# Modelling real vegetative filter strip (VFS) experiments with a new VFSMOD version – calibration and uncertainty analysis with DREAM-ZS


Stefan Reichenberger [1], Robin Sur [2], Carolin Kley [2], Stephan Sittig [1], Sebastian Multsch [1]

[1] knoell Germany GmbH, 68163 Mannheim, Germany
(contact: sreichenberger@knoell.com)
[2] Bayer AG, 40789 Monheim, Germany


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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 waters via surface runoff and erosion.
- 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; Muñoz-Carpena et al., 1999).
- While VFSMOD simulates reduction of total inflow (ΔQ) and reduction of incoming eroded sediment load (ΔE) mechanistically, the reduction of pesticide load by the VFS (ΔP) is calculated with alternative process-based equations, including empirical regressions and a mechanistic mass balance approach.

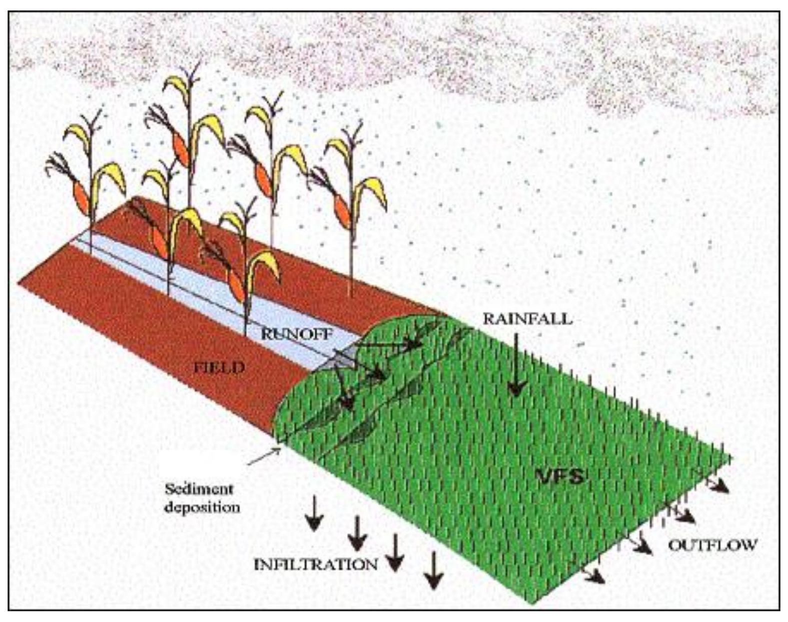


Fig. 1: Schematic representation of a VFS. http://abe.ufl.edu/carpena/vfsmod/

## Selected events / studies

**Table 1: VFS field experiments selected for the 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 %).

## Pesticide trapping options in VFSMOD

A) Original Sabbagh equation (Sabbagh et al., 2009)

$$\Delta P = 24.79 + 0.54\,\Delta Q + 0.52\,\Delta E - 2.42\ln(Fph + 1) - 0.89\,\%C$$

B) Revised Sabbagh equation (Reichenberger et al., 2019)

$$\Delta P = -11.5142 + 0.5949\,\Delta Q + 0.4892\,\Delta E - 0.3753\ln(Fph + 1) + 0.2039\,\%C$$

C) Mass balance approach (Reichenberger et al., 2019)

$$\Delta P/100\% = \min[(Vi + Kd * Ei), (\Delta E/100\% * Ei * Kd + \Delta Q/100\% * Vi)] / (Vi + Kd * Ei)$$

with

| | |
|---|---|
| ΔP | relative reduction (%) of total pesticide load |
| ΔQ | relative reduction (%) of total water inflow Qi (L) |
| ΔE | relative reduction (%) of incoming sediment load Ei (kg) |
| Fph | phase distribution coefficient (mass ratio) |
| Kd | linear sorption coefficient (L/kg) |
| %C | clay content of field soil (as proxy for clay content of the eroded sediment; %) |
| Vi | incoming run-on from the source area (L) |

## Preliminary study

- Reichenberger et al. (2018) simulated 4 VFS studies (cf. Tab. 1) with 16 hydrological events
- Conclusions:
  - ➢ The SWAN-VFSMOD (Brown et al., 2012) parameterization of saturated hydraulic conductivity seems too conservative (too little infiltration), while the parameterization of sediment filtration seems too optimistic (too much sediment trapping).
  - ➢ Biases in predicted ΔQ and ΔE propagate differently to ΔP predicted with the different trapping equations.

## Objectives

The objectives of this follow-up study were to

(1) calibrate hydrology and sediment trapping in VFSMOD for the 4 VFS studies

(2) compare the performance of the three pesticide trapping equations applied predictively to the calibrated VFSMOD runs

(3) elucidate which trapping equation performs better in which situation (e.g. soil type, Kd, characteristics of runoff/erosion event),

(4) help improve parameterization methodologies for the infiltration and sediment filtration modules for regulatory VFS scenarios

## Materials and Methods

- 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
- Four different VFSMOD settings:
  - ➢ no water table (noWT, 14 parameters) / shallow water table (Muñoz-Carpena et al., 2018; sWT, 17 parameters)
  - ➢ ICO switch (feedback of sedimentation on infiltration or not): 0 or 1
- Goodness-of-fit measure:
  - ➢ weighted Nash-Sutcliffe Efficiency ($NSE\_w = a * NSE\_\Delta Q + b * NSE\_\Delta E$)
  - ➢ sum of squared inversely weighted residuals (SSIWR)
- To limit the effect of the priors on the posterior distributions, flat, non-informative priors were used (cf. Table 2).
- After the calibration the three pesticide trapping equations were applied predictively to the best parameter sets.

## Results and Discussion

- Overall a good match of measured ΔQ and ΔE could be achieved.
- Only a few parameters could be well constrained (cf. Fig. 2) → equifinality
- For events with ΔQ close to 0 or 100 % parameter estimation is difficult (not enough information in data).
- For all studies, the sWT option yielded slightly or moderately better fits than the noWT option. However, sWT also had more equifinality.
- Activating the feedback of sedimentation on infiltration (ICO = 1) did on average not improve the calibration, but did influence the posterior distributions --> further investigations needed.
- Goodness-of-fit measure:
  - ➢ on average, NSE_w performed better than SSIWR
  - ➢ a = 0.6, b = 0.4 was a good compromise
- Using available outflow hydrographs for calibration did not improve the calibration of ΔQ and ΔE, but helped avoid best parameter sets which are "right for the wrong reason" (cf. Fig. 3)
- Results for ΔP are in line with previous observations (Reichenberger et al., 2018): The new Sabbagh equation yielded the best match of ΔP, while the mass balance approach was the most conservative of the three trapping equations (cf. Fig. 4).

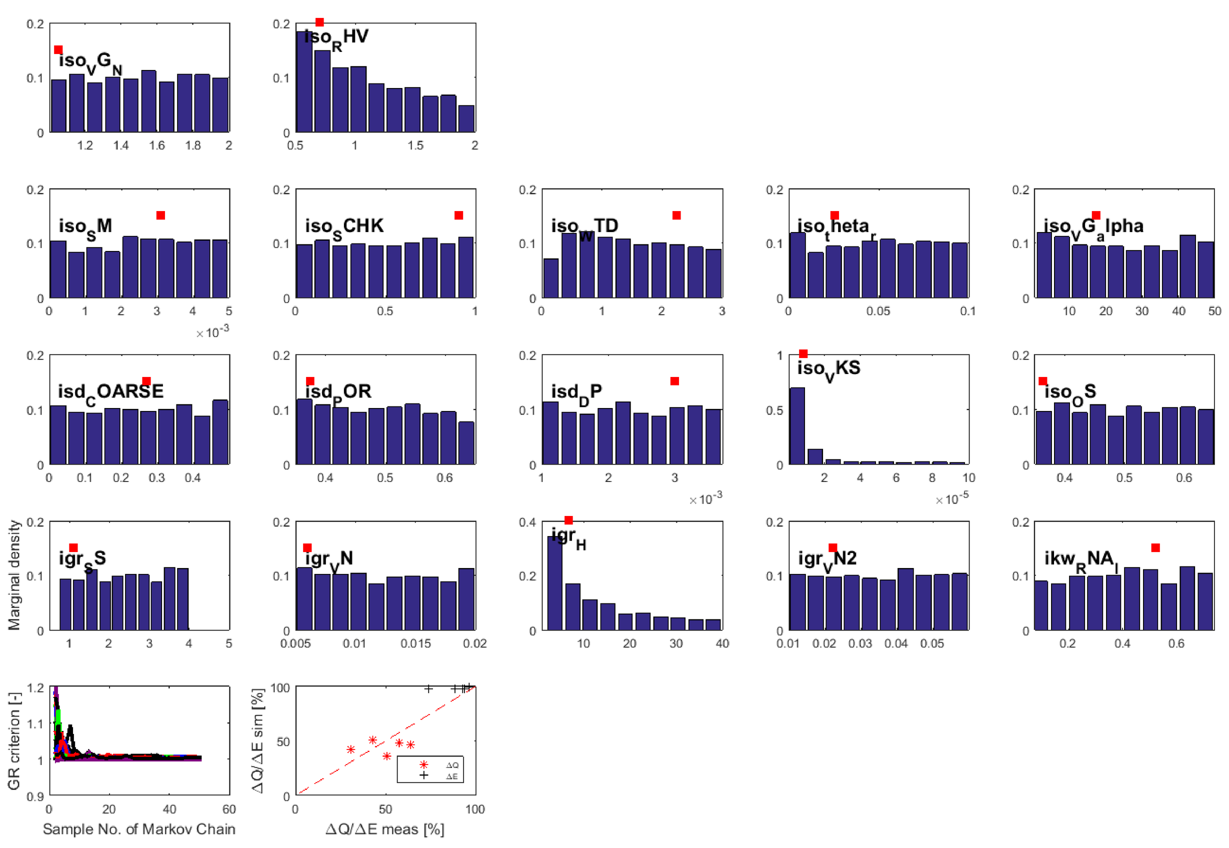

Fig. 2: Posterior parameter distributions obtained with DREAM-ZS for the White et al. (2016) study (90% confidence intervals, with best estimators as red markers), dynamics of convergence, and measured vs. simulated ΔQ and ΔE. VFSMOD settings: sWT, ICO = 0. DREAM-ZS settings: a = b = 0.25; weight for each outflow hydrograph = 0.1

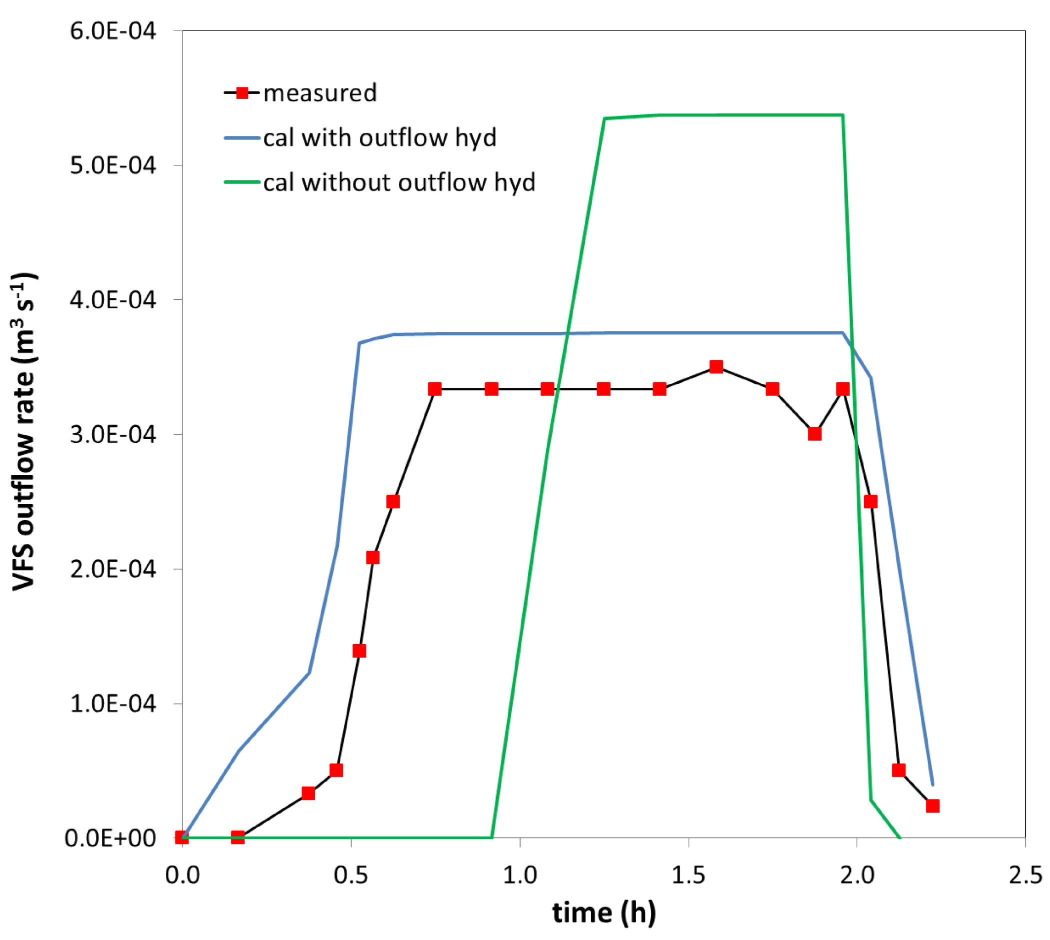


Fig. 3: Measured and simulated (sWT, ICO = 0) VFS outflow for an event from White et al. (2016). The blue and green curves correspond to the best parameter sets after calibration with and without outflow hydrographs, respectively.

## Prior distributions

**Table 2: VFSMOD parameters included in the calibration with DREAM, and prior distributions**

| parameter | description | unit | distribution type | min | max | VFSMOD option |
|---|---|---|---|---|---|---|
| SS | spacing of the filter media elements | cm | uniform | 0.75 | 4 | both |
| VN | filter media (grass) Manning's n | $s.cm^{-1/3}$ | uniform | 0.005 | 0.02 | both |
| H | filter media height | cm | log-uniform | 2 | 40 | both |
| VN2 | bare surface Manning's n for sediment-inundated area | $s.m^{-1/3}$ | uniform | 0.01 | 0.06 | both |
| RNA | Manning's roughness for each segment | $s.m^{-1/3}$ | uniform | 0.06 | 0.74 | both |
| COARSE | fraction of incoming sediment particles with diameter > 0.0037 cm | fraction | uniform | 0 | < 0.5 | both |
| POR | porosity of deposited sediment | fraction | uniform | 0.35 | 0.65 | both |
| DP | median sediment particle diameter | cm | uniform | 0.001 | < 0.0037 | both |
| VKS | saturated vertical hydraulic conductivity | $m\ s^{-1}$ | log-uniform | 1.00E-07 | 1.00E-04 | both |
| SAV | Green-Ampt's average suction at wetting front | m | log-uniform | 0.01 | 1 | noWT |
| OS | saturated soil-water content | $m^3\ m^{-3}$ | uniform | 0.35 | 0.65 | both |
| OI | initial soil water content | $m^3\ m^{-3}$ | uniform | 0.1 | 0.6 | noWT |
| SM | maximum surface storage | m | uniform | 0 | 0.005 | both |
| SCHK | relative distance from the upper VFS edge where ponding check is made | fraction | uniform | 0 | 1 | both |
| WTD | water table depth | m | uniform | 0 | 3 | sWT |
| theta_r | van Genuchten residual water content | $m^3\ m^{-3}$ | uniform | 0 | 0.1 | sWT |
| VG_alpha | van Genuchten alpha | $m^{-1}$ | uniform | 0.5 | 50 | sWT |
| VG_N | van Genuchten N | | uniform | 1.001 | 2 | sWT |
| VG_M | van Genuchten M | | n.a. [1)] | | | sWT |
| RHV | ratio of horizontal to vertical saturated conductivity | fraction | log-uniform | 0.5 | 2 | sWT |

[1)] VG_M was always calculated as VG_M = 1 - 1/VG_N

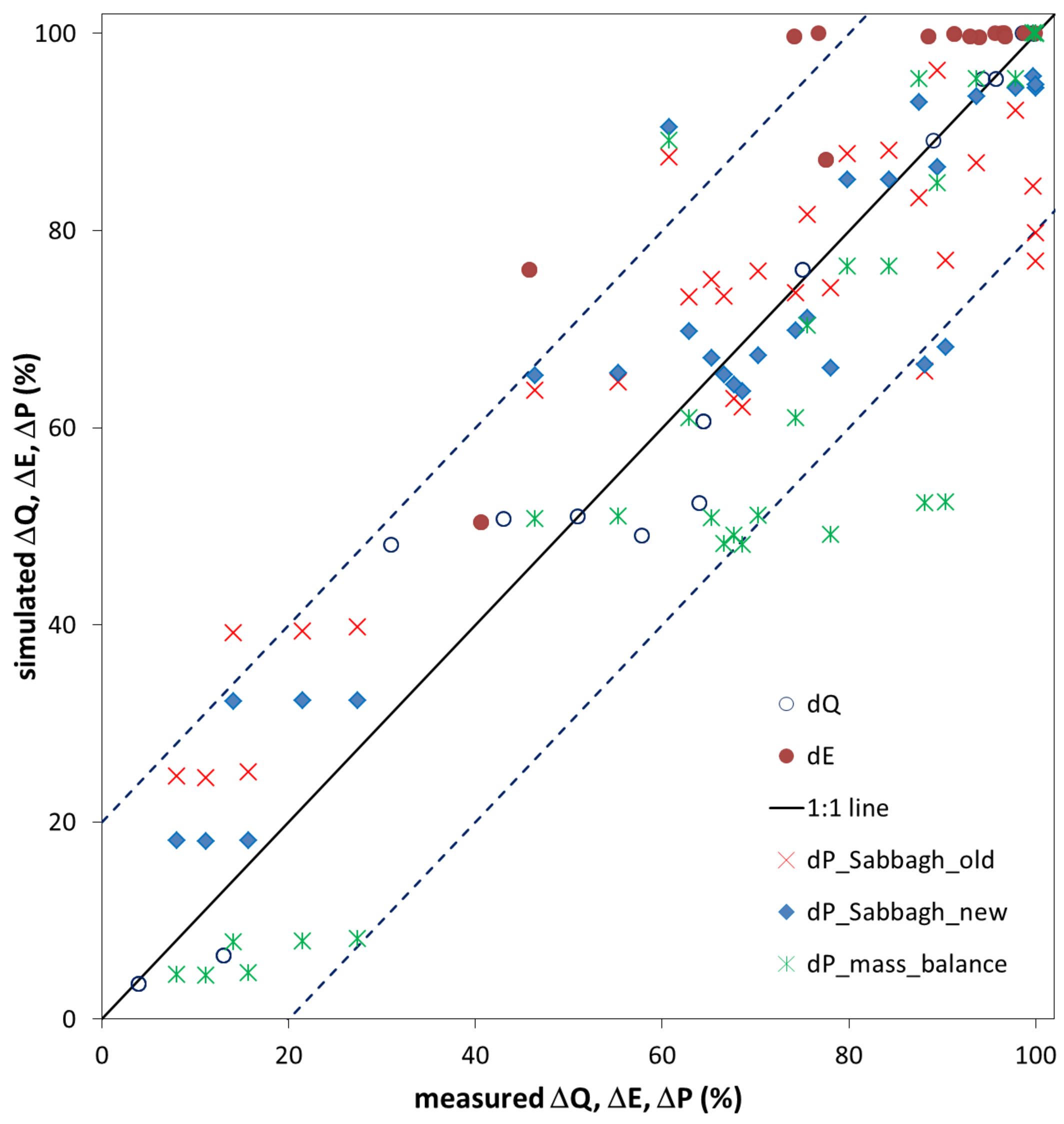


Fig. 4: Measured vs. simulated ΔQ, ΔE and ΔP (VFSMOD settings: sWT, ICO = 0; DREAM-ZS settings: a = 0.6, b = 0.4). Simulated ΔQ and ΔE correspond to the best VFSMOD parameter sets for each study found with DREAM-ZS. ΔP was predicted with the 3 trapping equations from the simulated ΔQ and ΔE values . NSE = 0.86 (Sabbagh new), 0.78 (Sabbagh old), and 0.70 (mass balance).

## Conclusions

- The relative reduction of total inflow (ΔQ) and incoming sediment load (ΔE) in VFSMOD could be successfully calibrated with DREAM-ZS.
- With regard to pesticide trapping (ΔP):
  - ➢ The revised Sabbagh equation performed best
  - ➢ The mechanistic mass balance equation provided conservative estimates
  - ➢ The original Sabbagh equation still performed acceptably well

## Next steps

- Reduce the number of parameters to be estimated (e.g. fix the ponding check point SCHK and the anisotropy ratio RHV) to decrease equifinality
- Use the gained knowledge to propose improvements for the parameterization of vegetated filter strip scenarios

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