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Modelling run-off mitigation efficiancy of vegetated filter strips (VFS) within the FOCUSsw framework using VFSMOD-W

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on behalf of ECPA-AIM

Run-Off

Run-Off occurrence after heavy rainstorm on wet clay soils

- Dominant route of diffuse exposure leading to high PEC_{ini} values

- Vegetated Filter Strips (VFS) effectively mitigate runoff inputs
  - Removal efficacy in VFS field trials often > 90 %, mostly > 50%
  - Variability 0 – 99 % raises concern
  - Simple width based ‘one size fits all’ runoff mitigation factors don’t seem to adequately capture the variability

Run-Off Vulnerability in FOCUS

Chemical or GAP factors

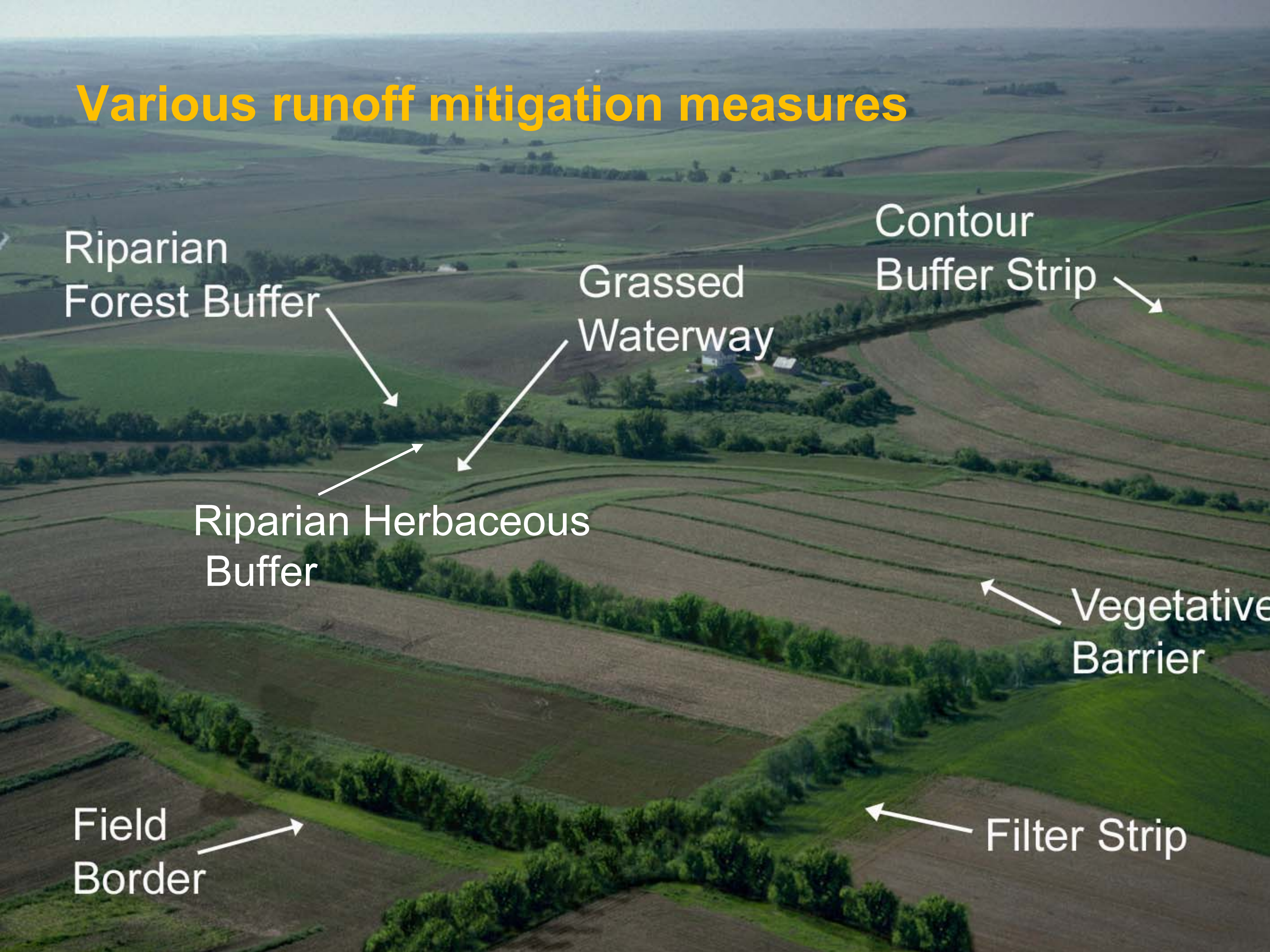
- Persistence characteristics
- Sorption characteristics
- Incorporation, surface or foliar application?
- Crop foliar development

Realistic worst-case scenario assumptions

- Soil characteristics (texture, hydrology)
- Topography
- Rainfall intensity and duration
- Tillage practices
- Filtering capacity of any vegetated margins is not represented (no mitigation)

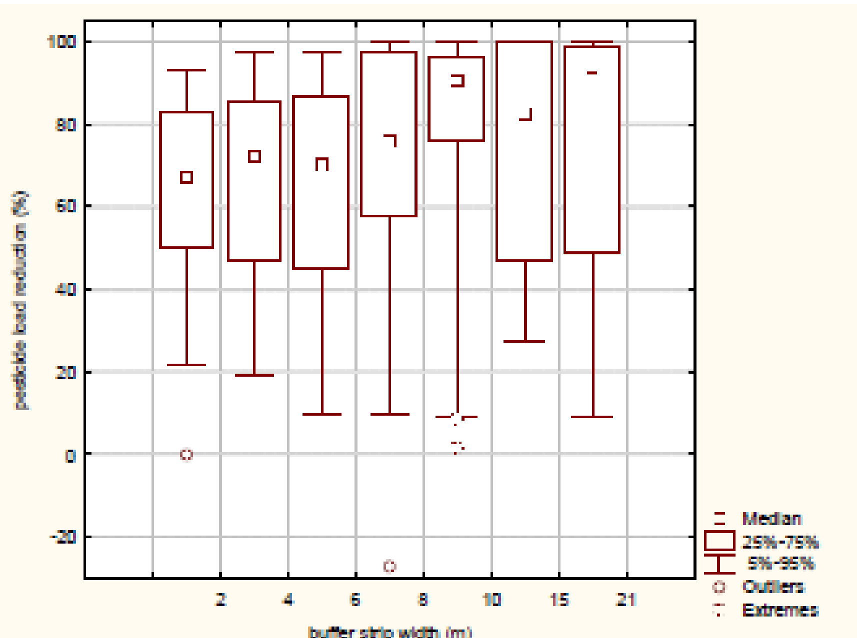
How to refine?
What is defensible in regulatory terms?
Width based FOCUS L&M factors as implemented in SWAN?

Various runoff mitigation measures

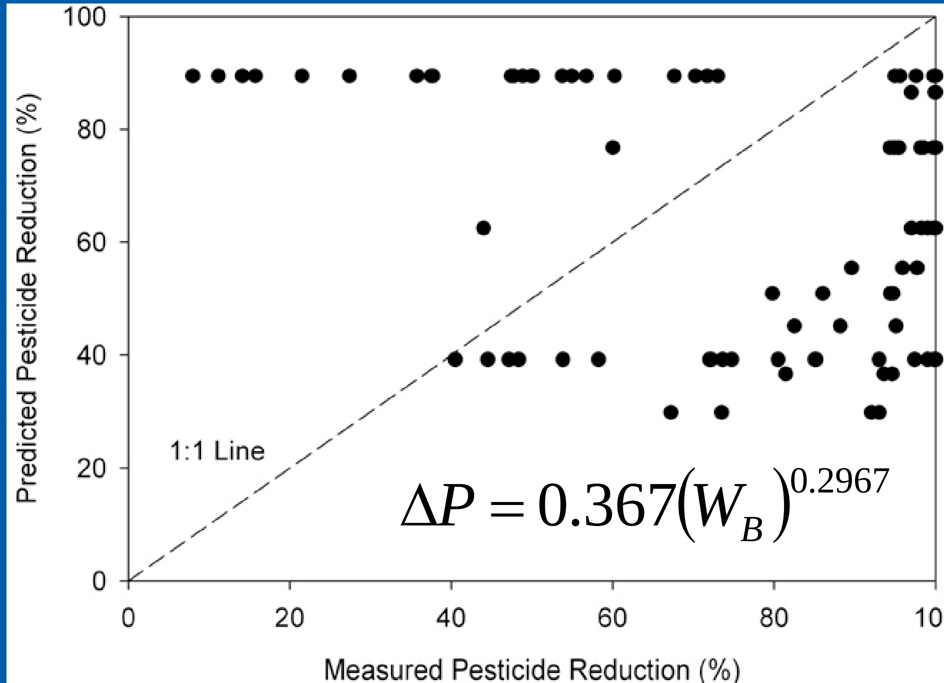


VFS - Complex and Dynamic Systems

Limited prediction capability of simple pesticide reduction (ΔP) equations



from: Reichenberger et al. (2006)



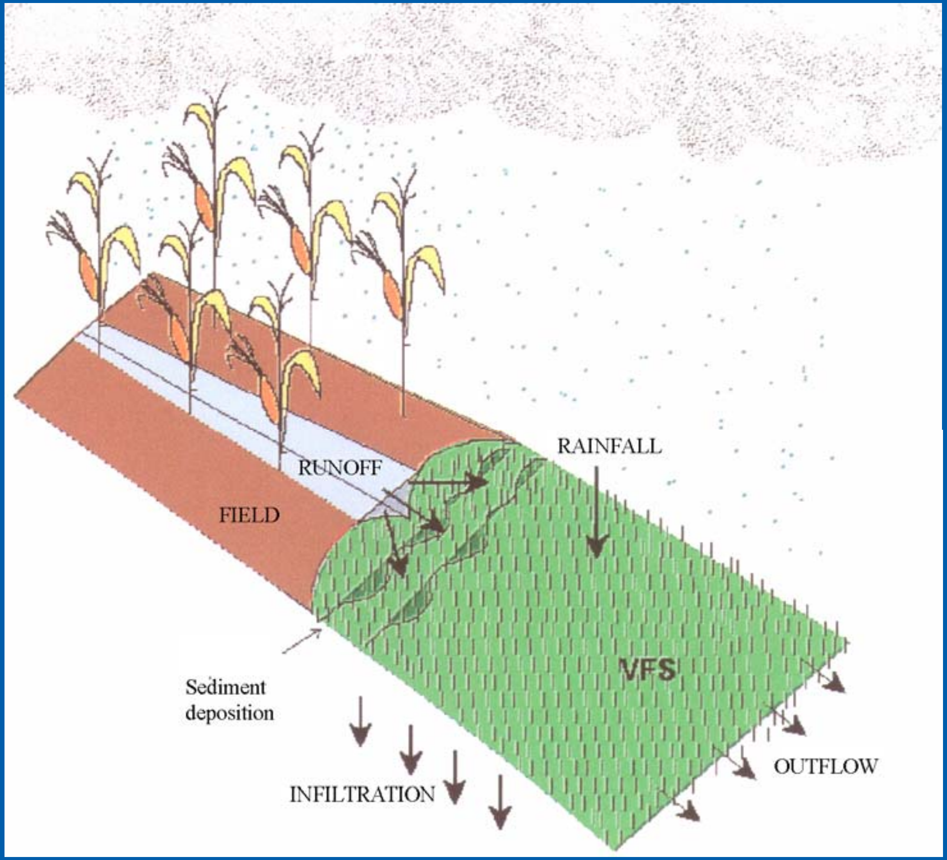
Average buffer strip efficiency:

- •50% for 5m
- •90% for 10m
- •97.5% for 20m

Predictions with SWAT empirical equation

<u>Other processes than VFS width</u> seem to be driving the retention potential!

Vegetative Filter Strips: mechanistic view



Increase in hydraulic resistance to flow and soil infiltration

↓

Overland flow (and dissolved pollutants) reduction and delay through infiltration

↓

Decrease in sediment/particles transport capacity of flow

↓

Sediment/particles deposition (and pollutants bonded) in filter

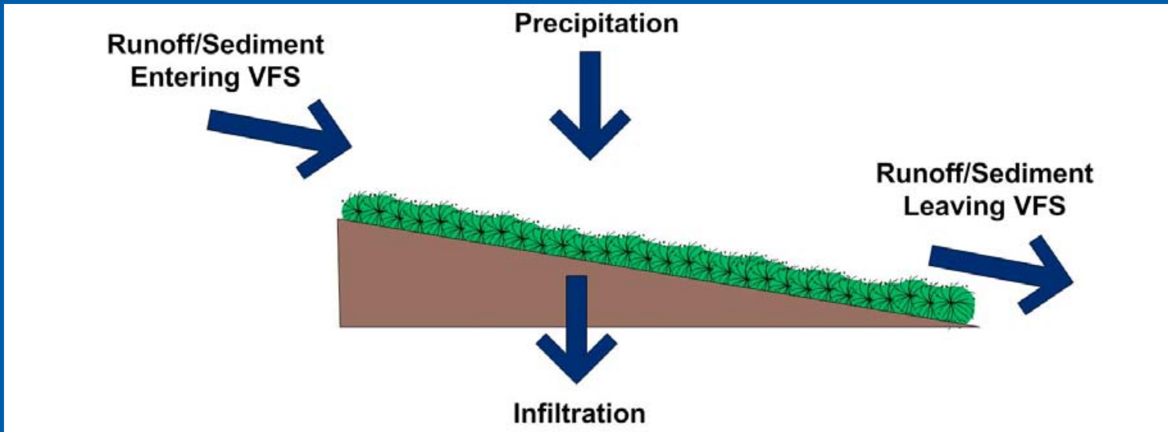
VFS Key Drivers – Hydrologic Response

VFS are complex dynamic systems!

Driving Mitigation

Infiltration

- Is governed by soil physical properties; vegetative cover; antecedent moisture content; rainfall intensity and inflow; slope



ΔQ = Infiltration = (Runoff Entering + Preciptation) – Runoff Leaving

ΔE = Sedimentation = Sediment Entering – Sediment Leaving

Hydraulic resistance

- Is a function of vegetation type; Inflow volume

Compound

- Sorption coefficient

Literature Study – VFS Model Development

- Data on effectiveness of VFS were compiled from 127 published journal articles
- Five publications reported values for the parameters identified as essential to run the analysis:
  - Water volume and sediment mass in and out of VBS
  - Dissolved pesticide mass in and out of the VBS
  - Sediment bound pesticide mass in and out of the VBS
  - Description of VFS
  - Description of field
  - Soil characteristics
- Five other publications for model evaluation

Model Development Dataset

- 47 observations: alachlor, atrazine, chlorpyrifos, metolachlor, and permethrin
- Percent pesticide reduction (ΔP) ranging from 22 to 100%
- VFS widths ranged from 3 to 20 m (VFS width in the primary direction of flow)
- Natural and simulated rainfall and runoff events
- Soils with % clay content from 21 to 30%

Pesticide VFS Model Development

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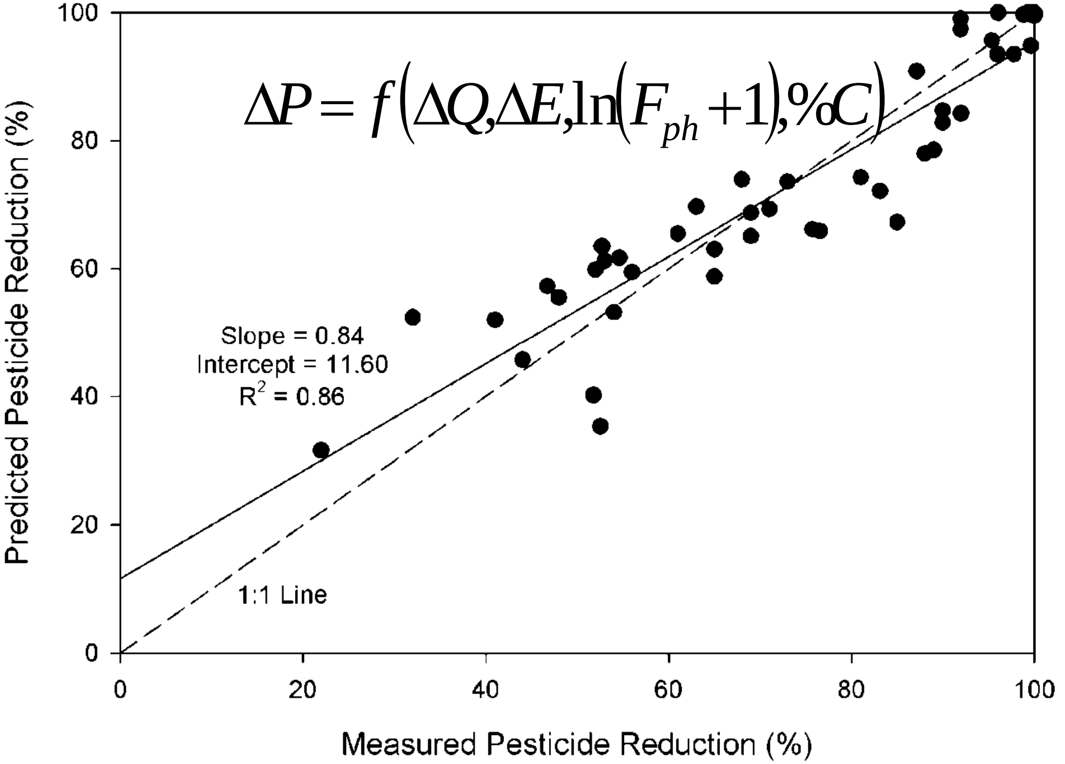
Pesticide reduction equation

- **ΔP = % mass reduction pesticide**
- ***%C* = % clay content of incoming sediment**
- ***Fph* = Phase distribution factor, driven by Koc**
- **Δ *Q* = % water infiltration in the VFS**
- **Δ *E* = % sediment trapped in the VFS**



Equation: $\Delta P = f\left(\Delta Q, \Delta E, \ln\left(F_{ph}+1\right), \%C\right)$

Number of Observations, n = 47

R^2= 0.86 Adjusted R^2 = 0.84

Standard Error of Estimate = 8.43

	Coefficient Value	Standard Error	t-statistic	P-value
Constant	24.8	12.9	1.92	0.06
ΔQ	0.54	0.05	10.11	<0.001
ΔE	0.53	0.09	6.01	<0.001
$\ln(F_{ph}+1)$	-2.42	0.66	-3.69	<0.001
$\%C$	-0.89	0.26	-3.44	0.001

Model Evaluation Dataset

- Five publications included data that can be used to test model performance (2 from USA, 1 from Australia, 1 from France and 1 from Germany)
- 120 measured ΔP ranging from 8.0 to 100%
- Nine compounds: atrazine, cyanazine, diflufenican, isoproturon, lindane, metolachlor, metribuzin, pendimethalin, and terbuthylazine
- VFS widths ranged from 0.5 to 20 m
- Soils with % clay content from 12 to 45%

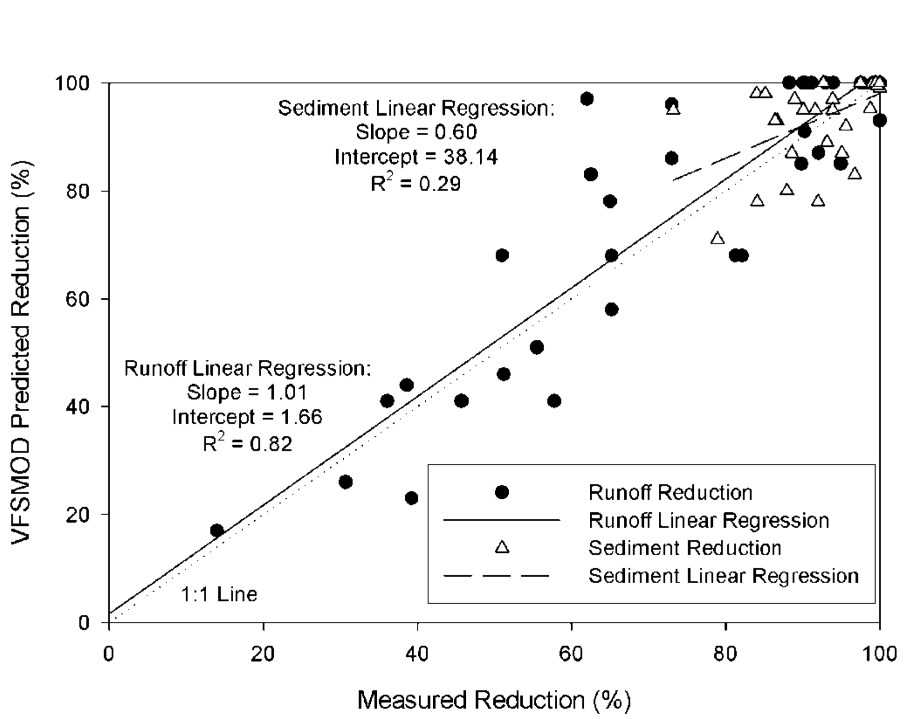
VFSMOD-Water Quality (VFSMOD-W)

- The proposed model requires knowledge of the reduction in the runoff (ΔQ) and erosion (ΔE)
- The well established numerical VFS model VFSMOD was used to predict flow and sediment transport through vegetated filter strips (ΔQ, ΔE)
- VFSMOD* is a finite-element, field-scale, storm-based model developed to
  - Route the incoming hydrograph and sedigraph from an adjacent field through a VFS
  - Calculate the resulting outflow, infiltration (based on curve number approach), and sediment trapping (based on Universal Soil Loss Equation)

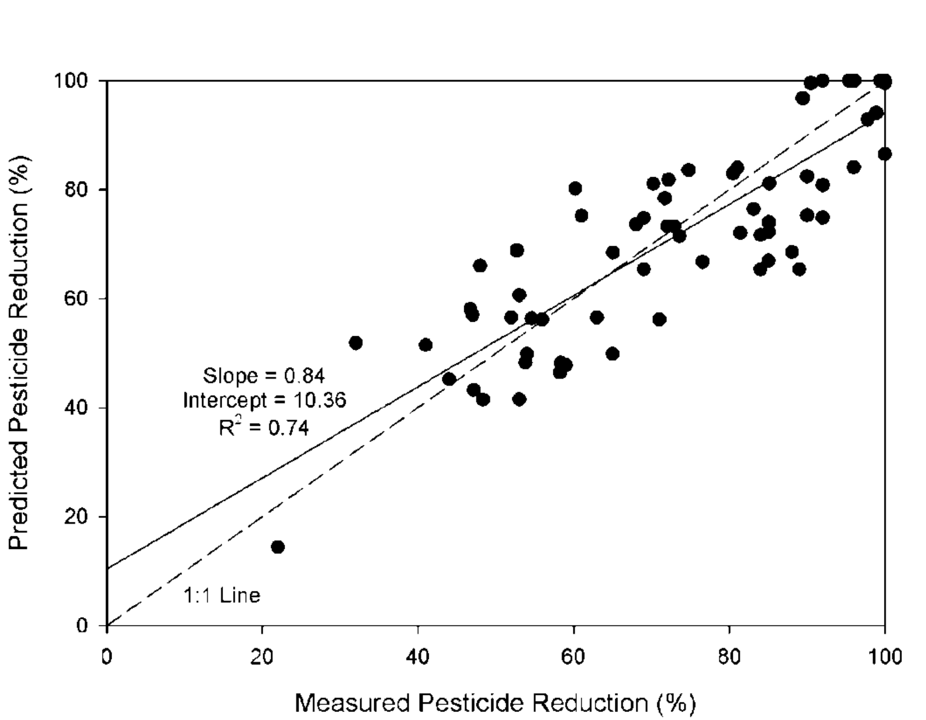
* Munoz-Carpena, R. and J.E. Parsons. 2004

VFSMOD-W performance (uncalibrated)

ΔQ and ΔE



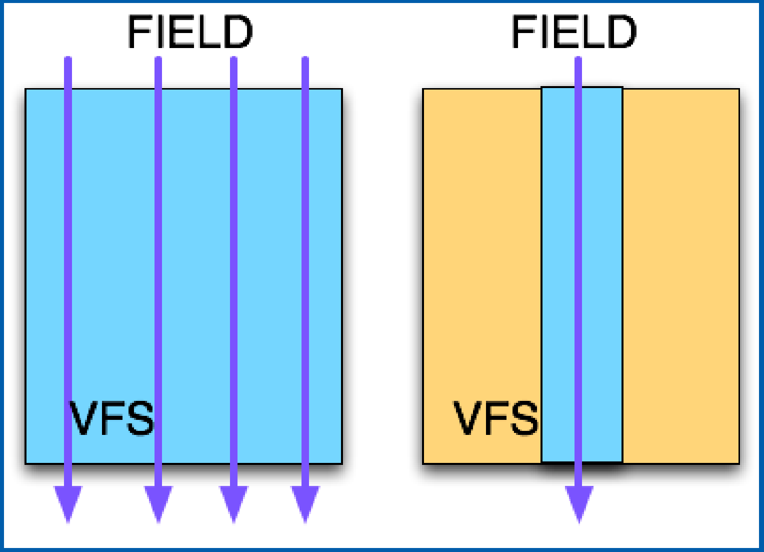
ΔP



Sabbagh, G.J.; Fox, G.A.; Kamanzi, A.; Roepke, B.; Tang, J.Z. Effectiveness of vegetative filter strips in reducing pesticide loading: Quantifying pesticide trapping efficiency. *J. Environ. Qual.* **2009**, 38 (2), 762-771.

Uniform vs. Concentrated Flow

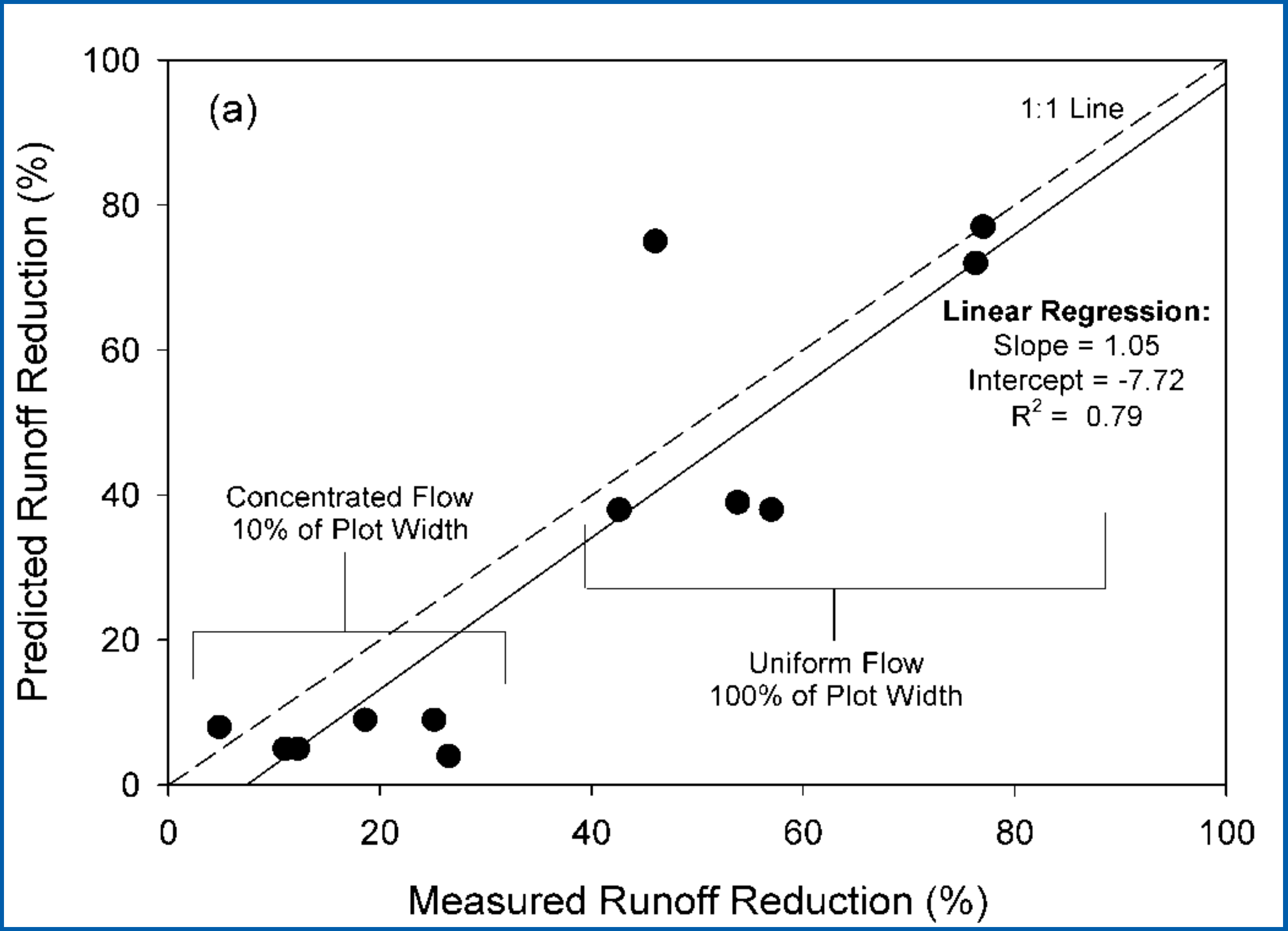
- What about the effect of flow uniformity?
  - Can the procedure account for concentrated flow?
- Is the pesticide component transferable?
  - Evaluation with additional data sets



Poletika, N.N., P.N. Coody, G.A. Fox, G.J. Sabbagh, S.C. Dolder, and J. White. Chlorpyrifos and atrazine removal from runoff by vegetated filter strips: Experiments and predictive modeling. *Journal of Environmental Quality* **2009**, 38(3), 1042-1052.

VFSMOD validity check field study - water

- Chlropyrifos & atrazine field study separating concentrated and uniform flow
- VFSMOD (uncalibrated) able to predict uniform and concentrated flow runoff (ΔQ)



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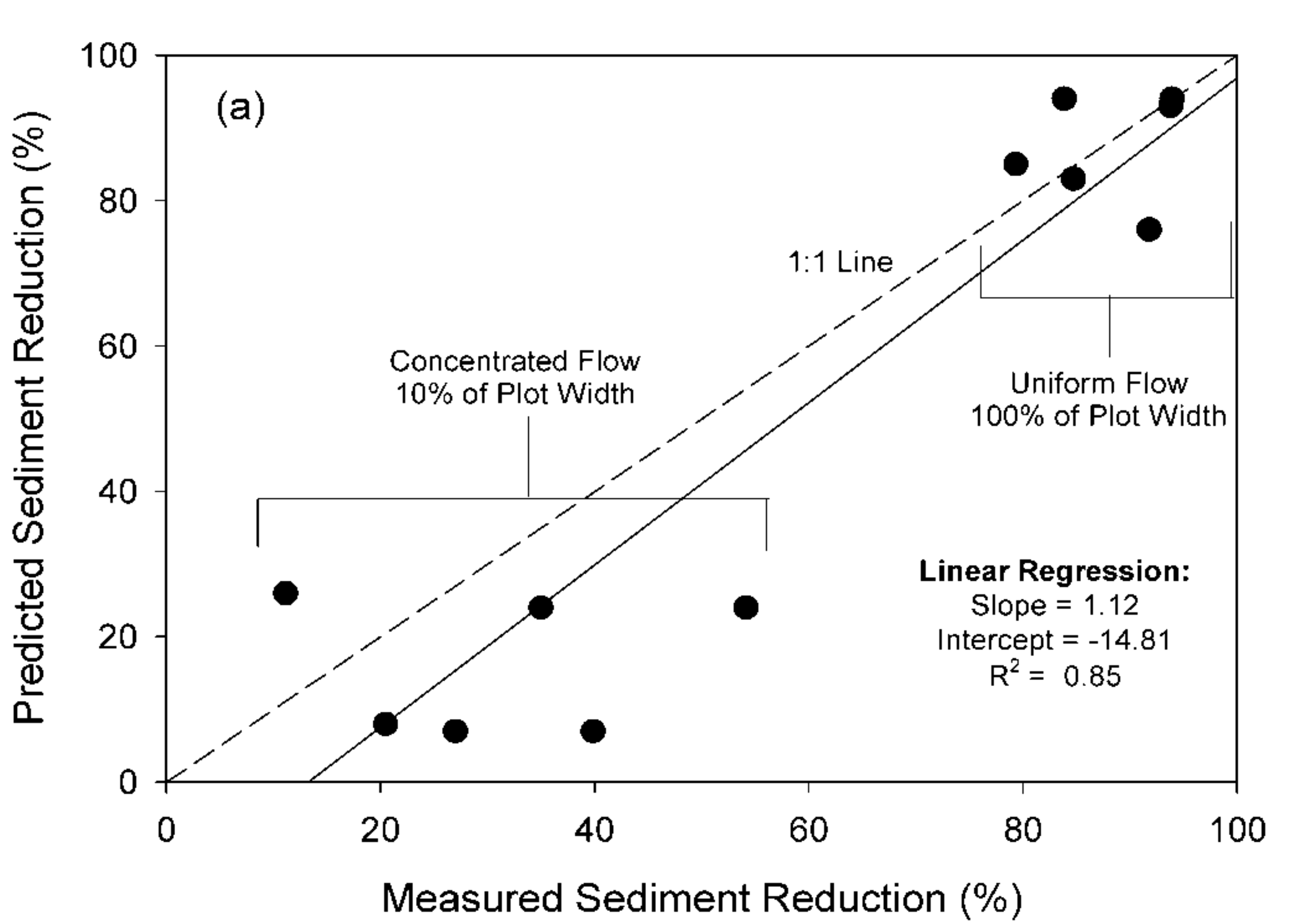
VFSMOD validity check field study - sediment

- VFSMOD (uncalibrated) able to predict <u>sediment reduction (ΔE)</u>



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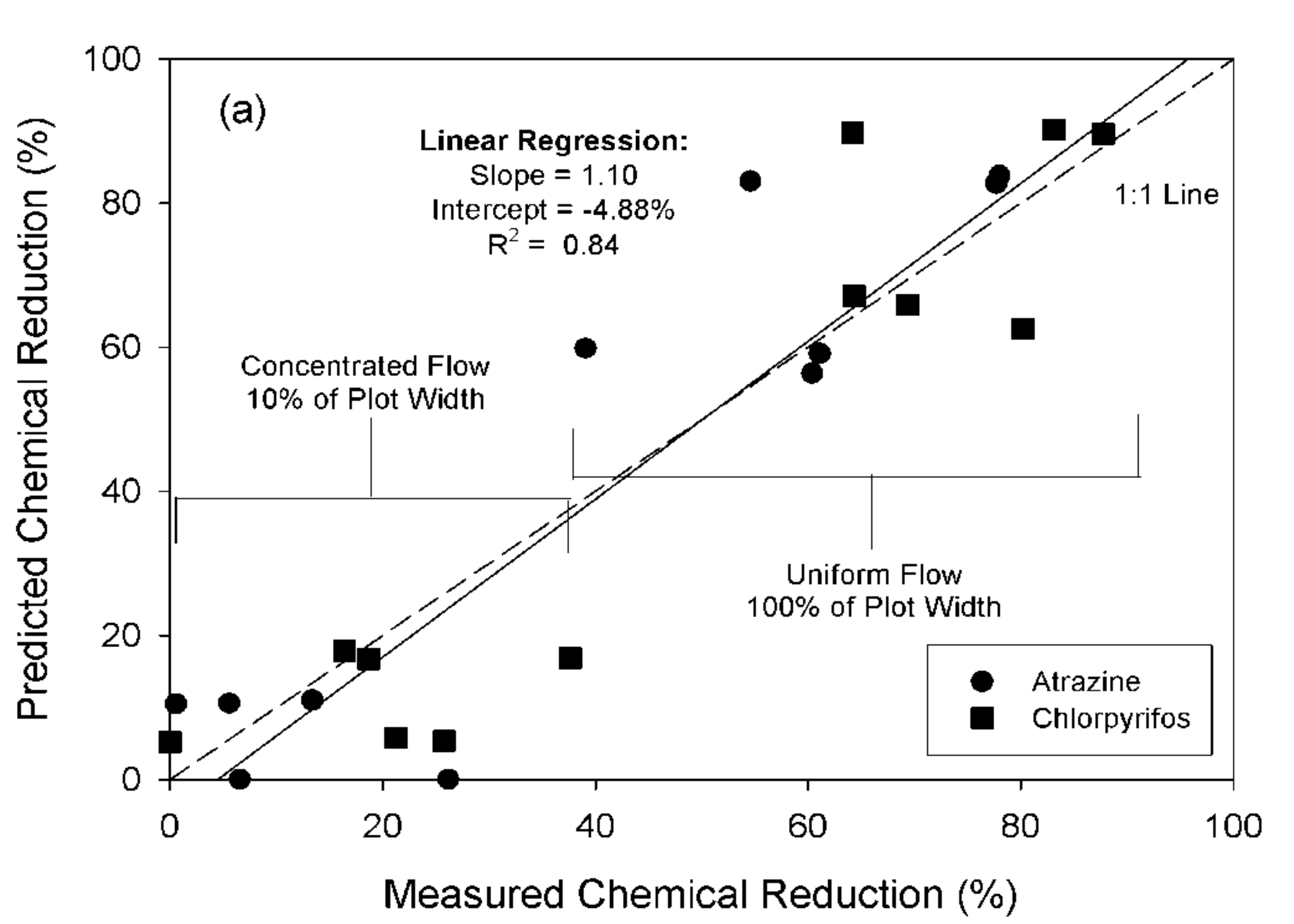
VFSMOD-W validity check field study - pesticide

- Combined VFSMOD + pesticide equation (=VFSMOD-W) able to predict VFS pesticide trapping (ΔP) performance



Poletika, N.N., P.N. Coody, G.A. Fox, G.J. Sabbagh, S.C. Dolder, and J. White. Chlorpyrifos and atrazine removal from runoff by vegetated filter strips: Experiments and predictive modeling. *Journal of Environmental Quality* **2009**, 38(3), 1042-1052.

Sensitivity/Uncertainty Analysis – Parameters

How does variability in the input factors affect the results?

How uncertain are the estimates?

Global sensitivity & uncertainty analysis

- Morris screening
- Fourier Analysis Sensitivity Test

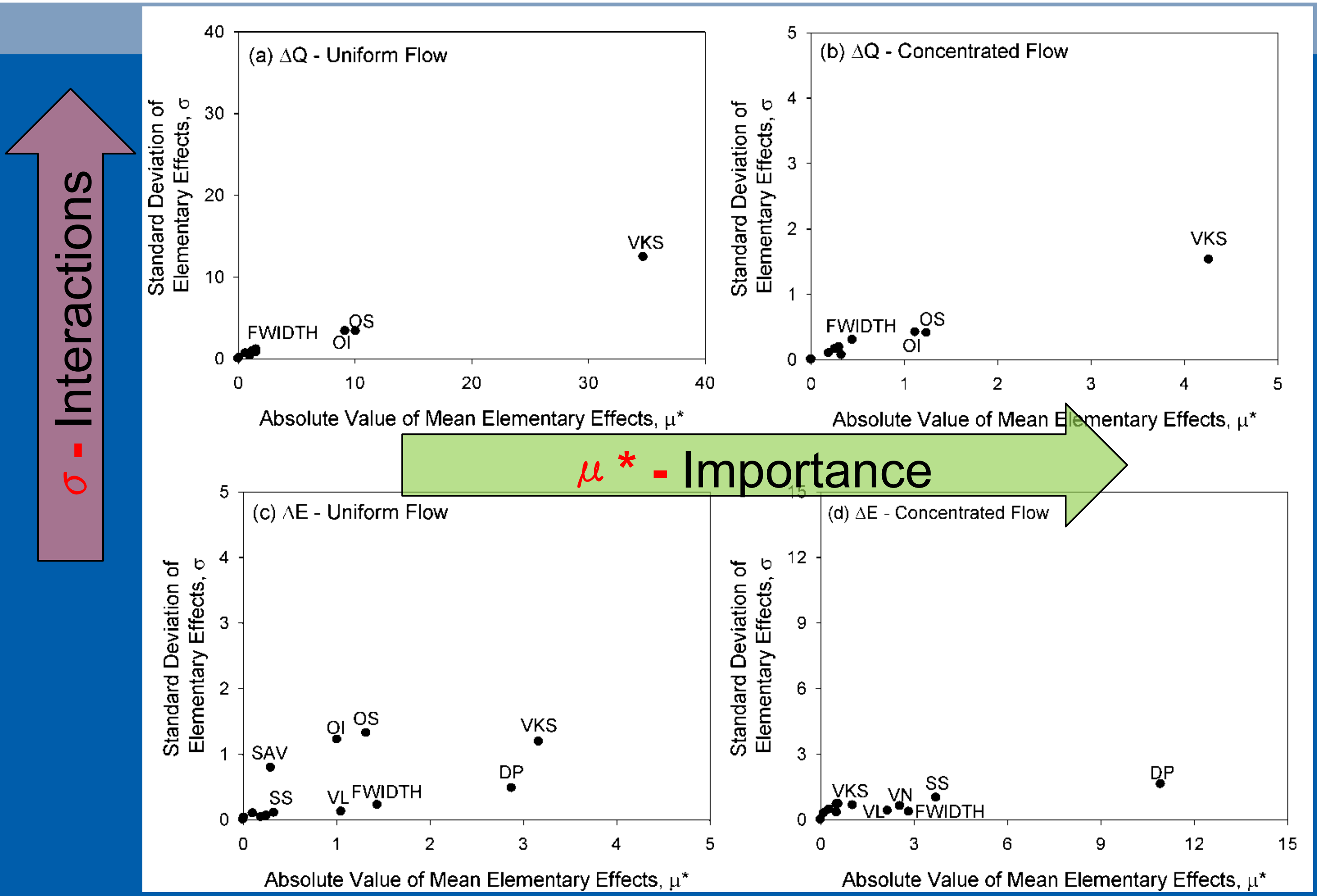
Parameter sets of 3 study sites: Poletika, Arora, Paetzold

Table 2. Input factors for VFSMOD-W explored in the sensitivity and uncertainty analysis.

No.	Input factor	Units	Description
Hydrological inputs			
1	FWIDTH	m	Effective flow width of the strip
2	VL	m	Length in the direction of the flow
3	RNA(I)	$s\ m^{-1/3}$	Filter Manning's *n* for each segment
4	SOA(I)	$m\ m^{-1}$	Filter slope for each segment
5	VKS	$m\ s^{-1}$	Soil vertical saturated hydraulic conductivity in the VFS
6	SAV	m	Green-Ampt's average suction at wetting front
7	OS	$m^3\ m^{-3}$	Saturated soil water content, θ_s
8	OI	$m^3\ m^{-3}$	Initial soil water content, θ_i
9	SCHK	–	Relative distance from the upper filter edge where check for ponding conditions is made (i.e., 1 = end, 0.5 = midpoint, 0 = beginning)
Sedimentation inputs			
10	SS	cm	Average spacing of grass stems
11	VN	$s\ cm^{-1/3}$	Filter media (grass) modified Manning's n_m (0.012 for cylindrical media)
12	H	cm	Filter grass height
13	VN2	$s\ m^{-1/3}$	Bare surface Manning's *n* for sediment inundated area in grass filter
14	DP	cm	Sediment particle size diameter (d_{50})
15	COARSE	–	Fraction of incoming sediment with particle diameter > 0.0037 cm (coarse fraction routed through wedge as bed load [unit fraction, i.e. 100% = 1.0])
Pesticide component inputs			
16	KOC	–	Organic carbon sorption coefficient
17	PCTOC	%	Percentage of organic carbon in the soil
18	PCTC	%	Percentage clay in the soil

Muñoz-Carpena, R., G.A. Fox and G.J. Sabbagh. 2010. Parameter importance and uncertainty in predicting runoff pesticide reduction with filter strips. *J. Environ. Qual. 39(1):1-12*

Sensitivity/Uncertainty Analysis – Results



Fox G.A., R. Muñoz-Carpena, G.J. Sabbagh. 2010. Influence of flow concentration on input factor importance and uncertainty in predicting pesticide surface runoff reduction by vegetative filter strips. *Journal of Hydrology 384:164-173. doi:10.1016/j.jhydrol.2010.01.020.*

Sensitivity/Uncertainty Analysis – Results

Runoff Reduction

- Saturated hydraulic conductivity was the most important input factor

Sediment Reduction

- Hydraulic conductivity; filter strip width; average particle size of the sediment

Pesticide Trapping

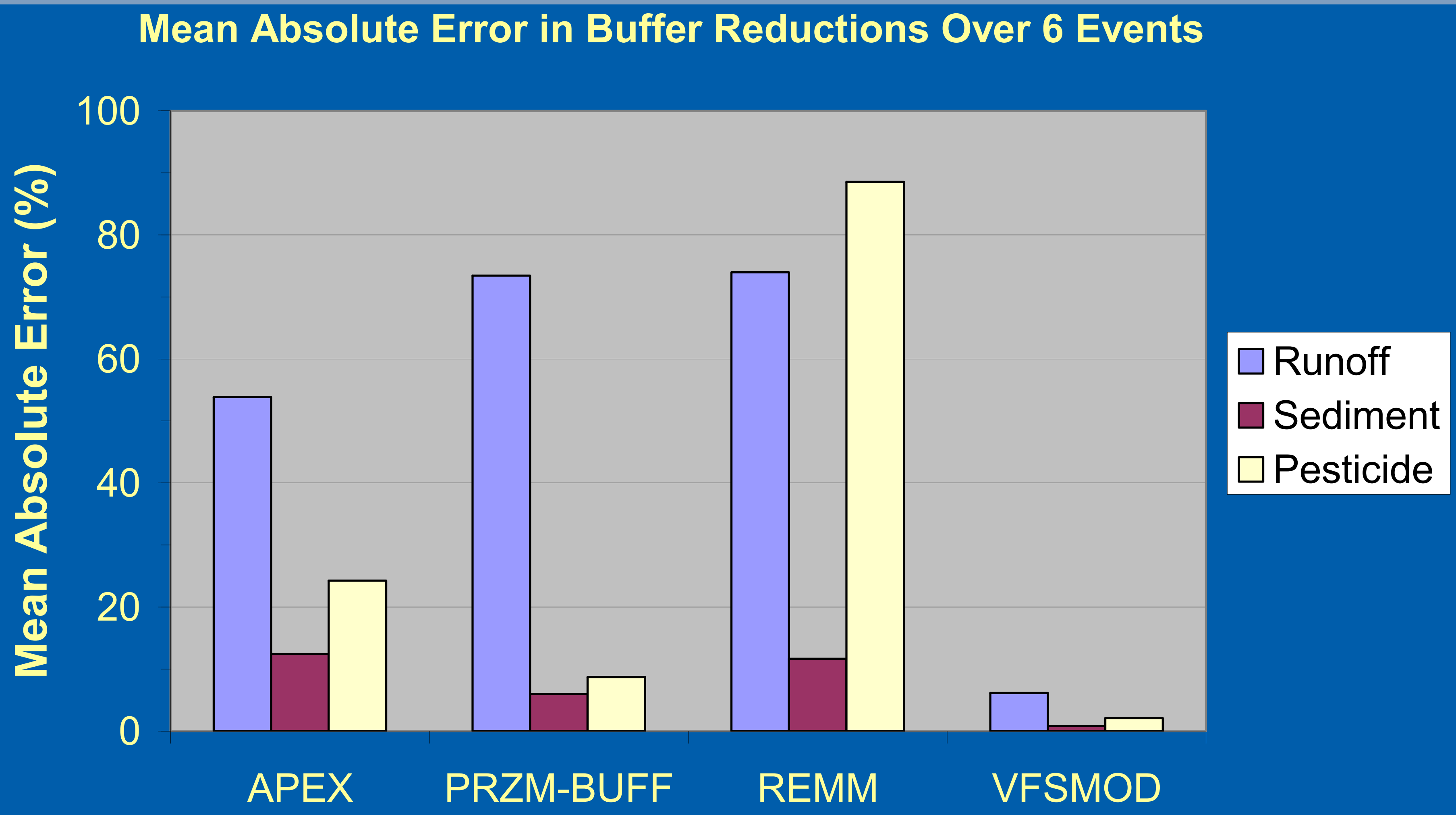
- Sheet Flow: Hydraulic conductivity
  - Explained more than 45% of the total output variance
- Concentrated flow: filter strip width, average particle size, percent clay, and hydraulic conductivity
  - No one input factor explained more than 15% of the total variance.

Benchmarking VFS models

- Testing the ability of four models in simulating buffer strip effectiveness on three common datasets in a **Cold Run** simulation mode
  - APEX
  - PRZM-BUFF
  - REMM
  - VFSMOD
- Understanding the sensitivity of model predictions to the uncertainty in key model input parameters

Winchell and Estes. 2009. A Review of Simulation Models for Evaluating the Effectiveness of Buffers in Reducing Pesticide Exposure. US EPA MRID No. 47773401
Winchell. 2010. A Comparison of Four Models for Simulating the Effectiveness of Vegetative Filter Strips at Reducing Off-Target Movement of Pesticides. (upon request: russell.jones@bayer.com)

Benchmarking VFS models
Mean Error in Buffer Reduction Efficiency



Paetzold study / Germany

Runoff mitigation – modelling VFS

Find way forward to quantify effectiveness of runoff buffers as mitigation measures

- Demonstrate effectiveness of VFS despite variability
- Predict rainstorm event specific pesticide load reductions (solved/sorbed) for VFS with mechanistic model (VFSMOD-W)
- Couple VFSMOD-W with PRZM to be used as an alternative to FOCUS L & M in STEP 4 submissions (STEP4 VFSMOD-W)
- Develop representative EU VFS scenarios to be used in STEP4 VFSMOD-W

Coupling VFSMOD-W with FOCUS$_{sw}$ models
STEP 4 VFSMOD-W GUI

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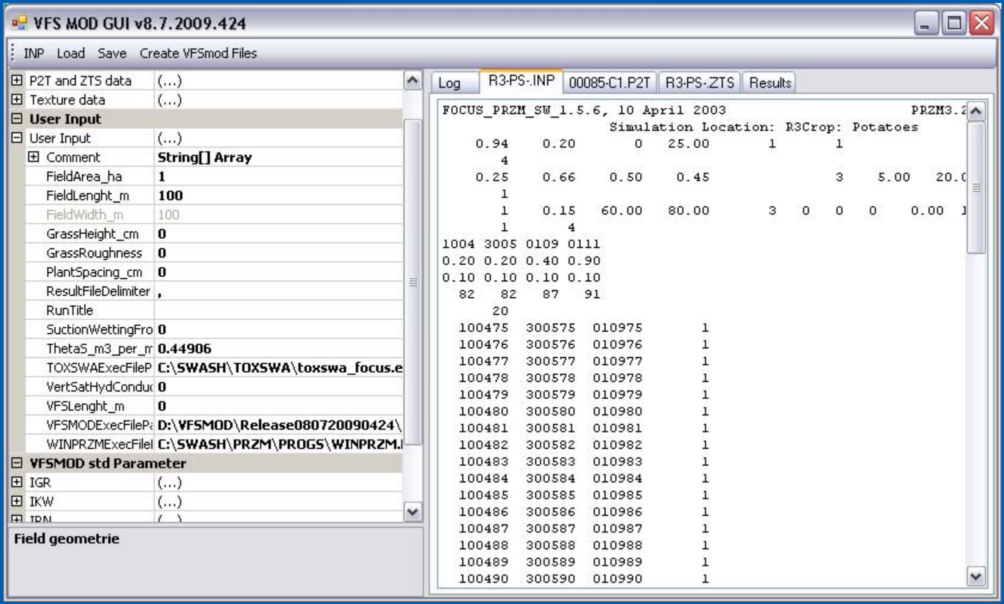
Runoff and sediment loads predicted from the field scale by watershed models (such as PRZM) can be linked as inputs to the routines in **VSFMOD** to predict Δ***Q*** and Δ ***E***

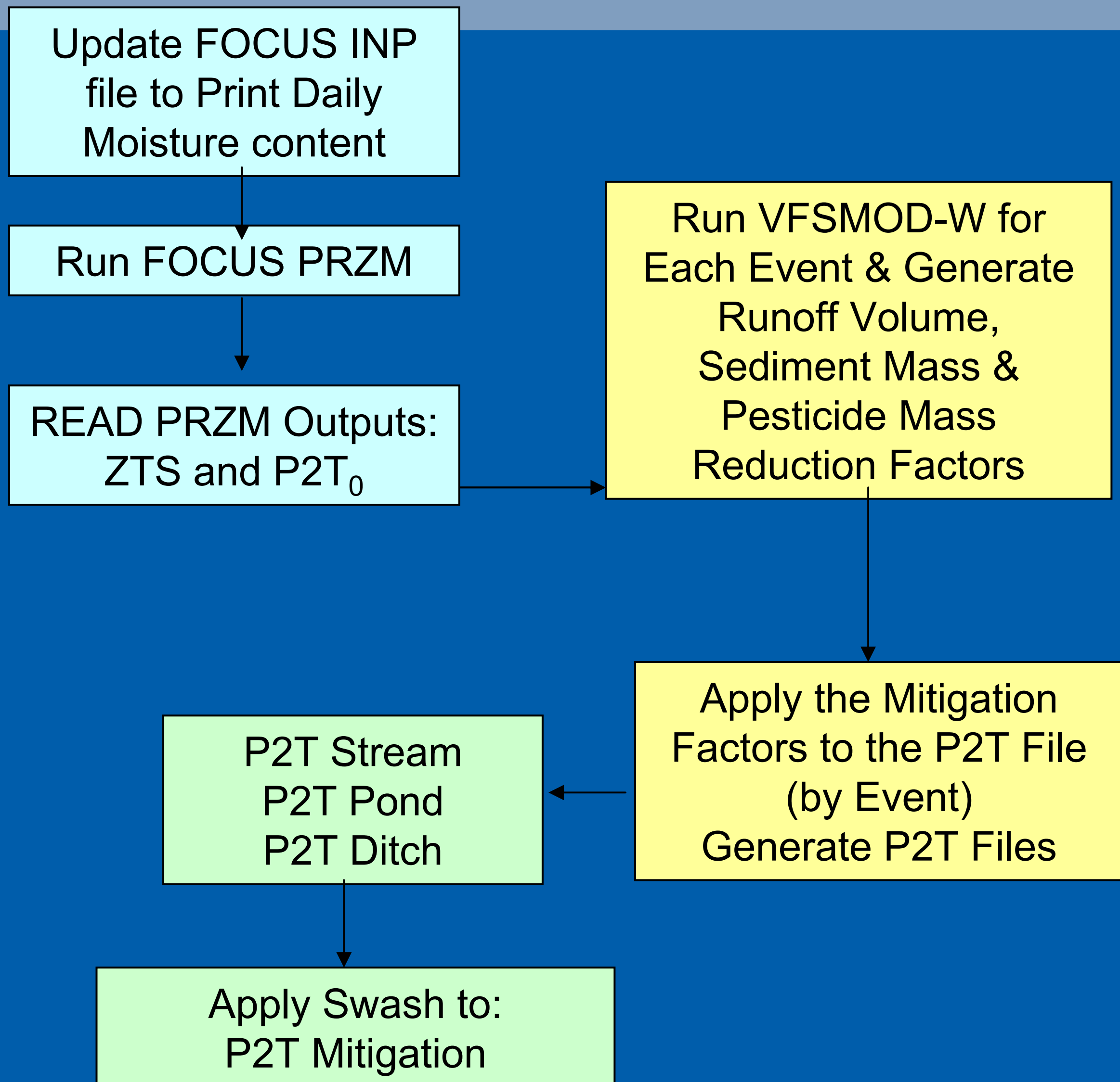
STEP 4 VFSMOD-W GUI available for batch runs linking:

- FOCUS PRZM + VFSMOD-W + FOCUS TOXSWA



GUI by H. Meyer

STEP 4 VFSMOD-W GUI - Workflow



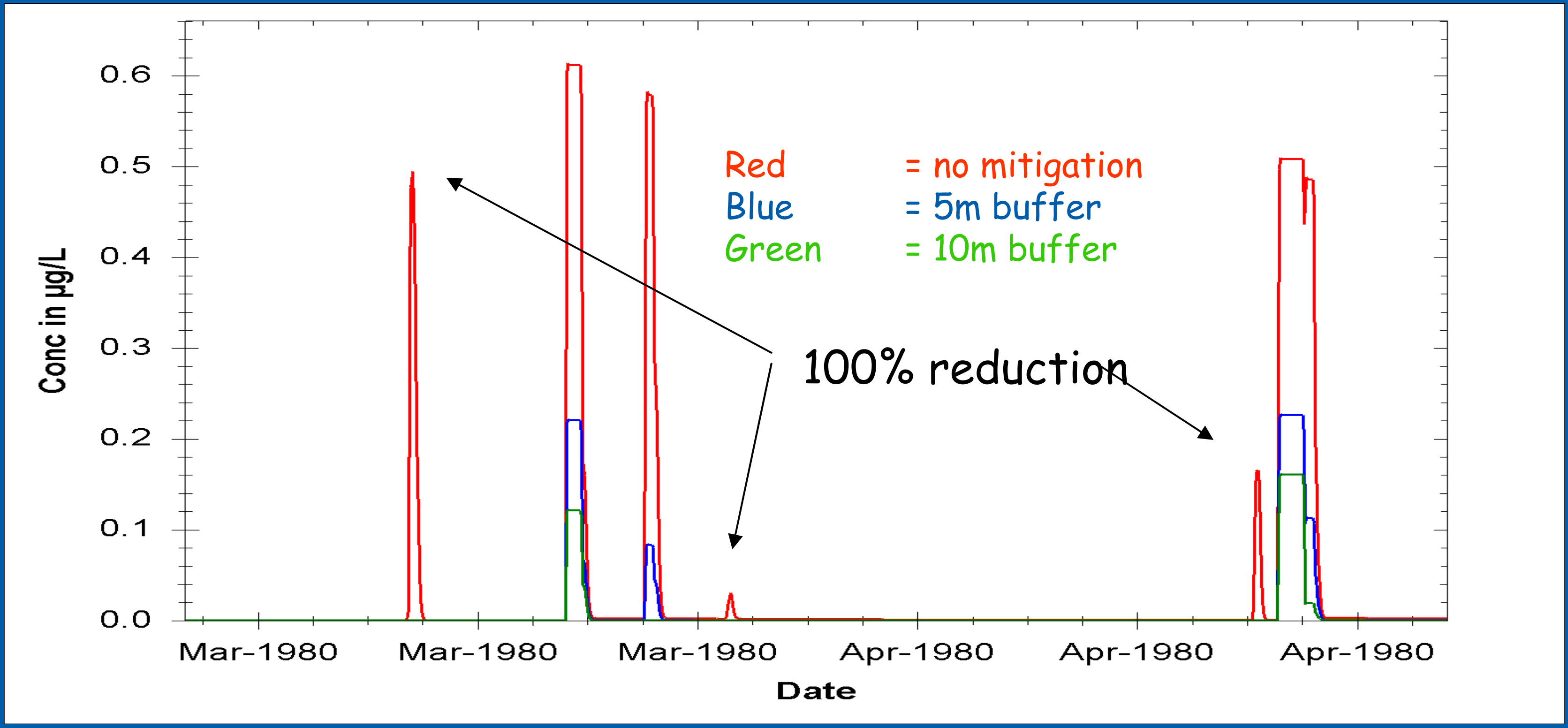
Assumptions:

For VFSmod:

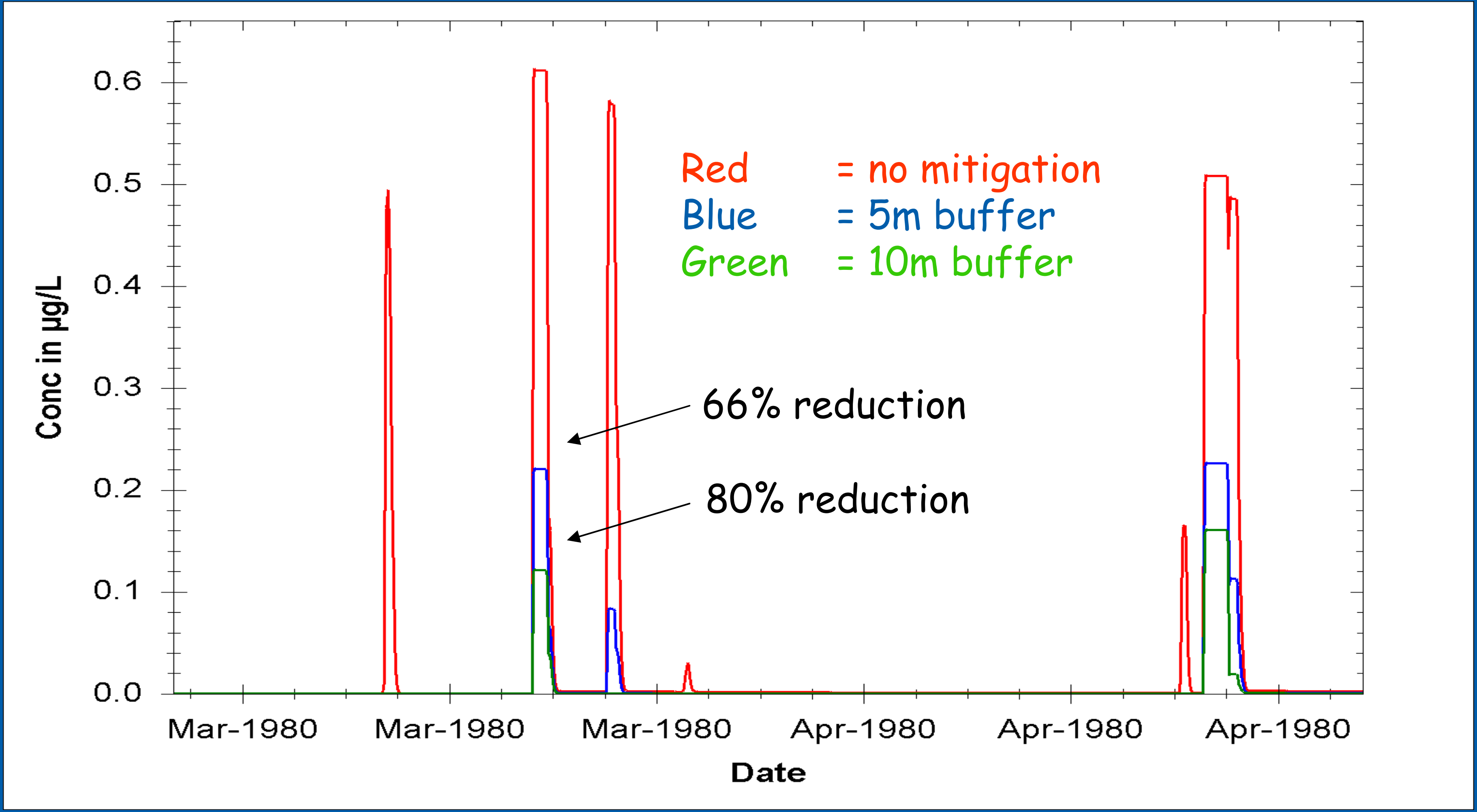
- 1 ha field with 100 m long buffer along the water body
- VFS characterized according to respective FOCUS 'R' scenario
- P2T Stream, Pond and Ditch are based on SWAN algorithms

Runoff Mitigation with VFSMOD

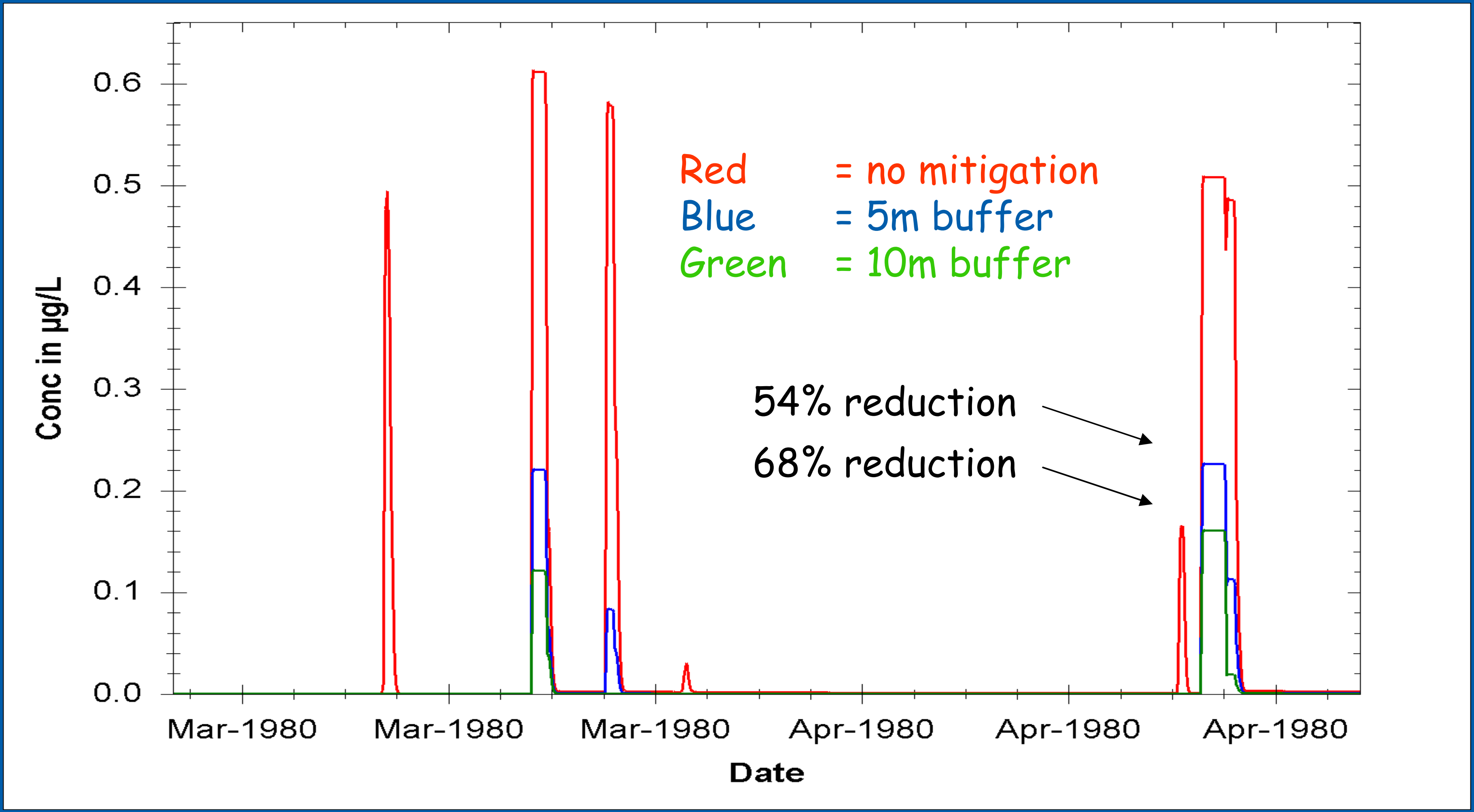
- VFSMOD-W can be used to assess the mitigation of vegetative buffer strips in risk assessments
  - e.g. within FOCUS Step 4



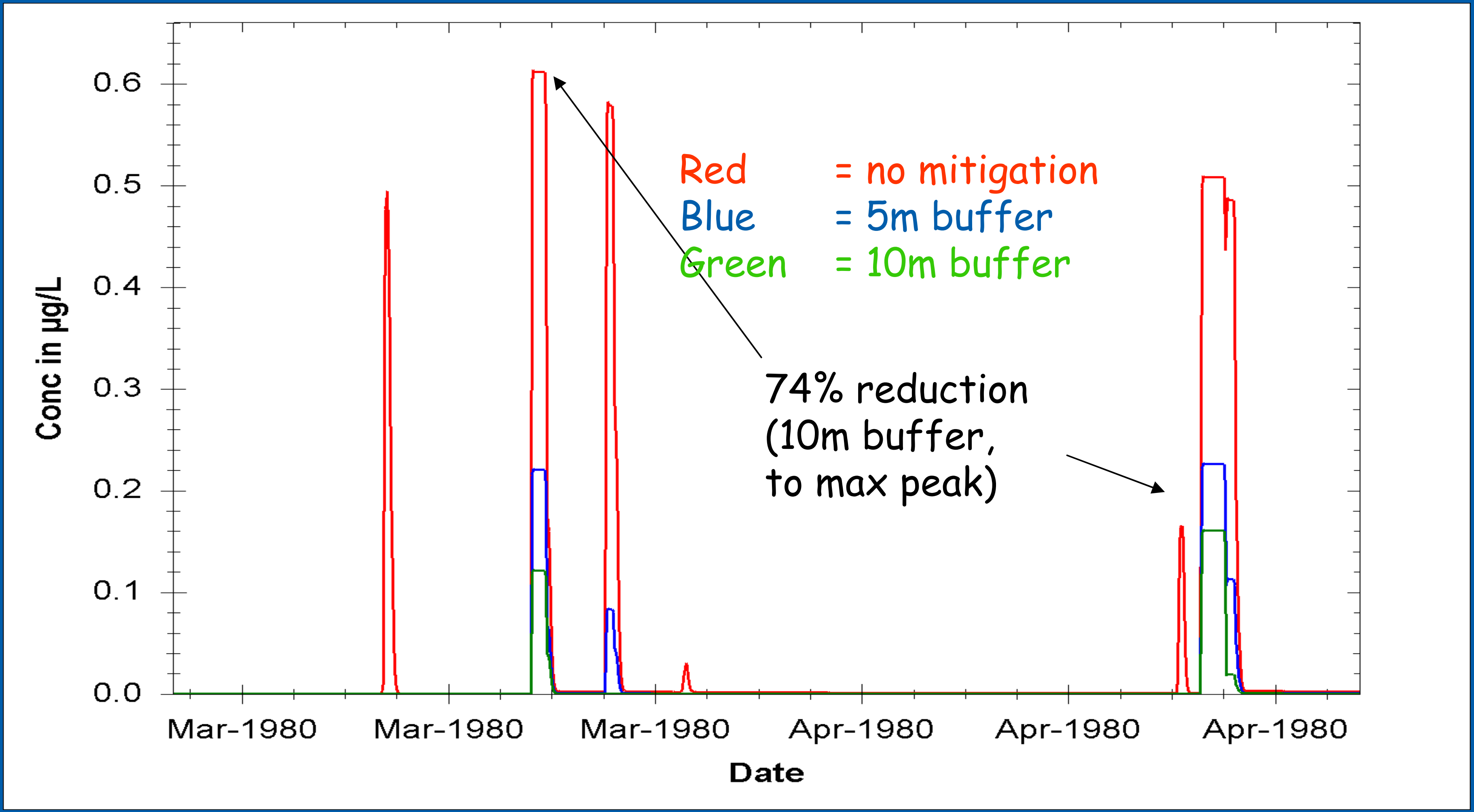
Runoff Mitigation with VFSMOD



Runoff Mitigation with VFSMOD



Runoff Mitigation with VFSMOD



Outlook – What's next

- STEP 4 VFS Scenario Project

Development of European VFS scenarios representative for the FOCUS 'R' landscapes to be used to parameterize the vegetated filter strip model VFSMOD-W (Sabbagh et al. 2009, Munoz-Carpena, 1999 etc) in STEP 4 PECsw calculations.

Project Contractors:
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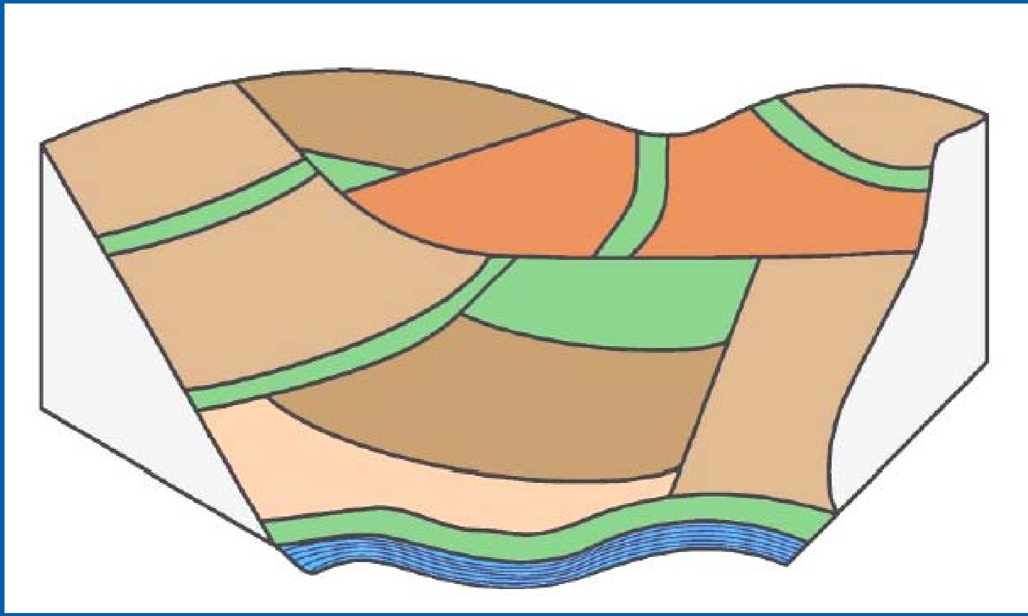
Timeline:
QIV 2010 until QII 2011



CORPEN audit

Outlook - STEP 4 VFS scenario development

- Based on sensitivity analysis decide which of the VFSMOD-W parameter/parameter clusters are driving the model and collect these with highest possible accuracy. Avoid over-parameterization and select defaults for less sensitive parameters
- Analyze readily available European data sources (e.g. SPADE2) to extract parameter distributions for the sensitive VFSMOD-W parameters to cover the FOCUS-R scenarios. Determine which percentiles of the respective parameters represent a realistic worst case
- Spatial analysis on types of buffer elements (CORPEN scheme) present in the R-scenario landscapes to give advice on which elements should be considered in the risk assessment / can be implemented with CEMAGREF's BMPs.
- Implementation of EU Buffer scenarios in FOCUS STEP 4 VFSMOD-W framework / SWAN

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Publications:

- Fox *et al.* (2010). Influence of flow concentration on input factor importance and uncertainty in predicting pesticide surface runoff reduction by vegetative filter strips. Journal of Hydrology 384:164-173. doi:10.1016/j.jhydrol.2010.01.020.
- Jones *et al.* (2010). Modeling the Removal of Pesticides in Runoff by Vegetative Buffer Strips. Paper EC04C-4 presented at the SETAC Europe 20th Annual Meeting 23-27 May 2010, Seville, Spain.
- Muñoz-Carpena *et al.* (2010). Parameter importance and uncertainty in predicting runoff pesticide reduction with filter strips. J. Environ. Qual. 39(1):1-12
- Poletika *et al.* (2009). Chlorpyrifos and atrazine removal from runoff by vegetated filter strips: experiments and predictive modeling. *Journal of Environmental Quality,* 38 (3) 1042-1052.
- Roepke *et al.* (2009): Modeling runoff mitigation capability of vegetated filter strips. Poster presentation at the Pesticide Behaviour in Soils, Water and Air Symposium; 14-16 September; York, UK.
- Sabbagh *et al*. (2009). Effectiveness of vegetative filter strips in reducing pesticide loading: Quantifying pesticide trapping efficiency. *Journal of Environmental Quality,* 38 (2) 762-771.
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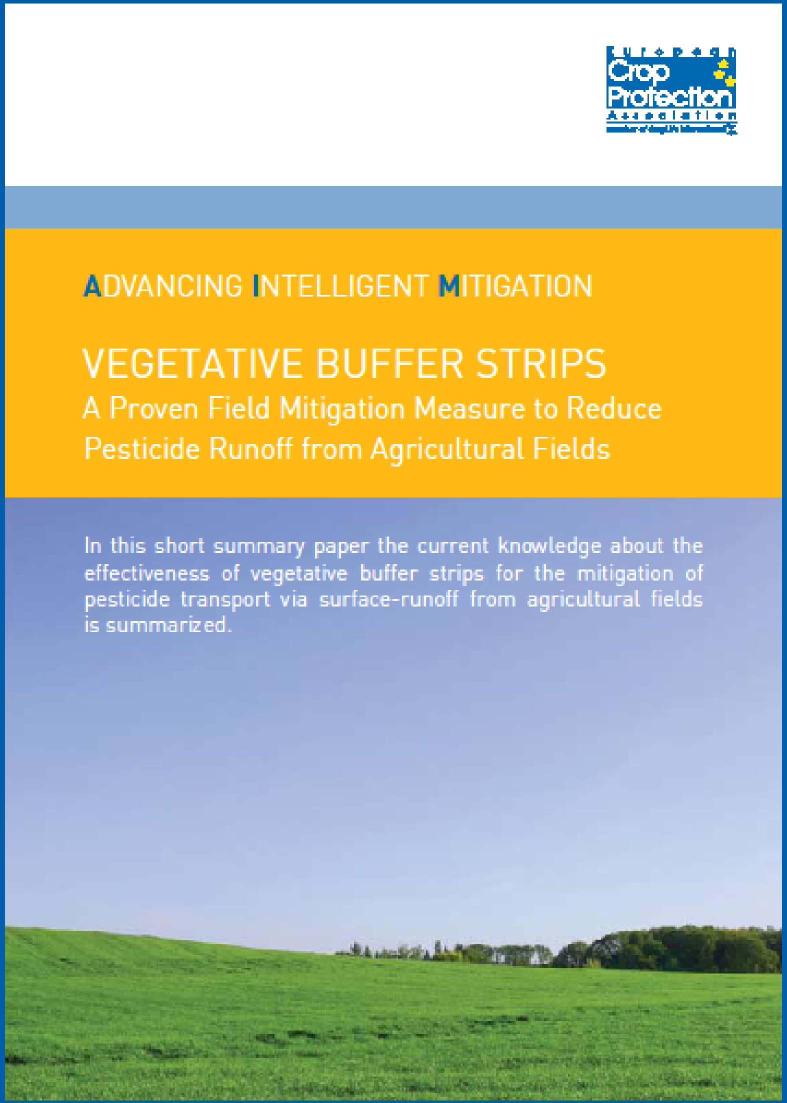

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Thank you for your attention…