	No*	Stockan et al. 2012
Europe	Scotland	Case study	No*	Bergfur et al., 2012
Europe	Sweden	Case Study	No*	Bergfur et al. 2012
Europe	Netherlands	Case study	No*	Sloots and van der Vlies, 2007
N. America	Canada	Case study	No*	Gharabaghi et al., 2006
N. America	Canada	Case study	Yes	Dunn et al., 2011
N. America	Canada	Case study	Yes	Caron et al., 2010
N. America	-	Modelling	Yes	Sabbagh et al., 2009
N. America	-	Modelling	Yes	Poletika et al., 2009
N. America	-	Case study	Yes	Mersie et al., 2003
N. America	USA-California	Case study	No*	Hay et al., 2006
N. America	USA-Georgia	Case study	No*	Lowrance and Sheridan, 2005
N. America	USA-Georgia	Case study	Yes	Gay et al., 2006
N. America	USA-Illinois	Case study	No*	Lemke et al., 2011
N. America	USA-Indiana	Case study	No*	Smith et al., 2008
N. America	USA-Iowa	Case study	No*	Webber et al., 2010
N. America	USA-Iowa	Case study	No*	Mickelson et al., 2003
N. America	USA-Iowa	Case study	Yes	Boyd et al., 2003
N. America	USA-Kansas	Case study	No*	Mankin et al., 2006
N. America	USA-Kansas	Case study	No*	Douglas-Mankin, 2011
N. America	USA-North Carolina	Case study	No*	Muñoz-Carpena and Parsons, 2004

Location	Country	Type of work	Specific for pesticides	Paper
N. America	USA-Oregon	Case study	No*	Sullivan et al., 2007
N. America	USA-Oregon	Case study	Yes	Seybold et al., 2001
N. America	Puerto Rico	Case study	No*	Sotomayor-Ramírez et al., 2008
N. America	Puerto Rico	Case study	No*	Ramírez-Avila et al., 2009
N. America	USA-Wisconsin	Case study	No*	Reed and Carpenter, 2002

* Nutrient or bacteria or nutrient plus pesticide

Appendix 4. Examples of vegetative filter strip structures across Europe

A3.1 Austria

Figure 28. Degraded buffer strip in Weinviertel (Weigelhofer et al., 2012)

Figure 29. Restored buffer strip in Weinviertel (Weigelhofer et al., 2012)

A3.2 Denmark

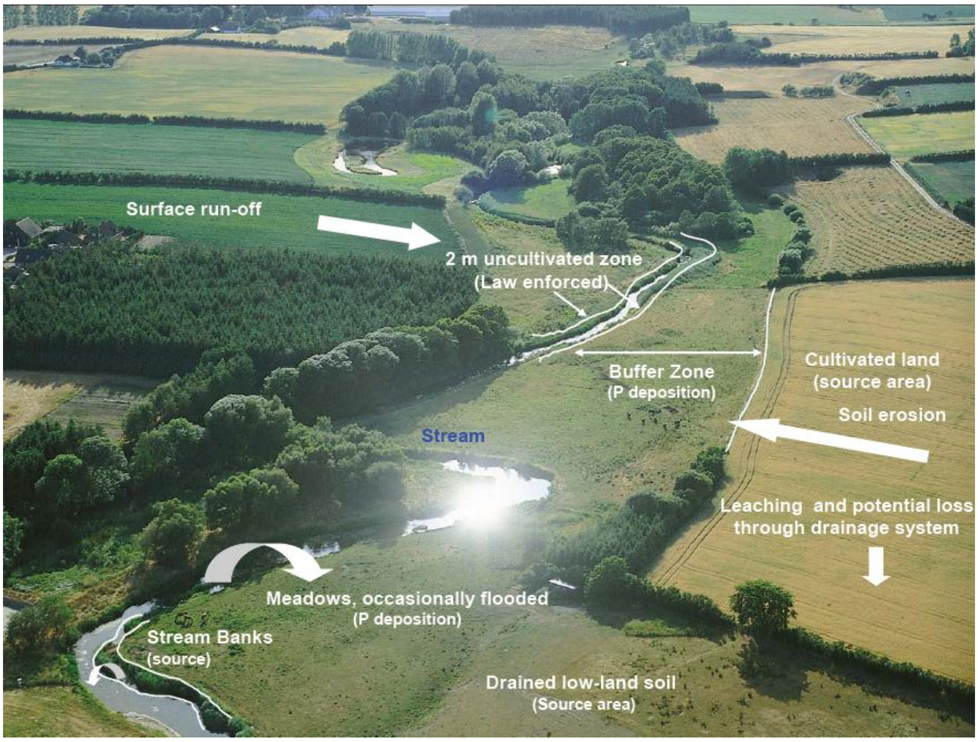

Figure 30. Processes affecting surface water quality in Danish environment (Dybkjær et al., 2012)

A3.3 Germany

Figure 31. Permanent buffer strip in Hachumerbach (Bereswill et al., 2012)

Figure 32. Vegetated buffer strips studied at Landau University (Bereswill et al., 2012)

Figure 33. Vegetated buffer strips studied at Landau University (Bereswill et al., 2012)

A3.4 Italy

Figure 34. Implementation of VFS in Italy according to the Ministerial Decree of December, 22nd 2011

Figure 35. Italian Fontanili riparian buffer; field cropped with maize, next to Fontanily

Figure 36. Italian Fontanili riparian buffer; Fontanili area

A3.5 Norway

Figure 37. Buffer strip and wetland at Lier experimental site (Elsaesser et al., 2011)

Figure 38. Buffer strip and wetland at Lier experimental site (Elsaesser et al., 2011)

A3.6 Scotland

Figure 39. Example of Scottish buffer strip (Stutter and Richards, 2012; Bergfur et al., 2012)

A3.7 The Netherlands

Figure 40. Example of buffer strip in Dutch landscape (Heinen et al., 2012; Noij et al., 2012)