Dynamic prediction of effective sediment particle size in runoff for an improved assessment of pesticide mitigation efficiency of vegetative filter strips

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Background

- Surface runoff from agricultural fields is a major input pathway of pesticides into surface waters (e.g. Wauchope, 1996).
- The most widely implemented mitigation measure to reduce transfer of pesticides and other pollutants to surface waters via surface runoff and erosion are vegetative filter strips (VFS).
- These are densely vegetated areas designed to intercept surface runoff and eroded sediment, often located at the downslope field border.

source: https://swat.tamu.edu/media/115036/k2_2_cibin.pdf

source: https://agriculture.vermont.gov/don%E2%80%99t-forget-your-buffers

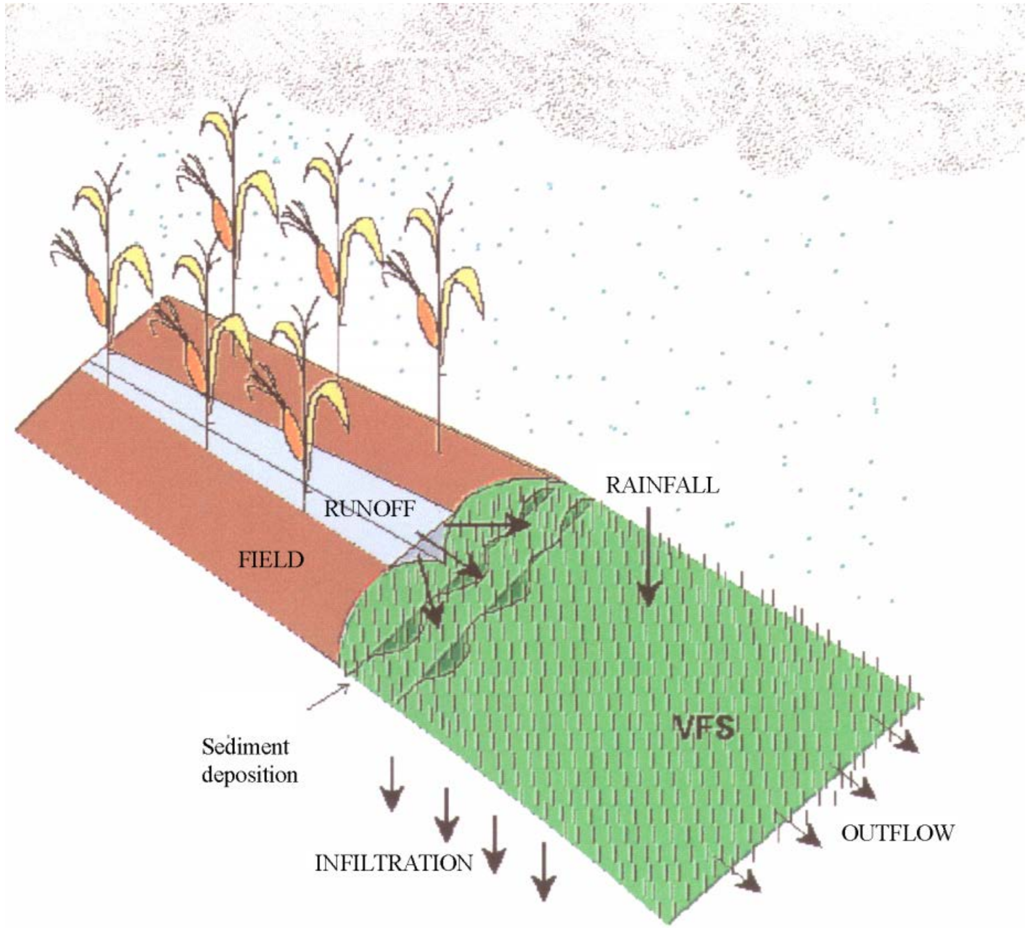
The model VFSMOD

- The most widely used dynamic, event-based model to simulate the reduction of surface runoff volumes, eroded sediment and pesticide loads by VFS is VFSMOD (Muñoz-Carpena and Parsons, 2014).

- VFSMOD simulates reduction of total inflow (ΔQ) and incoming eroded sediment load (ΔE) mechanistically.

- These variables are subsequently used to calculate the reduction of pesticide load by the VFS (ΔP).
  - several options (pesticide trapping equations) available

- Errors in ΔQ and ΔE propagate to ΔP → for strongly sorbing compounds an accurate prediction of ΔE is crucial for a reliable prediction of ΔP



source: Muñoz-Carpena and Parsons (2014)

Problem and objective

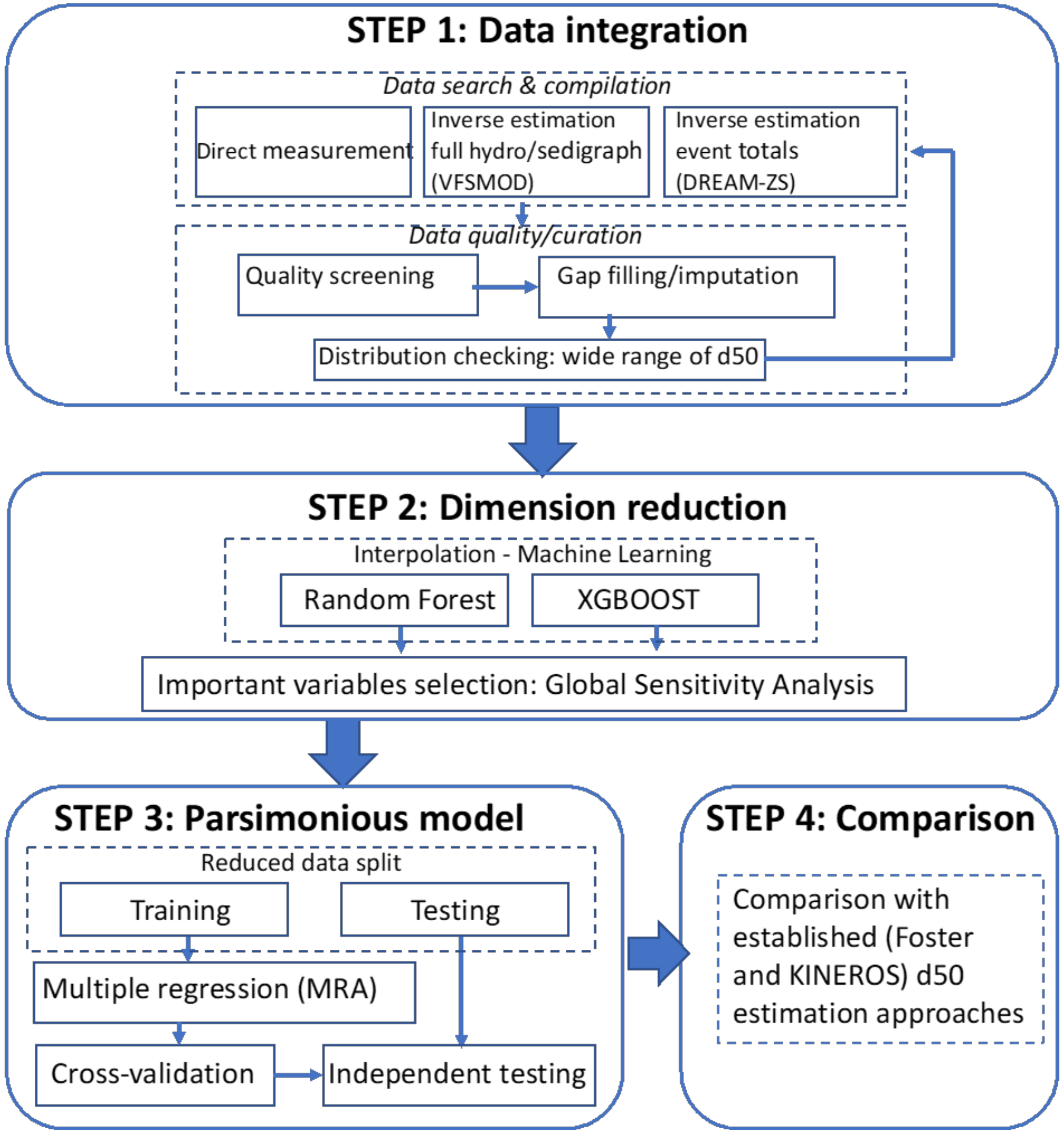
- The most important incoming sediment characteristic in VFSMOD is the median particle diameter (d50).

- VFSMOD simulations with the fixed value of d50 = 20 µm (Brown et al., 2012) used in the regulatory tool SWAN yielded an overestimation of ΔE compared with field measurements (Reichenberger et al., 2018)

- Objective: Derive an improved, event-based d50 parameterization equation for use in regulatory VFS scenarios

Derivation of a new d50 estimation method

- A test dataset of 93 d50 values and 18 explanatory variables has been compiled from heterogeneous data sources (13 surface runoff studies).
- The established test dataset (n = 93) was analysed using Machine Learning techniques (Random Forest, Gradient Boosting) and Global Sensitivity Analysis (GSA) for dimension reduction.
- With the help of the knowledge gained, a parsimonious multiple regression equation ($r^2 = 0.717$) with six predictor variables was established, thoroughly tested and compared with other approaches (Reichenberger et al., *in preparation*).



New multiple regression equation for d50

$$d50\ (\mu m) = 5.38827 + 35.27513\ \textit{tillage} + 0.32195\ (\textit{Ei\_g\_m2})^{0.5} + 0.06625\ \textit{rainfall\_int} + 0.11455\ \textit{peak\_runoff\_rate}$$

$$- 29.57603\ (\textit{slope\_length\_field})^{-1} - 1.51938\ (\textit{silt})^{-0.5}$$

If the equation predicts d50 < 1.1 µm (minimum value of the test dataset), the prediction is set to 1.1 µm.

- tillage: conventional tillage = 0, zero tillage = 1
- slope_length_field: slope length of source area (m)
- silt: silt content (fraction)
- rainfall_int: mean rainfall intensity (mm h^{-1})
- Ei_g_m2: eroded sediment yield (g m^{-2} source area)
- peak_runoff_rate: peak runoff rate (mm h^{-1})

red: source area characteristics

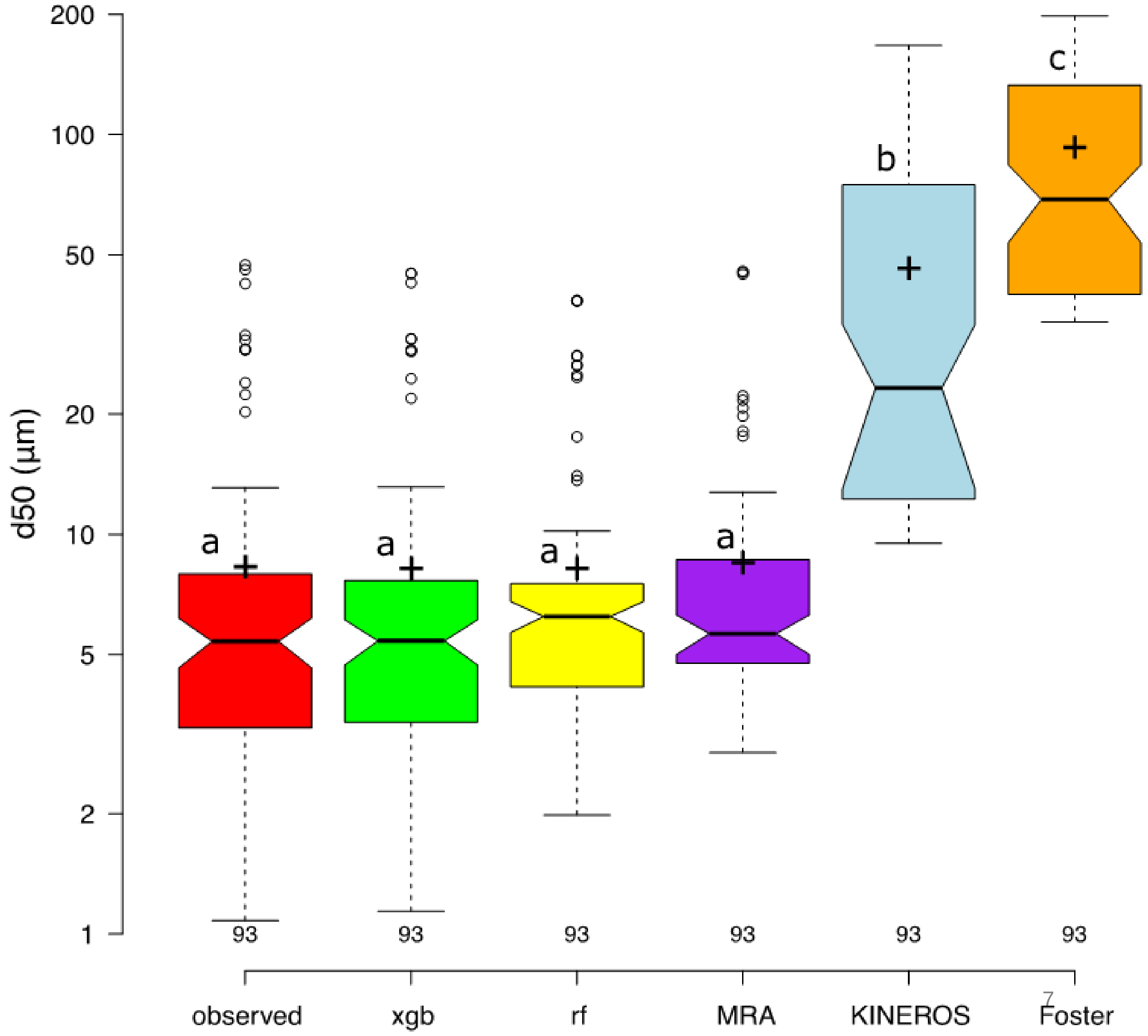
blue: event characteristics

green: response of source area to rainfall event

Boxplot of d50 values observed and predicted with various methods (n = 93)

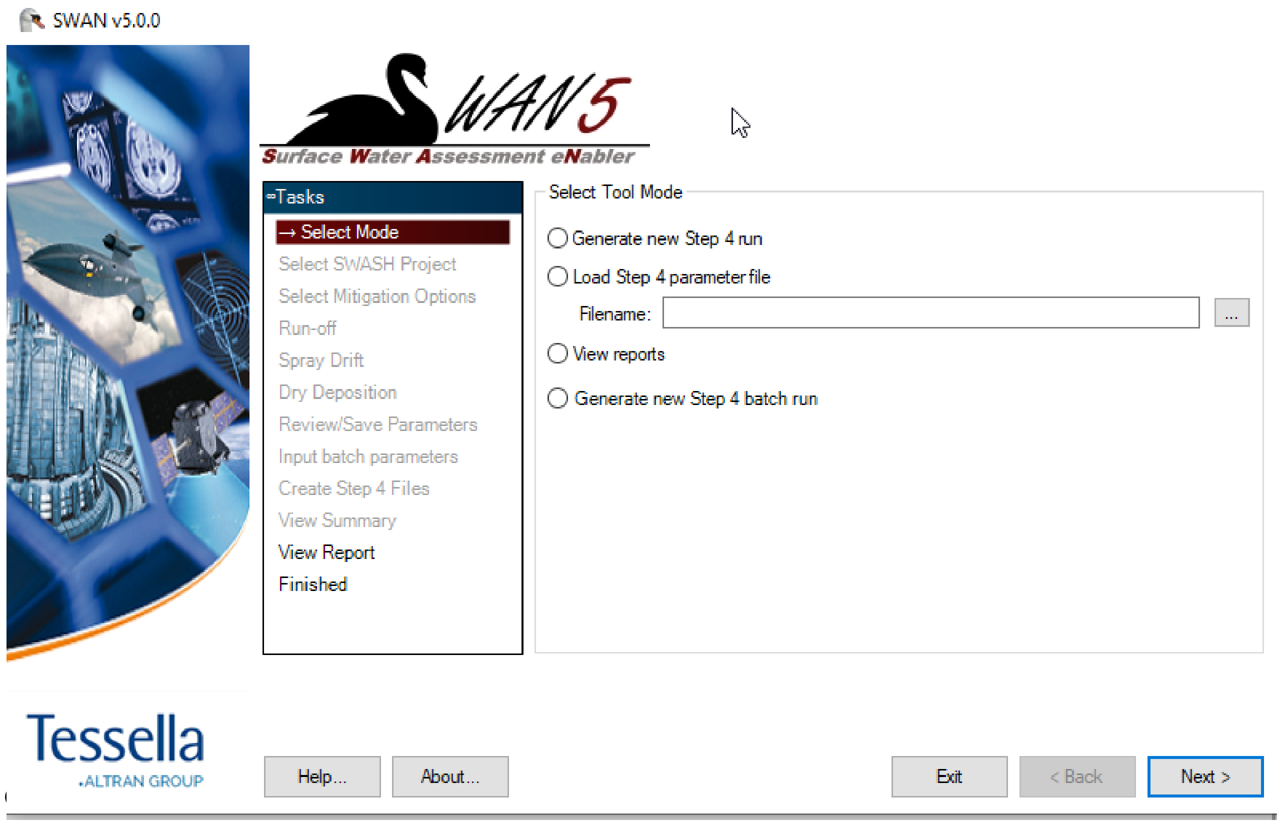
- Median d50 almost identical between the observed data (5.4 µm) , XGBoost (green) and multiple regression equation (purple)

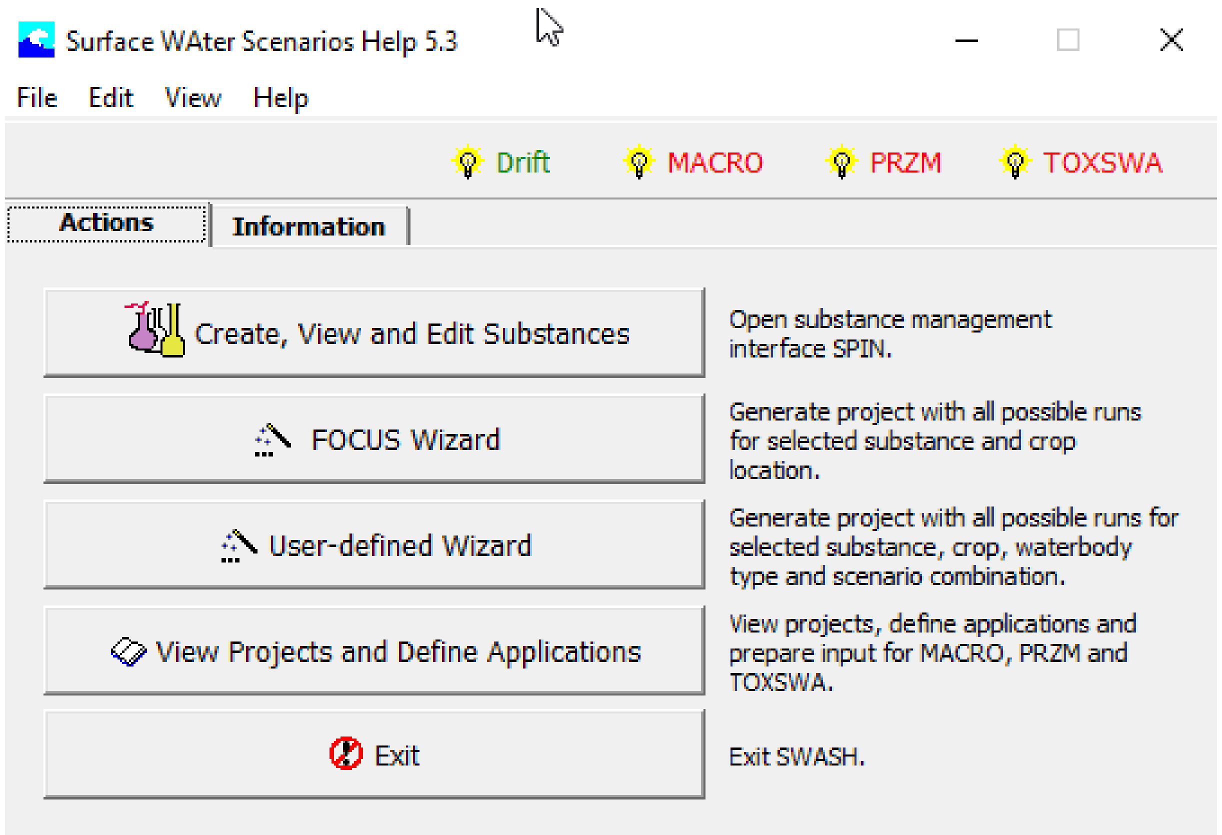
- Most d50 values predicted with the multiple regression equation << 20 µm



Predictive simulations

- A modified version of SWAN-VFSMOD containing the improved d50 parameterization method was run for a number of contrasting compounds and application scenarios.
- The obtained ΔE and ΔP values as well as the resulting pesticide concentrations in surface water and sediment (PECsw/sed) were compared with the current FOCUS step4 approach.





Results and Discussion

- Predicted range of d50: 1.74 - 7.9 µm

- Effect on sediment load reduction (ΔE)
  - 5 m VFS: minimum dE = 95.66 % (new method) vs. 95.94 % (old method)
  - 10 m VFS: minimum dE = 98.96 % vs. 99.10 %

→ very small impact on ΔE despite quite different d50 values

→ effect on pesticide load reduction (ΔP) and concentrations in surface water (PECsw) also very small

- Potential explanations for generally high ΔE in SWAN-VFSMOD:
  - assessment period in FOCUSsw of 12 months too short (no really large events)
    → will change with upcoming introduction of 20 year period
  - FOCUS scenario assumptions on event duration and thus rainfall and runoff hydrographs

Conclusions and Outlook

- In this study a new estimation equation for the median sediment particle diameter d50 was derived.
- The MR equation to predict d50 performed satisfactorily in a cross-validation analysis and in a predictive performance comparison with machine learning and other existing approaches.
- While the approach is empirical (data driven), the equation components are physically consistent with current understanding of processes controlling d50.
- The new d50 equation is applicable also in other field settings without VFS, including studies of erosion and runoff transport of other particle-bound pollutants (phosphorus, heavy metals etc.)
- The new sediment parameterization method constitutes a major scientific improvement compared with the constant default value of 20 µm currently used in SWAN-VFSMOD.
- However, effect on ΔE in SWAN-VFSMOD simulations very small → need to investigate

knoell worldwide registration

Many thanks for your attention!

Supplementary slides

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