Improved parameterization of sediment trapping in VFSMOD

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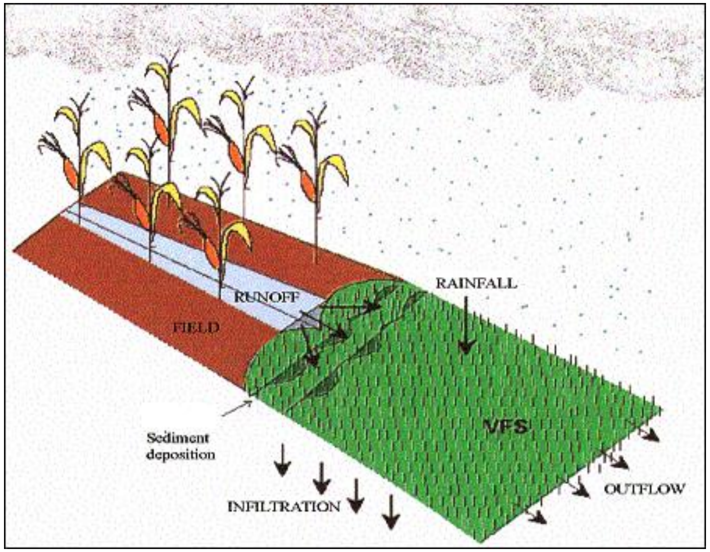

source: http://abe.ufl.edu/carpena/vfsmod/

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Introduction

- Vegetative filter strips (VFS) are the most widely implemented mitigation measure to reduce transfer of pesticides to surface water bodies via surface runoff.
- To reliably model VFS effectiveness in a risk assessment context, an event-based model is needed. The most commonly used dynamic, event-based model for this purpose is VFSMOD (Muñoz-Carpena and Parsons, 2014).
- VFSMOD simulates reductions of total inflow (ΔQ) and incoming eroded sediment load (ΔE) mechanistically. The reduction of pesticide load by the VFS (ΔP) is subsequently calculated with alternative process-based equations.
- Errors in ΔQ and ΔE propagate to pesticide trapping equations
→ reliable estimation of ΔQ and ΔE crucial for reliable prediction of ΔP

Problem

- The most important (sensitive *and* uncertain) parameter for sediment filtration in VFSMOD is the median particle diameter DP of the incoming eroded sediment (Muñoz-Carpena, 1999).
- In the regulatory tool SWAN-VFSMOD, a DP value of 20 µm is used, based on a literature review of measured DP (Brown et al., 2012).
- However, the sediment filtration parameterization in SWAN-VFSMOD was found to overestimate ΔE (Reichenberger et al., 2018)
- Overall objective of this study: improve the predictive accuracy of VFSMOD for regulatory purposes by deriving a generic parameterization method for sediment filtration via inverse modelling.

Study / event selection

- 4 studies with 15 hydrological events were selected from the data compiled by Reichenberger et al. (2019)
- 1 hydrological event = unique combination of site, treatment and date
- different levels of data availability and uncertainty in experimental data
- no information on presence/depth of a shallow water table available

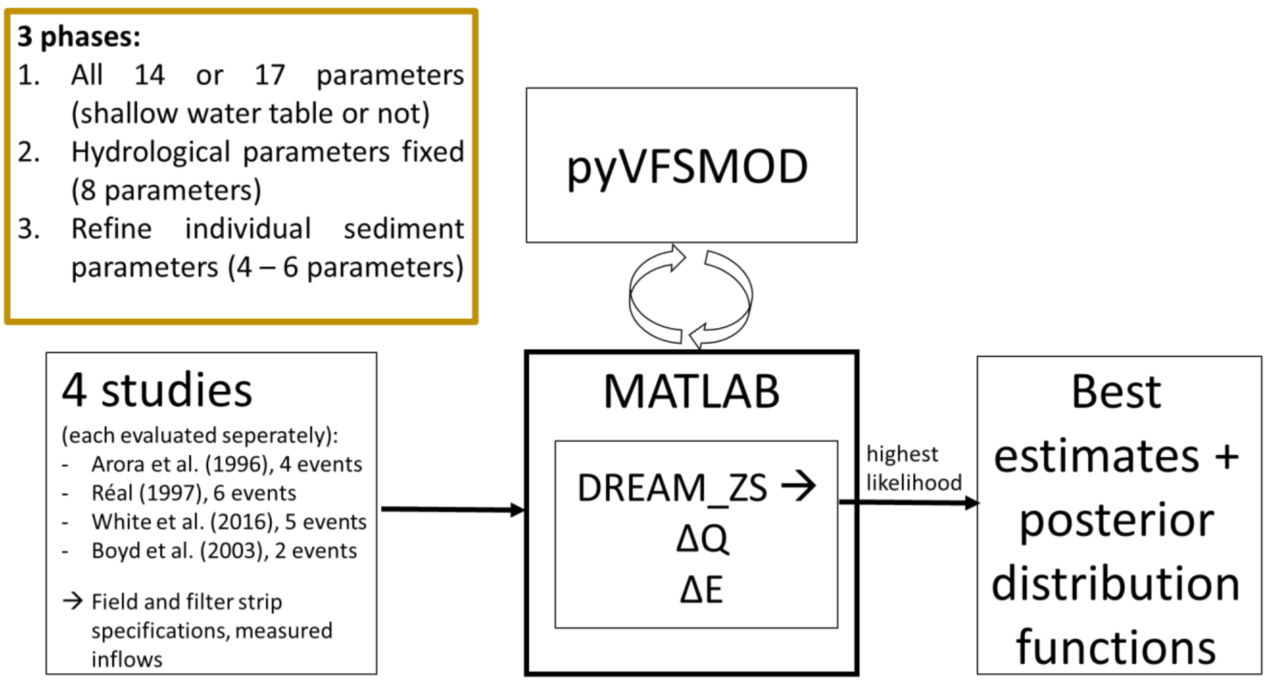
Study	country	site	event dates	surface runoff generation	nb hydrol. events	compounds	availability of hydrographs
Arora et al. (1996)	USA	Ames, Iowa [1)]	06/1993	natural rainfall	2	atrazine, cyanazine, metolachlor	run-on
Boyd et al. (2003)	USA	Ames, Iowa [1)]	06/1999	natural rainfall	2	acetochlor, atrazine, chlorpyrifos	rainfall duration, run-on, outflow
Réal (1997)	FR	Bignan, Bretagne [2)]	12/1994 – 02/1995	natural rainfall	6	diflufenican, isoproturon	none
White et al. (2016)	USA	St. Paul, Minnesota	06/2015-07/2015	Simulated run-on + simulated rainfall on VFS	5	tebuconazole, trichlorfon eq.	rainfall, run-on, outflow

[1)] same site, same experimental device

[2)] run-on, sediment and pesticide inputs into VFS estimated as outflow from control plots

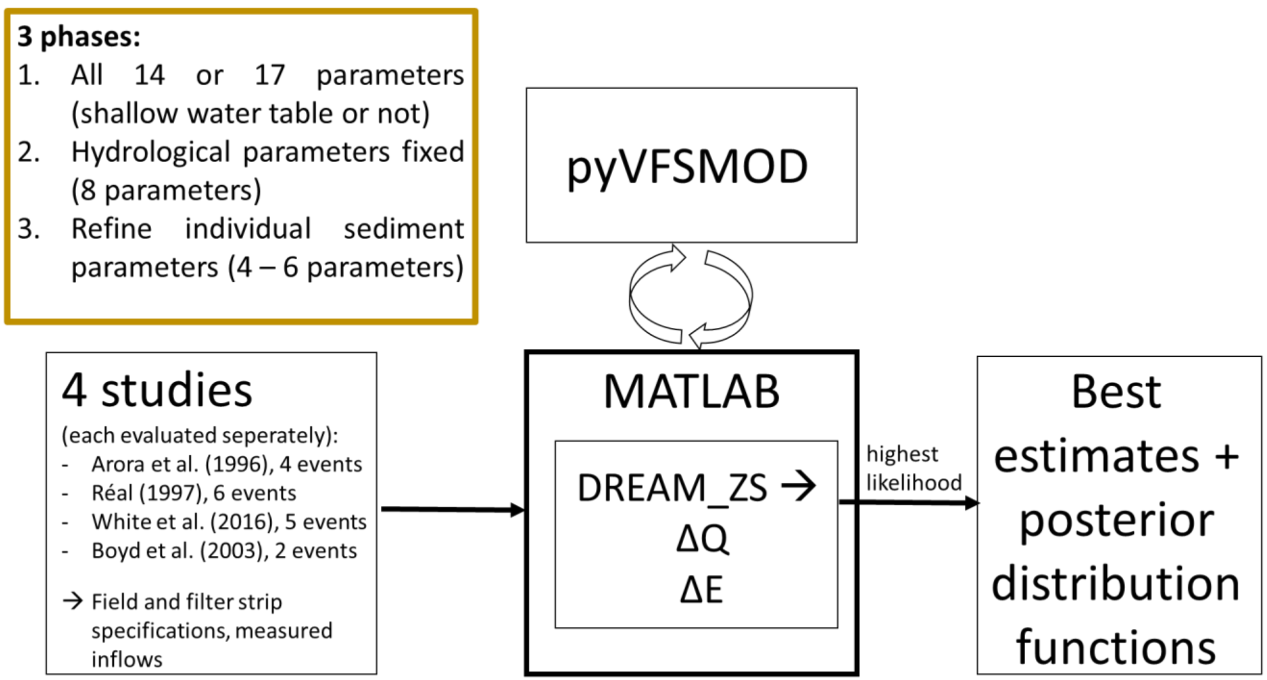
Calibration of VFSMOD

- For each VFS study, a calibration and uncertainty analysis was performed with the DREAM-ZS algorithm (Vrugt, 2016).
- A Python tool for automated VFSMOD simulations was coupled with the DREAM-ZS implementation in MATLAB.
- Target variables: ΔQ, ΔE, VFS outflow hydrographs (where available)
- Hydrologic events of the same study were calibrated simultaneously



Calibration of VFSMOD

- Goodness-of-fit measure: weighted Nash-Sutcliffe Efficiency
  NSE_w = a NSE_ΔQ + b NSE_ΔE
- Three phases:
  1) Calibrate both hydrological and sediment filtration parameters
  2) Hydrological parameters fixed to best parameter set → calibrate only sediment filtration
  3) Refine individual sediment parameters (notably DP)



Median particle diameter DP (1)

In one set of DREAM simulations, DP was not calibrated, but independently estimated:

1. Estimate sediment particle size fractions using the empirical equations of Foster et al. (1985)
   a) 3 classes (sand, silt, clay)
   b) 5 classes (sand, silt, clay + small and large aggregates)
2. Subsequently calculate DP according to the WEPP model (ARS-USDA, 1995; eq. 11.3.12)

$$d_{eff} = e^{\left(\frac{1}{\sum_{i=1}^{3} f_{\det i}} \sum_{i=1}^{3} f_{\det i} (\log[d_i]) \right)} \qquad [11.3.12]$$

where d_{eff} is effective diameter (m), d_i is particle diameter of size class i, and $f_{\det i}$ is the fraction of detached sediment in size class i. An effective value for particle specific gravity is calculated in an identical manner, substituting S_g for d values in the above equation. The use of this equation is still under evaluation and future refinements of the WEPP technology may include changes to this lumped function or implementation of a different procedure which uses characteristics of all particle size classes for computation of deposition.

Median particle diameter DP (2)

Calibrated DP values were compared with DP values from measured sediment particle size distributions (PSD) in the literature.

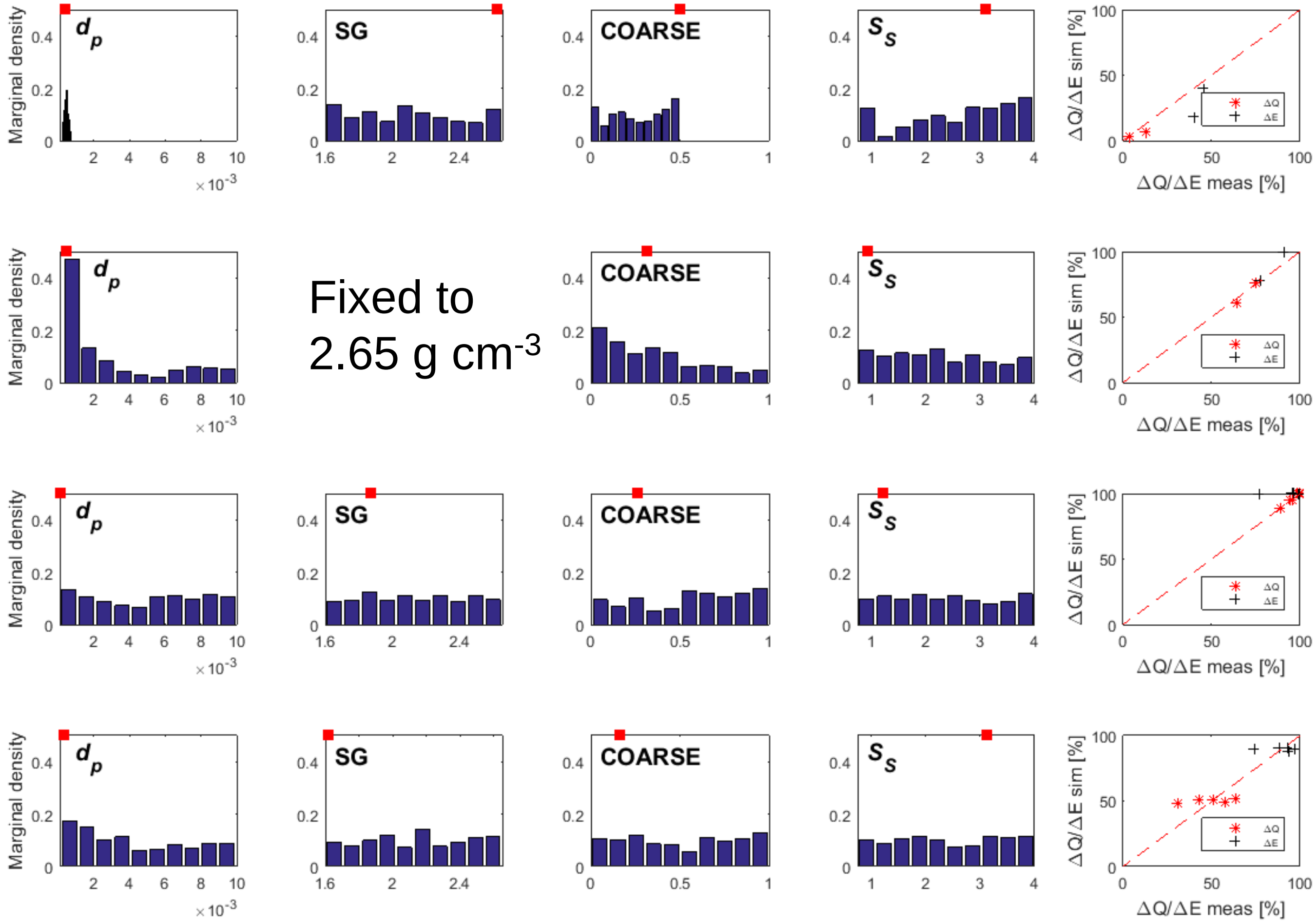
- Deizman et al. (1987) measured aggregate and primary particle size fractions in eroded sediment from a sandy silt loam soil
  → calculate DP using WEPP formula
  → DP range = 24-32 µm (conventional tillage), 42-47 µm (no tillage)

- Pieri et al. (2009) measured PSD of eroded sediment from a loam soil and fitted a normal distribution
  → µ = DP (4.3-13 µm)

Results and Discussion (1)

- A good match of measured ΔQ and ΔE was achieved with VFSMOD for all 3 calibration phases.
- Nevertheless, in Phase 1 and 2 only a few parameters could be well constrained → equifinality
- For all study sites, the sWT option yielded slightly or moderately better fits than the no water table option (due to higher model flexibility)
- Calibrated values for the median sediment particle diameter after phase 3:
  DP = 1.3-5.4 µm
  (cf. current value in SWAN: DP = 20 µm)

Calibration results Phase 3



	Best DP
Arora	5.4 µm
Boyd	4.6 µm
Réal	1.3 µm
White	2.6 µm

Posterior distributions (with the best estimators as red markers) of selected VFSMOD sediment filtration parameters and comparisons of measured vs. simulated reduction of total inflow (ΔQ) and eroded sediment load (ΔE) from the 3rd phase for all four studies. DP = median sediment particle diameter (cm), SG = particle density (g cm^{-3}), COARSE = fraction of incoming sediment particles with diameter > 37 µm, SS = spacing of grass stems (cm)

Results and Discussion (2)

- Foster / WEPP approach:
  - yielded much higher DP values (40-105 µm) and much worse calibration results for ΔE.
  - Reason: Foster et al. (1985) equations represent sediment directly after detachment and do not account for enrichment of fine particles due to deposition in the field.
    → equations not usable in this context

- Comparison with literature:
  - Calibrated DP values slightly lower than DP measured by Pieri et al. (2009), and
  - considerably lower than DP derived from the PSDs measured by Deizman et al. (1987)

- Sediment trapping in VFSMOD is physically-based, but models are always a simplification of reality → Low DP values seem to be necessary in VFSMOD to account for additional processes occurring in reality

Conclusions and Outlook

- Both hydrological and sediment filtration parameters could be successfully calibrated with DREAM-ZS.

- Ongoing statistical analysis of DP values calibrated here and DP calibrated with VFSMOD-W (not shown) to derive an equation to predict DP from available input data, e.g.
  - texture of field soil
  - field slope
  - eroded sediment yield
  - field OM content

- The updated sediment parameterization method will further improve the predictive performance of VFSMOD as the best available tool for simulating the effectiveness of VFS for regulatory purposes.

Many thanks for your attention!

Topsoil properties of field sites

Study	Soil description	% clay	% silt	% sand	remarks	silt range	OM	field slope
		— rescaled to 100 % —				µm	%	%
Arora / Boyd	Clarion loam	20.7	33.5	45.8		2-50	5.17	3
Réal	silt loam	17.2	46.2	36.6		?	7	8
White	Mollic Hapludalf	12	33	55	mean properties for 0-6’’ depth	2-50	3.25	-

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