

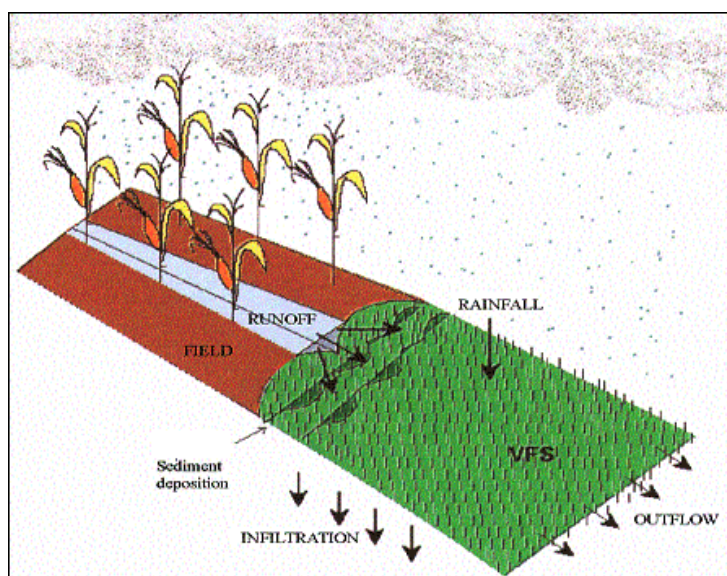
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VFSMOD Input Definitions, Literature References and Sensitivity Analyses for Evaluating Vegetative Filter Strips in Pesticide Risk Assessment



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INTRODUCTION: SCOPE AND PURPOSE

In Canada and the U.S., aquatic exposure to pesticides is modeled using field and waterbody models linked together using the Pesticide in Water Calculator (PWC v. 2.001)¹. The field model is the Pesticide Root Zone Model (PRZM v. 5) (USEPA 2020). The waterbody model is the Variable Volume Waterbody Model (VVWM v. 1.02) (USEPA 2019). Currently, US and Canadian pesticide regulatory agencies do not have the ability to quantitatively model potential pesticide runoff reductions from vegetative filter strips (VFS), an area of non-crop (typically grass) vegetation designed to remove sediment and other pollutants from surface water runoff.

In 2018, North Carolina State University's Center of Excellence for Regulatory Science in Agriculture (CERSA) held a workshop, "Incorporating the benefits of vegetative filter strips into risk assessment and risk management of pesticides." The workshop was organized by scientists from academia, government, and industry along with conservation experts and producers interested in evaluating VFS for reducing pesticide transport. A second workshop was held in September of 2020. This paper on VFSSMOD input parameter definitions, literature references, and sensitivity analyses of the parameters used in VFSSMOD is the result of the discussions following the second workshop.

VFSSMOD MODEL OVERVIEW

Vegetative Filter Strip Modeling System (VFSSMOD) is a design-oriented vegetative filter strip modeling system (Muñoz-Carpena and Parsons, 2004). VFSSMOD is a computer simulation model created to study water, sediment, and pollutant transport through VFS (Muñoz-Carpena et al., 1999; 2004; 2007; 2010; 2015; 2019; Fox et al., 2010; Poletika et al., 2009; Sabbagh et al., 2009, 2010). VFSSMOD is a field scale, mechanistic, storm-based model designed to route dynamically the incoming hydrograph and sedigraph from an adjacent field through a VFS, and to calculate the outflow, infiltration and sediment trapping efficiency. The model handles time-dependent hyetographs, space-distributed filter parameters (vegetation roughness or density, slope, and infiltration characteristics) and different particle size of the incoming sediment. Any combination of unsteady storm and incoming hydrograph types and soil and vegetation characteristics can be used. The model comprises the following modules (Figure 1):

- *Overland flow module*: Finite element numerical solution for the kinematic wave equations
- *Infiltration module*: Extended Green-Ampt infiltration method (GAMPT) for unsteady rainfall with deep/no water table, and an alternative mechanistic component (SWINGO) for infiltration when seasonal shallow water table is present
- *Sediment filtration module*: University of Kentucky grass sediment deposition dynamic algorithm including bedload transport for coarse sediment and suspended

¹ <https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#aquatic>

- transport for fine particles (Barfield et al., 1979; Hayes et al., 1984; Tollner et al., 1976, 1977; Muñoz-Carpena et al., 1999).
- *Water quality/pollutant module*: Pesticide (and other agrochemical) trapping. Includes mechanistic soil leaching (CDE) and sediment-sorbed trapping during the runoff event, surface residue degradation during the period between storms, runoff remobilization of residues in next storm event in the series.

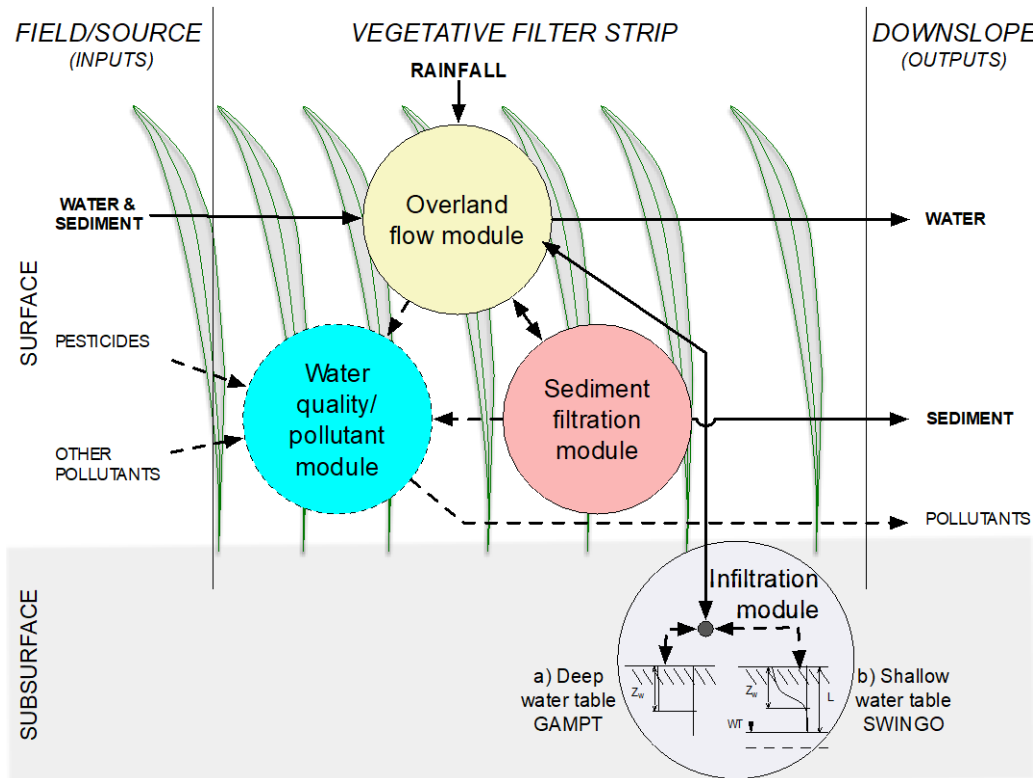


Figure 1. VFSSMOD program modules.

During a rainfall event, mechanistic and dynamic calculations of flow and sediment deposition provide the reduction of the liquid (runoff and rainfall) and solid (sediment) phases within the VFS and ensuing outflow. This provides the basis for the detailed pesticide mass balance at the end of the rainfall event (Figure 2) as the difference between the mass (dissolved and adsorbed) coming into the VFS minus the mass trapped in the buffer (infiltration and sediment deposition) and that exiting the VFS. The pesticide trapped in the VFS surface (mixing layer, ml) undergoes degradation between rainfall events and redistribution, runoff remobilization of the porewater residues in the next rainfall event, and carryover of the remaining matrix-sorbed residue that influence the pesticide mass on the surface. See the VFSSMOD User Manual (Muñoz-Carpena and Parsons, 2021) for more details on the model.

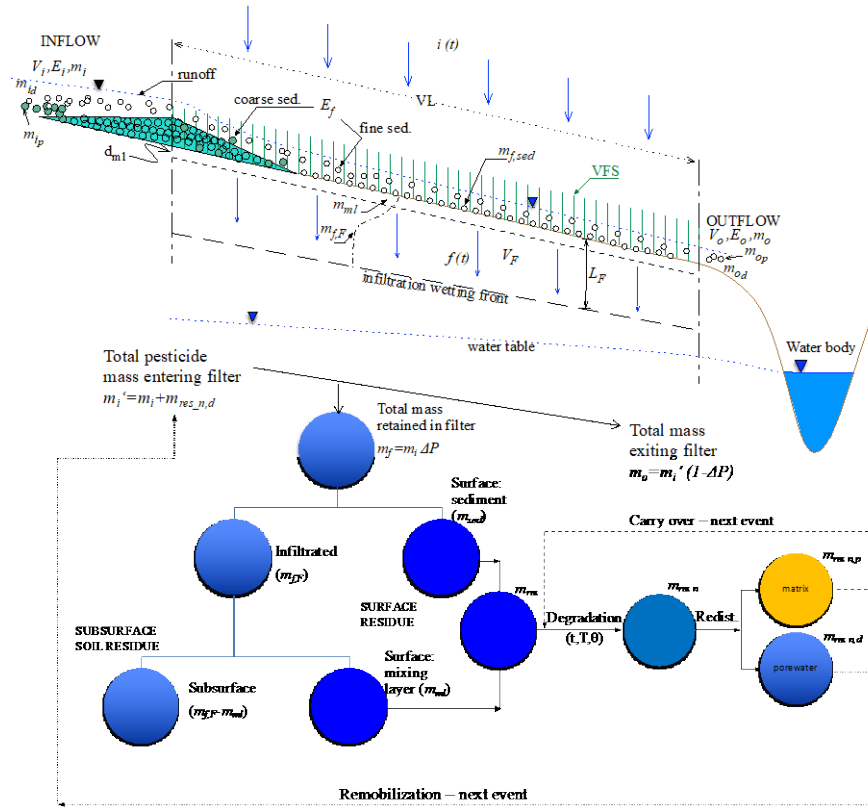



Figure 2. Conceptual pesticide component in VFSSMOD (adapted for Muñoz-Carpena, et al., 2023a). Symbols: V , E , m , ΔP are runoff volume, sediment mass, pesticide mass, and VFS pesticide removal efficiency, respectively; subscripts i , ml , f , F , sed , o , res , n are incoming, mixing layer, within vegetation filter, infiltration, sediment, outgoing, surface residue, and after degradation (beginning of next event in series), respectively; double-subscripts p and d are solid (particle) and dissolved (runoff) phases, respectively.

VFSSMOD is a public domain model under the terms of Creative Commons Attribution 4.0

International License  that allows free use, sharing and redistribution by attribution to the original developers. The model is freely accessible with source code, MS-Windows™ executable binaries, sample files and full documentation at the main VFSSMOD web site <https://abe.ufl.edu/faculty/carpena/vfssmod/updates.shtml>. VFSSMOD version 4.5.2 (released in February 2023) is the locked version so that it might be considered for regulatory use (no further changes will made to this version number). VFSSMOD 4.5 is backwards compatible with previous versions and adds new functionalities described in more detail in Appendix A. These new options are included in this document as default settings, as they increase model efficiency and realism in the description of VFS conditions at no additional (input, computational) cost.

VFSSMOD MODEL INPUT PARAMETERS

VFSSMOD has seven input files (Table 1). Table 2 presents the input parameters in the order in which those parameters appear in each input file in VFSSMOD version 4.5.2. The table also

provides the source and the sensitivity of each input value. The inputs are color coded to easily see which parameters are fixed (or default), which are obtained from the USEPA or PMRA standard ecological scenario², which are calculated for event or VFS width, or which parameters are obtained as defaults from the VFSMOD manual. Additionally, an evaluation of the sensitivity of the input parameters based on previous studies is provided with respect to the VFSMOD prediction of dQ (runoff reduction), dE (sediment reduction), dP (reduction of pesticide) in the VFS. Three qualitative levels are considered (Low/Medium/High) and some parameters are listed as “fixed” in the sensitivity column because they are based on default values for regulatory use or correspond to internal settings of the numerical solutions. More details on how to select values for the inputs that are not fixed or default are provided in Section 3.1.

Table 1. VFSMOD input files.

<u>Inputs (file extensions)</u>
igr= Buffer properties for the sediment filtration submodel
ikw= Parameters for the overland flow solution
irn= Storm hyetograph
iro= Storm hydrograph from the source area
isd= Sediment properties for the sediment filtration submodel
iso= Soil properties for the infiltration submodel
iwq= Water quality/transport submodel

Table 2. VFSMOD input parameters with definition, sources, sensitivity and default values for pesticide environmental assessments

Color key: *Blue* = default or fixed value; *Tan* (orange)= from USEPA or PMRA standard scenario input or output; *Purple*=calculated for event or VFS width; *Green* = value can be obtained from VFSMOD manual and Appendix B in this document; *No color*= user selected for the mitigation analysis (i.e., VFS width).

Parameter	Parameter Definition	Source	Sensitivity	Sensitivity References
Input file = .ikw (overland flow solution)				
FWIDTH (m)	Width of strip (perpendicular to flow)	Buffer length – depending on the field geometry in the USEPA or PMRA Standard Scenarios (see SWIDTH). See Figure 3 for ecological risk assessment geometry (316.228 m)	High	Abu-Zreig et al., (2001); Fox et al., (2010); Poletika et al. (2009); Sabbagh et al. (2010)
VL (m)	Length of strip (in the flow direction)	Buffer width - User defined	High	Muñoz-Carpena et al. (2007; 2010)
N	Number of nodes	Based on VFS size with VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014) (integer). N=-1 (default) will set N internally based on VL size, between N=11 and 101 nodes for VL from 1 to 100m.	Fixed	

² <https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#aquatic>

Parameter	Parameter Definition	Source	Sensitivity	Sensitivity References
THETA _W	Time weighted factor, Crank-Nicholson solution	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014) and Muñoz-Carpena et al., (1993), default, THETA _W =0.5	Fixed	
CR	Courant number	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), default, CR=0.8	Fixed	
MAXITER	Max number of iterations	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, default, MAXITER=350	Fixed	
NPOL	Order of interpolation polynomial for overland flow finite elements	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, default, NPOL=3	Fixed	
IELOUT	Flag for output	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, default, IELOUT=1	Fixed	
KPG	Flag for Petrov-Galerkin solution	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, default, KPG=1	Fixed	
NPROP	Number of segments	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, default, NPROP=1	Fixed	
SX (i) (m)	Distance of filter of uniform surface properties	Single segment (i=1), buffer width – Same as VL above	Fixed to VL	
RNA (i) (s m ^{-1/3})	Manning's <i>n</i> for segment	VFSMOD Appendix 3.2 Manning's roughness coefficient (Muñoz-Carpena and Parsons, 2014) and see Appendix B Table B - 1, <i>n</i> table based on surface cover and vegetation, Default RNA = 0.45 (grass, blue grass sod, well-maintained, good dense stand)	Medium/Low	Muñoz-Carpena et al. (1993; 2007; 2010)
SOA (i) (fraction)	Slope	USEPA or PMRA Standard Scenario field slope.	Medium/Low	Muñoz-Carpena et al. (1993; 2007; 2010)
IWQ	Flag for water quality	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), integer, IWQ=1=run runoff pesticide problem	Fixed	
Input file = .irn (storm hyetograph)				
NRAIN	Number of rainfall periods	For each runoff event (integer), default NRAIN = 4	Low	
RPEAK (m/s)	Maximum rainfall intensity	Calculated for each runoff event based on standard scenario weather inputs; rainfall intensity depends on the duration and total volume of the storm. When duration for each storm is known this should be used to distribute daily storms. If unknown, a critical storm duration for the region (T= 5-10 yr) should be used, i.e., 8 hours for PMRA Canada	High	Muñoz-Carpena et al. (1993)

Parameter	Parameter Definition	Source	Sensitivity	Sensitivity References
RAIN (i,j) (s, m/s)	Time series of rainfall intensity	Calculated for each event based on standard scenario weather inputs; paired values {time (sec), rainfall intensity (m/s)}. See comment above for RPEAK. See Section 3.1.2	High	Muñoz-Carpena et al. (1993)
Input file = .iro (runoff from the adjacent field into the VFS)				
SWIDTH (m)	Source area width	See Figure 3 for the field geometry in the USEPA or PMRA Standard Scenarios, default SWIDTH = FWIDTH = 316.228 m	High	Abu-Zreig et al., (2001); Fox et al., (2010); Muñoz-Carpena et al. (2007; 2010)
SLENGTH (m)	Source area flow path length	See Figure 3 for the field geometry in the USEPA or PMRA Standard Scenarios, default SLENGTH = 316.228 m	High	Muñoz-Carpena et al. (2007; 2010)
NBCROFF	Number of time steps of the field hydrograph	Calculated for each event from PRZM .zts runoff output and event duration (integer), default NBCROFF = 3.	Fixed, Low	
BCROPEAK (m³/s)	Peak flow of the incoming field hydrograph	Calculated from the runoff volume in the PRZM .zts file for event divided by the storm duration time. Peak runoff depends on the duration and total volume of the storm. When duration for each storm is known this should be used to distribute daily storms. If unknown, a critical storm duration for the region (T= 5-10 yr) should be used, i.e., 8 hours for PMRA Canada.	High	Fox et al., (2010)
BCROFF Time (s) vs flow (m³/s)	Incoming field hydrograph time & flow rate	Based on total time of the storm and the runoff from the PRZM .zts file for the event divided into time steps. See comment above for BCROPEAK. See Section 3.1.3.	High	Fox et al., (2010)
Input file = .iso (soil properties for the infiltration model)				
VKS (m/s)	Saturated hydraulic conductivity	VFSMOD Appendix 3.1 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 2. Soils data table – based on soil texture from the USEPA or PMRA standard scenario. Use Saxton and Rawls (2006).	High	Abu-Zreig et al., (2001); Fox et al., (2010); Muñoz-Carpena et al. (2007; 2010)
SAV (m)	Green Ampt's average wetting front suction	VFSMOD Appendix 3.1 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B – 2. Soils data table – based on soil texture from the USEPA or PMRA standard scenario. Use mean value.	Low	
OS (m³/m³)	Saturated soil-water content	VFSMOD Appendix 3.1 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 2. Soils data table – based on soil texture from the USEPA or PMRA standard scenario. Use Saxton and Rawls (2006).	Medium	Muñoz-Carpena et al. (2007; 2010)
OI (m³/m³)	Initial soil-water content	From PRZM .zts file (theta) for event (grass filter simulation).	Medium	Muñoz-Carpena et al. (2007; 2010)
SM (m)	Maximum surface storage	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014), SM=0 (no surface storage).	Fixed	Muñoz-Carpena et al. (1993)
SCHK (-)	Relative distance from upper filter edge where ponding is checked	VFSMOD User's Manual (Muñoz-Carpena and Parsons, 2014) – SCHK= 0.5 = mid-point in field	Fixed	Muñoz-Carpena (1993)

Parameter	Parameter Definition	Source	Sensitivity	Sensitivity References
Input file = .igr (buffer properties for sediment filtration model)				
SS (cm)	Spacing of filter media (grass)	VFSMOD User's Manual Appendix 3.3 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 3. VFS vegetation types, default SS= 2.15 (grass mixture)	Low/Medium	Muñoz-Carpena et al. (1999, Fig.5); Muñoz-Carpena et al. (2007; 2010)
VN (s/cm ^{1/3})	Filter media (grass) Manning's <i>n</i>	VFSMOD User's Manual Appendix 3.3 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 3. VFS vegetation types, default modified Manning's <i>n</i> , VN= 0.012 (grass mixture)	Medium	Muñoz-Carpena et al. (2007; 2010)
H (cm)	Filter media (grass) height	VFSMOD User's Manual Appendix 3.3 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 3. VFS vegetation types, default H=18 (grass mixture)	Low	Muñoz-Carpena et al. (2007; 2010)
VN2 (s/m ^{1/3})	Bare surface Manning's <i>n</i>	VFSMOD User's Manual Appendix 3.2 (Muñoz-Carpena and Parsons, 2014) also shown in Appendix B Table B - 1. Manning's roughness coefficient for bare soil, default VN2= 0.05 (fallow – no residue)	Low	Muñoz-Carpena et al. (2007; 2010)
ICO (0 or 1)	Feedback flag	VFSMOD User's Manual default, ICO= 0 (no sediment feedback on hydrology)	Fixed	Muñoz-Carpena, (1993)
Input file = .isd (sediment properties for sediment filtration model)				
NPART	Particle class	Default NPART=8 (Particle size of sediment calculated internally based on soil type and storm characteristics).	Fixed	Reichenberger et al., (2023)
COARSE (fraction)	Fraction of coarse sediment	Fraction of incoming sediment with diameter > 0.0037 cm, use default COARSE=0.5	Low	Muñoz-Carpena et al. (2007; 2010)
CI (g/cm ³)	Incoming flow sediment conc.	Calculated based on eroded sediment and runoff volume from the PRZM .zts file for event	High	Muñoz-Carpena et al. (2007; 2010)
POR (fraction)	Porosity of deposited sediment	Porosity = 1-(bulk density/2.65), based on USEPA or PMRA Standard Scenario bulk density, or set POR= OS (see above).	Low	Muñoz-Carpena et al. (2007; 2010)
SILT_FRAC (fraction)	Silt fraction	Fraction of silt in the field topsoil. Based on USEPA Standard Scenario (See Appendix B Table B - 4) or PMRA Standard Scenario (See Appendix B Table B - 5). If just texture is known, see Appendix B, Table B - 6.	High	Reichenberger et al., (2023)
ITILLAGE	Tillage type	Flag for tillage. 0 = conventional tillage, 1 = no tillage. Default ITILLAGE = 0	Low	Reichenberger et al., (2023)
Input file = .iwq (water quality/transport model)				
IWQPRO	Pesticide trapping equation	Select equation to use 1= Sabbagh, 2=Refit Sabbagh, 3=Mass balance, 4= Chen, default IWQPRO=3.	Fixed	Reichenberger et al., (2019)
IKD	Flag for using Koc or Kd	1 = Koc, 2=Kd (sorption coefficient), based on user selected pesticide for scenario.		Muñoz-Carpena et al. (2007; 2010; 2019)
KOC or KD (L/kg)	Partition coefficient	Koc or Kd value for user defined pesticide for scenario. Same as PRZM input.	High/Medium	Muñoz-Carpena et al. (2007; 2010; 2019)
OCP (%)	Runoff organic carbon	Selected based on source topsoil from USEPA or PMRA Standard Scenario.	High/Medium	Muñoz-Carpena et al. (2019)

Parameter	Parameter Definition	Source	Sensitivity	Sensitivity References
CCP (%)	Runoff clay content	Clay based on topsoil from USEPA Standard Scenario (See Appendix B Table B - 4), PMRA Standard Scenario (See Appendix B Table B - 5), or texture only (See Appendix B Table B - 6) A number must be provided in all cases although it is not used for IWQPRO=3 (only used for IWQPRO=1, 2, 4)	IQPRO=1,2,4 – High / Med. IQPRO=3 - Fixed	Muñoz-Carpena et al. (2007; 2010; 2019)
IDG	Degradation type	Flag to calculate degradation modifiers, 1= degradation changes with temperature and moisture, 2= degradation only, 3= degradation changes with temperature, 4 = degradation changes with moisture. USEPA, PMRA setting default IDG=2, half-life only.	Fixed	Muñoz-Carpena et al., (2015)
Ndgday	Number of days between events	No. of days between runoff events, i.e. until the next event. Calculated from PRZM .zts file.	Low/Medium	
dgHalf (days)	Half-life	Value for aerobic soil half-life for pesticide (user defined). Same as PRZM input.	Low/Medium	Muñoz-Carpena et al., (2015)
FC (m ³ /m ³)	Topsoil field capacity	Topsoil field capacity from USEPA or PMRA Standard Scenario.	Low	
dgPin (mg/m ²)	Pesticide mass entering filter	Total pesticide mass (dissolved and solid) entering filter from PRZM file	High	
dgML(cm)	Surface mixing layer thickness	VFSMOD User's Manual, PRZM default, dgML= 2 cm.	Fixed/High	Muñoz-Carpena et al., (2015)
dgLD (m)	Lambda, dispersion length of chemical	FOCUS-Pearl Manual, default, dgLD = 0.05 m (Tiktak et al. 2000; Van Ommen et al. 1989).	Low/Medium	Muñoz-Carpena et al. (2023a)
dgMRES0 (mg/m ²)	Remobilized pesticide surface residue when event starts	Remobilized residue from last event. The value is read from the last line on the .owq file from the previous event and written here in the new event .iwq file.	Low/Medium	
dgT (i) (°C)	Daily air temperature series between events	For i=1,NGDAY. Read from PRZM weather .dvf file for USEPA or PMRA. Not used for IDG=2.	Low/Medium	Muñoz-Carpena et al., (2015)
dgTheta (m ³ /m ³)	Soil water content series between events	For i=1,NGDAY. Soil Moisture (theta) read from PRZM .zts file (grass filter simulation). Not used for IDG=2.	Low/Medium	Muñoz-Carpena et al., (2015)
IMOB	Flag for remobilization of residues	1 or missing = partial/porewater; 2: 100% total residues remobilize; 3:no remobilization. Default =1	Low/Medium	Muñoz-Carpena et al. (2023a)

ADDITIONAL DISCUSSION ON SELECTING OF VFSMOD INPUT PARAMETERS

This section expands on the discussion of value selection for inputs that are not fixed or default. The input file format is shown for each VFSMOD input file. **Bolded** variables are user inputs that change for each standard scenario and/or each runoff event. Additional detail,

rules, or sources are given for these variables. Non-bolded variables presented in the input files are provided default values as presented in the previous section.

Overland flow solution (.ikw input file)

Input file format:

```

LABEL
FWIDTH
VL N THETAW CR MAXITER NPOL IELOUT KPG
NPROP
(SX(I), RNA(I), SOA(I), I=1, NPROP)
IWQ

```

FWIDTH is the filter width in m (i.e., the size in the dimension perpendicular to the flow). **FWIDTH** depends on the geometry of the standard 10-ha field used in the USEPA and PMRA ecological scenarios. The field/VFS area ratio has an impact on the predicted VFS pesticide removal efficiency. For simple geometries, e.g., a square or rectangular field with VFS along the downslope edge, the area ratio can be represented by the length ratio. The square field configuration (Figure 3) and the assumption that flow from the field is sheet flow uniformly distributed across the entire width of VFS used in this document are consistent with the conceptual model in Plant Assessment Tool (PAT) model that is currently being developed by USEPA to evaluate potential risk to terrestrial and aquatic plants. These assumptions can be adjusted when needed to reflect actual field condition as VFSSMOD has the capability to simulate concentrated flow by changing the VFS dimension (Poletika et al., 2009; Fox et al., 2010).

Figure 3 shows the configuration of a square field with a downslope VFS adjacent to a pond or other waterbody based on the USEPA Plant Assessment Tool framework (USEPA 2022). The pond geometry, however, does not impact VFS model simulation.

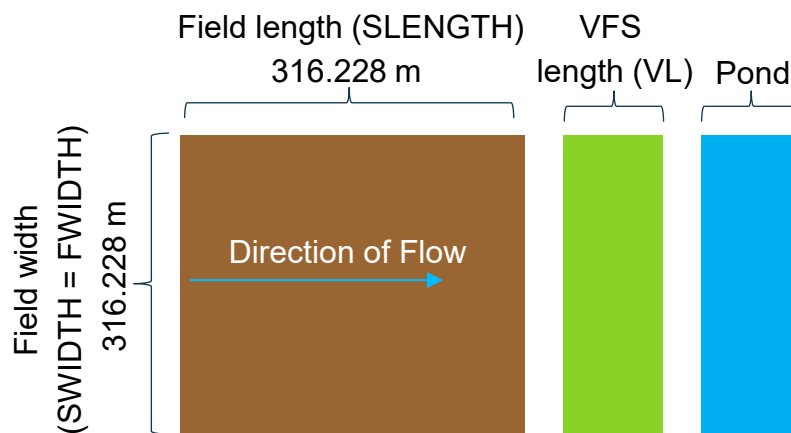


Figure 3. Configuration of a square field with downslope VFS adjacent to a pond based on USEPA pesticide aquatic ecological risk assessment framework (a 10-ha treated field draining into a 1-ha pond).

VL is user defined corresponding to the VFS width (m) desired.

SX(I), filter distance (m), is the same as **VL** (VFS width) and **SOA(I)** is the slope from the standard scenario PRZM input file. A single homogeneous segment is used ($I=NPROP = 1$).

Other inputs use default values as described in Section 2.0, Table 2.

File .ikw example:

.ikw file for a VFS of 10 m with an average slope of 3 % and blue grass or mixed grass, well-maintained, good dense stand ($RNA = 0.45$).

```
File example for IKW
316.23
10.0 -1 0.5000 0.8000 350 3 1 1
1
10.0 0.45 0.030000000
1
```

Storm hyetograph (.irn input file)

Input file format:

NRAIN, RPEAK
(RAIN (I, J), I=1, NRAIN; J=1, 2)

NRAIN is the number of rainfall periods including period to end simulation (integer set to 4, see below).

RPEAK is the maximum rainfall intensity for the storm (m/s). **RPEAK** is set as the total rainfall (x cm * 1 m/100 cm) divided by the rainfall duration (x hour * 3600 s/hr).

RAIN (I, J) are the paired values of time(s) and rainfall rate/intensity (m/s) over the VFS for each of the 4 standard periods described below.

The PRZM weather files associated with the USEPA/PMRA ecological scenarios contain the daily rainfall. The duration of the rainstorm can be read from the USEPA hourly rainfall file for the current ecological scenarios (example link for CA weather - <https://www.epa.gov/ceam/meteorological-data-california>). It is assumed that the hours with rainfall are continuous and do not account for start and stop of rainfall during the day (e.g., if it rains 1 cm at 1 pm and 1 cm at 5 pm, then the total rainfall is 2 cm over 2 hours [7200 seconds]). **If there isn't an hourly weather file**, the daily storm volume is assumed to be distributed over an 8-hour duration. Rainfall is assumed to follow a rectangular hyetograph.

To build the input file, it is assumed that all rainfall events have 4 timesteps (**NRAIN**). The first timestep starts at 0 seconds and the second timestep is the duration of the storm event. The third timestep is set to 1 second after the storm duration to close the hyetograph to 0 at the end. The last timestep is the VFSMOD simulation length, set to the storm duration

multiplied by 1.25 so the water has time to outflow the VFS and the calculation isn't stopped before that.

File .irn example:

.irn file with hourly weather file for a 2-hour rainstorm with 2 cm rain in one day. **RPEAK** = (2 cm x 1 m/100 cm)/7200 s = 2.8E-06 m/s. The final simulation time is set on the last line = 7200 s x 1.25 = 9000 s.

4	2.77778E-06
0.	2.77778E-06
7200.	2.77778E-06
7201.	0.00
9000.	0.00

Field runoff into the VFS (.iro input file)

Input file format:

SWIDTH SLENGTH
NBCROFF BCROPEAK
(BCROFF(I, J), I=1,NBCROFF; J=1, 2)

SWIDTH is the source (field) area width (m)

SLENGTH is the source (field) area path length (m)

NBCROFF is the number of time steps of the incoming field hydrograph (integer)

BCROPEAK is the peak flow of the incoming field hydrograph (m³/s)

BCROFF(I, J) are the paired values of the incoming field hydrograph – time (s) vs. runoff (m³/s)

For the standard USEPA/PMRA 10-ha field (Figure 3), **SWIDTH** and **SLENGTH** are each 316.23 m (100,000 m² area). The PRZM .zts file output of total daily runoff in cm from the field should be converted to m³ (runoff in cm * 1 m/100 cm * 100,000 m² field = m³). The duration of the runoff is the same as in the .irn storm hyetograph file (i.e., read from the USEPA hourly rainfall file or daily runoff duration distributed over 8 hours). If the **runoff is from snowmelt (no rainfall)**, then the runoff duration is assumed to be distributed over 12 hours in a day.

The shape of the runoff hydrograph can affect the pesticide reductions achieved within the VFS. The impact on runoff trapping (dQ), sediment trapping (dE), and pesticide trapping (dP) in the VFS was analyzed in Appendix C of this document for three typical hydrograph types (triangular, rectangular and NRCS tabular based on TR55). Figure 4 shows rectangular and triangular runoff hydrographs (Muñoz-Carpena, 2013). From the sensitivity analysis in Appendix C, a simple triangular hydrograph shape is useful for the .iro file as it as it

produces a realistic representation of the daily field runoff (flow, sediment and pesticides) from PRZM compared to the more computationally expensive NRCS Unit Hydrographs (Muñoz-Carpena, R. and Parsons, J.E., 2004), at a similarly low computation cost to the simplistic rectangular alternative.

To build the field triangular hydrograph (Figure 4), the runoff is assumed to start and stop at the same time as the storm hyetograph (t_b) and the peak flow, **BCROPEAK** (m^3/s) is calculated from the total runoff volume (m^3) divided by the storm duration and multiplied by 2. This is described in the .irn file with 3 timesteps (**NBCROFF**=3). The first time is zero with zero incoming runoff. The second time step is set to the peak runoff **BCROPEAK** (m^3/s) with timestep equal to the total hydrograph duration divided by 2.67, $t_p = t_b / 2.67$. The last time is the total duration period (t_b), with zero incoming runoff.

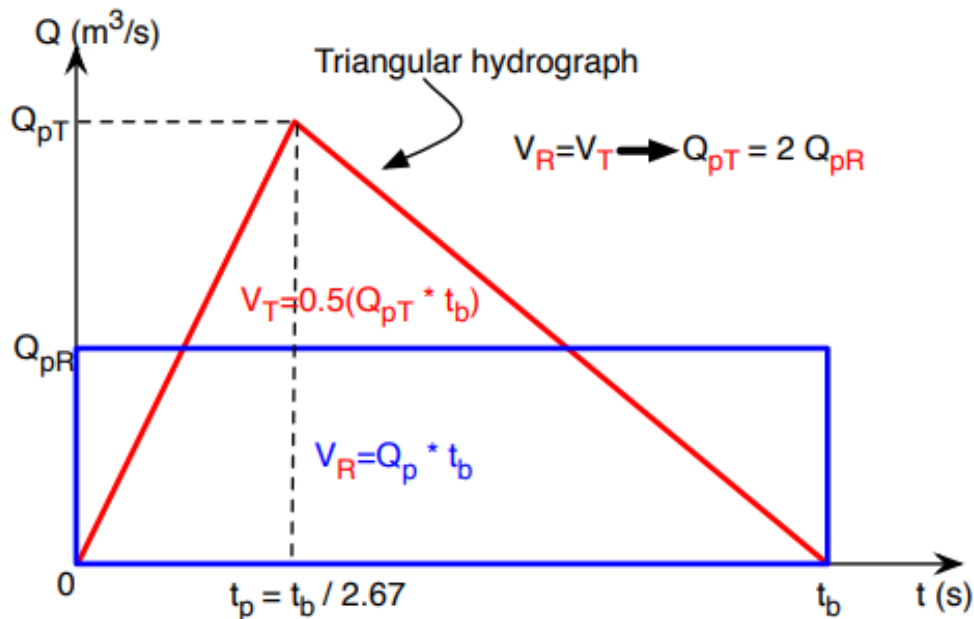


Figure 4. Types of synthetic field hydrograph into the VFS (blue line = rectangular, red line = triangular).

File .iro example:

Below is an .iro file for a $t_b = 2$ -hour rainstorm with 0.05 cm runoff. Then, 2 hours = 7,200 s (total storm duration), peak flow **BCROPEAK** = $2 \times (0.05 \text{ cm} \times 1\text{m}/100 \text{ cm} \times 316.228 \text{ m} \times 316.228 \text{ m}) / 7200 \text{ s} = 0.01389 \text{ m}^3/\text{s}$, $t_p = 7200 / 2.67 = 2697 \text{ s}$. Note that the simulation will run until the longer final time set on the .IRN file (last line) to allow for sufficient for the inflow to runoff the VFS.

316.228	316.228
3	0.01389
0.	0.0
2697.	0.01389
7200.	0.0

Soil infiltration properties (.iso input file)

Input file format (no water table present):

VKS **SAV** **OS** **OI** **SM** **SCHK**

VKS is Green-Ampt's soil saturated hydraulic conductivity (m/s),

SAV is Green-Ampt's soil average suction at wet front (m)

OS is the soil saturated soil-water content (θ_s , m^3/m^3).

The values for **VKS**, **SAV** and **OS** can be obtained from the VFSSMOD user's manual (Appendix 3, 3.1 Soils Data (Green-Ampt parameters table) by looking up the soil texture. This table is also provided in Table B - 2 in Appendix B of this document where the Saxton and Rawls (2006) values can be used for VKS and OS. The mean value of the range for each texture can be used for SAV.

Table B - 4 in Appendix B provides the texture for USEPA ecological standard crop scenarios and Table B - 5 shows the soil texture for the PMRA standard crop scenarios. If only the %sand and %clay are known, texture can be determined from the NRCS soil texture pyramid, available at the website:

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_054167

Other inputs use default values for the specific scenario as described in Section 2.0, Table 2.

File .iso example:

In this example a clay loam soil with default infiltration parameters (Appendix B) is used, with an initial water content (theta from PRZM .zts file on day of event so varies for each event) THETA-i = 0.11, and the rest of the inputs are VFSSMOD defaults presented in the Table on the front of this document.

1.194E-06 0.2088 0.48 0.11 0. 0.5

Vegetation properties (.igr input file)

Input file format:

SS **VN** **H** **VN2** **ICO**

These values are all fixed or default values used for all scenarios (see Table 2) based on "grass mixture" from the VFSSMOD user's manual (Appendix 3, 3.3 Vegetation types for VFS's). The table is also in Appendix B of this document (Table B – 3).

File .igr example:

This example provides the default VFS properties for a Grass Mixture (same for all scenarios, see Appendix B).

2.25 0.012 18. 0.05 0

Incoming sediment properties (.isd input file)

Input file format:

```
NPART      COARSE      CI      POR
SILT_FRAC  ITILLAGE
```

Where:

CI is the incoming flow sediment concentration (g/cm^3) which changes for each event. This value is computed from the PRZM .zts file using ESLS (tonnes/day) and RUN0 (cm/day) for the rainfall/runoff event. One tonne is $1\text{E}+06$ grams. The standard field size is 10 ha ($1\text{E}+09 \text{ cm}^2$). Convert ESLS into g/day and divide by RUN0 converted into cm^3 for a 10-ha field. See equation: $\text{CI} = (\text{ESLS} * 1\text{E}+06) / (\text{RUN0} * 1\text{E}+09)$.

POR (porosity of deposited sediment, fraction) can be computed from the equation, ($\text{POR} = 1 - [\text{bulk density} / 2.65]$) using the standard scenario bulk density in the PRZM input file.

SILT_FRAC, the silt fraction, is determined from the texture of the topsoil layer in the PRZM input file. This variable is a new feature in version 4.5.2 that is used in VFSMOD for the dynamic calculation of the median sediment particle for each event based on the event characteristics option ($\text{NPART} = 8$, fixed value) based on soil properties and storm characteristics. See Appendix A for more details.

Table B - 4 in Appendix B shows the percent silt for USEPA standard scenarios, Table B - 5 has values for PMRA standard scenarios, and Table B - 6 is based on texture (need to convert the percentage to a fraction).

Other inputs use default values as described in Section 2.0, Table 2: NPART sediment type selection (=8), COARSE fraction of runoff sediment particles from the field greater than 0.0034 cm (=0.5), and ITILLAGE for conventional field tillage (=0).

File .isd example:

In this example, incoming flow sediment concentration $\text{CI} = 0.001616521$, calculated based on eroded sediment and runoff volume from the PRZM .zts file for event (eroded sediment/runoff volume). The porosity of deposited sediment $\text{POR} = 1 - (\text{BD} / 2.65) = 0.453$ and the silt fraction = 0.3 (based on clay loam field soil, see Appendix B). Remaining variables are defaults.

```
8 0.5 0.001616521 0.453
0.30 0
```

Pesticide transport (water quality) (.iwq input file)

Input file format:

```
IWQPRO
IKD  VKOC/VKD  OCP
CCP
IDG
```

NDGDAY **DGHALF** **FC** **DGPIN** **DGML** **DGLD** **DGMRES0**
DGT(I)
DGTHETA(I)
IMOB

IKD if set by the user to 0 (-) the K_d value (**VKD**) is read. If $VKD=1$, a K_{oc} value in L/kg (**VKOC**) is read for the adsorption coefficient and the OCP input (see below) is also read and used to calculate VKD. This must match the value from the PRZM input file.

OCP is the organic carbon (%) on the incoming runoff, which is assumed to match the top layer of the source area (field) soil. This can be taken from the surface horizon on the standard PRZM scenario input file.

CCP is the percent clay in the incoming sediment, which is assumed to match the top layer of the source area (field) soil. This is either given in the standard scenario or can be computed from the texture. See Appendix B for %clay in soils for ecological standard scenarios.

NDGDAY is the number of days between runoff events. It is used to calculate the residue mass remaining in the VFS to remobilize or carry-over on the next event. For example, if the previous event occurred on 13-December-1984 and the next event occurs on 15-December-1984, then there are 2 days. This can be computed from the PRZM .zts file.

DGHALF is the aerobic soil degradation half-life in days and should be the same as used in the PRZM input file. However, the PRZM input file has the value as a decay rate in days^{-1} so the inverse value from PRZM must be used here.

FC is the field capacity (m^3/m^3) of the VFS, assumed to be the same as the source area (field). Therefore, this value can be taken from the standard scenario PRZM input file.

DGPIN is the total pesticide mass runoff from the field, i.e., the liquid + solid pesticide mass in mg/m^2 . This is computed for each runoff event in the PRZM .zts file by adding the RFLX (pesticide dissolved in runoff) plus EFLX (pesticide in erosion). The RFLX and EFLX in the .zts file are in g/cm^2 . These need to be converted to mg/m^2 .

DGMRES0 is the runoff-remobilized VFS surface residue from last event in mg/m^2 . The value is read from the last line on the .owq file from the previous event (mresn) and written in the new event .iwq file as this input dgmres0. If not given, it is assumed 0. This remobilized residue from last event must be provided separately from DGPIN, as it is used to calculate the “carry-over” (i.e., initial sorbed pesticide at equilibrium in the mixing layer) at the beginning of the new event.

DGT(I) is the series of daily air temperature ($^{\circ}\text{C}$) between runoff events that can be read from the weather file associated with the standard scenario, where $I=1, \text{NDGDAY}$. The temperature for each day between events is listed in the file.

DGTHETA(I) is the series of topsoil daily water content (m^3/m^3) between runoff events, where $I=1,\text{NGDAY}$. This can be read from the soil moisture in a PRZM .zts simulating a grass area using the same soil properties as the standard scenario field. Section 4.0 of this document describes how to set up the PRZM input file to compute the soil moisture.

Other inputs use default values as described in Section 2.0, Table 2: IWQPRO water quality equation (=3), DGML surface mixing layer thickness (=2 cm), DGLD dispersion length of chemical (=0.05m), and IMOB portion of residue available for remobilization to the next runoff event (=1).

File .iwq example:

Below is an .iwq file for pesticide of Koc=1000 L/Kg and half-life =300 d, 1% and 40% organic carbon and clay in runoff sediment, soil with field capacity of 28%, with 11 days of rainfall hiatus after the first event (with corresponding air temperatures and soil water contents), and runoff remobilized pesticide from the previous event of 0.953323E-01 mg/m^2 .

```
3 -11.5142 0.5949 0.4892 -0.3753 0.2039 ;IWQPRO
1 1000 1. ;IKD Kd/Koc %OC
40. ; %Clay content in field soil
1 ; IDG
11 300 0.28 100. 2. 0.05 0.953323E-01 ;ndgday dgHalf FC dgPin dgML dgLD dgmres0
11.1 13.4 14.9 14.1 16.9 18.9 20.4 17.4 16.1 14.8 14.1 ; dgT(i)
0.274 0.272 0.272 0.276 0.267 0.257 0.247 0.238 0.23 0.226 0.223 ; dgTheta(i)
1 ;IMOB
```

FILTER STRIP DAILY MOISTURE

VFSMOD uses the daily soil-water content in two input files: .iso and .iwq. In the .iso file, the parameter is OI for initial soil-water content (m^3/m^3) in the VFS at the beginning of the storm. The .iwq file lists the topsoil water content (m^3/m^3) for the period between events (DGTHETA(I)). If IDG is set to 2, then the soil-water content (DGTHETA) is not used in calculating degradation. However, the soil-water content will affect the degradation of the residues in the VFS if IDG flag is set to 1 (temperature and moisture impact degradation) or set to 4 (soil moisture impacts degradation). The standard crop scenarios do not have the soil moisture (THET) output in the PRZM input file generated by PWC. Therefore, the soil-water content is read from the THET output in a PRZM .zts file from a separate run that is set up for the VFS (grassed area) for the standard scenario. A “turf” file is shown in Appendix D that highlights modifications using the USEPA IL Corn standard scenario PRZM input file as an example.

To generate the “turf” PRZM run, the standard scenario should be revised to simulate a grassed area. The user can either run PRZM outside of PWC or check the “Pause before PRZM Run” box under the “Advanced” tab in PWC after making the changes to the PRZM input file listed below:

- Start with the PWC standard crop scenario. Modify the PRZM5.inp input file for the turf cropping/erosion parameters and for the output which are highlighted in yellow in Appendix D.

- Modify crop parameters based on proximity of crop scenario to a standard turf scenario (e.g., PA_{turf}STD.scn); Records 4-7 (i.e., turf crop parameters, cropping dates, etc.).
- Curve numbers (CN) (Record 4) are based on Hydrologic Soil Group (HSG) standard scenario soil (Table B - 4³ and Table B - 5). All curve numbers should be the same and set according to the sub-bullet below.
 - HSG A = 39; HSG B = 61, HSG C = 74; HSG D = 80
 Dates, USLE c-factor and Manning's N are based on the selected standard turf scenario
- If there is irrigation in the standard scenario, modify the file to turn irrigation off (set Record 8 to 0, 0 and delete Record 9).
- Replace infiltration (INFL) output name with "THET" output name to generate the soil moisture output (theta) with compartment set for 10 cm (typically compartment 100). Change TCUM to TSER.
- Once the turf input file (PRZM5.inp) is created and saved, either run PRZM5.exe to generate the separate PRZM .zts file (e.g., ST_{crop}_TF.zts) to use in the VF_{SMOD} run for the daily soil moisture (THET) or hit the "OK" button to continue if paused PWC.

Adding a thatch layer to the VFS "turf" PRZM input file was discussed with the Working Group. The thatch layer would have much higher organic carbon in the top 2 cm of the soil profile. One consideration is that not including a thatch layer would be more conservative.

EXAMPLE INPUT FILES FOR USEPA STANDARD SCENARIO

An example of a full set of VF_{SMOD} input files is shown in Appendix E using the USEPA IL Corn standard scenario³. The scenario example assumes that there is a script that fills in the values that change for each runoff event (CI, DGPIN, DGTHETA(I), .irn file and .iro file) for the long-term simulation. In this example, the rainfall and runoff input files reflect the examples shown in Section 3.

EXAMPLE OF PESTICIDE REDUCTION OUTPUTS

Pesticide reduction outputs are contained in the VF_{SMOD}.owq output file. An annotated example is provided below (highlighted in yellow are end outputs of interest). The .owq file provides the percent reductions for the runoff inflow, sediment, and total pesticide. The file also gives the pesticide leaving the VFS in the solid phase (mop) and liquid phase (mod). The residue available for remobilization for the next event is also provided in the last line of the .owq file.

File: output/sampleP.owq

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³ Hydrologic Soil Groups for standard scenarios can be found in the scenario metadata folder that is zipped up with the "PWC Scenarios and Weather Files for Ecological assessments" available from <https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#PWC>

Parameters for Water Quality		

Type of problem - Pesticide trapping (mass balance (Reichenberger 2019))		
Partition coefficient (Kd)=	10.000000	L/Kg
% Clay in sediment (%CL) =	40.000000	%
Dispersion length (l)=	0.050000	m
Residue remobilisation (IMOB)=	1: partial (surface porewater)	
Degradation type (IDG)=	1: EU-FOCUS k=Kref.k(T).k(theta)	
Pesticide half-life (Ln2/Kref)=	300.000000	days
Soil field capacity (FC)=	0.280000	(-)
Incoming pesticide mass (mi)=	100.000000	mg/m2
Mixing layer thickness (dml)=	2.000000	cm
Pest. surface residue (mres0)=	95.332300	mg/m2
No. of days between events=	11	
	day	T (C) theta (-)
	1	11.10000 0.27400
	2	13.40000 0.27200
	3	14.90000 0.27200
	4	14.10000 0.27600
	5	16.90000 0.26700
	6	18.90000 0.25700
	7	20.40000 0.24700
	8	17.40000 0.23800
	9	16.10000 0.23000
	10	14.80000 0.22600
	11	14.10000 0.22300
Soil leaching and mixing layer calculations (CDE)		

Huang & van Genuchten (1995) CDE analytical solution		
Single pulse with C1=dissolved in mass/(runoff+rain)		
Wetting front depth (z)=	0.4298	m
Incoming runoff volume (Vi)=	1324.7213	L
Event rainfall (P)=	842.2920	L
Total infiltration (F)=	1266.7959	L
Incoming sediment (Ei)=	45.0453	Kg
Incoming dissolved mass (mdi)=	145.7664	mg/m2
Incoming sed-sorbed mass (mpi)=	49.5659	mg/m2
Incoming dissolved mass (mdi)=	19824.2335	mg
Incoming sed-sorbed mass (mpi)=	6740.9593	mg
Pulse concentration (C1)=	9.1482	mg/L
Retardation factor (R)=	59.7090	(-)
Transformed time (T)=	0.1216	(-)
	Z (m)	C (mg/L) S (mg/mg)

	0.0000	1.9041 19.0413
	0.0100	0.7644 7.6435
	0.0200	0.2189 2.1890
	0.0300	0.0429 0.4293
	0.0400	0.0056 0.0560
	0.0500	0.0005 0.0048
	0.0600	0.0000 0.0003
	0.0700	0.0000 0.0000
	0.0800	0.0000 0.0000
...		
Soil profile total mass (mfF mg)=	11588.9408	100.00%
Soil profile dissolved mass (mfFd mg)=	194.0903	1.67%
Soil profile sorbed mass (mfFp mg)=	11394.8505	98.33%
Mixing layer total mass (mfml mg)=	10763.2087	92.87%
Mixing layer dissolved mass (mfmlD mg)=	180.2611	1.56%
Mixing layer sorbed mass (mfmlp mg)=	10582.9476	91.32%

Outputs for Water Quality

0.132E+01 m3 = Runoff inflow
0.450E+02 Kg = Sediment inflow
4.811 = Phase distribution, Fph
58.458 % = Infiltration (dQ)
97.163 % = Sediment reduction (dE)
32.045 % = Runoff inflow reduction

68.280 % = Pesticide reduction (dP)

Pesticide mass balance, degradation & remobilization

0.265652E+05 mg = Pesticide input (mi)
0.842659E+04 mg = Pesticide output (mo)
0.117942E+03 mg = Pesticide outflow in solid phase (mop)
0.830864E+04 mg = Pesticide outflow in liquid phase (mod)
0.181386E+05 mg = Pesticide trapped in VFS (mf)
0.654973E+04 mg = Pesticide trapped with sediment (mfsed)
0.107632E+05 mg = Pesticide trapped in mixing layer (mfml)
0.106155E+07 mg = Pesticide in mixing layer from last event (mfml0)
0.107886E+07 mg = Total surface residue (mres1=mfml+mfsed+mfml0)
0.105875E+07 mg = Total surface residue after degradation (11 days)
0.127750E+05 mg = Dissolved surface residue after degradation (11 days)
0.104597E+07 mg = Sorbed surface residue after degradation (11 days)
0.127750E+05 mg = Next event residue remobilization (mresn, IMOB=1)

Normalized values by source area:

136.00 m^2 = Source Area (input)
0.195332E+03 mg/m2= Pesticide input (mi)
0.619602E+02 mg/m2= Pesticide output (mo)
0.867224E+00 mg/m2= Pesticide outflow in solid phase (mop)
0.610930E+02 mg/m2= Pesticide outflow in liquid phase (mod)
0.133372E+03 mg/m2= Pesticide trapped in VFS (mf)
0.481598E+02 mg/m2= Pesticide trapped with sediment (mfsed)
0.791412E+02 mg/m2= Pesticide trapped in mixing layer (mfml)
0.780549E+04 mg/m2= Pesticide in mixing layer from last event (mfml0)
0.793279E+04 mg/m2= Total surface residue (mres1=mfml+mfsed+mfml0)
0.778490E+04 mg/m2= Total residue after degradation (11 days)
0.939335E+02 mg/m2= Dissolved surface residue after degradation (11 days)
0.769097E+04 mg/m2= Sorbed surface residue after degradation (11 days)
0.939335E+02 mg/m2= Next event residue remobilization (mresn, IMOB=1)

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APPENDIX A – NEW OPTIONS IN VERSION 4.5

New processes that add realism to the simulations are included in VFSMOD version 4.5. These avoid the arbitrary parametrization of the incoming sediment characteristics in favor of a dynamic calculation of these based on each event's characteristics and provides robust mechanistic runoff remobilization of residues across all products (from low to high sorption and from labile to persistent). The number of nodes on the surface (N) can also now be selected automatically. These new processes are described in more detail below.

1. *Dynamic calculation of the median sediment particle (DP) for each event based on the event characteristics (option NPART=8 in ISD).* The selection of sediment particle characteristics (median particle size and density) in runoff at the edge of the field is complex. It depends on the characteristics of the soil in the source area (field) and, importantly, on the runoff event characteristics dictated by the rainfall and runoff intensity that provide the energy to transport the sediment within the runoff. As a result, the sediment characteristics are dynamic for each event and not just a property of the soil at the site. However, current approaches (Foster et al., 1985; Woolhiser et al., 1990) disregard the hydrology of the events and propose the estimation of the sediment characteristics based solely on the soil texture and organic matter. In other cases, like in EU-FOCUS SWAN (Brown et al., 2012), a fixed, relatively large particle size is used because of limited data available for the EU FOCUS scenarios. This leads to an overestimation of the efficiency of sediment retention in the buffer (Sur et al., 2019). Instead, the new approach in VFSMOD v4.5 is included as the default option. The sediment characteristics are calculated internally using a robust algorithm developed from a database of 100 studies. The algorithm estimates the sediment characteristics (DP and SG [sediment particle density]) dynamically based on the field characteristics (length of field and texture from PRZM files), tillage (conventional vs. no-tillage), sediment load (from PRZM outputs), and precipitation event characteristics (mean rainfall and peak runoff also from PRZM outputs). For this, a new parameter is needed (silt fraction) in the ISD file, in the same place (last line) where DP, SG were given in previous versions of VFSMOD.

2. *Partial remobilization of residues in VFS after degradation (option IMOB=1 in IWQ).* After initial trapping of runoff pesticides in the VFS, simulating the fate of surface pesticide residues involves degradation and remobilization in a subsequent event of the mixing layer porewater and retention of part of the mass sorbed in the surface as “carryover” (Figure 2). The correct quantitation of pesticide residue remobilization is particularly important for highly-sorbed compounds (e.g., $K_{oc} > 100,000$). A general mechanistic solution for all compounds, valid across all values of K_{oc} , is now used in VFSMOD. Only porewater (dissolved) pesticide is remobilized at the beginning of the next event in the series, where the sorbed fraction stays on the soil and contributes to the equilibrium distribution at the mixing layer for the next event. Also, importantly, the pesticide mass in the mixing layer is calculated based on non-uniform leaching with soil depth during infiltration based on the physical CDE (convective-dispersive equation) transport. This improved algorithm addresses the issue of excessive availability and remobilization with highly-sorbed pesticides that was encountered in the past version and simulates remobilization in a physically consistent manner. Only one new input variable is needed in the program input file .iwq, *DGMRES0*, the last event surface residue pesticide mass dissolved in porewater remobilized in the next

runoff event, that is provided in the .owq file from previous event simulated in the series. The .owq file now has been extended with more information on the new processes, but for backwards compatibility, the content on the first part of the output file has not changed. Minor modifications for linking scripts/programs created to work with previous versions may be needed when using the revised .iwq and .owq files.

3. *Automatic number of nodes N setting.* The number of nodes in the VFS surface (.IWK file) can now be set for internal calculation ($N = -1$). This setting allows the model to identify the number of nodes on the VFS needed for efficient calculation for filter sizes from 1-100 m. This eliminates the need to parametrize this and improves the computational efficiency of the model in most cases. The value $N = -1$ is set as default for regulatory calculations. Other values can still be given for other cases as desired.

APPENDIX B - VFSSMOD INPUT PARAMETER TABLES

Table B - 1. Manning's roughness coefficient for segment.

3.2 Manning's roughness coefficient, n

There are several publications dedicated to the estimation of this important parameter for overland flow routing (see Arcement et al., 1989). A summary of the most common values used in overland flow routing can be taken from Engman (1986), as:

Cover	Manning's n range (recommended) $\text{ms}^{-1/3}$
Bare sand	0.01-0.013 (0.011)
Bare clay-loam (eroded)	0.012-0.033 (0.02)
Fallow - no residue)	0.006-0.16 (0.05)
Range (natural)	0.01-0.32 (0.13)
Range (clipped)	0.02-0.24 (0.10)
Grass (bluegrass sod)	0.39-0.63 (0.45)
Short grass prairie	0.10-0.20 (0.15)
Dense grass ^a	0.17-0.30 (0.24)
Bermuda grass	0.30-0.48 (0.41)

^aWeeping lovegrass, bluegrass, buffalo grass, blue gramma grass, native grass mix (OK), alfalfa, lespedeza

Source: VFSSMOD User's Manual, Appendix 3.

Use 0.45 grass (bluegrass sod) for RNA and 0.05 fallow (no residue) for VN2.

Table B - 2. Green-Ampt parameters for soil textures.

3.1 Soils data (Green-Ampt parameters)

The model developers encourage the users to obtain the soil inputs for the model based on soil samples taken on site. If that is not possible or the model is applied to study the effect of soil type on the effectiveness of the VFS, the following table gives values for the Green-Ampt parameters as suggested by Rawls and Brakensiek (1983).

Soil Texture (USDA)	K_z (m/s) $\times 10^{-6}$	S_{av} (m)	Porosity $\approx \theta_s (m^3/m^3)$
Clay	0.167 ^a 0.306 ^b	0.0639-1.565 ^a (0.3163) ^a	0.475(0.427-0.523) ^a 0.50 ^b
Sandy-clay	0.333 ^a 0.389 ^b	0.0408-1.402 ^a (0.2390) ^a	0.430(0.370-0.490) ^a 0.44 ^b
Clay-Loam	0.556 ^a 1.194 ^b	0.0479-0.9110 ^a (0.2088) ^a	0.464(0.409-0.519) ^a 0.48 ^b
Silty-Clay	0.278 ^a 1.028 ^b	0.0613-1.394 ^a (0.2922) ^a	0.479(0.425-0.533) ^a 0.52 ^b
Silty-clay-loam	0.556 ^a 1.583 ^b	0.0567-1.315 ^a (0.2730) ^a	0.471(0.418-0.524) ^a 0.51 ^b
Sandy-clay-loam	0.833 ^a 3.139 ^b	0.0442-1.080 ^a (0.2185) ^a	0.398(0.332-0.464) ^a 0.43 ^b
Loam	3.67 ^a 4.306 ^b	0.0133-0.5938 ^a (0.0889) ^a	0.463(0.375-0.551) ^a 0.46 ^b
Silt-loam	1.89 ^a 4.472 ^b	0.0292-0.9539 ^a (0.1668) ^a	0.501(0.420-0.582) ^a 0.48 ^b
Sandy-loam	6.06 ^a 13.93 ^b	0.0267-0.4547 ^a (0.1101) ^a	0.453(0.351-0.555) ^a 0.45 ^b
Loamy-sand	16.6 ^a 26.86 ^b	0.0135-0.2794 (0.0613) ^a	0.437(0.363-0.506) ^a 0.46 ^b
Sand	65.4 ^a 30.03 ^b	0.0097-0.2536 ^a (0.0495) ^a	0.437(0.374-0.500) ^a 0.46 ^b

^a Rawls and Brakensiek (1983); ^b Saxton and Rawls (2006) assuming MO: 2.5%

Note: Values in parenthesis are mean values. For an alternative source of Green-Ampt soil parameters see also McCuen et al. (1981).

Source: VFSMOD User's Manual, Appendix 3.

For Ks and porosity, use Saxton and Rawls (2006). Use the mean value for Sav.
 Use sandy loam for very fine sandy loam, fine sandy loam and coarse sandy loam.
 Use loamy sand for loamy very fine sand, loamy fine sand, loamy coarse sand, gravelly loam, very gravelly loam.
 Use sand for very fine sand, fine sand, and coarse sand.

Table B - 3. Vegetation data for VFS.

3.3 Vegetation types for VFS's

The following data on vegetation is taken from Haan et al. (1994).

Vegetation (good stand) ^a	Density (stems/m ²)	Grass spacing S_g (cm)	Maximum height, H (cm)	Modified n n_m cm.s ^{-1/3}
VEGETATION TYPICALLY RECOMMENDED FOR VFS				
Yellow bluestem	2700	1.9	--	--
Tall fescue	3900	1.63	38	0.012
Blue gramma	3750	1.65	25	0.012
Ryegrass (perennial)	3900	1.63	18	0.012
Weeping lovegrass	3750	1.65	30	--
Bermudagrass	5400	1.35	25	0.016
Bahiagrass	--	--	20	0.012
Centipedegrass	5400	1.35	15	0.016
Kentucky bluegrass	3750	1.65	20	0.012
Grass mixture ^b	2150	2.15	18	0.012
Buffalograss	4300	1.5	13	0.012
VEGETATION NOT RECOMMENDED FOR VFS ^c				
Alfalfa	1075	3.02	35	0.0084
Sericea lespedeza	650	3.92	40	0.0084
Common lespedeza	325	5.52	13	0.0084
Sudangrass	110	9.52	--	0.0084

a. To convert densities for good stand to other stands, multiply the given densities by 1/3, 2/3, 1, 4/3 and 5/3 for poor, fair, good, very good and excellent covers

b. Values vary depending on mixture. If a given grass type predominates, values for that species should be used.

c. Values of S_g above 2.5 cm can cause scour and are not recommended.

Source: VFSSMOD User's Manual, Appendix 3.

Use grass mixture values.

Table B - 4. USEPA ecological standard scenario – soil parameters.

Scenario	HSG	Soil Name	Soil Texture	%Sand	%Clay	%Silt	%OC	BD
CAalfalfa_WirrigOP	D	Sacramento	Clay	20	50	30	1.770	1.43
CAalmond_WirrigSTD	C	Manteca	Fine Sandy Loam	60	15	25	0.810	1.55
CAAvocadoRLF	C	Cieneba	Coarse Sandy Loam	60	15	25	0.440	1.55
CACitrus_WirrigSTD	C	Exeter	Loam	34	41	25	0.460	1.59
CAColeCropRLF	C	Marimel	Silty Clay Loam	15	35	50	1.740	1.50
CAColeCropRLF_Nirrig	C	Marimel	Silty Clay Loam	15	35	50	1.740	1.50
CAcornOP	C	Madera	Loam	34	41	25	0.580	1.55
CAcotton_NirrigSTD	C	Twisselman	Clay	20	50	30	0.290	1.45
CAcotton_WirrigSTD	C	Twisselman	Clay	20	50	30	0.290	1.45
CAForestryRLF	C	Marpa	Gravelly Loam	84	8	8	1.160	1.40
CAfruit_WirrigSTD	C	Exeter	Fine Sandy Loam	60	15	25	0.580	1.70
CAGarlicRLF_V2	C	Cerini	Clay Loam	35	35	30	0.460	1.45
CAGrapes_WirrigSTD	C	San Joaquin	Loam	34	41	25	0.720	1.84
CAImperviousRLF	D	Tierra	Loam	34	41	25	0.000	1.90
CAlettuceSTD	D	Placentia	Sandy Loam	60	15	25	0.725	1.575
CAlettuce_slope1	D	Placentia	Sandy Loam	60	15	25	0.725	1.575
CAMelonsRLF_V2	C	Cerini	Clay Loam	35	35	30	0.460	1.45
CAnurserySTD_V2	C	Cieneba	Coarse Sandy Loam	60	15	25	0.440	1.55
CAOliveRLF_V2	D	Porterville	Clay	20	50	30	1.160	1.35
CAonion_WirrigSTD	D	Ciervo	Clay	20	50	30	0.910	1.40
CAPotatoRLF_V2	C	Lewkalb	Sandy Loam	60	15	25	0.140	1.55
CArangelandhayRLF	C	Los Osos	Silty Clay Loam	15	35	50	1.160	1.25
CAresidentialRLF	D	Tierra	Loam	34	41	25	35.60	0.37
CArightofwayRLF_V2	D	Gaviota	Sandy Loam	60	15	25	0.440	1.55
CARowCropRLF_V2	B	Mocho	Silt Loam	20	20	60	1.740	1.35
CAstrawberry-noplasticRLF	A	Oceano	Loamy Sand	84	8	8	0.580	1.65
CAsugarbeet_WirrigOP	C	Ryde	Clay Loam	35	35	30	3.480	1.40
CAtomato_NirrigSTD	D	Stockton	Clay	20	50	30	0.950	1.30
CAtomato_WirrigSTD	D	Stockton	Clay	20	50	30	0.950	1.30
CATurfRLF	D	Capay	Silty Clay Loam	15	35	50	35.60	0.37
CAWheatRLF_V2	D	San Joaquin	Loam	34	41	25	0.440	1.55
CAWineGrapesRLF_V2	C	Haire	Clay Loam	35	35	30	1.160	1.40
FLavocadoSTD	A	Krome	Very Gravelly Loam	84	8	8	31.68	1.00
FLcabbageSTD	C	Riviera	Sand	90	5	5	1.160	1.65
FLcarrotSTD	C	Riviera	Sand	90	5	5	1.160	1.65
FLcitrusSTD	D	Wabasso	Fine sand	90	5	5	2.320	1.45
FLcucumberSTD	C	Riviera	Sand	90	5	5	1.160	1.65
FLnurserySTD_V2	D	Biscayne	Silt Loam	20	20	60	2.610	1.10
FLpeppersSTD	C	Riviera	Sand	90	5	5	1.160	1.65
FLpotatoNMC	D	Placid	Fine Sand	90	5	5	3.000	1.30
FLstrawberry_WirrigSTD	D	Myakka	Sand	90	5	5	1.160	1.25
FLsugarcaneSTD	D	Wabasso	Fine Sand	90	5	5	2.320	1.45
FLsweetcornOP	C	Riviera	Sand	90	5	5	1.160	1.65
FLtomatoSTD_V2	C	Riviera	Sand	90	5	5	1.160	1.65
FLturfSTD	C	Adamsville	Sand	90	5	5	7.500	0.37
GAOnion_WirrigSTD	C	Clarendon	Loamy Sand	84	8	8	1.740	1.60
GAPeachesSTD	B	Greenville	Fine Sandy Loam	60	15	25	0.290	1.30

Scenario	HSG	Soil Name	Soil Texture	%Sand	%Clay	%Silt	%OC	BD
GApecansSTD	C	Williston	Loamy Fine Sand	84	8	8	1.160	1.45
IAcornstd	B	Fayette	Silty Clay Loam	15	35	50	0.930	1.40
IDNpotato_NirrigSTD	C	Malm	Fine Sandy Loam	60	15	25	0.870	1.55
IDNpotato_WirrigSTD	C	Malm	Fine Sandy Loam	60	15	25	0.870	1.55
ILalfalfaNMC	D	Varna	Silt Loam	20	20	60	1.500	1.50
ILbeansNMC	D	Varna	Silt Loam	20	20	60	1.500	1.50
ILCornSTD	C	Adair	Clay Loam	35	35	30	2.320	1.45
INCornStd	C	Fincastle	Silt Loam	20	20	60	1.160	1.45
KSCornStd	D	Wymore	Silty Clay Loam	15	35	50	1.740	1.30
KSsorghumSTD	C	Dennis	Silt Loam	20	20	60	1.740	1.55
LA sugarcaneSTD	C	Commerce	Silt Loam	20	20	60	2.320	1.65
MEpotatoSTD	C	Conant	Silt Loam	20	20	60	4.640	1.25
MIAsparagusSTD	A	Spinks	Loamy Sand	84	8	8	0.655	1.66
MIbeansSTD	D	Toledo	Silty Clay	10	45	45	3.480	1.10
MICherriesSTD	C	Kewaunee	Silt Loam	20	20	60	1.740	1.60
MImelonStd	B	Selfridge	Loamy Sand	84	8	8	1.160	1.32
MINurserySTD_V2	D	Granby	Loamy Sand	84	8	8	4.060	1.40
MNalfalfaOP	C	Bearden	Silty Clay Loam	15	35	50	4.060	1.40
MNCornStd	C	Guckeen	Silty Clay Loam	15	35	50	2.900	1.25
MNsugarbeetSTD	C	Bearden	Silty Clay Loam	15	35	50	4.060	1.40
MOmelonStd	B	Dubbs	Loamy Sand	84	8	8	0.725	1.42
MScornSTD	C	Grenada	Silt Loam	20	20	60	1.160	1.70
MScottonSTD	C	Loring	Silt Loam	20	20	60	1.280	1.40
MSsoybeanSTD	C	Loring	Silt Loam	20	20	60	1.280	1.40
NCalfalfaOP	C	Helena	Sandy Loam	60	15	25	1.160	1.55
NCappleSTD	C	Hayesville	Loam	34	41	25	0.580	1.30
NCcornESTD	C	Craven	Silt Loam	20	20	60	1.160	1.45
NCcornWOP	C	Chewacla	Loam	34	41	25	2.320	1.60
NCcottonSTD	D	Boswell	Sandy loam	60	15	25	2.320	1.80
NCpeanutSTD	C	Craven	Silt Loam	20	20	60	1.160	1.45
NCSweetPotatoSTD	C	Craven	Silt Loam	20	20	60	1.160	1.45
NCtobaccoSTD	B	Norfolk	Loamy Sand	84	8	8	0.290	1.55
NDcanolaSTD	C	Hamerly	Loam	34	41	25	2.360	1.48
NDcornOP	C	Bearden	Silty Clay Loam	15	35	50	4.060	1.40
NDwheatSTD	C	Bearden	Silty Clay Loam	15	35	50	4.060	1.40
NECornStd	D	Filbert	Silt Loam	20	20	60	1.740	1.30
NJmelonStd	B	Sassafras	Loamy Sand	84	8	8	0.960	1.60
NJnurserySTD_V2	C	Woodstown	Sandy Loam	60	15	25	0.870	1.55
NYGrapesSTD	C	Lordstown Channery	Silt Loam	20	20	60	3.480	1.40
OHCornSTD	C	Cardington	Silt Loam	20	20	60	1.160	1.60
ORappleSTD	C	Cornelius	Silt Loam	20	20	60	2.300	1.30
ORberriesOP	C	Woodburn	Silt Loam	20	20	60	1.860	1.44
ORfilbertsSTD	C	Cornelius	Silt Loam	20	20	60	2.300	1.30
ORgrassesSTD	D	Dayton	Silt Loam	20	20	60	2.320	1.40
ORhopsSTD	C	Woodburn	Silt Loam	20	20	60	1.860	1.44
ORMintSTD	C	Newberg	Fine Sandy Loam	60	15	25	1.160	1.20
ORNurserySTD_V2	C	Woodburn	Silt Loam	20	20	60	2.320	1.30
ORsnbeansSTD	D	Dayton	Silt Loam	20	20	60	2.320	1.40
ORswcornOP	C	Woodburn	Silt Loam	20	20	60	1.860	1.44
ORwheatOP	D	Bashaw	Clay	20	50	30	4.640	1.30
ORXmasTreeSTD	C	Pilchuck	Fine Sand	90	5	5	1.160	1.55
PAalfalfaOP	C	Glenville	Silt Loam	20	20	60	1.740	1.30

Scenario	HSG	Soil Name	Soil Texture	%Sand	%Clay	%Silt	%OC	BD
PAappleSTD_V2	C	Elioak	Silt Loam	20	20	60	1.160	1.70
PAcornSTD	C	Hagerstown	Silt Loam	20	20	60	2.900	1.60
PAtomatoSTD	C	Glenville	Silt Loam	20	20	60	1.740	1.30
PAturfSTD	C	Glenville	Silt Loam	20	20	60	7.500	0.37
PAvegetableNMC	C	Clarksburg	Silt Loam	20	20	60	1.800	1.30
PRcoffeeSTD	D	Mucara	Clay	20	50	30	2.300	0.96
TNnurserySTD	C	Captina	Silt Loam	20	20	60	1.200	1.35
STXcornNMC	D	Harlingen	Clay	20	50	30	1.200	1.45
STXcottonNMC	D	Harlingen	Clay	20	50	30	1.200	1.45
STXgrapefruitNMC	B	Hidalgo	Sandy Clay Loam	55	25	20	1.200	1.50
STXmelonNMC	D	Harlingen	Clay	20	50	30	1.200	1.45
STXvegetableNMC	D	Harlingen	Clay	20	50	30	1.200	1.45
ImperviousBSS	C	Brackett	Clay Loam	35	35	30	0.000	1.90
MeadowBSS	C	Brackett	Clay Loam	35	35	30	1.160	1.40
NurseryBSS	D	Tarrant	Clay	20	50	30	2.610	1.25
OrchardBSS	C	Brackett	Clay Loam	35	35	30	1.160	1.40
RangeBSS	C	Brackett	Clay Loam	35	35	30	1.160	1.40
ResidentialBSS	C	Brackett	Clay Loam	35	35	30	7.500	0.37
RightOfWayBSS	C	Brackett	Clay Loam	35	35	30	1.160	1.40
TurfBSS	C	Brackett	Clay Loam	35	35	30	7.500	0.37
TXalfalfaOP	D	Lufkin	Sandy Loam	60	15	25	1.160	1.55
TXcornOP	D	Axtell	Fine Sandy Loam	60	15	25	0.580	1.60
TXcottonOP	C	Crockett	Fine Sandy Loam	60	15	25	0.730	1.55
TXsorghumOP	D	Axtell	Fine Sandy Loam	60	15	25	0.580	1.60
TXwheatOP	D	Crockett	Fine Sandy Loam	60	15	25	0.730	1.55
WAbeansNMC	C	Ekrub	Fine Sand	90	5	5	0.150	1.45
WAonionsNMC	C	Ekrub	Fine Sand	90	5	5	0.150	1.45
WAorchardsNMC	C	Taunton	Silt Loam	20	20	60	0.450	1.25
WApotatoNMC	D	Skoon	Silt Loam	20	20	60	0.450	1.25

Source: Texture and HSG for USEPA standard scenarios was obtained from the scenario metadata folder that is zipped up with the “PWC Scenarios and Weather Files for Ecological assessments” available from

<https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#PWC>

or from the USEPA PE5 .txt PRZM input files

% sand and % clay were assigned base on texture using Table 1 in the VFSSMOD User’s Manual (also shown in Appendix B, Table B - 6).

HSG = Hydrologic Soil Group; BD = Bulk Density

Table B - 5. PMRA ecological standard scenarios – soil parameters

Scenario	HSG	Soil Texture	%Sand	%Clay	%Silt	%OC	BD
Apple BC	C	Sandy Loam	70	9	21	1.0	1.40
Apple NS	C	Sandy Loam	60	10	30	2.8	1.25
Apple ON	C	Loam	40	19	41	3.4	1.20
Apple QC	C	Sandy Clay Loam	60	20	20	1.9	1.40
Barley AB	C	Clay Loam	25	37	38	2.5	1.45
Corn ON	C	Clay Loam	25	37	38	2.5	1.45
Corn QC	C	Sandy Clay Loam	55	23	22	3.2	1.40
Grape ON	C	Loam	40	19	41	3.4	1.20
Potato MB	C	Loam	27	26	47	3.4	1.30
Potato PEI	C	Sandy Loam	58	5	37	0.4	1.32
Raspberry BC	B	Silt Loam	22	11	67	3.5	1.20
Sugarbeet AB	C	Sandy Loam	72	10	18	1.0	1.40
Wheat MB	C	Loam	27	26	47	3.4	1.30
Wheat SK	C	Clay	8	62	30	2.0	1.40

Source: Texture for PMRA standard scenarios was obtained from the NRCS soil texture pyramid using the standard scenario % sand and % clay from the topsoil layer. %Silt = 100-%Sand - %Clay

HSG = Hydrologic Soil Group

Table B - 6. Percent sand, silt, and clay per soil texture.

Soil Texture	%Sand	%Silt	%Clay*
Clay	20	30	50
Silty Clay	10	45	45
Sandy Clay	50	10	40
Silty Clay Loam	15	50	35
Clay Loam	35	30	35
Sandy Clay Loam	55	20	25
Silt	5	85	10
Silt Loam	20	60	20
Loam	34	25	41
Very Fine Sandy loam	60	25	15
Fine Sandy Loam	60	25	15
Sandy Loam	60	25	15
Coarse Sandy Loam	60	25	15
Loamy very fine sand	84	8	8
Loamy Fine Sand	84	8	8
Loamy Sand	84	8	8
Loamy Coarse Sand	84	8	8
Gravelly Loam	84	8	8
Very Gravelly Loam	84	8	8
Very Fine Sand	90	5	5
Fine Sand	90	5	5
Sand	90	5	5
Coarse Sand	90	5	5

Source: Based on VFSMOD User's Manual, Table 1.

*%Clay = 100 – %Sand - %Silt

APPENDIX C – SENSITIVITY ANALYSIS OF RUNOFF HYDROGRAPH TYPES IN VFSMOD

Executive Summary

A systematic exploration of the effects of selecting alternative hydrograph and hyetographs of increasing complexity (calculated from daily value of rainfall and field runoff) is presented. A simplistic average rectangular shape is compared with more realistic NRCS triangular and tabular unit hydrographs. Three criteria for selecting the distribution to use for quantitative VFS mitigation in the regulatory (long-term) exposure analysis were selected: a) computational efficiency; b) complexity of implementation; c) additional tools needed. A combination of storms (intensity, duration) and corresponding field hydrographs for return periods corresponding to T=1, 5, and 10 yrs are selected for a North Carolina Piedmont site. The effect of choosing the 3 synthetic hydrograph types for these storms is studied on two typical soils of the area, 3 alternative VFS widths (1-10 m), and a wide range of pesticides (Koc=10-10000 L/Kg). Simulated VFS removal efficiency for runoff (dQ), sediment (dE) and pesticide (dP) were selected as outputs of interest of the model and global sensitivity analysis (GSA) is employed to identify the importance (direct effects and interactions) of all the factors studied. The more complex method (NRCS) can potentially offer a more realistic description of the runoff dynamics but requires the introduction of an additional computational tool (i.e., UH) in the regulatory framework and doubles the simulation time. The results indicate that the rectangular graph option produced significantly lower dQ, less conservative (lower) exposure estimates (compared to the other two options) and lower dE and dP. The computational cost of the full NRCS hydrograph was double the other 2 options. The GSA confirmed the relative importance of the hydrograph selection in the context of the other variable factors. For the reduction of runoff on the filter dQ, the hydrograph type was second in the order of importance, after the filter size (VL), storm and soil type. For dE the hydrograph selection was unimportant whereas VFS size and soil were the most important factors followed by storm characteristics. For dP, hydrograph selection was the least globally important factor where the increase of pesticide sorption largely increased the efficiency of the buffer in this case, followed in importance by the factors that controlled dQ and dE (i.e., filter size, soil and storm type). For all outputs, the increase in duration of the storm (from 4 to 8 h) had a smaller effect overall increasing <5% the efficiency of the VFS on all the outputs. These results support the use of the triangular hydrograph as it produces a more realistic representation of the daily field runoff (flow, sediment, and pesticides) from PRZM at a similarly low computation cost compared to the simpler rectangular alternative and produces more risk-conservative estimates (lower) VFS efficiency.

Analysis of effect of the selection of alternative synthetic hydrographs when calculating VFS mitigation efficiencies in the regulatory context with VFSMOD

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Motivation and Objectives

The high-tier regulatory risk analysis (USEPA, EU FOCUS, Canada PMRA, etc.) uses the model PRZM to calculate edge of the field surface flow, sediment and pesticide runoff mass in daily time steps within long-term simulations (20-30 years). VFSMOD is currently used for vegetative filter strip (VFS) pesticide mitigation within these regulatory frameworks to reduce pesticide concentrations. Critical to this analysis is that the inputs required to run VFSMOD for each daily event simulation in long-term assessments are those already available within the regulatory risk analysis framework. For the case of rainfall data, in some instances, hourly rainfall records exist for the regulatory ecological scenarios, where in other cases only daily rainfall totals are available. Daily values are used by PRZM to simulate daily edge-of-field runoff, sediment, and pesticide values. VFSMOD operates at the sub-hourly hydrographs time step so different alternatives could be considered to handle the daily edge-of-field inputs from PRZM. Since the rainfall and runoff inputs define the flow and transport (sediment, pesticide) processes along the VFS during the event, it is critical to assess the effect of these alternatives towards the final implementation in the regulatory context. Specifically, are the estimated VFS efficiencies similar for these alternatives? If not, do any of them offer more conservative values (lower efficiencies than the others)? Is there a computational cost of selecting some alternatives over the others?

To quantify the effects of using different synthetic hydrographs for quantitative pesticide mitigation with VFSMOD in regulatory risk analysis, three alternatives with increasing complexity will be compared as alternatives: simplified rectangular, simplified triangular, and full NRCS tabular hydrographs.

Methods

Field conditions

Field conditions were chosen to analyze mitigation of runoff pesticides under risk conservative conditions of high probability of pesticide runoff. One representative case for this is field conditions of a row crop (corn) under conventional tillage on low infiltration soils and high rainfall intensity. For this, conditions in the Neuse River region, NC described in Muñoz-Carpena and Parsons (2004) were selected in this analysis, encompassing low (clay) and medium (sandy-clay) permeability soils. In this region, VFS are required for surface water quality protection (TMDL). To test the sensitivity of the VFS mitigation efficiency to rainfall/runoff magnitudes, 3 characteristic rainfall events (with return periods of 1-10 yrs) for the region were selected.

Hydrograph comparison

When hourly rainfall records exist for the regulatory ecological scenarios, where in other cases only daily totals are available. In the first case, the actual event duration D (hours of rainfall in the day of the event) is used as the duration for the rainfall-runoff event for that day. In the case where hourly storm values are unavailable, the daily values from PRZM are distributed over a typical storm duration (i.e., 8 h). In both cases, with the available data, three types of synthetic hyeto- and hydrographs can be constructed with increasing levels of complexity:

- a) Simplified rectangular, the daily rainfall and runoff values are distributed over the corresponding duration as an average constant value for that event.
- b) Simplified triangular, the daily runoff is distributed over the corresponding duration of that event as a triangle following NRCS unit triangular hydrograph (peak at time $D/2.67$ and rate equal to twice the average value used in *a*), and the hydrograph is distributed as a rectangular hydrograph as described before.
- c) NRCS TR-55, the hyetograph is synthesized based on the storm type for the region (I, IA, II, III, or a user supplied 24h normalized cumulative hydrograph), and the hydrograph is synthesized based on the hydrograph tabular method based on convolution of unit hydrograph increments during the storm (duration is the same as options *a*, *b* above).

The NRCS TR55 hyeto- and hydrographs were calculated with the program UH (Muñoz-Carpena et al., 2004). This utility uses the storm inputs and field conditions and automatically prepares VFSSMOD input files for storm (.irn file), field incoming runoff (.iro) and sediment characteristics (.isd). The program is part of the distribution of VFSSMOD and when run in sequence (UH+VFSSMOD) it serves to obtain response curves of VFS efficiency when varying the VFS size and storm magnitude. These curves are then superimposed to a target reduction (i.e., from a TMDL) to optimize the VFS characteristics for a specific field setting and also test the expected efficiency of existing field buffers (Muñoz-Carpena et al., 2004), as well as considering the uncertainty in the design based on intrinsic variability of the field and VFS characteristics (Shirmohammadi et al, 2006).

The hydrograph characteristics obtained by each of the methods are summarized in Table C - 1. Examples of the NRCS hyetographs and a comparison of resulting field runoff hydrographs from the 3 options presented above is depicted in Figures C - 1 and C - 2.

Table C - 1. Selected storms and field runoff characteristics low infiltration soils in the Neuse River, NC region used for testing. T is storm return period, P and Q are precipitation and runoff volume from the 0.5-hectare field, and D is duration of the storm, and q_p is peak runoff for different types of hydrographs and soils compared. d_{50} is median sediment particle size.

T (years)	P (mm)	Duration (h)	Clay ($d_{50} = 0.23 \mu\text{m}$)				Sandy Clay ($d_{50} = 0.66 \mu\text{m}$)			
			Q	q_p	q_p	q_p	Q	q_p	q_p	q_p
			(mm)	(m ³ /s) NRCS	(m ³ /s) triangle	(m ³ /s) rectang.	(mm)	(m ³ /s) NRCS	(m ³ /s) triangle	(m ³ /s) rectang.
1	54.0	4	29.0	0.0904	0.0201	0.0101	22.7	0.0673	0.0158	0.0079
		8	29.0	0.0769	0.0101	0.0050	22.7	0.0438	0.0079	0.0039
5	88.0	4	59.5	0.1130	0.0413	0.0207	50.8	0.1230	0.0353	0.0176
		8	59.5	0.1570	0.0207	0.0103	50.8	0.0943	0.0176	0.0088
10	102.6	4	73.2	0.2270	0.0508	0.0254	63.8	0.1880	0.0443	0.0222
		8	73.2	0.1890	0.0254	0.0127	63.8	0.1160	0.0222	0.0111

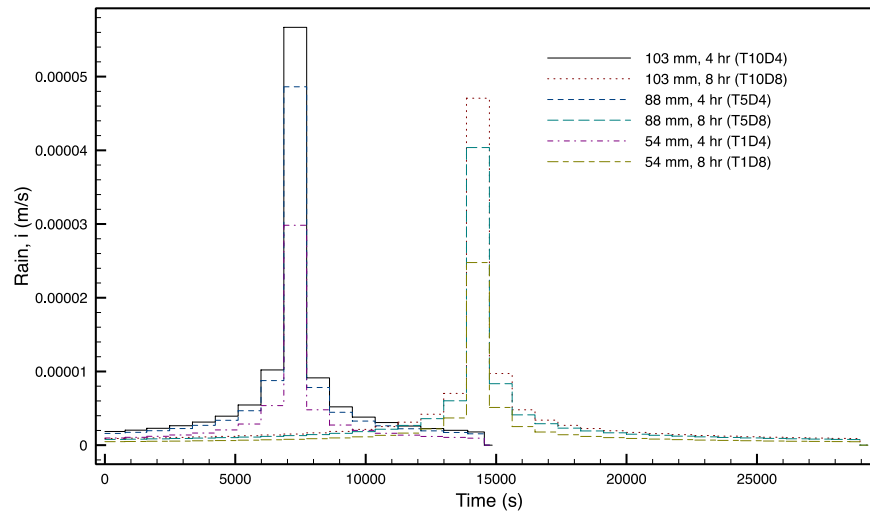


Figure C - 1. Synthetic NRCS hietographs used in the analysis

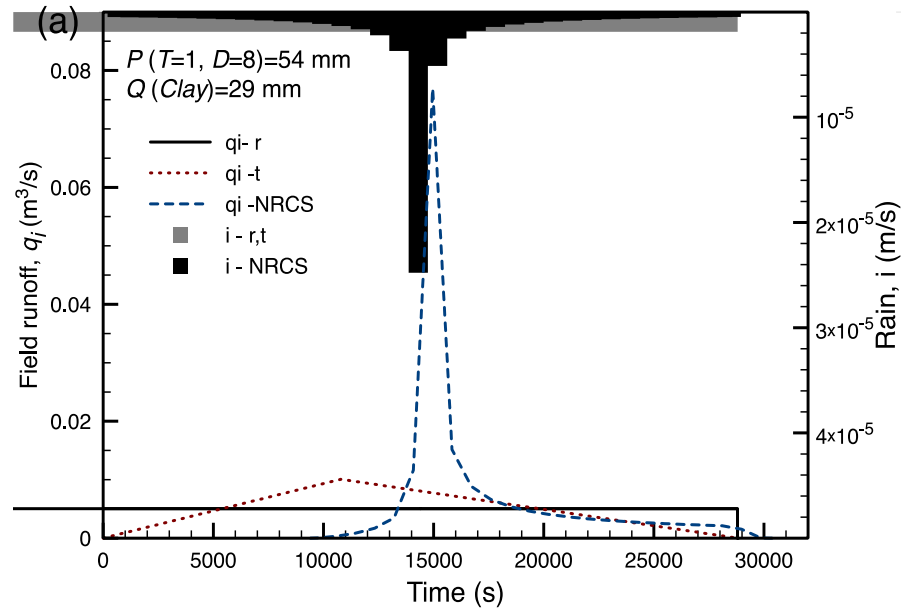


Figure C - 2. Example of rainfall hyetographs and field runoff hydrographs for the storm event of $T = 1$ yr, and duration 8 h on the clay soil. Symbols are r, t, NRCS for the rectangular simplification, triangular simplification, and full NRCS method, respectively. a) field runoff, q_i .

Analysis of factors controlling VFS efficiency in comparison with hydrograph method

Two soil types and 3 design storms for the Piedmont, NC described in Muñoz-Carpena and Parsons (2004) were combined with other potentially important factors controlling VFS mitigation efficiency (Table C - 2). These include typical VFS sizes (5, 10 m) used in field mitigation with a small 1 m size to include a case of a degraded filter (Abu-Zreig et al., 2001). Design storms of 1-10 year are also typical in the design of other vegetative or non-permanent structures used for environmental management (vegetated channels, small detention basins, and constructed wetlands, etc.). Three pesticide sorption classes (low, medium and high) were also selected in the analysis. In all, this resulted in $n=324$ model simulations.

Table C - 2. Input factors and distributions used.

Input	Description	Distribution ^(*)	Source
VL	VFS length in the flow direction (m)	DU(1,5,10)	Typical recommended VFS sizes for pesticide mitigation
T	Storm return period (yr)	DU(1,5,10)	City of Cary and Neuse River, NC (Muñoz-Carpena et al., 2004).
D	Storm duration (h)	DU(4,8)	Durations for regulatory risk analysis
Soil	Soil types (USDA texture)	DU(Sandy Clay, Clay)	Main soils at Carey and Neuse River, NC (Muñoz-Carpena et al., 2004).
Koc	Pesticide Koc (L/Kg)	DU(10,1000,10000)	EPA typical values for low, medium, and high adsorption products (USEPA, 2020)
Hydro	Synthetic field hydrograph types for regulatory analysis	DU(NRCS, <i>t</i> , <i>r</i>)	Alternatives for regulatory use

(*) DU: discrete uniform distribution, with equal probability for each level; *t* and *r* are triangular and rectangular simplifications.

For computational efficiency, the number of nodes *N* in the surface finite element grid for each simulation (ikw file) was set so that the spacing of the nodes along the filter of VL length is the closest rounded odd number to $(90/99(VL-1)+11)$, i.e. *N*=11, 15 and 21 for VL=1, 5, 10 m, respectively.

The VFS removal efficiency for runoff (dQ), sediment (dE) and pesticide (dP) were selected as outputs of interest of the model. The simulation time for each model run (PC intel i7 processor) was also collected to assess the computational expense of each hydrograph alternative. The output dataset was first compared graphically (1:1 lines), and then the results were segmented by different factors (hydrograph type, Koc, Soil) and depicted with boxplots. Statistical comparison of median values for different treatments were also obtained based on the notches in the boxplots ($\pm 1.58 \cdot IQR / \sqrt{n}$, IQR=interquartile range, *n* is the number of values in each treatment), where no overlap depicts ~95% confidence that two medians differ (Chambers et al., 1983).

Global sensitivity analysis

For higher dimensional problems (with many inputs), global sensitivity analysis (GSA) identifies the importance of the factors when considering the co-variation of the others, and the influence of the factors on the output by themselves (direct or first order effects) and through interactions. The screening method of Morris (1991) was employed here because of its easily interpretable results. The Morris GSA screening method (Morris, 1991) was used to determine the most important input factors controlling dQ, dE, dP and simulation time, and in particular the importance of the selection of the hydrograph against other factors controlling the model outputs. The method computes the elementary effects computed at

evenly spaced values of each parameter over its entire range, calculating the final effect from the average of the partial effects (Campolongo et al., 2007). Therefore, this method obtains results with significantly fewer model runs and considerable reduction in computational costs, compared to other methods ($n_{sim}=r[k+1]$, where r is number of trajectories, typically between 8-24). Two Morris sensitivity indexes are provided for each model input, the mean of the elementary effects μ (a measure of direct or first order effects of each factor in the units of the output) and the standard deviation of the mean effects σ (a measure of higher order effects or interactions). Campolongo et al., 2007 proposed also a modified μ^* , based on the average of the absolute values of the elementary effects that avoids the potential problem of cancelling effect when averaging for non-monotonic outputs. When the multivariate sampling of the model inputs is done properly, the method provides a robust estimation of the global importance of the model inputs, even compared with quantitative, more expensive variance-decomposition methods (Campolongo et al, 2007). Here we employ the enhanced sampling for uniformity eSU sampling method that ensures correct sampling of the inputs and robust sensitivity indices (Khare et al. 2015, 2019; Chitale et al., 2017). The eSU MatLab package for sampling and postprocessing was used (Khare et al. 2015, 2019). When plotting μ (or μ^*) vs. σ for all the input factors, those close to the origin are considered unimportant (non-influential) factors, where those separated from the origin are considered important due to their direct effects (closer to the x-axis) or interactions (closer to the y-axis). This provides an easy to interpret graphical output. Since μ averages the elementary effects, its sign indicates the direction of the input effect (positive or negative), and when compared to μ^* it also identifies the monotonicity of the factor (i.e., $\mu=\mu^*$ monotonic).

Three criteria for selecting the recommended distribution to use in the regulatory analysis were selected: a) computational cost; b) complexity of implementation; c) additional tools needed.

Results and discussion

Comparison of results

The results with the comparison of results (Fig. C-3, C-4, Table C-3) offer important insights. For a given runoff volume, the properties of the runoff hydrograph in terms of duration and shape are critical for the trapping efficiency of a VFS as predicted by VFSSMOD and in turn the outcome of a pesticide surface water risk assessment (EC, 2014). Neither hyetographs nor hydrographs are typically provided at a sub-daily resolution as input or output in runoff models such as PRZM, however VFSSMOD as an event-based model needs sub-daily input of runoff events. Therefore, the realistic derivation of subdaily runoff hydrograph from daily data is a crucial step of the assessment of the mitigation effectiveness by VFS. Differences among hyeto/hydrographs alternatives were found. The more complex method (NRCS) can potentially offer a more realistic description of the runoff dynamics but requires the introduction of an additional computational tool (i.e. UH) in the regulatory framework and doubles the simulation time. Among simplified approaches, the triangular method has less computational cost than NRCS, does not result in statistical differences in dP, dE, and dQ with the others, and is more realistic and risk conservative than the rectangular option with respect to protecting aquatic species in waterbodies next to agricultural fields. The

rectangular hydrograph produced significantly larger runoff reduction estimated (dQ) than the full NRCS method.

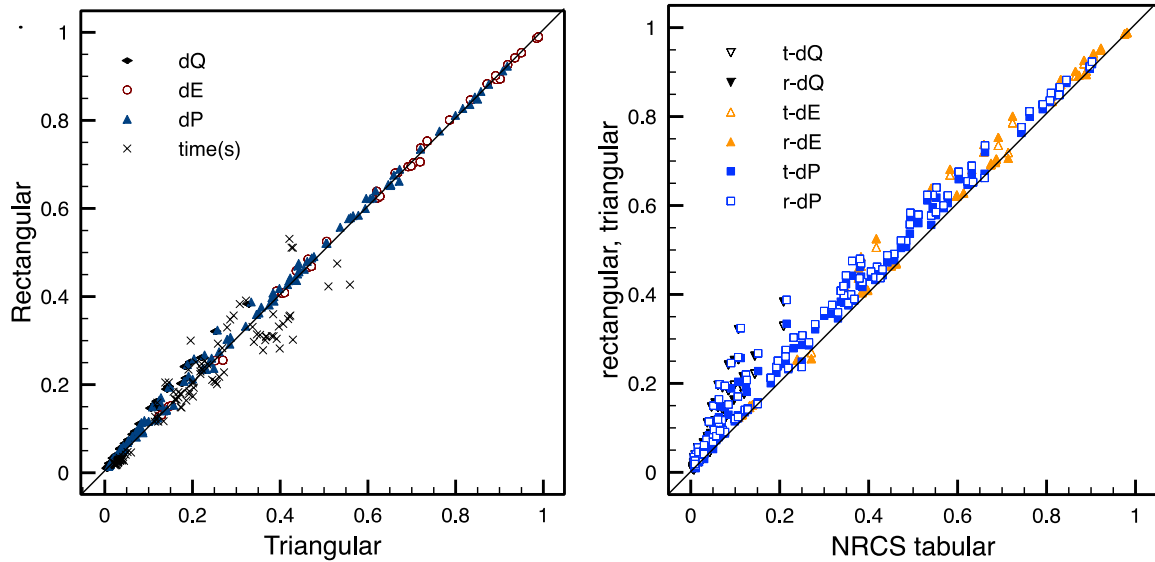


Figure C - 3. Comparison of agreement among calculated buffer reduction efficiencies for runoff (dQ), sediment (dE), pesticide (dP), and time (x) obtained with different types of hyeto- and hydrographs. Labels: r, t- simplified rectangular and triangular hydrographs, and the full NRCS tabular method.

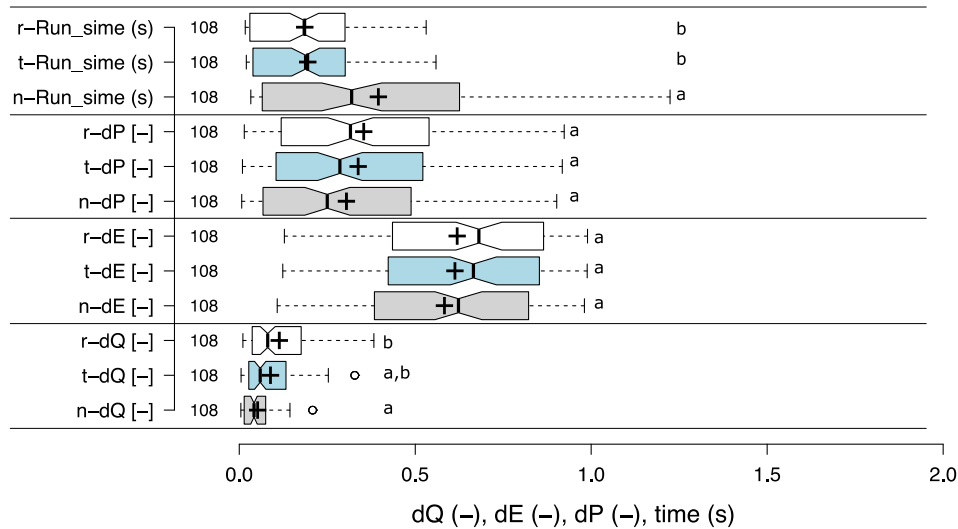


Figure C - 4. Comparison of distributions of outputs (dP, dE, dQ, and run time) for each type of hydrograph (r, t- simplified rectangular and triangular hydrographs; n the full NRCS tabular method). Different letters (a,b,c) in each comparison block represent significant differences at 5% level (Chambers et al., 1983).

Table C - 3. Statistics of comparison between distributions of the VFS outputs for each of the hydrograph alternatives. Labels: r, t- simplified rectangular and triangular hydrographs, and n the full NRCS tabular method.

Statistics	n-dQ[-]	t-dQ[-]	r-dQ[-]	n-dE[-]	t-dE[-]	r-dE[-]	n-dP[-]	t-dP[-]	r-dP[-]	n-time (s)	t-time (s)	r-time (s)
Upper whisker	0.14	0.25	0.38	0.98	0.99	0.99	0.90	0.92	0.92	1.22	0.56	0.53
3rd quartile	0.07	0.13	0.18	0.82	0.85	0.86	0.49	0.52	0.54	0.63	0.30	0.30
Median	0.04	0.06	0.08	0.62	0.67	0.68	0.25	0.29	0.32	0.32	0.19	0.18
1st quartile	0.01	0.03	0.04	0.38	0.42	0.44	0.07	0.10	0.12	0.07	0.04	0.03
Lower whisker	0.00	0.01	0.01	0.11	0.12	0.13	0.01	0.01	0.01	0.03	0.02	0.02
n data points	108	108	108	108	108	108	108	108	108	108	108	108
Mean	0.05	0.09	0.11	0.58	0.61	0.62	0.30	0.34	0.35	0.39	0.19	0.19

These results do not warrant a significant increase on complexity, computational time, and the need for another modeling component (like UH) in the long-term assessment framework. The triangular hydrograph emerges as an attractive option as it produces a more realistic representation of the daily field runoff (flow, sediment and pesticides) from PRZM, at a similarly low computation cost to the simpler rectangular alternative and produces more risk-conservative estimates (lower) of VFS efficiency. The latter is desirable in many regulatory contexts for added protection of surface water.

Global Sensitivity Analysis

Figure C - 5 presents the results of the Morris GSA for the 3 outputs of interest that describe the VFS efficiency. For the reduction of runoff on the filter dQ, the hydrograph type was in the second order of importance, after the filter size (VL), storm and soil type. The decrease in complexity of the hydrograph (from full NRCS to rectangular) produced a monotonic increase of ~5% in the average values of dQ (i.e., less risk with conservative values). All inputs exhibited interactions among themselves, except Koc. Koc was classified correctly as not important ($\mu=0$) as it does not participate in the calculation of dQ or dE. The hydrograph selection was unimportant (close to the origin in Figure B - 5c-d) for the case of dE, whereas for dQ the VFS size and soil were the most important factors followed by storm. All the important factors had a monotonic effect on dE, where the increase in VL produced a large increase in sedimentation efficiency, and a similar increase was obtained when changing from clay to the coarser sandy clay soil. As expected, the increase in storm size decreases the efficiency of sedimentation in the filter. Finally, for pesticide reduction dP, hydrograph selection was the least globally important factor compared to the others, where the increase of pesticide sorption largely increased the efficiency of the buffer in this case, followed in importance by the factors that controlled dQ and dE (i.e., filter size, soil and storm type). For all outputs, the increase in duration of the storm (from 4 to 8 h) had a smaller effect overall increasing <5% the efficiency of the VFS on all the outputs.

These global sensitivity analysis results corroborate those from the boxplots descriptive statistics considering just one or two factors at the time. Overall, the choice of simplified hyeto- and hydrographs in the regulatory long-term, high-tier assessments has limited effect on the quantitative mitigation efficiency of runoff pesticides with VFS. These results do not warrant a significant increase on complexity, computational time, and the need for another modeling component (like UH) in the modeling framework. Combining the GSA results with

the comparison of results offers important insights. The triangular hydrograph emerges as an attractive option as it produces a more realistic representation of the daily field runoff (flow, sediment and pesticides) from PRZM, at a similarly low computation cost to the simpler rectangular alternative and produces more risk-conservative estimates (lower) of VFS efficiency. The latter is desirable in many regulatory contexts for added protection of surface water.

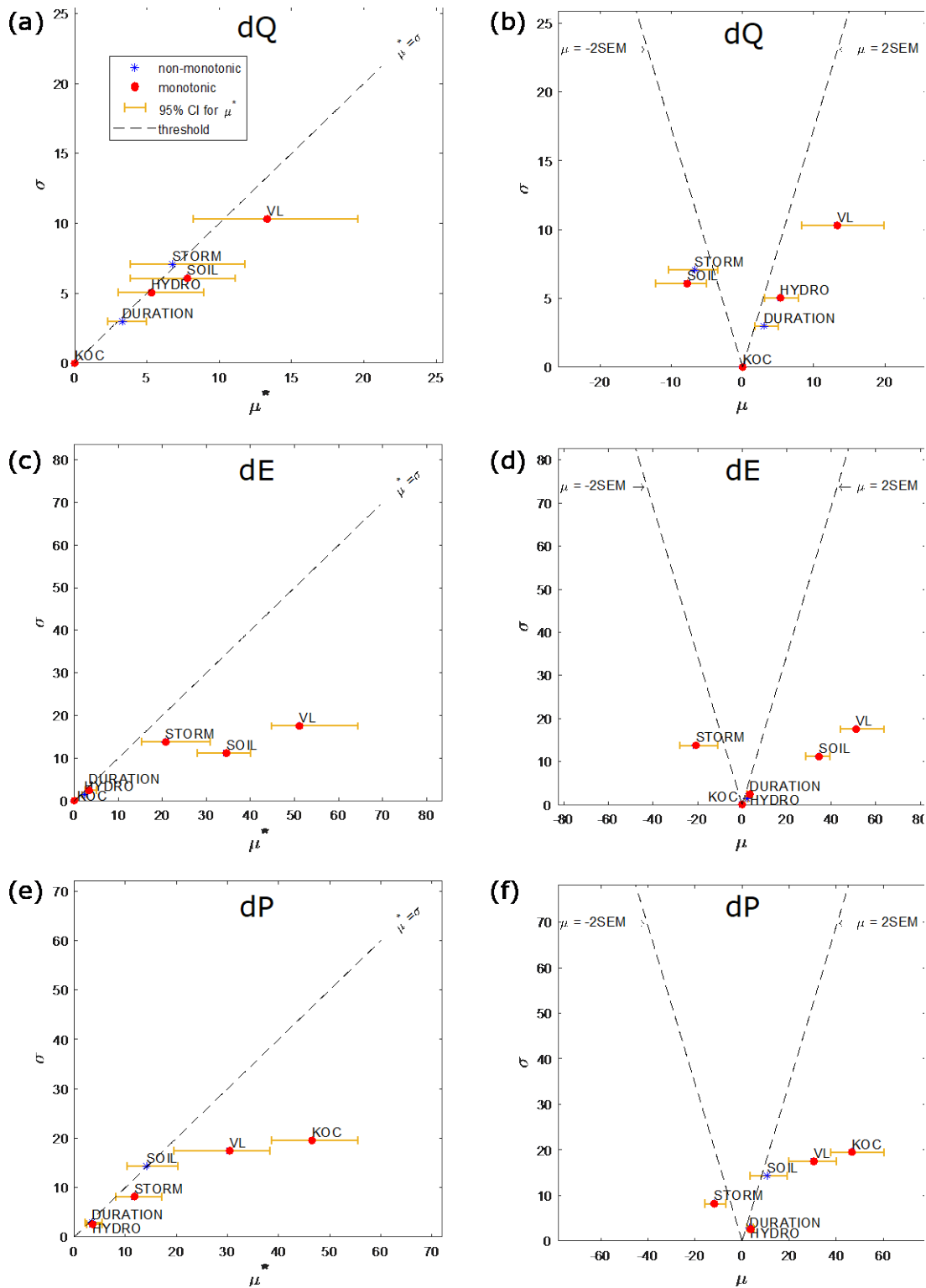


Figure C - 5. Morris eSU global sensitivity analysis results for buffer reduction efficiencies for runoff (dQ), sediment (dE) and pesticide (dP) obtained with different types of hyeto- and hydrographs. The labels for the input factors are described in Table C - 1.

Conclusions

Differences among hyeto/hydrographs alternatives were found. The more complex method (NRCS) can potentially offer more realistic description but requires the introduction of an additional model (UH) in the regulatory framework and doubles the simulation time. Among simplified approaches, the triangular method has less computational cost than NRCS, does not result in statistical differences in dP with the others, but is it more risk conservative than the rectangular option. As a result, the triangular option represents a good compromise and is recommended for regulatory use, including implementation in existing EU FOCUS SWAN, PMRA and CA-DPR tools and new development within USEPA PWC framework to incorporate quantitative mitigation of pesticides with VFS.

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APPENDIX D – EXAMPLE IL CORN SCENARIO MODIFIED FOR GRASSED AREA

USEPA PRZM Standard Scenario IL Corn modified for grass

*** 9/14/2021 10:28:07 AM

*** PRZM5 Input File Generator

***Record A1: Weather File

D:\Models\PWC\EcoWeatherFiles\wl4842.dvf

***Record A2: PRZM5 Time Series Output File

D:\YOUR PATH HERE\ilcor_tf.zts

This is your PRZM output filename and path

***Record A3: PRZM5 Advanced Options

False, True, True, False, False, 1, True

***Record 1: pfac, sfac, anetd

0.77, 0.36, 17.5

***Record 2: Erosion Flag 4 = MUSS, 3= MUST, 1= MUSLE

4

***Record 3: uslek, uslels, uslep, FieldSize, ireg, slope, hydraulic length

0.32, 1.34, 1, 10, 3, 6, 356.8

***Record 4 Number of hydro-event changes

26, 0

***Record 5 Day, Month, Year, C, n, CN

1, 4, .006, .110, 74

16, 4, .002, .110, 74

1, 5, .007, .110, 74

16, 5, .004, .110, 74

1, 6, .002, .110, 74

15, 6, .007, .110, 74

16, 6, .005, .110, 74

1, 7, .003, .110, 74

16, 7, .001, .110, 74

1, 8, .005, .110, 74

16, 8, .003, .110, 74

1, 9, .003, .110, 74

16, 9, .005, .110, 74

1, 10, .009, .110, 74

16, 10, .013, .110, 74

1, 11, .013, .110, 74

16, 11, .014, .110, 74

1, 12, .014, .110, 74

16, 12, .015, .110, 74

1, 1, .015, .110, 74

16, 1, .015, .110, 74

1, 2, .015, .110, 74

16, 2, .015, .110, 74

1, 3, .015, .110, 74

15, 3, .017, .110, 74

16, 3, .012, .110, 74

These records are updated to reflect date, USLE c-factor, Manning's N taken from a standard turf scenario (CATurf, FLturf, PATurf or TXturfBSS). CN based on hydrologic soil group (HSG) for standard crop scenario (see Table B - 4 or Table B - 5). CN for turf based on HSG: A = 39, B = 61, C = 74, and D = 80

These records are updated to reflect cropping parameters from a standard turf scenario (CATurf, FLturf, PATurf or TXturfBSS).

***Record 6: Number of crop periods that follow

30

***Record 7: Emergence (d/m/y), Maturity (d/m/y), Harvest (d/m/y), depth (cm), cover, height(cm), holdup (cm), post-harvest disposition

1, 4, 1961, 15, 4, 1961, 1, 11, 1961, 10, 1, 5, 0.1, 1

1, 4, 1962, 15, 4, 1962, 1, 11, 1962, 10, 1, 5, 0.1, 1

1, 4, 1963, 15, 4, 1963, 1, 11, 1963, 10, 1, 5, 0.1, 1

1, 4, 1964, 15, 4, 1964, 1, 11, 1964, 10, 1, 5, 0.1, 1

1, 4, 1965, 15, 4, 1965, 1, 11, 1965, 10, 1, 5, 0.1, 1

1, 4, 1966, 15, 4, 1966, 1, 11, 1966, 10, 1, 5, 0.1, 1

1, 4, 1967, 15, 4, 1967, 1, 11, 1967, 10, 1, 5, 0.1, 1

1, 4, 1968, 15, 4, 1968, 1, 11, 1968, 10, 1, 5, 0.1, 1

1, 4, 1969, 15, 4, 1969, 1, 11, 1969, 10, 1, 5, 0.1, 1

1, 4, 1970, 15, 4, 1970, 1, 11, 1970, 10, 1, 5, 0.1, 1

1, 4, 1971, 15, 4, 1971, 1, 11, 1971, 10, 1, 5, 0.1, 1

1, 4, 1972, 15, 4, 1972, 1, 11, 1972, 10, 1, 5, 0.1, 1

1, 4, 1973, 15, 4, 1973, 1, 11, 1973, 10, 1, 5, 0.1, 1

1, 4, 1974, 15, 4, 1974, 1, 11, 1974, 10, 1, 5, 0.1, 1

1, 4, 1975, 15, 4, 1975, 1, 11, 1975, 10, 1, 5, 0.1, 1

1, 4, 1976, 15, 4, 1976, 1, 11, 1976, 10, 1, 5, 0.1, 1

1, 4, 1977, 15, 4, 1977, 1, 11, 1977, 10, 1, 5, 0.1, 1

1, 4, 1978, 15, 4, 1978, 1, 11, 1978, 10, 1, 5, 0.1, 1

1, 4, 1979, 15, 4, 1979, 1, 11, 1979, 10, 1, 5, 0.1, 1

1, 4, 1980, 15, 4, 1980, 1, 11, 1980, 10, 1, 5, 0.1, 1

1, 4, 1981, 15, 4, 1981, 1, 11, 1981, 10, 1, 5, 0.1, 1

1, 4, 1982, 15, 4, 1982, 1, 11, 1982, 10, 1, 5, 0.1, 1

1, 4,1983,	15, 4,1983,	1,11,1983,	10,	1,	5,	0.1,	1
1, 4,1984,	15, 4,1984,	1,11,1984,	10,	1,	5,	0.1,	1
1, 4,1985,	15, 4,1985,	1,11,1985,	10,	1,	5,	0.1,	1
1, 4,1986,	15, 4,1986,	1,11,1986,	10,	1,	5,	0.1,	1
1, 4,1987,	15, 4,1987,	1,11,1987,	10,	1,	5,	0.1,	1
1, 4,1988,	15, 4,1988,	1,11,1988,	10,	1,	5,	0.1,	1
1, 4,1989,	15, 4,1989,	1,11,1989,	10,	1,	5,	0.1,	1
1, 4,1990,	15, 4,1990,	1,11,1990,	10,	1,	5,	0.1,	1

```

***Record 8: irrflag, tempflag
0, False
***Record 14: Number of horizons
4
*** Record 15
*** #,thk, Del, Dsp, bd, W0, FC, WP, oc, snd, cly, tmp
1, 10, 100, 0.0, 1.45, 0.355, 0.355, 0.185, 2.32, , , ,
2, 34, 17, 0.0, 1.45, 0.355, 0.355, 0.185, 2.32, , , ,
3, 44, 11, 0.0, 1.6, 0.338, 0.338, 0.208, 0.174, , , ,
4, 12, 3, 0.0, 1.7, 0.307, 0.307, 0.167, 0.116, , , ,
*** Record 16: New Runoff Extraction Parameters: rDepth, rDecline, Bypass
2.0,1.55,0.266,
*** Record 17: New Erosion Extraction Parameters: eDepth, eDecline, eEfficiency
0.1,0,1.0
***** START OF CHEMICAL INPUTS *****
***Record C1 Number of Applications, Number Of Chemicals
30, 1, False, 0, 0, 0, 0
***Record C2 dd, mm, yy, cam, dep, Rate, eff, tband, lcam, lDep, 1.0Rate, leff, 0, 2cam,
2Dep, 2.0Rate, 2eff, 0
31,5,1961,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1962,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1963,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1964,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1965,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1966,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1967,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1968,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1969,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1970,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1971,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1972,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1973,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1974,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1975,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1976,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1977,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1978,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1979,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1980,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1981,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1982,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1983,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1984,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1985,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1986,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1987,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1988,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1989,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
31,5,1990,2,4,0.1,0.99,0, 1, 4.0, 0, 0, 0, 1, 4.0, 0, 0, 0
***Record C3: UPTKF (uptake factors)
0,0,0
***Record C4 (Chem #1)
0, 0, 0.5
***Record C6: volatilization
0,0,0,
*** Record C7: Kf1, Kf2, Kf3 for each horizon
8.12,
8.12,
0.609,
0.406,
*** Record C7A: N1, N2, N3 Freundlich Exponents for each horizon
1.0,
1.0,

```

```

1.0,
1.0,
*** Record C7B: Region 2 Freundlich Coefficient for each horizon
1,
1,
1,
1,
*** Record C7C: Region 2 Freundlich Exponents for each horizon
1,
1,
1,
1,
*** Record C7D: Lowest Concentration (mg/L) for Freundlich Exponent
1.0e-12,
*** Record C7E: Sorbed-Phase-Referenced Mass-Transfer Coefficient
1,
*** Record C8: Degradation Rates Aqueous, Sorbed, Gas
0.0138628,0.0138628,0,
0.0138628,0.0138628,0,
0.0138628,0.0138628,0,
0.0138628,0.0138628,0,
*** Record C9: Molar Conversions 1 to 2, 1 to 3, 2 to 3
0,0,0,0,0,0
0,0,0,0,0,0
0,0,0,0,0,0
0,0,0,0,0,0
***** OUTPUT SPECIFICATIONS *****
*** Record U1
6
*** Record U2
RUNF,0,TSER, 0, 0, 1.0
ESLS,0,TSER, 0, 0, 1.0
RFLX,1,TSER, 0, 0, 1
EFLX,1,TSER, 0, 0, 1
DCON,1,TAVE, 2, 131, 1000
THET,0,TSER, 100, 100, 1.0

```



PRZM output for daily soil-water content

APPENDIX E – EXAMPLE IL CORN SCENARIO VFSMOD MODEL INPUTS FOR A 3 METER VFS

This Appendix shows an example using the USEPA IL Corn Standard Scenario with a 3 m VFS. The values outlined with red boxes in the example input files are specific to each crop scenario, user defined VFS width, and user defined pesticide environmental fate. Other values (not outlined) in the input files either change per rainfall/runoff event or are fixed/default values.

Parameter	Parameter Definition	IL Corn value	Source
Input file = .ikw			
FWIDTH (m)	Width of strip (perpendicular to flow)	316.228	Based on 10-ha field
VL (m)	Length of strip (in the flow direction)	3	Buffer width – User defined
N	Number of nodes	-1	Default value. Internally computed to a number between 11 and 101 (based on VL between 1 and 100 m), rounded to the closest odd number
THETAW	Time weighted factor, Crank-Nicholson solution	0.5	VFSMOD User's Manual, default
CR	Courant number	0.8	VFSMOD User's Manual, default
MAXITER	Max number of iterations	350	VFSMOD User's Manual, default
NPOL	Number of nodal points	3	VFSMOD User's Manual, default
IELOUT	Flag for output	1	VFSMOD User's Manual, default
KPG	Flag for Petrov-Galerkin solution	1	VFSMOD User's Manual, default
NPROP	Number of segments	1	VFSMOD User's Manual, default
SX (i) (m)	Distance of filter of uniform surface properties	3	Buffer width – same as VL
RNA (i) (s m ^{-1/3})	Manning's <i>n</i> for segment	0.45	VFSMOD Appendix 3.2, grass (bluegrass sod)
SOA (iprop) (fraction)	Slope	0.06	USEPA Standard Scenario slope
IWQ	Flag for water quality	1	1=run runoff pesticide problem
Input file = .irn			
NRAIN	Number of rainfall periods	4	Default value
RPEAK (m/s)	Maximum rainfall intensity	Varies	See example in Section 3.
RAIN (I,J) (s, m/s)	Time and rainfall intensity	Varies	See example in Section 3.
Input file = .iro			
SWIDTH (m)	Source area width	316.228	Based on USEPA and PMRA 10- ha square field
SLENGTH (m)	Source area flow path length	316.228	
NBCROFF	Number of time steps of the field hydrograph	3	Default value
BCROPEAK (m ³ /s)	Peak flow of the incoming field hydrograph	Varies	See example in Section 3.
BCROFF Time (s) vs flow (m ³ /s)	Incoming field hydrograph time & flow rate	Varies	Calculated as a triangular hydrograph. See example in Section 3.
Input file = .iso			
VKS (m/s)	Saturated hydraulic conductivity	1.194 x 10 ⁻⁶	VFSMOD Appendix 3.1 Soils data table (b value) – based on soil texture from the USEPA IL Corn Standard Scenario (clay loam) (See Appendix B Table B – 2)
SAV (m)	Green Ampt's average wetting front suction	0.2088	VFSMOD Appendix 3.1 Soils data table (mean value), based on soil texture from the USEPA IL Corn Standard Scenario (See Appendix B Table B – 2)

Parameter	Parameter Definition	IL Corn value	Source
OS (m ³ /m ³)	THETA-S, saturated soil-water content	0.48	VFSMOD Appendix 3.1 Soils data table (b value) – based on soil texture from the USEPA IL Corn Standard Scenario (clay loam) (See Appendix B Table B – 2)
OI (m ³ /m ³)	THETA-I, initial soil-water content	Varies	From PRZM modified crop file for grass area, THET output from “turf”.zts file for event
SM (m)	Maximum surface storage	0.00	VFSMOD default value
SCHK (ponding ck)	Relative distance from upper filter edge	0.5	VFSMOD User’s Manual = mid-point in field
Input file = .igr			
SS (cm)	Spacing of filter media (grass)	2.15	VFSMOD Appendix 3 Vegetation types for VFS table, grass mixture (See Appendix B Table B – 3), default value
VN (s/cm ^{1/3})	Filter media (grass) Manning’s <i>n</i>	0.012	VFSMOD User’s Manual, cylindrical media, default value (See Appendix B Table B – 3)
H (cm)	Filter media (grass) height	18	VFSMOD Appendix 3 Vegetation types for VFS table, grass mixture (See Appendix B Table B – 3) – default value
VN2 (s/m ^{1/3})	Bare surface Manning’s <i>n</i>	0.05	VFSMOD Appendix 3 Manning’s roughness coefficient, <i>n</i> table, fallow (no residue) (See Appendix B Table B - 1) – default value
ICO (0 or 1)	Sed. feedback flag	0	VFSMOD User’s Manual default, 0=No feedback
Input file = .isd			
NPART	Particle class	8	VFSMOD User’s Manual, default value, 8 = internal calculation for each event
COARSE (fraction)	Fraction of coarse sediment	0.5	Default value
CI (g/cm ³)	Incoming flow sediment conc.	Varies	Calculated based on eroded sediment and runoff volume from the PRZM .zts file for event
POR	Porosity of deposited sediment	0.453	Porosity = 1-(bd/2.65), based on USEPA IL Corn Standard Scenario bulk density – 1.45 g/cm ³
SILT_FRAC (fraction)	Silt fraction	0.30	Fraction of silt in the topsoil of the USEPA PRZM standard scenario. (Appendix B)
ITILLAGE	Tillage type	0	Default = 0 (conventional tillage)
Input file = .iwq			
IWQPRO	Pesticide trapping eq.	3	VFSMOD User’s Manual – 3 = mass balance
IKD	Flag for Koc or Kd	User defined	1 = Koc used
KOC or KD (L/kg)	Partition coefficient	User defined	EFED K _{OC} or K _d value used in PRZM
OCP (%)	Runoff organic carbon	2.32	USEPA Standard Scenario
OCC (%)	Runoff clay content	35	Clay based on USEPA IL Corn Standard Scenario soil texture (see Appendix B)
IDG	Degradation type	2	2 = decay rate only
Ndgday	Number of days between events	Varies	No. of days between events, calculated from PRZM .zts file
dgHalf (days)	Pesticide half-life	User defined	EFED value for aerobic soil half-life used in PRZM
FC (m ³ /m ³)	Topsoil field capacity	0.355	Topsoil field capacity from USEPA IL Corn Standard Scenario
dgPin (mg/m ²)	Pesticide mass entering filter	Varies	Calculated from total pesticide mass (dissolved and solid) entering filter from PRZM file
dgML(cm)	Surface mixing layer thickness	2	VFSMOD User’s Manual, default
dgLD (m)	Lambda, dispersion length of chemical	0.05	Default value
dgMRES0	Remobilized pesticide surface residue when event starts	Varies	This value is from the .owq file from the previous event

Parameter	Parameter Definition	IL Corn value	Source
dgT (i) (°C)	Daily air temperature series between events	Varies	Read from PRZM weather .dvh file for USEPA IL Corn Standard Scenario (W14842.dvh)
dgTheta (m ³ /m ³)	Soil water content series between events	Varies	Soil moisture (THET) read from Turf PRZM .zts file (See Appendix D)
IMOB	Residue remobilization flag	1	Partial (porewater) remobilization

.IKW – Overland flow solution input file

ILCORN03.IKW	
1	ilcorn- 03 m buffer
2	316.228
3	03. -1 .5 .8 350 3 1 1
4	1
5	03. .45 .0600
6	1
7	-----
8	title
9	fwidth
10	vl n thetaw cr maxiter npol ielout kpg
11	nprop
12	sx(iprop), rna(iprop), soa(iprop), iprop=1,nprop
13	WQ flag=1 if Pesticides Bayer Option has been chosen
14	

- ilcorn- 03 m buffer (file description)
- 316.228 = Width of VFS (m), this is set for a 10-ha field
- 03. = Length of VFS (m)
- 03. = Length of VFS (m)
- .0600 = Fractional slope of the field in IL Corn scenario
- Remaining values are VFSMOD default properties or consistent across scenarios and do not need to be edited by user.

.IRN – Storm hyetograph input file

ilcorn.irn	
1	4 2.77778E-06 Nrain, rpeak (m/s)
2	0 0.0000027778
3	7200 0.0000027778
4	7201 0.0
5	9000 0.0

Values are calculated for each event using the hourly rainfall time (storm duration) and the total rainfall

- The values shown here reflect a 2-cm rainfall event lasting 2 hours (7200 seconds)

.IRO - Runoff from the adjacent field into the VFS input file

ILCORN.IRO					
1	316.228	316.228	Swidth(m),	Slength(m)	
2	3	0.01389	nbcroff, bcropeak(m3/s)		
3	0	0.0			
4	2697	0.01389			
5	7200	0.0			

- 316.228 316.228 = Field width and length in meters is set for a 10-ha field
- Remaining values are calculated for each event using the hourly rainfall time (storm duration) and the total runoff from the PRZM .zts file
- The values shown here reflect a 0.05-cm runoff event lasting 2 hours (7200 seconds)
- The hydrograph is triangular

.ISO - Soil properties input file

ilcorn.ISO						
1	1.194E-06	.2088	.48	.11	.00	0.5
2						
3						
4	-----					
5	Ks (m/s)	Sav (m)	Theta-s	Theta-i	Sm(m)	Schk(ponding ck)

- 1.194E-06 = Ks, Saturated hydraulic conductivity, (See Appendix B for clay loam)
- 0.2088 = Sav; Green Ampt parameter (See Appendix B for clay loam)
- 0.48 = Theta-s, Porosity (See Appendix B for clay loam)
- 0.11 = Theta-i, soil moisture (theta from PRZM .zts file on day of event so varies for each event)
- The last 2 values are VFSSMOD default properties.

.IGR - Buffer properties input file

ilcorn.igr					
1	2.15	.012	18	.05	0
2					
3	-----				
	SS (cm)	Vn (s/cm ^{1/3})	H (cm)	Vn2 (s/m ^{1/3})	ICO (0 or 1)

- VFS properties for a Grass Mixture (same for all scenarios)
- See Appendix B

.ISD - Sediment properties input file

ilcorn.ISD									
1	8	50	.001616521	.453	Npart, Coarse, Ci(g/cm3), Por				
2	.30	0	Silt_frac, Itillage						

- .001616521 = incoming flow sediment concentration varies per event (eroded sediment/runoff volume)
- .453 = Porosity of deposited sediment (porosity = 1-(BD/2.65))
- 0.30 = Silt fraction (based on clay loam, see Appendix B)
- Remaining variables are defaults

.IWQ – Water quality input file

ILCORN.IWQ*									
1	3	-10.9578	0.60689	0.47316	-0.35039	0.1998	;wqpro(1-4): select pest. eqs.		
2	1	300	2.32	; Kd proc.:0= Kd(L/Kg); 1=Koc (Koc L/Kg),%OC					
3	35	%Clay content							
4	2	IDG							
5	3	50.0	0.355	6.0970E+00	2	0.05	1.0330E-02	ndgday dgKref FC dgPin dgML dgLD dgMRES	
6		20.3	22.1	20.5	dgT(i)				
7		0.330	0.328	0.330	dgTheta(i)				
8	1	IMOB							
9	-----								
10	IWQPRO: Pesticide trapping: 1=Sabbagh;2= Sabbagh(refit);3=mech.mass bal.;4=Chen								
11	IKD	: Sorption type: 0, Kd(L/Kg); 1, Koc (L/Kg),%OC							
12	IDG	: flag to calculate degradation (1=EU,2=US,3=temp,4=moisture only).							
13	ndgday:	no. of days between events							
14	dgHalf:	pesticide half-life (days)							
15	FC	: top soil field capacity (m3/m3).							
16	dgPin	: Pin, pesticide mass entering filter (mg/m2)							
17	dgML	: Surface mixing layer thickness (cm, std.=2cm)							
18	dgLD	: Dispersion length (m, std=0.05 m)							
19	dgMRES:	Pesticide residue on VFS surface (mg/m2)							
20	dgT(i):	T, daily air temperatures (C) for period between events							
21	dgTheta(i):	Soil water content for period between events							
22	IMOB	: 1 or missing:partial;2:100% ml;3:no remob							
23	-----								
24									

- 1 = Koc/Kd flag, user defined, same as PRZM input (Koc used in example)
- 300 = Koc value, user defined, same as PRZM input
- 2.32 = % Organic Carbon in IL Corn Standard Scenario
- 35 = % Clay content of soil (see Appendix B)
- 3 = This value varies for each event (the number of days until the next event)
- 50.0 = Soil degradation half-life (days), user defined, same as PRZM input
- 0.355 = Topsoil layer field capacity for IL Corn Standard Scenario
- 6.0970E+00 = Pesticide entering the filter varies per event
- 1.0330E-02 = Pesticide residue in VFS varies per event
- dgT and DgTheta = Temperature and soil water content between events, varies for each event.

- 1 = IMOB, (default shown) partial remobilization of porewater pesticide residue from the last event.
- Remaining values are VFSSMOD default properties and do not need to be edited by user