Modelling experiments with vegetated filter strips with a new version of VFSMOD

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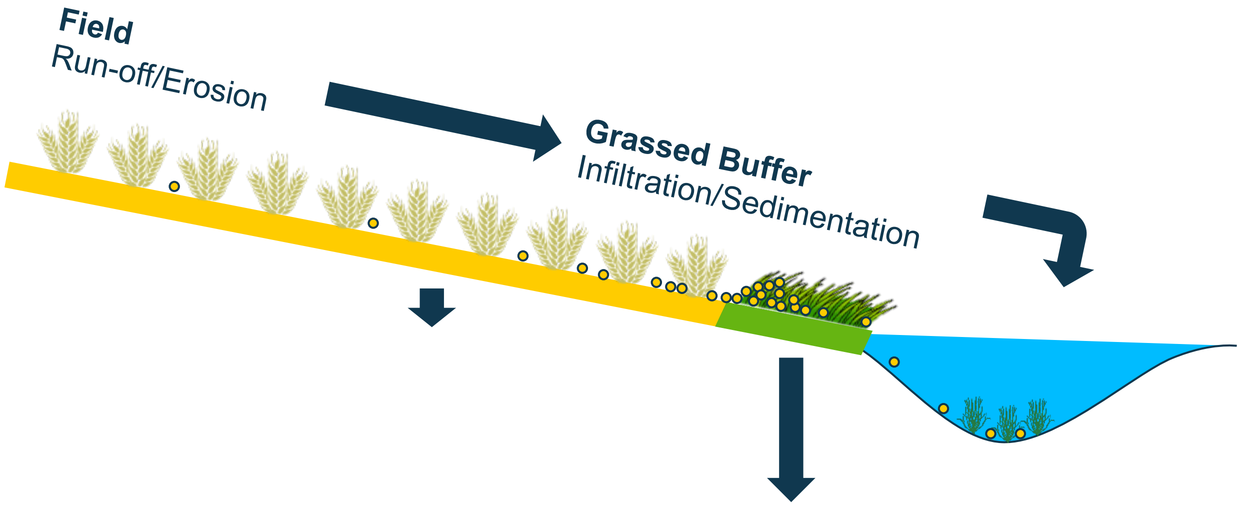
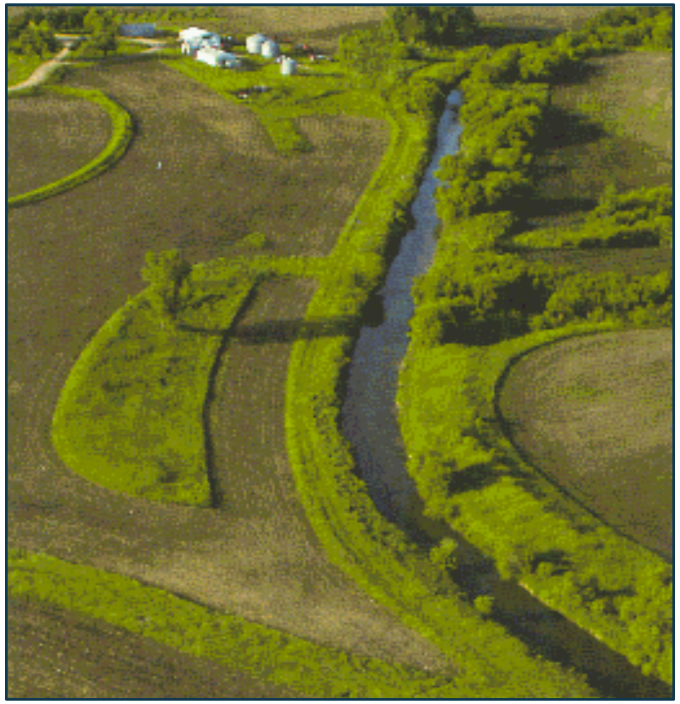
Function of Vegetated Filter Strips

- Reduction of run-off, erosion, and pesticide load to surface water due to dense vegetation and high vertical hydraulic conductivity slowing down flow and leaving time for
  - Infiltration of Water/Pesticides
  - Trapping of Sediment/Pesticides
  - Sorption of Pesticides





USDA, NRCS

Regulatory Landscape for the Use of VFS

EU ‚FOCUS Landscape & Mitigation (2007)'

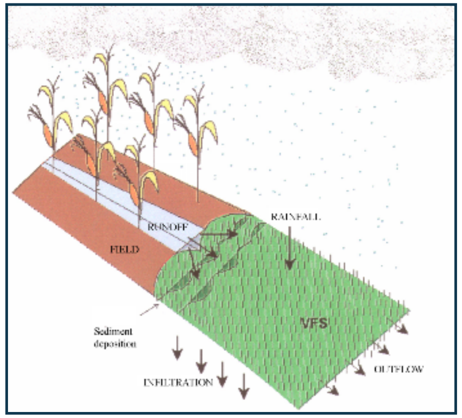
- Fixed empirical reduction factors for water and sediment from field studies
- Pesticide retention then calculated from phase distribution (dissolved/particle-bound)
- No dependence on event magnitude or other environmental conditions
- Broad regulatory acceptance in EU-28

Buffer Width (m)	10	20
Reduction in volume of runoff water (%)	60	80
Reduction in mass of pesticide transported in aqueous phase (%)	60	80
Reduction in mass of eroded sediment (%)	85	95
Reduction in mass of pesticide transported in sediment phase (%)	85	95

SANCO/10422/2005, ver. 2.0, Sep. 2007

VFSMOD

- Mechanistic model to predict VFS efficiency
  - Physically-based overland flow (kinematic wave) and infiltration (Green-Ampt)
  - Physically-based sediment trapping (University of Kentucky sediment filtration algorithm)
  - Empirical or mechanistic pesticide retention
- Reduction efficiency depends on event magnitude and environmental conditions
- Interest in EU-28 regulatory use but limited acceptance yet (MAgPIE report)



Munoz-Carpeña and Parsons (2014)

Automated FOCUS Step 4 Calculation

SWAN 4
Surface Water Assessment eNabler

European Crop Protection

FOCUS-PRZM

Edge-of-field run-off/erosion

Runoff Volume
Runoff Flux a.s.
Erosion Mass
Erosion Flux a.s.

VFSMOD or FOCUS L & M

- Retention in VFS
- Scenarios R1, R2, R3, R4

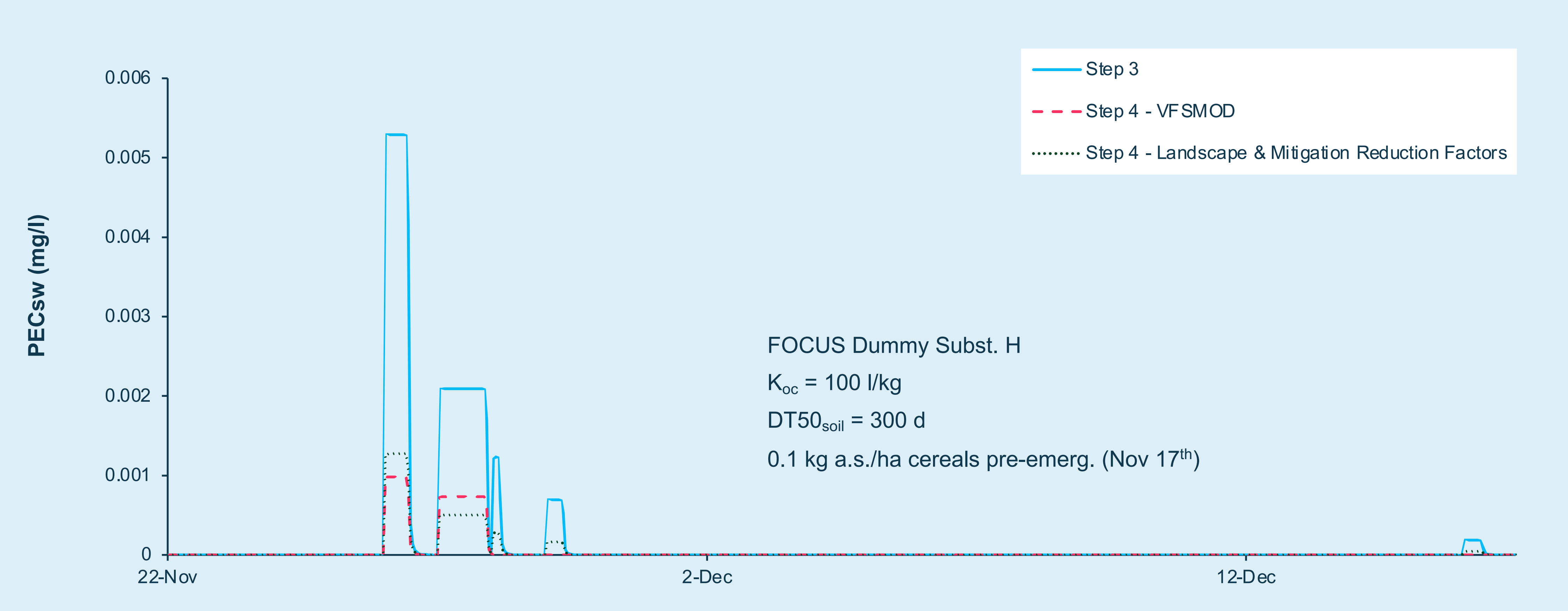
Modified
Volume,
Mass,
Flux

TOXSWA

Fate in Surface Water

Results FOCUS Step 4 Calculation

FOCUS R3-Stream Scenario with 20 m VFS



VFSMOD - Regulatory Opportunities and Challenges

knoell

Why do we need VFSMOD?

- Most critical for VFS efficiency is the hydraulic load (volume of water per area)
  - Fixed reduction fractions (FOCUS L&M) will underestimate efficiency for small and overestimate it for large runoff events
  - To model the reduction of runoff, erosion and pesticide into surface water by VFS for risk assessment, an event-based, dynamic model is needed

What are the regulatory obstacles?

- The pesticide trapping equation (Sabbagh) has not been widely accepted, as its reliability had not been sufficiently demonstrated (too little calibration data)
- Too little validation data available for the whole model with real-world studies
- Testing of VFS scenarios (SWAN) against real-world studies lacking

Pesticide Trapping Equations in VFSMOD

Sabbagh Equation

$$\Delta P = a + b\,\Delta Q + c\,\Delta E + d\,\ln\left(\frac{Q_i}{K_d E_i} + 1\right) + e\,\%C$$

- Empirical multiple-regression equation
- 6 Independent variables/5 regression parameters

Mass Balance Equation

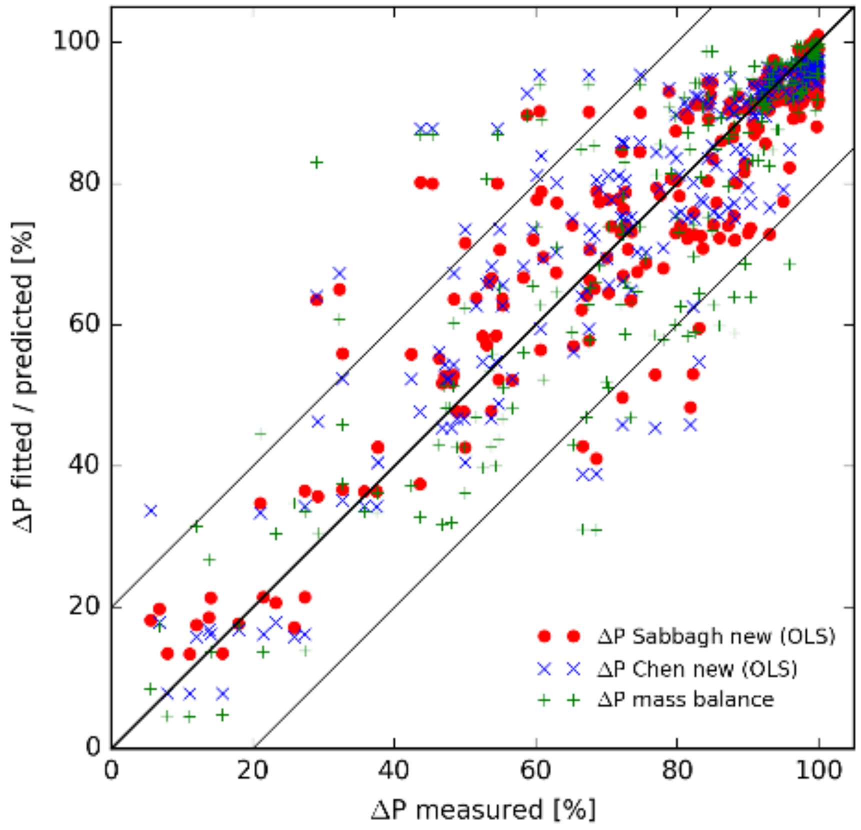
$$\Delta P = \frac{\min[(V_i + K_d E_i);(\Delta Q V_i + \Delta E K_d E_i)]}{(V_i + K_d E_i)}$$

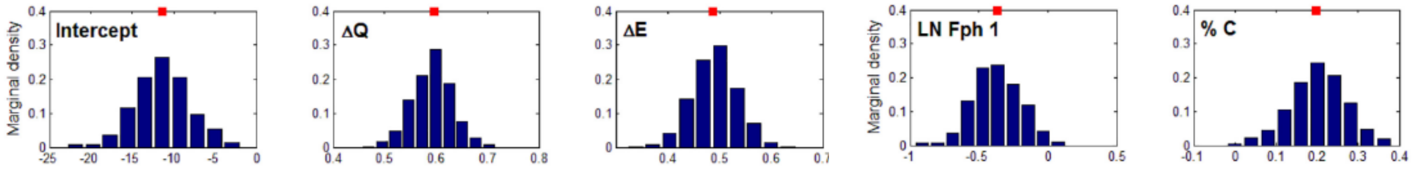
- Mechanistic, process-based equation
- 5 independent variables/0 regression parameters
- Key Assumptions
  - Instantaneous and complete mixing of run-on and rainfall on the VFS
  - Constant particle-bound pesticide concentration in runoff during the typically relatively short events
  - Infiltration and sedimentation are the only relevant pesticide trapping mechanisms in the VFS (negligible sorption of dissolved pesticide to soil or plants in the VFS)

ΔQ:	Relative reduction of total inflow Qi (rainfall + run-on) (%)
ΔE:	Relative reduction of incoming sediment load E_i (%)
Q_i:	Total water inflow into the VFS (run-on + rainfall) (L)
E_i:	Incoming sediment load (kg)
V_i:	Incoming run-on volume (L)
%C:	Clay content of incoming sediment (%)
K_d:	Linear adsorption coefficient (L/kg)

Improved Pesticide Trapping Equations

- Additional experimental VFS data (n = 48 → n = 244) was used to recalibrate the Sabbagh equation and to test the regression-free mass balance approach
- Sabbagh Equation
  - OLS regression (full dataset): Pearson $r^2 = 0.819$
  - Cross-validation confirms good predictive capability
    - Calibration: Pearson $r^2 = 0.820$ (median)
    - Prediction: Pearson $r^2 = 0.815$, $Q^2 = 0.81$ (median)
  - Maximum-likelihood-based calibration & uncertainty analysis with the DREAM algorithm
    - Confirms regression parameters obtained with OLS and small confidence bounds
- Mass Balance Equation
  - Independent of any calibration
  - Prediction (full dataset): $R^2 = 0.74$





Reichenberger et al. (2019)

Simulate Real Experiments with VFSMOD (Manual Calibration)

Field Studies

4 studies with 31 combinations of hydrological event and compound

VFSMOD Parameterization

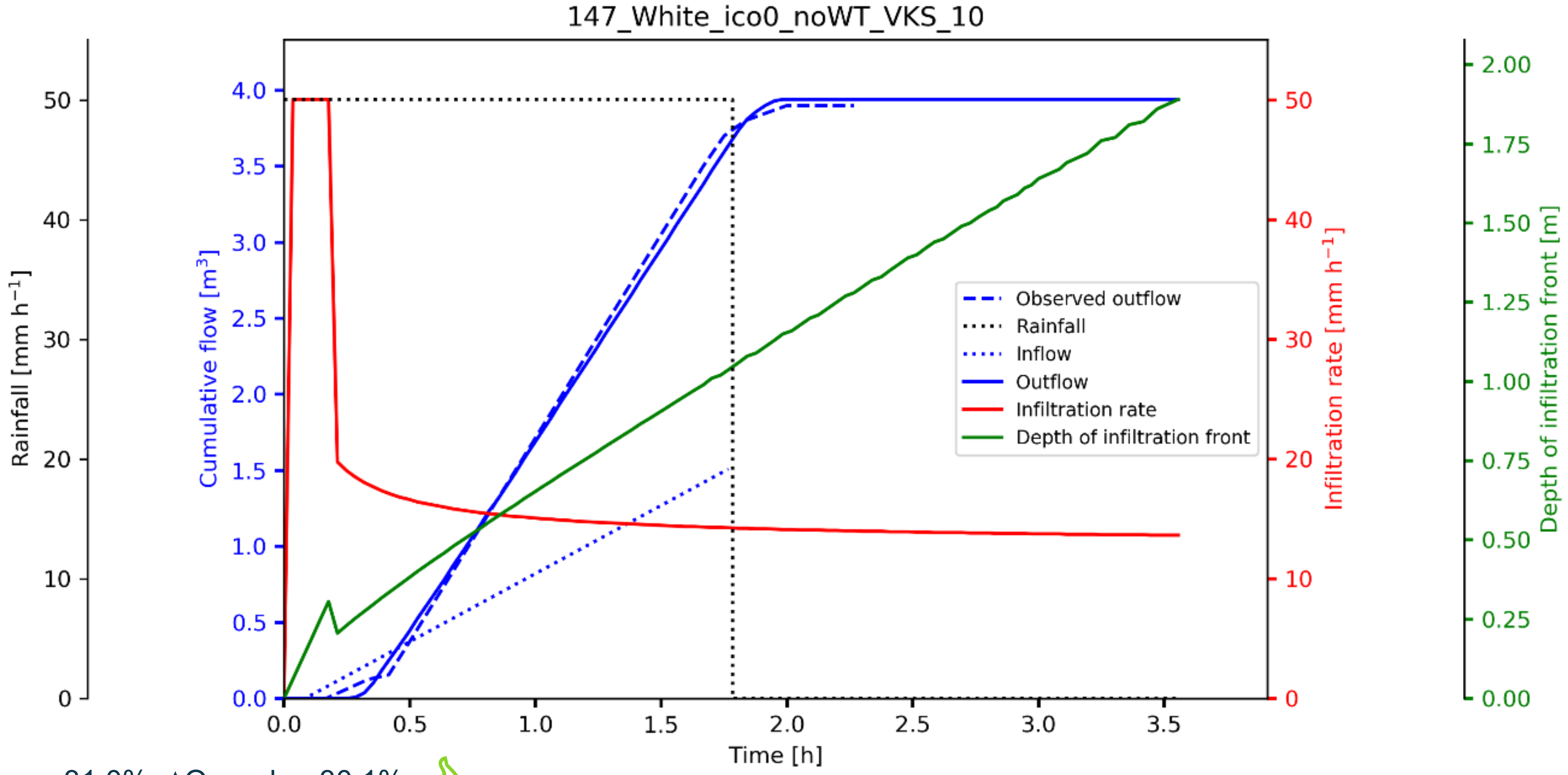
- Soil water retention and saturated hydraulic conductivity: HYPRES PTF
- Overland flow and sediment filtration: Defaults from SWAN-VFSMOD
- Hydrographs:
  - Use measured rainfall and run-on hydrographs if available
  - If not: use rectangular hyetograph, triangular run-on hydrograph

Manual Calibration

- VKS: Vary HYPRES estimate from 0.1- to 15-fold
- Water table depth: None to 1.5 m

Simulation of a VFS Event

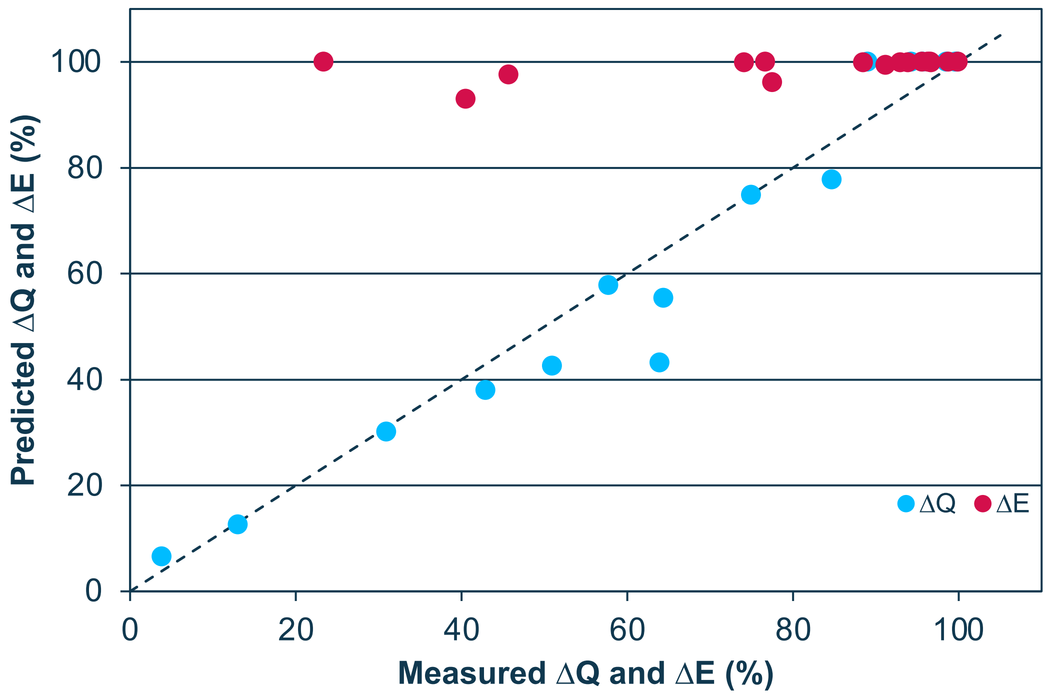
// VFS length = 15 m



- // ΔQ meas = 31.0%; ΔQ pred = 30.1%
  - // 1.5-fold higher saturated hydraulic conductivity (VKS = 12.89 mm/h) and no water table needed to match ΔQ
- // ΔE meas = 74.2%; ΔE pred = 99.8%
- // ΔP meas = 66.6%; ΔP pred = 54.8%

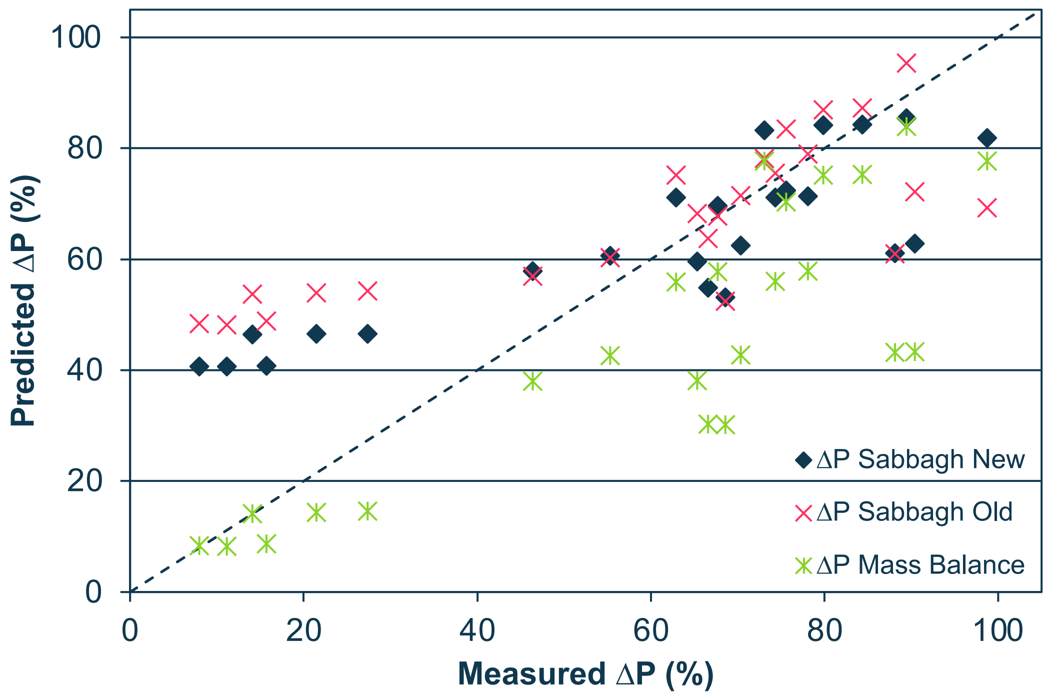
Observed vs. Predicted Infiltration and Sedimentation

- Good match of ΔQ after adjusting vertical hydraulic conductivity (VKS) and water table depth (WTD)
- The HYPRES Ksat formula performed well in predicting VKS
  - Geomean calibration factor: 0.8 (0.4 – 1.5)
- ΔE was generally overestimated (due to defaults for sediment filtration)



Observed vs. Predicted Pesticide Trapping

- Sabbagh Equation
  - Performed best
  - But relies on well predicted ΔQ and ΔE
- Mass Balance Equation
  - Conservative as it underestimates ΔP
  - Less sensitive to errors in ΔE (for substances with K_{oc} ≤ 10000 L/kg)

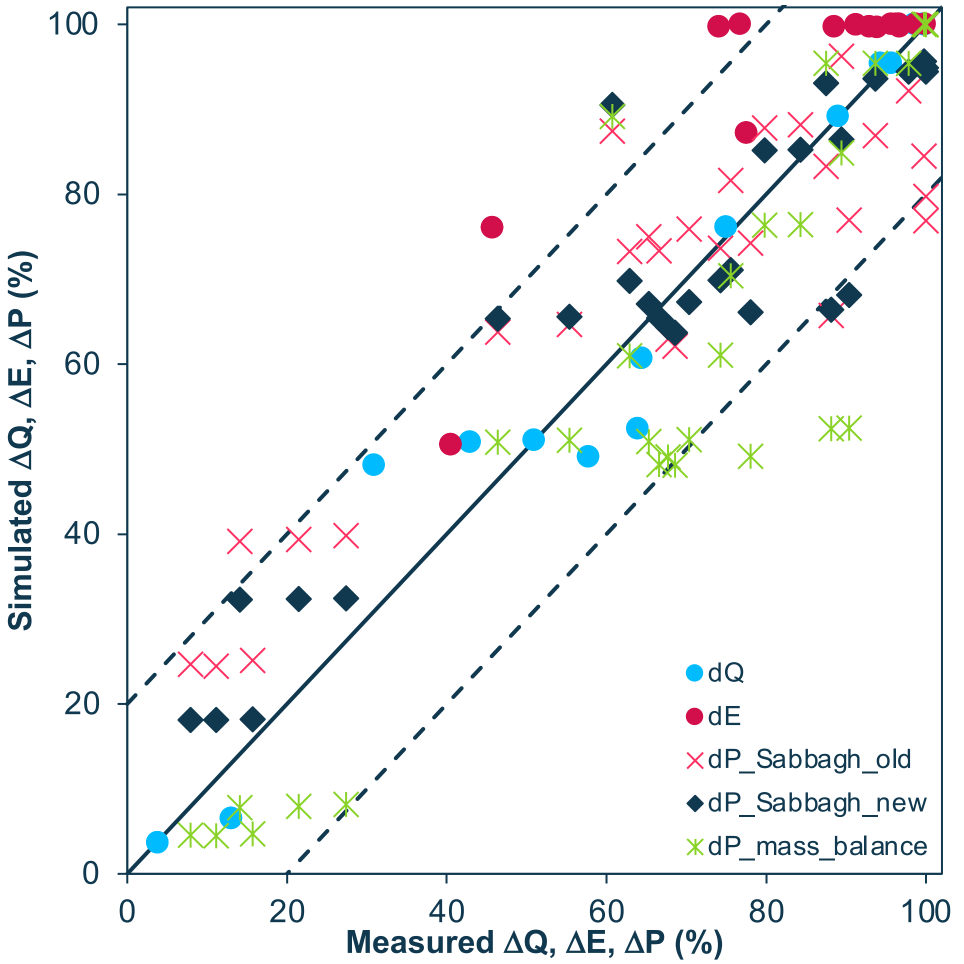


DREAM Calibration of VFSMOD

- Infiltration/sedimentation:
  Successful calibration of ΔQ and ΔE
- Pesticide Trapping (ΔP):
  - Sabbagh equation
    - Revised equation performed best
    - Original equation still performed acceptably well
  - Mass balance equation
    - Provides conservative estimates

→ Consistent with manual calibration for ΔQ

→ ΔE and in turn ΔP well improved



Regulatory VFS Scenarios

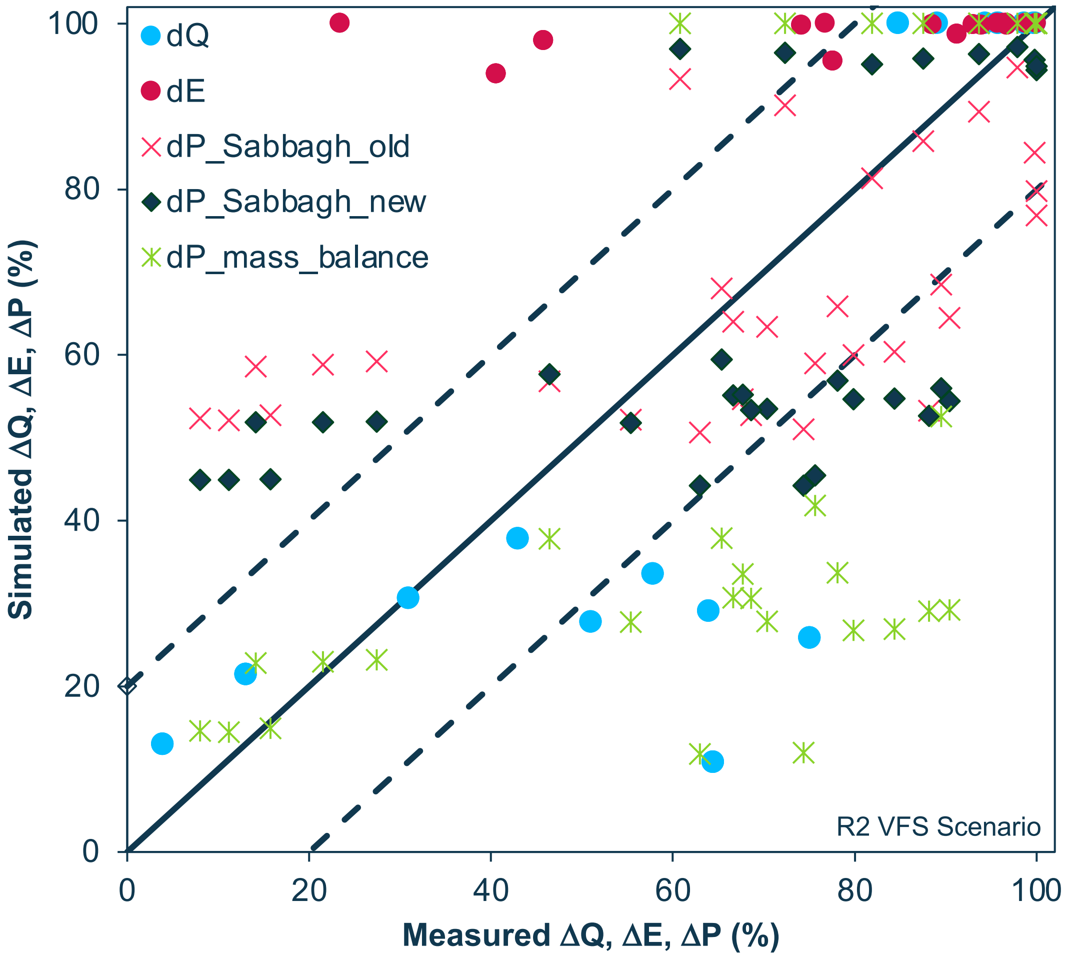
Are the EU VFS scenarios protective for real-world run-off events?

- Combine 31 run-off events (4 studies) with all 4 EU Run-off-VFS scenarios
- Parameterization
  - Defaults from SWAN-VFSMOD (Brown et al., 2012)
    - Filter medium, overland flow, eroded sediment, VFS hydraulic properties
  - Study-specific
    - VFS geometry
    - Source area related properties
    - Rainfall and run-on hydrographs

Regulatory VFS Scenarios

- A 1-by-1 match is not intended but a conservative representation of most real-world experiments
- ΔQ Underestimated
- ΔE Overestimated
- ΔP Partly Overestimated
  - Sabbagh new: 25% of events overestimated by > 20 %
  - Mass balance: 6% of events

→ Overestimated ΔE propagates to ΔP



Conclusions

- Infiltration
  - HYPRES provides realistic K_{sat} values for the parameterization of the VFS
- Sedimentation
  - Defaults overestimate sediment trapping in VFSMOD
- Pesticide trapping
  - Considerably widened validation database of the Sabbagh equation
  - Newly proposed mechanistic mass balance equation
- Regulatory Performance of EU VFS Scenarios
  - Pesticide trapping is overestimated for only 6% to 25% of all events
- Primary recommendation
  - Improve the parameterization of sediment trapping in VFSMOD

Thank you!

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