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Improved Parameterization of Sediment Trapping in VFSMOD

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Introduction

- Vegetative filter strips (VFS) are the most widely implemented mitigation measure to reduce transfer of pesticides and other pollutants to surface water bodies via surface runoff (cf. Fig. 1)
- 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
- 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, as a conservative assumption 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

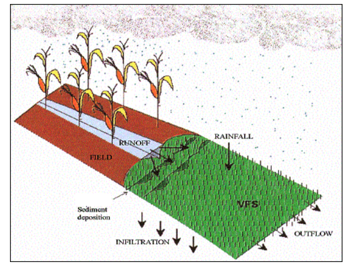

Fig. 1: Schematic representation of a VFS. http://abe.ufl.edu/carpena/vfsmod/

Materials and Methods

Field data
- Four VFS studies with 16 hydrological events were selected from the data compiled by Reichenberger et al. (2019), representing different levels of data availability and uncertainty (Table 1)

Calibration of VFSMOD
- For each VFS study, a calibration and uncertainty analysis was performed by coupling VFSMOD with DREAM-ZS (Vrugt, 2016), as shown in Fig. 2
- Different VFSMOD settings:
  - no water table (noWT, 14 parameters)
  - shallow water table (Muñoz-Carpena et al., 2018; sWT, 17 parameters)
- Target variables: ΔQ, ΔE, VFS outflow hydrographs (where available)
- Hydrologic events of the same study site were calibrated simultaneously
- Goodness-of-fit measure: weighted Nash-Sutcliffe Efficiency (NSE_w = a NSE_ΔQ + b NSE_ΔE)

Three calibration phases:
1. Including both hydrological and sediment filtration parameters
2. Hydrological parameters fixed to best parameter set → calibrate only sediment filtration parameters
3. Refine individual sediment parameters (notably DP)

Median particle diameter DP
- 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 + small and large aggregates); 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)
- 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)

Table 1: VFS field experiments selected for the DREAM-VFSMOD simulation study

Study	country	site	event dates	surface runoff generation	nb hydrol. events	run-on / total inflow (%)	compounds	availability of hydrographs
Arora et al. (1996)	USA	Ames, Iowa [1]	06/1993	natural rainfall	2	86-93	atrazine, cyanazine, metolachlor	run-on
Boyd et al. (2003)	USA	Ames, Iowa [1]	06/1999	natural rainfall	2	74-90	acetochlor, atrazine, chlorpyrifos	rainfall duration, run-on, outflow
Réal (1997)	FR	Bignan, Bretagne [2]	12/1994 - 02/1995	natural rainfall	6 [3]	9-33	diflufenican, isoproturon	none
White et al. (2016)	USA	St. Paul, Minnesota	06/2015 - 07/2015	Simulated run-on + simulated rainfall on VFS	5	27-46	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
[3] One of the orginally 7 events was excluded from the DREAM calibration because of an unrealistically low measured ΔE (23 %).

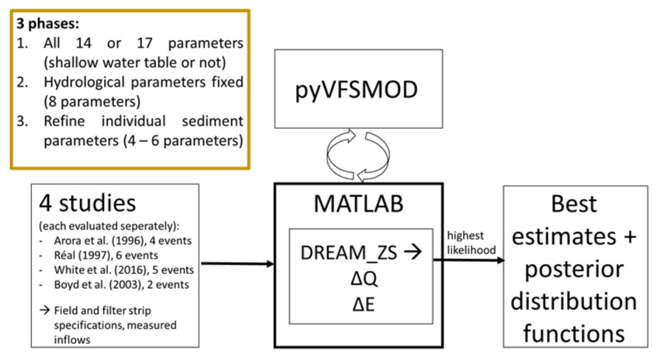

Fig. 2: Procedure to calibrate the parameters describing sediment trapping in VFSMOD.

Results & Discussion

- A good match of measured ΔQ and ΔE was achieved with VFSMOD for all 3 calibration phases (cf. Fig. 3 for phase 3)
- 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: 1.3-5.4 µm (one order of magnitude lower than the SWAN default value of 20 µm)
- The Foster / WEPP approach yielded much higher DP values (40-105 µm) and much worse calibration results for ΔE. The likely reason is that the Foster equations represent sediment directly after detachment and do not account for enrichment of fine particles due to deposition in the field. → not usable in this context
- Calibrated DP values were slightly lower than those measured by Pieri et al. (2009) and considerably lower than those 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

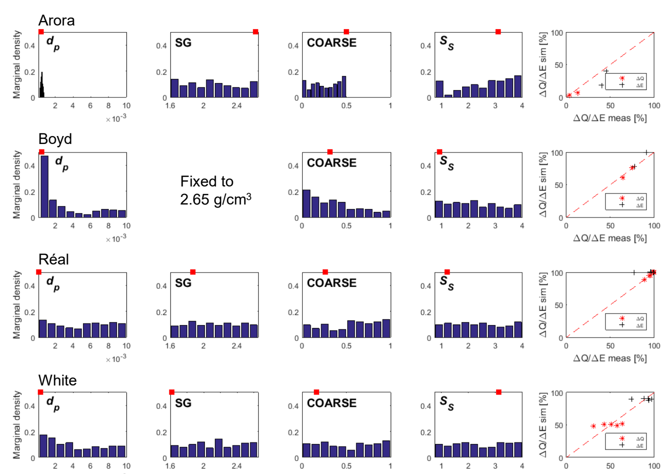

Fig. 3: Posterior distributions (with the best estimators as red markers) of selected VFSMOD sediment filtration parameters and comparisons of measured vs. simulated reduction of total inflow (ΔQ) and eroded sediment load (ΔE) from the 3rd phase for all four studies under investigation. DP = median sediment 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).

Conclusions & 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. clay and silt contents, field slope, eroded sediment yield)
- 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

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